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29-31 January
Fribourg, Switzerland

FINAL PROGRAM AND PROCEEDINGS

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WELCOME TO ADVANCED INKJET TECHNOLOGY 2024

In the face of a global crisis, we recognize the urgent need to balance environmental sustainability with economic activities for the future of our planet. In the manufacturing sector, the imperative is to minimize the environmental impact by producing only what is necessary, in optimal forms, precisely when needed. Despite attempts to address this through inkjet technology, many applications have faced significant technical challenges that hinder practical implementation. This has prompted the creation of the Advanced Inkjet Technology Conference, which aims to bring together global leaders in inkjet research and development. The conference serves as a platform for the exchange of ideas among researchers, developers, and users, with the collective goal of shaping the next era of inkjet technology through shared knowledge and enthusiasm.

I would like to express deep gratitude to my colleagues at iPrint who collaborated in planning this conference, the Committee members, HEIA-FR for providing an excellent venue, and IS&T, the experienced co-organizer. Above all, my heartfelt thanks go to the speakers who have prepared outstanding presentations, the sponsors supporting this conference, the exhibitors showcasing intriguing displays, and all the attendees. This is my opportunity to convey my sincere appreciation for everyone who helped bring about this inaugural conference. Together, I hope we can co-create the future of inkjet.

—Warm regards,
Yoshinori Domae, general chair, Advanced Inkjet Technology 2024

CONFERENCE CO-ORGANIZERS

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CONFERENCE SCHEDULE AND TABLE OF CONTENTS

MONDAY 29 JANUARY 2024

DROPLET GENERATION AND VISUALIZATION

Session Chair: Yoshinori Domae, iPrint (Switzerland)

13:00 - 15:00

13:00 **Welcome,** *Yoshinori Domae, iPrint (Switzerland)*

13:10 **KEYNOTE: A Helicopter View of Ink Jet Printing,** *Stephen Temple, Cambridge University (UK)*

The aim of this talk is to take an overview of Ink Jet Printing (IJP) within the whole field of printing. This is the sort of approach which I got used to taking when working as a professional inventor at Cambridge Consultants. It begs the question "What is Printing?"

I start with a brief review of the millennia old history of the development of printing technologies (including 3D reproduction), which culminates with the invention of IJP in the last century.

I will then review the different approaches to IJP and make some comments on their limitations and potential. The bottom line of this is that there is no reason why this technique could not replace all past printing technologies. But it can also go beyond this and contribute to the wider issue of manufacturing all types of objects.

Then what limits the introduction of this technology? The crucial answer is "Ink". It is the chemists who will determine the ultimate potential of IJP. In principal, piezo-electric IJP is ink agnostic, though it does set limits on the physical fluid characteristics. To my mind, it is an open question as to whether this will turn out to be a serious restriction on the application fields for IJP. Even today, it has a much broader potential scope than any preceding technology, and I would expect to see this expand further.

And it is already beginning to influence the whole of engineering/manufacturing. At the highest level, there is an urgent need for us to stop using energy hungry and wasteful processes to convert materials to our purposes. We need to think more along the lines of Nature, which grows its materials molecule by molecule and makes quite spectacular structures with the minimal use of energy and wastage. This is where Ink Jet has the potential to change the game for 3D printing and to be the process of choice for a very wide range of manufacturing.

My own pet project is to print wooden structures by investing a structurally efficient scaffold of tubes with meristem cells that will then grow to fill in the tubes. The end result would be a printed house or larger structures, delivering better performance, whilst sequestering millions of tons of CO_2.

Achieving an optimal print quality in inkjet application relies on the precise definition of waveform parameters. This process, however, remains a challenging scientific endeavor characterized by its complexity and a lack of well-defined methodologies. In this presentation, we will dive into the science behind optimizing waveforms. One major challenge lies in balancing factors like drop volume, speed, and stability to achieve the desired print quality. We'll explore the latest developments, such as machine learning and iterative solvers. These algorithms rely on big data to analyze vast datasets of printing outcomes, helping to refine waveform settings for improved quality. Such innovations may revolutionize this field, making high-quality, precise prints more accessible across various applications, from graphics to functional electronics.

In this paper we report what we believe is the first-time observation of femtolitre drop generation from a nozzle in an industrial inject printhead. While femtolitre drops have been observed and reported, it has been mostly in the context of jet ligament thinning and subsequent breakdown into drops by Rayleigh-Plateau instability. This communication will show jetting of femtolitre size drops directly from the ink meniscus formed on the nozzle exit of two different industrial printheads. The printheads are from different manufacturers, with different microchannel and piezoelectric structures, and the two inks used are very similar, one of them having one extra polymer component used to increase the ink viscosity. The jetting events happen at random times, from immediately after the ligament detachment from the nozzle up to several hundreds of microseconds later. While the physical mechanism underlying this jetting phenomena is not understood, we will analyse our results and compare with existing theories small drop formation, to try to build an understanding of how this jetting process works.

Inkjet printing has been widely used in conventional graphic arts, publishing, textile industries, and more. It has also been adopted in the production lines of TFT LCD TVs for forming a PI layer and depositing liquid crystal, and OLED/QD-OLED TVs for forming a thin film encapsulation layer and colorant subpixels. However, the jetting precision and reliability required for the color pixelation of QD-OLED TVs are far higher than those for conventional applications. Although all nozzles of inkjet printheads need to be inspected before printing, the existing jetting status inspection methods are incapable of inspecting tens of thousands of nozzles within a minute. Furthermore, they hardly provide historical data of nozzles whether they worked well during the inspection period. In this study, a novel jetting status inspection method is introduced that provides spatial and temporal information on the jetting status during the inspection period.

EXHIBITOR PRESENTATIONS I

15:00 – 15:20

Advanced Inkjet Technology 2024 Exhibitors provide an overview of their services/products:

ChemStream
DataPhysics
Droptimize
Epson
FEMTOprint SA
ImageXpert LLC

EXHIBITS AND COFFEE

15:20 – 15:50

INKJET-BASED PROCESSES IN NEW APPLICATION DOMAINS

Session Chair: Gioele Balestra, iPrint (Switzerland)
15:50 – 17:10

15:50 **Biotech and Printing Technology for Next Generation Computer Storage,** *Tomaž Karcnik, Marko Matijevic, and Rok Luzar, BioSistemika d.o.o. (Slovenia)* **A-5**

DNA holds exceptional promises as a medium for storing digital data due to its exceptional data density, data longevity, and maintenance-free storage. The key requirement of the "write-to-DNA" process is manipulating a massive number (millions per second) of minuscule droplets (pL) whose composition is determined on demand. The potential of Drop-on-Demand (DoD) printing technology for such an application is obvious, as it addresses several key challenges.

An experimental DoD based Liquid Handling Machine (LHM) was developed and used to synthesize digital data carrying DNA strands. The development challenges included ink development, maintaining cleanliness, establishing cleaning procedures, novel print head control, reliable mixing of many reagents, and preventing evaporation.

Limited amounts of digital data were successfully recorded on DNA strands using LHM while also clearly pointing out the challenges for further advancement of DNA based data storage technology.

16:10 **Inkjet Platform for Additive Manufacturing Processes in Electronics Production,** *Jochen Seeser and David Hahn, Notion Systems GmbH (Germany)* **A-6**

The presentation aims at providing an overview of the potential as well as limitations of additive technologies for the manufacturing of electronic devices. Inkjet printing of solder mask for PCB production will serve as a blueprint of an additive process that has been adopted successfully in mass production. Already saving the adopters energy and waste. At the same time, the 3D nature of inkjet printing has the potential to replace or simplify other electronic components.

The presentation will also give an insight in the vision of the EU funded TINKER project. Its goal is to provide a new cost- and resource efficient pathway for RADAR and LIDAR sensor package fabrication with high throughput, improved automation, improved accuracy and reliability to the European automotive and microelectronic industry via additive manufacturing.

Within the TINKER project, an advanced inkjet platform was developed which also includes components for IR-ink drying, UV curing and laser sintering. In the presentation it will demonstrate how fully digital inkjet printing expands the capabilities of conventional manufacturing processes with a maskless, multi material and high precision process.

16:30 **3D Printed Electronics: Embedding AM Technologies in a Hybrid Process Chain for Customized Production of Micro-Mechatronic-Systems,** *J. C. Janhsen, O. Refle, and L. Cirstea, Fraunhofer Institute for Manufacturing Engineering and Automation IPA (Germany)* **A-7**

This paper presents a new approach to the production of microelectronic and mechatronic systems that combines multi-material additive processes with conventional manufacturing techniques. We show a fully automated modular hybrid machine platform comprising four central modules: 3D inkjet printing, material deposition, micro-assembly and UV/IR/NIR curing with integrated quality control. This platform enables the automated production of individualised microsystems in small quantities while ensuring scalability. This paper provides an overview of the project's vision, focuses on the hardware setup and gives an outline of the current process development.

16:50 **Printing of Use-cases by Direct-to-shape Inkjet Printing with Industrial Robot,** *Philip Kessler, Johannes Renner, Benoît Sahli, Vincent Schneuwly, Vincent Nidegger, and Gilbert Gugler, iPrint Institute, HEIA-FR, HES-SO University of Applied Sciences and Arts Western Switzerland; Florian Fässler, Polytype AG; and Danijel Tipura, Mabi Robotic AG (Switzerland)* **A-9**

In the initial phase of this project, a single-colour printing system was developed to perform printing tests on 2D surfaces in different orientations and robot workspaces. These test prints were scanned by a microscope and treated by an image processing software, which allowed the statistical characterisation of the drop placement error and its different parameters. An active ink pressure control system was developed, implemented and tested to mitigate the pressure fluctuations caused by the dynamics that occur within the system. Using high-precision distance sensors, a correlation between drop placement error and robot path accuracy was proven, confirming the effectiveness of the ink pressure control. In the second phase, a four-colour printing system was developed to test high quality graphic printing and selective coating on an automotive part. This phase involved several considerations, including path generation, correcting positioning errors, ensuring stitching quality, achieving coating uniformity and implementing UV curing on 3D surfaces. The DTS workflow developed in this project was tested and improved on various use cases including automotive parts and furniture.

EXHIBITOR PRESENTATIONS II

17:10 – 17:30

Advanced Inkjet Technology 2024 Exhibitors provide an overview of their services/products:

ISTintech
Kao
KNF
Mankiewicz
Meteor
Neatjet

NETWORKING WELCOME DRINK

17:30 – 18:30

TUESDAY 30 JANUARY 2024

NOVEL PRINTING TECHNOLOGIES

Session Chair: Dong-Youn Shin, Pukyong National University (Republic of Korea)
09:00 - 10:50

09:00 **KEYNOTE: Can I Jet Any Inkjet Ink Reliably?,** *Tri Tuladhar, TriJet Limited (UK)*

The intricate and dynamic properties of ink are pivotal in influencing various aspects of the inkjet process and determining jetting behaviour. These characteristics directly affect the pumping ability of the printhead, drop behaviour during ejection, dynamics of in-flight jetting, break-up patterns, post-jetting meniscus damping profile, and the refilling capacity of the ink channel.

Optimising the bulk properties of inkjet inks to meet printhead specifications during formulation alone is insufficient for ensuring reliable jetting. Minor adjustments in ink components or batch variations can notably change the high-frequency viscoelastic properties of inks in the printhead channel during waveform actuation and the subsequent in-flight non-linear extensional viscoelastic properties during ejection. These changes impact fluid flow dynamics in the printhead, in-flight jetting, and break-up behaviour.

In exploring high-viscosity and high-solid-loading inks within the inkjet industry, it becomes evident that only a specific subset of high-viscosity inks reliably jet, while others with similar bulk properties may encounter issues. On the contrary, aqueous inks, containing water with distinctive bulk and dynamic properties like speed of sound and dynamic surface tension, pose challenges during ink formulation and jetting reliability by influencing fluid interactions in the printhead micro-channel during waveform actuation.

We will present advanced inkjet ink characterization techniques aimed at quantifying the complex rheological properties of inkjet under conditions similar to those encountered in the printhead channel and during in-flight inkjet printing. Real case examples will illustrate how these sophisticated rheological analyses are applied in (i) developing and quality controlling inks to differentiate between seemingly identical inks resulting in different jetting behaviours and (ii) recommending optimal jetting temperature, print frequency, and waveform conditions.

9:50 **Introduction of "GELART JET" Technology: Expanding Graphic Painting based on Valvejet Technology,** *Ryo Idehara, RICOH Digital Painting Company Ltd. (Japan)* **A-11**

Ricoh Digital Painting Co., Ltd. is a venture company that has provided new value and solutions with unique technology and products. This time, we will introduce an example of a system configured by combining multiple types of GELART JET heads and special ink. We hope this presentation will serve as a valuable resource to enable all of you to connect the potential of our innovative GELART JET technology for your own applications.

10:10 **Transforming Industrial Manufacturing: Harnessing the Potential of Ultra High Viscosity Jetting for Functional Printing,** *Ramon Borrell, Quantica GmbH (Germany)* **A-13**

The potential for transforming industrial manufacturing lies in the utilization of jetting ultra high viscosity fluid, merging the scalability, flexibility, and digital printing capabilities of inkjet technology with the superior properties of functional materials.

Capability to jet ultra high viscosity fluids by drop on demand inkjet well beyond state of the art was first announced in 2021 by Borrell et al. At the time only small printheads with limited commercial capabilities had been built and tested, but a tentative specification for a commercial printhead was anticipated. For the past two years substantial progress has been made in optimisation of the underlaying actuator technology, enabling jetting up to 380mPa s in lab conditions, close to 10,000mPa s at 20 C. The commercial spec however has been set at 250mPa s when using Newtonian fluids. The new technology has been named Novojet.

10:30 **A New Printhead Generation that Breaks Barriers of Inkjet Technology in Terms of Resolution and Ink Viscosity,** *Patrick Galliker, Scrona AG (Switzerland)* **A-15**

A new type of ultra-high resolution inkjet printhead will be presented, its guiding principles of electrohydrodynamic (EHD) ejection and how it can be applied in the area of functional printing, particularly in semiconductor/electronics and display markets. As the core differentiation factor the EHD process will be elaborated and how it can help break barriers in viscosity and resolution. In comparison to traditional inkjet technology, EHD does not create pressure inside the nozzle which is prone to heavy flow resistance and viscous dissipation but instead relies on a pulling-mechanism, where the force required for droplet generation is directly formed inside the ink itself, with the benefit that all energy is created exactly where it is required and in a focused manner that enables ejection of droplets that are substantially smaller than the nozzle itself.

EXHIBITS AND COFFEE

10:50 - 11:20

NOVEL MICRO-MANUFACTURING TECHNOLOGIES

Session Chair: Mathieu Soutrenon, ISI, HEI-VS, HES-SO University of Applied Sciences and Arts Western Switzerland (Switzerland)
11:20 - 12:20

11:20 **The Possibilities for Printhead Manufacturers of Next Generation Electroforming,** *Dave Dekker, Nicolas Hildenbrand, and Michel Duits, Veco Precision (the Netherlands)* **A-17**

Electroformed nozzle plates have long been a common sight within inkjet printheads. Veco Precision has over 40 years' experience in this field and now introduces new possibilities using advanced lithography electroforming.

Veco is a world-leading manufacturer of micro-precision parts. It serves the world's most innovative, hi-tech companies from industries that demand high quality and precision.

To meet customers' specifications and demands, Veco has developed high standards of performance in Electroforming. This technology allows a powerful combination of precision and economical production; for high volumes and prototypes, standard and custom-made products.

11:40 **Innovative Fabrication of Glass Nozzle Heads, Ink Manifolds, and Nozzle Guards for Advanced Inkjet Printheads using LIDE Technology,** *Rafael Santos, Norbert Ambrosius, Aaron Vogt, and Roman Ostholt, LPKF Laser & Electronics SE (Germany)* **A-19**

Inkjet printheads play a pivotal role in modern printing technology, demanding high precision and durability. This paper presents a groundbreaking approach to fabricating essential components of inkjet printheads by using glass as the core material, namely nozzle heads, ink manifolds, and nozzle guards. With Laser Induced Deep Etching (LIDE) technology, we achieve excellent outcomes in terms of positional and dimensional accuracy, surface quality, and functionality due to the design freedom LIDE provides.

Glass has unique properties and LIDE allows leveraging them to create high-precision glass nozzle plates with a wide range of nozzle dimensions, pitch and arrangements, in different cross-section geometries such as straight through-holes, tapered, V-shaped, and funnel-shaped. The resulting glass components exhibit exceptional chemical resistance, thermal stability, abrasion resistance, high rigidity providing mechanical stability, while also exhibiting very high transparency which could be of high interest when using UV-curable inks, for example. We demonstrate the versatility of LIDE by fabricating surface structures and through-glass structures in the same substrate and process step, allowing the fabrication of ink manifolds with complete design freedom. Our technology doesn't generate any defects and maintains all the material characteristics of glass, particularly mechanical ones, which is of particular importance for glass-based nozzle guards.

12:00 **Ultrafast, 3D Laser Micro-manufacturing of Novel Glass-based Microfluidics,** *Davide Farina, FEMTOprint SA (Switzerland)* . . **A-21**

The present work aims to introduce the novel FEMTOPRINT® microfabrication technology, based on ultrafast laser and chemical wet etching processing, to create three-dimensional, high-precision patterns into transparent, glass materials for a wide range of applications and microdevices. Thanks to the ability to generate 3D geometries with micrometric precision, to treat surfaces to achieve optical transparency on virtually any surface topography, and to laser weld hermetically microdevices without the need of glue or adhesive, new horizons for integrated microfluidics are yet to be explored. More specifically in the inkjet industry, novel micronozzle arrays with a high degree of shape freedom and features dimensional repeatability over centimeter long substrates, within an exceptionally stable material as it is glass, can be now conceived at an industrial scale. Beyond that, the technology enables the integration of certain functional coatings to modify surface properties or the application of 3D electrodes, contributing to a new microfabrication approach suitable for a wide spectrum of microfluidic devices.

EXHIBITOR PRESENTATIONS III

12:20 – 12:40

Advanced Inkjet Technology 2024 Exhibitors provide an overview of their services/products:

- PromFR
- Polytype
- Quantica
- OPTIMAE INNOVATIONS/FOODINK
- Seiko Instrument Gmbh
- Veco

LUNCH

12:40 - 14:00

LATEST NEWS ABOUT INKJET PRINTHEADS

Session Chair: Ramon Borrell, Quantica GmbH (Germany)

14:00 - 15:20

14:00 **A Numerical Analysis of Piezoelectric Inkjet,** *San Kim, Dong Kee Sohn, and Han Seo Ko, Sungkyunkwan University (Republic of Korea)* **A-23**

The jetting behavior and pressure inside the piezoelectric inkjet head was investigated using numerical methods. A computational fluid dynamics model was developed for a cylindrical inkjet head, facilitating the calculation of multiphase flow and acoustic pressure wave propagation. This developed model reliably simulated jetting and meniscus behaviors. In addition, a lumped element method model was constructed to quickly predict the internal pressure and flow rate. Both numerical models demonstrated good agreement in their pressure calculation. The developed numerical models can provide practical information that is challenging to obtain experimentally and can be employed to optimize the operating conditions, such as the waveform shape.

14:20 **Epson's MEMS Technology: PrecisionCore—Development Strategy and Future Plan,** *Eiju Hirai, Seiko Epson Corporation (Japan)* **A-25**

PrecisionCore is a next-generation inkjet printing technology created by Epson. It achieves excellent image quality even as it greatly boosts print speed. In addition, it significantly expands the range of inks that can be used and materials that can be printed. PrecisionCore was created by merging high-precision MEMS fabrication processes, thin-film piezoelectric (TFP) technology, and more with Epson's inkjet technology and experience accumulated over many years.

In this presentation, we describe the strategy used to develop thin-film piezo and MEMS technologies, along with technical details, and describes how we plan to evolve them in the future.

14:40 **Xaar's Ultra High Viscosity Technology: Redefining the Boundaries of Inkjet Printing,** *Renzo Trip, Angus Condie, and Karl Forbes, Xaar plc (UK)* **A-26**

The ability of Xaar printheads to jet high viscosity fluids for 3D applications has been known for several years. How can traditional and upcoming inkjet markets, such as ceramics, labels and direct-to-garment, benefit from a high viscosity fluid? It will be shown that Xaar's Ultra High Viscosity Technology is redefining the boundaries of inkjet printing.

15:00 **Development of Effective Driving Methods for Inkjet Drop-on-demand Jetting of High Viscosity Liquids,** *Takayuki Shimizu and Masakazu Hirata, SII Printek Inc.; and Masanori Tamura, SEIKO FUTURE CREATION INC. (Japan)* **A-27**

Drop On Demand inkjet printheads are widely used for imaging applications and have the potential to be used in various production processes in the future. However, the upper limit of liquid viscosity that enables stable jetting is less than 20 mPa-s for most products. Therefore, we investigated a method for jetting high-viscosity liquids exceeding 20 mPa-s using SII Printek's RC1536 head, which has an advantage in high-viscosity liquid jetting. As a result, we confirmed that the heat generated by the actuator contributes to the high viscosity jetting by actual measurement and simulation.

POSTER SESSION AND COFFEE

15:20 - 16:40

Fully Integrated Airflow Visualization System for Improved Inkjet Printing, *Johannes Renner, Jonas Maturo, Vincent Schneuwly, Benoît Sahli, Yoshinori Domae, and Gioele Balestra, iPrint, HEIA-FR, HES-SO University of Applied Sciences and Arts Western Switzerland (Switzerland)* **A-29**

Several new inkjet printing applications require high throw distances or high printing speeds. In such configurations, complex airflows occur in the gap between the printhead and the substrate, potentially jeopardizing the print quality by deviating the ink droplets. To better understand the airflow effects on the droplet's trajectories, a novel inkjet printing platform has been developed. The latter allows the full control of the different parameters, from the laser sheet intensity to the axis motion, to the fog generation, to the print head driving waveform. The system has been fully automatized and allow for large parametric study to be performed, key for unstable flows requiring for statistics.

Inertial Microfluidic based Particle Sorting Device, *Thibault Maillard and Gioele Balestra, iPrint, HEIA-FR, HES-SO University of Applied Sciences and Arts Western Switzerland (Switzerland)* **1**
More and more functional inks are developed to enlarge the applications of inkjet printing. Yet, the stability of the inks is often challenging. For example, particles might agglomerate and clog the printhead, eventually compromising the whole printing process. Having a reliable filtering system is therefore key for complex inks. Here, we present a novel passive filtering system based on the inertial microfluidic concept that can potentially be used to filter inkjet inks in a continuous manner. The system has been first optimized thanks to numerical simulations and then characterized experimentally.

New Designs and Manufacturing Possibilities for Inkjet Print Head Nozzle Plates, *Jonas Maturo, Johannes Renner, Jérémy Vuilleumier, Yoshinori Domae, and Gioele Balestra, iPrint, HEIA-FR, HES-SO University of Applied Sciences and Arts Western Switzerland (Switzerland)* **5**
The design of today's inkjet printheads is often limited by the micromanufacturing methods used. Furthermore, today's inkjet technology suffers from several limitations in term of ink viscosity, particle size and jetting distance. Yet, new micromanufacturing technologies have been recently developed. In this work, we explore the potential of using femtosecond laser glass micromanufacturing to fabricate inkjet printheads parts. The performance of such modified printheads is compared to their commercial counterparts.

Smart Materials by Inkjet, *Muriel Mauron[1], Lucie Castens Vitanov[1], César Michaud[1], Raphaël Wenger[1], Derek Kiebala[2], Roseline Nussbaumer[1], Gilbert Gugler[1], and Stephen Schrettl[2]; [1]iPrint Institute, HEIA-FR, University of Applied Sciences and Arts Western Switzerland and [2]Adolphe Merkle Institute, University of Fribourg (Switzerland)* **A-31**
There is growing interest in voxelated matter as it allows to build up tailored made surface functionalization and innovative new gradient materials. Inkjet-based printing is the only method that can create voxelated materials with high precision, digital and extremely versatile through high controlled formation of small pico-liter droplets. In this case the droplet will be the smallest material unit called voxel. The spatially controlled deposition allows to functionalize surfaces, build materials gradients, and combine different materials to generate printed surfaces with new features. In this way, the preparation of surfaces and coatings with a tailored functionalization and performance on demand becomes possible.

Through the vehicle of inks with different softness grades, which are doped with mechanochromic additive, we have developed a multi-material inkjet platform, which allows to create gradient materials with new performance. The additive has helped to characterize this new kind of materials on one hand and on the other hand it will be the start of creating new smart materials with gradient properties by inkjet. The first drop casting tests of these two inks has proven the mechanochromism by the measurement of the ratio between the intensity of the monomer and the excimer under UV light. The intensity in the mixing zone was measured at different strain. Finally, it was proven that the hardness in the mixing zone could be defined.

Combining Laser Engraving and UV-Inkjet Printing for Personalization of Security Documents, *Philip Kessler, Vincent Schneuwly, Fabrice Roubaty, Guillaume Guinot, Gilbert Gugler, and Yoshinori Domae, iPrint Institute, HEIA-FR, HES-SO University of Applied Sciences and Arts Western Switzerland (Switzerland); and Mauro Costantini, Riccardo Pogliotti, Corrado Caizzi, and Rudi Bressan, IXLA s.r.l. (Italy)* **A-33**
Italian company IXLA partnered with the iPrint Institute to develop a ground-breaking solution for decentralised desktop colour inkjet printing within IXLA's laser engraving machines, addressing the demand for larger colour images and innovative security features in the personalisation of security documents. The project followed iPrint's 'digital manufacturing' process, including materials analysis, ink selection and extensive testing. The resulting 'XPrint' platform, which was unveiled at the TRUSTECH exhibition in Paris in November 2023, attracted considerable interest. The collaboration facilitated the in-house development of XPrint and helped position IXLA as a leading player in the personalisation of security documents. The future plans include delivery of first platforms in 2024, ongoing work to improve processes and a focus on developing new security features by combining laser and inkjet technologies. The aim is to exploit the full potential and synergies of both technologies for revolutionary, cost-effective and easily detectable security features.

Multi-nozzle Inkjet 3D Printing with CNC Motion, *Johannes Renner and Vincent Nidegger, iPrint, HEIA-FR, HES-SO University of Applied Sciences and Arts Western Switzerland (Switzerland)* **9**
3D printing with current multi-nozzle drop on demand print heads is lacking in terms of surface quality (without post treatment) or printing of overhanging structures without support material in contrast to single nozzle inkjet 3D printing (where the part perimeters are printed with a CNC motion), which in turn is lacking in terms of volume throughput (and therefore only used for the fabrication of small parts) as everything has to be printed with one nozzle. In order to print with enhanced surface quality and overhanging structures—free of support material—as well as reasonable productivity for the production of larger 3D parts, a printing process for industrial multi nozzle printheads with CNC printing motion was developed. First 3D parts printed with paraffin wax were produced and characterized to estimate the potential of this process.

Lateral InkJet Printhead for Narrow Gaps, *Marco Hölzle, Urs Lippuner, Michelle Müller, Aaron Lenherr, Raneem Achor, Katrin Albrecht, and Rudolf Buser, Eastern Switzerland University of Applied Sciences (Switzerland)* **A-35**
A novel concept in inkjet technology exploits the intrinsically low design height of MEMS components. Since the nozzle is not attached at the front but laterally, drops can also be deposited in narrow gaps. Two different types of fluid displacement mechanisms have been deployed, a time controlled electromagnetic valve and a piezoelectric actuation. Thus, two types of MEMS-based printheads of only 1 mm thickness were developed and characterised with application related inks.

PIEZO SELF-SENSING: UNLOCK NEW OPPORTUNITIES

Session Chair: Kye-Si Kwon, Soonchunhyang University (Republic of Korea)
16:40 - 18:10

16:40 **FOCAL TALK: Why Inkjet Printing Systems Need Closed-loop Control,** *Yoshinori Domae, iPrint HEIA-FR HES-SO (Switzerland)*
Inkjet technology, especially inkjet printheads, which are the key components to configure and realize it, have been forced to align many related technologies and peripheral elemental components to complement or conceal them due to the difficulty caused by their imperfections and sensitive nature. For example, optimization to prevent individual printhead variation in printing results, technology and system design to ensure quality and stability during continuous printing, knowledge and know-how for operators to properly manage printing equipment, and appropriate operating conditions and environmental requirements to ensure that printing equipment continues to operate without problems, and many other aspects must be taken care of. The complexity and subtlety (i.e., fragility) of inkjet integration with such inkjet printheads, as well as the investment and development time required to achieve the industrial-

ization necessary for such integration, have been factors in the lack of success of many new industrial inkjet applications and are one reason why they have not yet emerged as a next-generation digital production technology. This session focuses on closed-loop control with the inkjet printhead. Therefore, my focal talk will show what is happening in and around the inkjet printhead and its surroundings during and after printing, and what problems are caused by these events that are undetectable due to the current open-loop control condition.

17:10 **Recent Progress in Inkjet Monitoring based on Piezo Self-sensing,** *Kye-Si Kwon, Jeong Yeop Jo, and Sang Hyeon Park, Soonchunhyang University (Republic of Korea)* **A-36**

Inkjet technology, a maskless additive manufacturing process, utilizes multiple nozzles to selectively deposit ink at precise locations. This process offers significant material efficiency, minimizing waste and making it well-suited for additive manufacturing. Moreover, inkjet technology boasts exceptional throughput capabilities, employing numerous heads equipped with tens of thousands of nozzles simultaneously ejecting ink at frequencies exceeding tens of kHz. However, the reliability of ink ejection across all nozzles remains a critical challenge in implementing inkjet technology. Even after rigorous efforts, such as pre-printing vision inspections, to identify and select properly functioning nozzles, it remains difficult to actively address ejection defects that may arise during the printing process. This research project aims to develop and demonstrate a comprehensive monitoring and printing system capable of scanning tens of thousands of nozzles in real-time, effectively preventing printing defects caused by misfiring or poor ink ejection. To achieve this goal, a modularized sensing and data processing unit is developed for commercial inkjet heads. This unit is designed for seamless integration into the connection ports of commercial heads. The modular design enables the monitoring of up to 64 heads simultaneously, allowing for real-time monitoring of over 65,000 nozzles within 3 seconds. The system's effectiveness is demonstrated through simultaneous monitoring of two heads, showcasing zero-defect printing enabled by real-time classification and selection of normally functioning nozzles.

17:30 **In-process Ink Rheology Monitoring for Inkjet Printing using Piezo Self-sensing,** *Sebastian Filliger, Luca Brügger, Julian Piller, Gaël Perritaz, Loïc Bullot, and Carlos Chabert Ull, iPrint, HEIA-FR, HES-SO University of Applied Sciences and Arts Western Switzerland (Switzerland)* **14**

Inkjet is gaining popularity in digital production for its high flexibility, productivity and compatibility with many substrates. The core of the inkjet system is the printhead, a sophisticated device depositing ink accurately and on demand through thousands of independent nozzles. However, the complexity of the printhead presents challenges for maintenance and stable operation. Therefore, maintaining precise control over all process parameters is essential to ensure consistent quality and optimal performance.

Ink rheology is an important process parameter to control. Changes in rheology caused by solvent evaporation, ink aging, sedimentation or simply a slightly different formulation of the manufacturer can lead to major quality flaws in the printing process. Commercial solutions for rheology measurements can typically only measure viscosities at frequencies of up to 10 kHz and the measurement takes place outside of the printing process.

Here, a measurement system has been developed, which can monitor the rheology in the process at internal resonance frequencies of 100-200 kHz using only the printhead as the measurement device together with printing electronics which has piezo self-sensing capabilities. This system is an upgrade to a previously developed and industry tested nozzle status monitoring system that uses the piezoelectric effect to map printhead internal acoustics for nozzle failure detection.

17:50 **Piezoelectric-based Monitoring of Pressure Variations in Inkjet Printhead,** *Loïc Bullot, Carlos Chabert Ull, Sebastian Filliger, and Luca Brügger, iPrint, HEIA-FR, HES-SO University of Applied Sciences and Arts Western Switzerland (Switzerland)* **21**

The popularity of inkjet technology is growing in the industry due to the many benefits it brings. However, the complexity of the process and hardware required to deliver a drop on demand accurately and at high speed poses a reliability challenge. With many complex parameters in the ink and printhead affecting drop quality, maintaining a stable environment is key.

There has been increasing interest in sensing technologies that use the piezoelectric actuator in the nozzle to measure the acoustic response of the nozzle chamber. Several papers have been published on the use of piezo sensing to detect nozzle status.

The aim of this paper is to present an innovative way of measuring the ink pressure within the nozzle chamber by sensing piezoelectric sensing. Driving and measurement are performed using custom hardware to quantify the acoustic response of the system after actuation of the piezo. The variations in the dominant frequency of the response signal can then be correlated with variations in pressure.

This method makes it possible to measure pressure variations along the print head, opening up a range of new possibilities for identifying events that can have a direct impact on print quality.

TRANSPORTATION TO/FROM AND CONFERENCE DINNER

18:20 - 22:50

WEDNESDAY 31 JANUARY 2024

KEY TECHNOLOGIES OF INKS: FORMULATION, SUPPLY, AND DRYING

Session Chair: Katrin Albrecht, OST - Eastern Switzerland University of Applied Sciences, IMP - Institute for Microtechnology and Photonics (Switzerland)

09:00 - 10:20

09:00 **Customized Design of Dispersing Agents and their Application: Improving Inkjet Ink Reliability and Performance,** *Nils De Vos, ChemStream bv (Belgium)* **A-38**

How to tackle the design of an (inkjet) ink? What are some of the pitfalls? Important components of the ink can be found in the dispersion, and more specifically the dispersing agent(s), and resins such as binders. These polymers can have large effects on ink stability, rheology and other important physical phenomena such as adhesion on substrates, drying of the ink etc. By applying a targeted design to e.g. a dispersing agent one can achieve much better control over the aforementioned parameters of inks.

9:20 **Printing Semiconductors Pixel by Pixel,** *Franziska Krieg, Avantama AG (Switzerland)* **A-40**

In the last years the Perovskite nanocrystals (PNC) have gathered enormous attention from worldwide scientific community, due to their outstanding optical properties. High photoluminescence quantum yields in combination with narrow emission widths and high absorption coefficients are unbeatable by any quantum dot technologies. Avantama AG pioneered work on commercialization of PNCs into the display industry. This presentation will show advantages as well as challenges of using PNCs in broad variety of display technologies ranging from LCD, OLED to micro-LED with a focus on their device inclusion using additive printing technologies.

9:40 **Liquid Diaphragm Pumps for Controlling Meniscus Pressure in Stationary and Moving Printheads,** *Raphael Frey and Manuel Roos, KNF Flodos AG (Switzerland)* **A-42**

Pressure pulsations and the ability of a pump to respond to pressure changes are key properties in order to control meniscus pressure in a printhead. New, specially designed liquid diaphragm pumps with integrated dampeners achieve low pressure pulsation levels so that they can be used directly to operate a statically mounted print head. Meniscus pressure can be controlled directly with the pumps, no ink reservoir with control chamber is needed. Furthermore, if the rotary drive is replaced with a specially designed drive a pump with fast reaction velocities and low pressure pulsation levels can be obtained. Such diaphragm pumps can be used to control meniscus pressure for a printhead which is moved at high acceleration levels. No additional dampeners or active pressure compensation devices are needed.

10:00 **Drying as a Digital Process,** *Thomas Poetz, 3T Industry InkJet Consulting (Germany), Gunther Ackermann, Lambda Technology GmbH (Germany), and Christian Gächter, Lambda Technology GmbH (Austria)*

The market for drying systems will change overall in the coming years. Energy and emissions are key drivers (climate protection). Analogue drying systems, as they are currently still used in many printing applications, will have to disappear.

The answer is digital drying technology - and the very flexible and targeted use of hybrid elements. By selectively combining NIR and IR with air, hybrid drying technology works for a variety of surfaces and with more functionalities.

For the Digital Printing process, the correct cross-linking of the prints is required after drying. This process can be done in one step with hybrid dryer systems. Hybrid dryer systems optimise the use of energy resources.

With the monitoring elements in the dryer units, these dryer systems are prepared for industrial use in Industry 4.0.

Drying waterbased inks is a process you need additional air circulation.

The decisive advantages of Lambda Technology's dryer technology for various aqueous applications in printing technology are the continuous availability and the possible 24/7 operation, even for printing applications with very high ink throughputs.

COFFEE AND EXHIBITS

10:20 - 10:50

WHEN INK DROPS MEET SUBSTRATES

Session Chair: Gilbert Gugler, iPrint (Switzerland)

10:50 - 12:30

10:50 **KEYNOTE: Inkjet Dot Spreading and Liquid Penetration: Modeling and Analysis from Solid- and Liquid Surface Energies,** *Ulrich Hirn, Graz University of Technology (Austria)*

In inkjet printing, spreading and ab-sorption processes determine the final area of a printed dot, which is decisive for print quality in terms of coverage and resolution. In this work, the printed dot area of overall 140 paper-liquid pairings representative for the operational window of an inkjet printer is evaluated. The results are explained by a model including spreading, absorption, and evaporation. The surface tension and viscosity of the liquids, as well as the pore size and polarity of the substrates were varied systematically to represent the range of uncoated paper-liquid pairings applicable for inkjet printing. We propose a novel modeling approach for liquid wetting and liquid penetration from surface energies of substrate and liquid. For this purpose, the contact angle and liquid penetration is modeled by polar and dispersive surface energies, utilizing the theories of Owens-Wendt-Rabel-Kaelble (OWRK), Wu, or van Oss, God, Chaudhury (vOGC).

11:40 **Decorating Polystyrene Puzzle Pieces Straight from the Moulding Tool and Going Straight to the Printing Line,** *Klaus Ammann, Mankiewicz Gebr. & Co. (Germany)*

The widely used plastic moulding technology can be implemented very well in a production cell. Integrating additional production steps, such as direct printing, brings considerable time and cost benefits.

However, this requires additional development work and adaptation of the process and chemistry. Only then can "inline production cells" be realised from such production cells.

At Mankiewicz, we started working with customers and machine manufacturers at a very early stage to develop solutions together. I will talk about this in this presentation.

12:00 **Decreasing Measurement Error for Rub Resistance of Printouts Located on Previously Bent Substrates: Development of Device and Method,** *Frédéric Mondiot, Claudiu Neagu, Serge Marchioni, and Frédéric Bodino, Markem-Imaje; Philip Kessler and Benoît Sahli, iPrint Institute, HEIA-FR, HES-SO University of Applied Sciences and Arts Western Switzerland; and Jan Huber and Gabrielle Thurnherr, iSIS Institute, HEIA-FR, HES-SO University of Applied Sciences and Arts Western Switzerland (Switzerland)* **25**

Rub resistance is a parameter of major importance for the quality of inkjet printouts used in marking and coding. Yet, it becomes challenging to evaluate when the substrate has been bent prior to testing, like in the case of electrical cables, wires, or optical fibers.

This communication presents a solution embodied by a prototype machine specifically designed and built for this purpose and a testing method associated with it. In particular, all the parameters of interest, i.e. the bending speed, angle and radius, and the rubbing speed and applied force can be adjusted over a range representative of the real industrial constraints. The processing of the data allows for a precise quantification of the rub resistance of the ink printed on previously bent substrates.

12:20 **Closing Comments**

LUNCH

12:30 – 13:50

IPRINT PRESENTATION & VISIT

14:00 - 15:00

EXHIBITOR DEMONSTRATIONS

14:30 - 17:30

THURSDAY 1 FEBRUARY 2024

ADVANCED INKJET WORKSHOP

Separate registration required

8:30 - 17:30

IS&T CORPORATE MEMBERS

STRATEGIC PARTNERS

Adobe

Google

Meta

SUSTAINING

Qualcomm

xerox

SUPPORTING

Dolby

hp

RICOH

DONOR

APPLIED IMAGE

COLORADO STATE UNIVERSITY

DXOMARK

Felix Schoeller Group
Best Performing Papers. Worldwide.

FUJIFILM

Image Engineering
MEMBER OF THE NYNOMIC GROUP

NTNU
Norwegian University of Science and Technology

OMNIVISION

TELELUMEN
The Recording and Playback of Light

APPENDIX A: EXTENDED ABSTRACTS

The Power of Waveforms and How to Find the Perfect One

Raphaël Wenger, Droptimize Sàrl, Marly, Fribourg, Switzerland

Abstract

Achieving an optimal print quality in inkjet application relies on the precise definition of waveform parameters. This process, however, remains a challenging scientific endeavor characterized by its complexity and a lack of well-defined methodologies. In this presentation, we will dive into the science behind optimizing waveforms. One major challenge lies in balancing factors like drop volume, speed, and stability to achieve the desired print quality. We'll explore the latest developments, such a machine learning and iterative solvers. These algorithms rely on big data to analyze vast datasets of printing outcomes, helping to refine waveform settings for improved quality. Such innovations may revolutionize this field, making high-quality, precise prints more accessible across various applications, from graphics to functional electronics.

Context

The search for optimal print quality in inkjet applications relies on the fine tuning of waveform parameters, a challenge underscored by complexity and a scarcity of well-established methodologies. This process typically relies on time-consuming iterations by rare specialists, with results entirely dependent on their expertise. The delicate balance of all key factors (Figure 1) relevant to the print quality remains a significant challenge, prompting an exploration of innovative approaches.

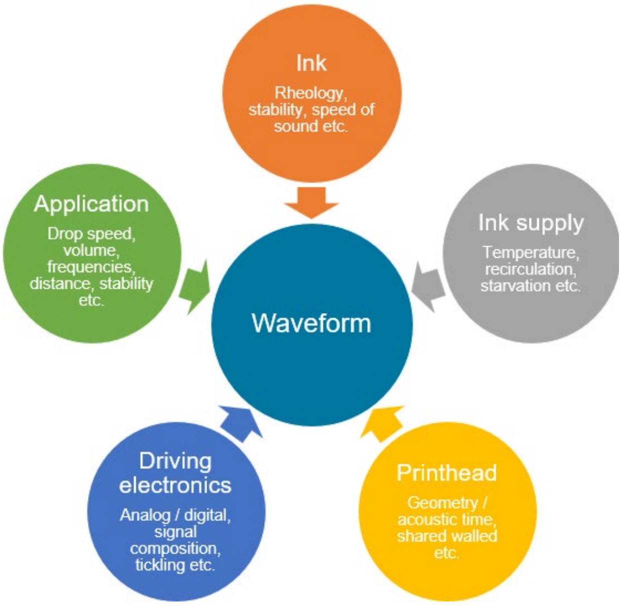

Figure 1: Key factors relevant for waveform tuning

Recent advancements have introduced novel methodologies relying on big-data. These technologies introduce adaptive, data-driven strategies for waveform optimization. Their potential lies in their ability to address the multidimensional aspects of the challenge.

Machine Learning

Machine learning algorithms excel in discerning patterns within voluminous datasets. In the context of waveform optimization, they can not only analyze drop size, speed, and stability but also their intricate correlations with ink rheology and any other quantifiable inputs. The adaptive nature of machine learning allows it to learn from diverse printing scenarios, enabling the development of comprehensive models that inform refined waveform settings. The key differentiator is the reliance on data-driven insights to optimize parameters based on a holistic understanding of the printing process.

A recent study [1] investigated the use of a machine learning-based predictive model for jetting behavior that incorporates the Deborah number, the Ohnesorge number, and the waveform parameters. The final predictive model exhibited remarkable accuracy for an unknown ink based on waveform parameters, and the correlation between jetting behavior and ink properties proved reasonable.

Iterative Solvers

Iterative solvers, by contrast, operate through an evolving, trial-and-error mechanism. These solvers iteratively refine waveform parameters based on feedback from prior print outcomes. This iterative process allows for continuous improvement by learning from mistakes and successes. While machine learning focuses on comprehensive data analysis, iterative solvers adapt by refining settings in a more dynamic, evolving manner. The iterative approach is particularly effective in scenarios where the optimization landscape is not fully understood, allowing for a gradual convergence towards optimal settings.

Droptimize investigated the development of an iterative solver through a collaboration with the Bern University of Applied Sciences. The algorithms developed within this study could identify the same optimal waveforms as an experienced operator in less than 100 iterations on a static dataset.

Future implications

The discussion encompasses the potential for a more holistic and adaptive approach to waveform optimization to make high-quality prints more accessible. By considering a broader spectrum of elements and leveraging novel big-data tools, the future of inkjet printing holds promises for enhanced precision and accessibility across diverse applications.

References

1] Seongju Kim et al 2023 Flex. Print. Electron. 8 035007 (2023)

Author Biography

Raphael Wenger received his BSc in Microtechnics from the Bern University of Applied Sciences in 2012 and his MSc in Biomedical Engineering from the University of Bern in 2018. He co-founded Droptimize with Florian Bourguet as a spin-off of iPrint in 2020. They developed their idea of automatized printing optimization into a software that they now use to provide services and integrated into a commercial dropwatching instrument. In parallel to this activity, Raphaël still works at iPrint as a Senior R&D Engine

Femtolitre drop generation in industrial inkjet printheads.

Fernando Rodriguez Llorente[1, 2]. [1] iPrint, HEIA-FR, HES-SO University of Applied Sciences and Arts Western Switzerland, CH-1700 Fribourg, Switzerland. [2] Meteor Inkjet Ltd., Harston, Cambridge CB22 7GG, United Kingdom.

Abstract

In this paper we report what we believe is the first-time observation of femtolitre drop generation from a nozzle in an industrial inject printhead. While femtolitre drops have been observed and reported, it has been mostly in the context of jet ligament thinning and subsequent breakdown into drops by Rayleigh-Plateau instability. This communication will show jetting of femtolitre size drops directly from the ink meniscus formed on the nozzle exit of two different industrial printheads. The printheads are from different manufacturers, with different microchannel and piezoelectric structures, and the two inks used are very similar, one of them having one extra polymer component used to increase the ink viscosity. The jetting events happen at random times, from immediately after the ligament detachment from the nozzle up to several hundreds of microseconds later. While the physical mechanism underlying this jetting phenomena is not understood, we will analyse our results and compare with existing theories small drop formation, to try to build an understanding of how this jetting process work.

Introduction

Industrial commercial inkjet printheads are widely used in printing and manufacturing processes where non-contact printing or variable data printing offer an advantage over contact fixed image printing. As printing technologies are a key enabler of many microfabrication processes, inkjet printing is finding wider applicability and acceptance in different and novel microfabrication processes. To meet the needs of the graphics industry and due to some engineering considerations related to the physical mechanisms used for drop ejection, industrial inkjet printheads have been designed to jet drops of volumes ranging from ~1pl to ~200pl. While this range is well suited for imaging, text and decoration applications, some microfabrication applications require smaller drop sizes down to the femtolitre volume range. A physical phenomenon that can generate femtolitre drops is therefore of great interest, as it could potentially be engineered into a device that can jet femtolitre drops on demand and be used in non-contact microfabrication processes.

Methods

To visualize femtolitre drops we needed to develop a sub-micron resolution stroboscopic drop microscope, commonly known as a dop watcher. The device we developed is now commercially available as a Meteor UltraSharp Optics drop watcher. The optical magnification of the microscope objectives used were x20 and x50, with numerical apertures of 0.42 and 0.55. The light strobe was a 452nm blue light LED with a pulse duration of 200ns.

Results

To visualize femtolitre drops a dop watcher was used. Nothing special was done to generate the drops, as they seem to occur spontaneously sort after a typical picolitre drop is jetted and its ligament has detached from the nozzle, for time durations of several hundreds of microseconds after this event. The drop size has some dependency on how the picolitre drop is generated. Typical waveform jetting picolitre drops at speeds of a few meter per second created these secondary drops of 1um to 2um in diameter. Slower drop waveform(~1m/s) can create, in addition of the 1um to 2um drops in diameter, drops with diameters of 3um to 6um.

Femtolitre drop generation in Ricoh Gen5

Femtolitre drops being ejected form a Ricoh Gen5 printheads can be seen on Figure 1 below. The drops start to appear from a few microseconds after the detachment of the main picolitre drop up to several hundreds of microseconds afterwards. Single, double and triple drop ejection have been noticed all across this time scale.

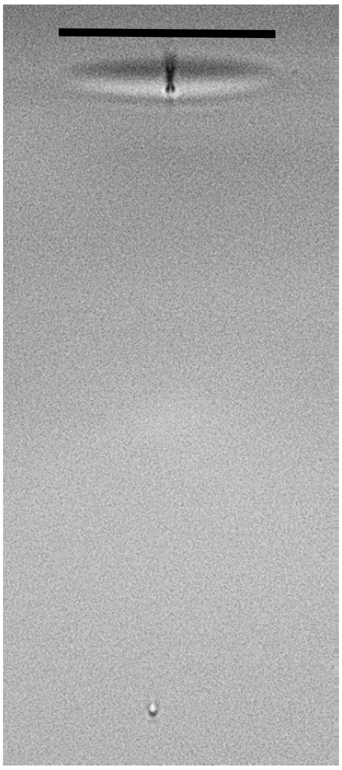

Figure 1. Femtolitre drops being ejected from a nozzle of a Ricoh Gen5 printhead. Black line is the same dimension as the nozzle diameter, 25um. Single flash exposure photograph.

Femtolitre drop generation in Dimatix Samba

Femtolitre drops being ejected form a Dimatix Samba printheads can be seen on Figure 2 below. The drops start to appear from a few microseconds after the detachment of the main picolitre drop up to several hundreds of microseconds afterwards. Single, double and triple drop ejection have been noticed all across this time scale.

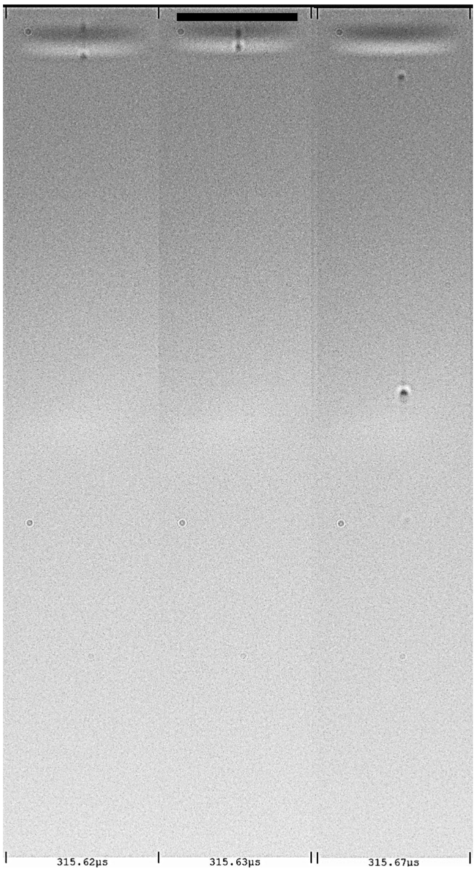

Figure 2. Femtolitre drops being ejected from a nozzle of a Dimatix Samba printhead. Black line is the same dimension as the nozzle diameter, 25um. Single flash exposure photograph, 300us after nozzle waveform excitation. The last frame shows two femtolitre drops jetted close in time to each other, at about 300us after the waveform actuation was finished.

Femtolitre drop generation in Ricoh Gen5 printheads

Two different sizes femtolitre drops being ejected form a Ricoh Gen5 printheads long time after the main drop ligament detachments (see Figure 3). A detailed view of the drops emerging form the nozzle can be seen in Figure 4.

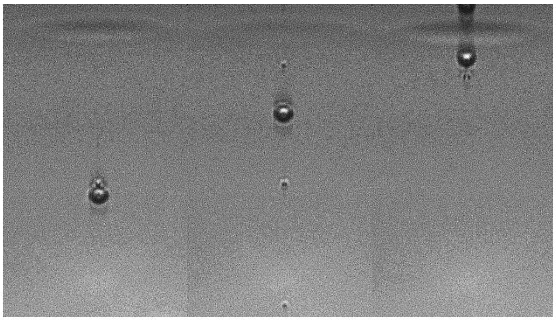

Figure 3. Two different sizes femtolitre drops being ejected from a nozzle of a Ricoh Gen5 printhead. Small drops are ~1fl to ~10fL, bigger drops ~100fL.

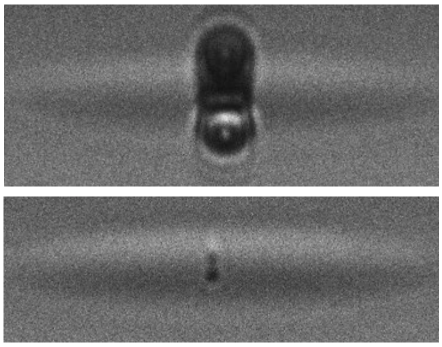

Figure 4. Detail of the moment of emergence from the nozzle of two different sizes femtolitre drops being ejected from a Ricoh Gen5 printhead.

Discussion

The ejection of femtolitre drops from two industrial inkjet printheads, Ricoh Gen5 and Dimatix Samba, has been detected shortly after the main drop filament detached from the nozzle until several microseconds later. The ejection seems to happen multiple times after one main drop (picolitre) ejection, at what appear to be random time intervals. Sometimes two drops are seen being jetted very close together.

Although it has not been possible to measure the drop velocity directly, this can be inferred for low blur caused by the 200ns light strobe. Form this we estimate the drops speeds to be of a few meters per seconds maximum.

Different size femtoliter drops can be generated by changing the jetting speed of the main picolitre drop. Smaller drops can generate bigger size femtolitre drops. Even when this is the case, smaller (1 to 10fL) drops are also generated.

Conclusion

This paper shows for the first time the ejection of femtolitre drops from the ink meniscus boundary of two industrial inkjet printheads. Although the underlying ejection mechanism is not currently well understood, we hope this result will raise the interest in this jetting mechanism and its potential for on demand femtolitre drop printing.

Acknowledgement

The author would like to acknowledge the help from his old colleagues Mathew Pullen and Istvan Szalai from Meteor Inkjet Ltd. Using and setting up Meteor Drop Watching and printing equipment.

This Author Biography

Fernando Rodriguez Llorente received his MSc and PhD in physics from the University Complutense of Madrid (1993, 1999). Since then he has worked in Research and Technology for electrical metrology, ultra long haul fiber optic communication, ultrasound non-destructive testing, big-data algorithm development and multiple aspects of inkjet printing for the last 15 years.

Novel Jetting Status Inspection Method for Acquiring the Spatial and Temporal Information of Ink-jetted Droplets

Dong-Youn Shin; Pukyong National University; Busan, Republic of Korea

Abstract

Inkjet printing has been widely used in conventional graphic arts, publishing, textile industries, and more. It has also been adopted in the production lines of TFT LCD TVs for forming a PI layer and depositing liquid crystal, and OLED/QD-OLED TVs for forming a thin film encapsulation layer and colorant subpixels. However, the jetting precision and reliability required for the color pixelation of QD-OLED TVs are far higher than those for conventional applications. Although all nozzles of inkjet printheads need to be inspected before printing, the existing jetting status inspection methods are incapable of inspecting tens of thousands of nozzles within a minute. Furthermore, they hardly provide historical data of nozzles whether they worked well during the inspection period. In this study, a novel jetting status inspection method is introduced that provides spatial and temporal information on the jetting status during the inspection period.

Author Biography

Dong-Youn Shin obtained his BS and MS in mechanical engineering from Seoul National University in Republic of Korea (1997), and UMIST in UK (1999). His PhD in materials science was obtained from UMIST in UK (2003). He served at LG Chem Research Park (2005~2006) and Korea Institute of Machinery and Materials (2006~2011) to develop ink-jet printed displays, devices, and equipment. After moving to Pukyong National University in 2011, his research has extended to electronic materials and photovoltaic devices fabricated by non-contact printing techniques.

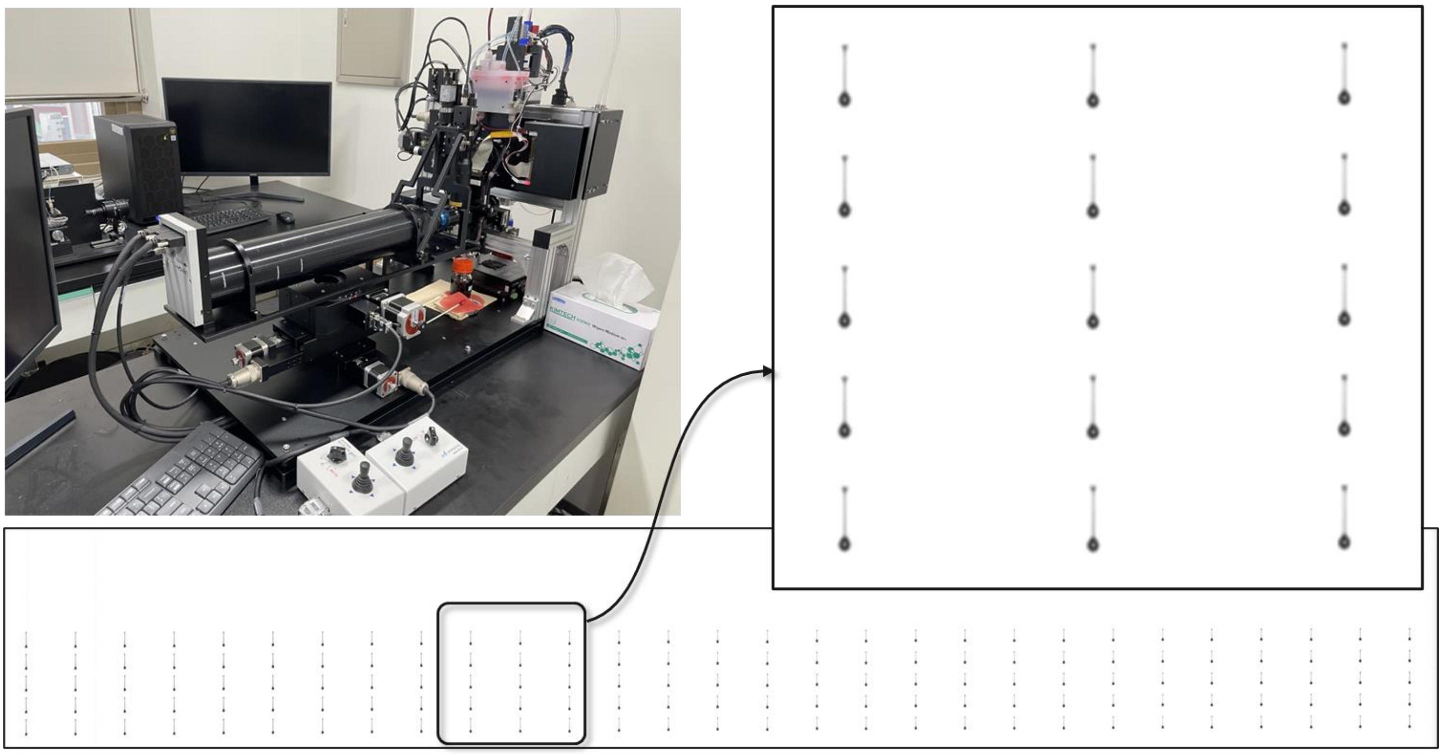

Figure 1. The developed rapid jetting inspection system which can inspect 58 nozzles of an inkjet printhead (KM1024i) at a time and provides the spatial and temporal information of individual droplets.

Biotech and printing technology for next generation computer storage

T. Karčnik, M. Matijević, R. Luzar
BioSistemika d.o.o., Ljubljana, Slovenia

Abstract

DNA holds exceptional promises as a medium for storing digital data due to its exceptional data density, data longevity, and maintenance-free storage. The key requirement of the "write-to-DNA" process is manipulating a massive number (millions per second) of minuscule droplets (pL) whose composition is determined on demand. The potential of Drop-on-Demand (DoD) printing technology for such an application is obvious, as it addresses several key challenges.

An experimental DoD based Liquid Handling Machine (LHM) was developed and used to synthesize digital data carrying DNA strands. The development challenges included ink development, maintaining cleanliness, establishing cleaning procedures, novel print head control, reliable mixing of many reagents, and preventing evaporation.

Limited amounts of digital data were successfully recorded on DNA strands using LHM while also clearly pointing out the challenges for further advancement of DNA based data storage technology.

Introduction

DNA holds great promise as a medium for storing digital data due to its exceptional data density, data longevity, and maintenance-free storage. Church [1] in 2012 was the first to successfully demonstrate the proof of concept. More research have followed since including attempts to commercialize the approach [2].

Background

The key requirement of the "write-to-DNA" process is manipulating a massive number (millions per second) of minuscule droplets (pL) whose composition is determined on demand. The droplets consist of a mix of chemical reagents, selected from a larger set, depending on the data to be recorded. Water-based inks serving as reagents, pure demineralized water, and various oils are used for DNA synthesis, cleaning, and evaporation prevention respectively. The potential of Drop-on-Demand (DoD) printing technology for such an application is obvious, as it addresses several key challenges.

Methods

We developed an experimental DoD based Liquid Handling Machine (LHM), used to synthesize digital data-carrying DNA strands. The output from LHM passes through sensitive chemical post-processing before proceeding to storage. The development challenges included ink development, maintaining cleanliness, establishing cleaning procedures, novel print head control, reliable mixing of many reagents, and preventing evaporation. Nevertheless, we have successfully recorded limited amounts of digital data on DNA strands using LHM.

Unlike standard printing, jetted ink is collected and mixed in individual wells of a standard well plate widely used in biotech. The number of different inks in the existing LHM exceeds 50 and may scale into thousands in the future. Also, the distance from printhead to the well bottom is more than 1cm what further complicates the matter. To address this, we developed both printhead electronics and firmware in-house that are also particularly focused on minimizing energy consumption and heat dissipation; the reagents for DNA synthesis are temperature sensitive so the whole printing process is done in a controlled environment. With an eye to the future, electronics can be scaled to handle many printheads and inks at best possible timing resolution.

Cleaning procedures are of special concern as inks are basically water solutions of bio-reagents such as buffers, enzymes, DNA building blocks (dNTPs), etc. So, inks are subject to contamination by environmental factors and patches of structures with mucus-like properties may form. That prevents successful chemical postprocessing and can also irreversibly clog the printhead filter and/or nozzles. The solution is to clean the printheads after each printing session. The ink supply system supports this through a series of valves so that the cleaning solution, pure water or ink can be delivered to each printhead. The pressure control system also supports all these options.

Results

To move the "write-to-DNA" tech to the next level we need to improve the speed of the entire process by a few orders of magnitude. Printing, as an isolated process, is not a bottleneck, but the postprocessing of well plates filled with inks is time consuming. We need to find a solution where the plastic well plates as a substrate are replaced by some other approach.

Acknowledgement

This project has received funding from European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 970550.

References

[1] George Church, Yuan Gao, Sriram Kosuri, Next-Generation Digital Information Storage in DNA, Science, 337, 1628 (2012).

[2] I. Shomorony, R. Heckel, Information-Theoretic Foundations of DNA Data Storage, Foundations and Trends® in Communications and Information Theory, 19, 1, (2022).

Author Biography

Tomaž Karčnik received his B.S., M.S. and D.Sc. from University of Ljubljana, Department of Electrical Engineering in 1990, 1993 and 1997 respectively. At the University he worked on the field of robotics and biomedical engineering. Later he served in CTO or similar roles in private companies working on instrumentation for particle accelerators, sensors and implantabile medical devices. Recently, he has leading the project for DNA based data storage co-funded by EIC Accelerator and Pathfinder grants.

Inkjet Platform for Additive Manufacturing Processes in Electronics Production

Jochen Seeser, David Hahn; Notion Systems GmbH; Schwetzingen, Germany*

Abstract

The presentation aims at providing an overview of the potential as well as limitations of additive technologies for the manufacturing of electronic devices. Inkjet printing of solder mask for PCB production will serve as a blueprint of an additive process that has been adopted successfully in mass production. Already saving the adopters energy and waste. At the same time, the 3D nature of inkjet printing has the potential to replace or simplify other electronic components.

The presentation will also give an insight in the vision of the EU funded TINKER project. Its goal is to provide a new cost- and resource efficient pathway for RADAR and LIDAR sensor package fabrication with high throughput, improved automation, improved accuracy and reliability to the European automotive and microelectronic industry via additive manufacturing.

Within the TINKER project, an advanced inkjet platform was developed which also includes components for IR-ink drying, UV curing and laser sintering. In the presentation it will demonstrate how fully digital inkjet printing expands the capabilities of conventional manufacturing processes with a maskless, multi material and high precision process.

Context

Notion Systems has demonstrated with a large and diverse installed base in various industries, that additive processes, in particular functional inkjet printing already has a positive impact on production efficiency. Inkjet technology is utilized to minimize waste and process steps to make the production of current products more efficient and sustainable. This presentation will offer insights into the use of functional inkjet printing for production of 3D waveguide structures and an ink jet wire bonding process. We will demonstrate how fully digital inkjet printing expands the capabilities of conventional manufacturing processes with a maskless, multi material and high precision process.

Objectives

High performance RADAR sensors integrated in automotive vehicles are indispensable for modern mobility applications. Current bottlenecks of RADAR systems are the relevantly large size of such sensor devices, their weight and power consumption. Here complex 3D waveguide antennas are beneficial a highly efficient alternative to the commonly used 2D patch antenna arrays, with the potential advantages of the reduction of RF material, what can be associated with a reduction in costs and reduction of power consumption due to increased antenna efficiency.

Additive manufacturing, especially multi-material inkjet printing, opens the possibility for further miniaturization of the RADAR systems by a digital deposition of conductive interconnections and shielding. This makes it possible to fabricate complex 3D waveguide antenna structures with inner metallization with shorter production time and reduced waste.

The objective is a prototype fabrication of RADAR sensor packages via inkjet printing.

The challenge is to develop a stable production process which not only includes the printing itself but also the pre- and posttreatment of all printed components.

Method

Developing, assembly and commissioning of an inkjet printer platform which includes components for IR-drying, UV curing and laser sintering. Developing a printing process for a 3D waveguide and an inkjet wire bonding process.

Results

First successfully printed samples of metallized waveguides. Realization of a "gap-filling" process to be one part of the planned inkjet wire bonding process.

Expected results: Realization of functional prototypes of the inkjet printed components.

Author Biography

David Hahn is currently VP Process R&D at Notion Systems. With over 12 years of professional experience in functional inkjet printing his focus and passion is to support the world's leading manufacturers in key high-tech industries. With his team he develops and scales up inkjet process solutions from lab to fab to produce products in a more ecological and economical way.

3D printed Electronics: Embedding AM Technologies in a Hybrid Process Chain for Customized Production of Micro-Mechatronic-Systems

J. C. Janhsen, O. Refle, L. Cirstea; Fraunhofer Institute for Manufacturing Engineering and Automation IPA; Stuttgart, Germany

Abstract

This paper presents a new approach to the production of microelectronic and mechatronic systems that combines multi-material additive processes with conventional manufacturing techniques. We show a fully automated modular hybrid machine platform comprising four central modules: 3D inkjet printing, material deposition, micro-assembly and UV/IR/NIR curing with integrated quality control. This platform enables the automated production of individualised microsystems in small quantities while ensuring scalability. This paper provides an overview of the project's vision, focuses on the hardware setup and gives an outline of the current process development.

Introduction and State of the Art

Additive Manufacturing (AM) technologies and the technological field of printed electronics, seem to be quite closely related at first sight. This leads to the fact, that printed electronics are meant to have the same degree of freedom as known from AM technologies. Vice versa, AM technologies tend to be sold as the most versatile technologies, even though the realistic benefits are mostly limited to a comparatively small bandwidth of applications where the area of microsystems and electronics is not included.

If both technological fields – AM and printed electronics – could be merged, the promises of both technologies might become much more realistic. Especially in the field of complex electronics and microsystems this would meet the increasing market demand for highly compact, individualized and smart electro-mechanical systems and products. Manufacturers therefore aim for advanced production technologies that can integrate in few stages and ideally at one site all (micro-) components and functionalities. However, manufacturing of complex micro-mechatronic systems is usually reserved to large companies and high-volume applications. Nowadays, multilateral processes in this field are time consuming, expensive and inefficient, for small lot sizes or individualized products. In many cases the market introduction of products fails as applicable process chains are not available or require a disproportionate investment. The introduction of AM methodologies has the potential to trigger a major step forward in microsystem-manufacturing by reducing the number of process stages. At the same time, this step opens new possibilities for tailoring product features to the specific needs of individual or small groups of customers.

In order to pave the way towards this vision, AM technologies either need to adapt the technological capabilities of mature and established technologies in the field of microsystems, or they need to be directly combined to a hybrid process chain, which utilizes the advantages of different technologies.

The approach of the NextFactory [1] project has chosen the latter option by implementing a hybrid process chain based on a multitude of different technologies. As a result, Surface-mounted device (SMD) components can be directly embedded in an all-in-one manufacturing process that follows the rationale of AM-technologies. At the same time, the promises of printed electronics may become a little closer.

In the field of printed electronics, screen printing is the most common technology [2]. It is based on masks and consequently, restrictions exist not only concerning geometrical freedom, but also concerning personalization and customization: Due to the use of costly masks [3] it is more suitable for large volume production than for individual microsystems [4]. Other conventional techniques used for printed electronics are gravure, flexography, offset and lithography printing [5].

Integration of electronic functionality – especially conducting tracks – in complex, three-dimensional constructs is state-of-the-art, even for individualized components: The expression “MID” (Moulded Interconnect Device) embraces different processes aiming at the integration of conducting tracks on free formed surfaces, resulting in complex, three-dimensional interconnect devices. The conductive tracks are normally applied within a post-processing step, e.g. by laser based processes.

There are currently two main companies offering 3D printed electronics based on inkjet technology: NanoDimension, based in Israel, and Fuji based in Japan, with its FPM Trinty printer. NanoDimension’s printing system “DragonFly” enables the production of complex 3D inkjet printed electronic structures, but currently lacks the ability to assemble components in-line, limiting the process to subsequent surface mounting of components.

Approach and Overall Process Chain

The state-of-the-art technologies neither offer the possibilities to directly integrate discrete components, nor do they implement an automated process, which achieves a sufficient degree of freedom concerning the arrangement of functional elements and materials like conducting tracks.

But each process itself has clear advantages and as a whole, the capabilities would be sufficient to manufacture functional and individualized micro-mechatronic systems. Based on this idea, the NextFactory process chain is combining five core processes into a holistic and interwoven process chain:

- *3D-Inkjet-printing*, is used for selective material deposition. Using different printheads, versatile material arrangements – especially conductive and non-conductive– are possible.
- Different curing processes like UV and NIR curing and temperature-based sintering methods are integral part of the NextFactory process chain, in order to process different types of materials – e.g. particle based silver inks in direct combination with acrylic insulating materials.
- Flexible *micro-assembly* processes allow for component placement directly onto – respectively into – the printed 3D-substrate. This gives the potential to boost the functionality of the printed product, as the functional scope of the overall part is no more limited to printable functionality. Instead, premanufactured parts like electronic components, sensors or can become an integral part of the overall system.

- To further broaden the range of applicable materials, robust and versatile *dispensing technologies* are used to complement the effective inkjet-technology for high-viscous, non-printable materials. Thus, state-of-the art materials like conducting glues or fillers can be processed.
- *Inline inspection* methods based on camera systems are used for process monitoring, quality prediction and process alignment. As the overall hybrid process chain achieves an increased degree of complexity, this way of continuous monitoring is inevitable to set up a stable process without the need for time-consuming, product-dependent optimization processes.

Equipment Design and Machine Integration

The machine platform integrates an overall process chain, whereas modularity and extendibility is the basic rule for this development: Each process described is implemented in one module with standardized interfaces for module control, mechanical alignment and media supply.

Figure 1 shows the overall machine assembled with four different process modules.

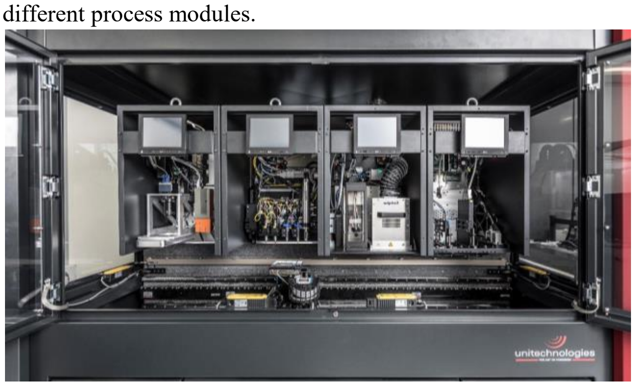

Figure 2. *CAD-model of the NextFactory machine*

One x-y-z axis systems is used to transport the build-platform from one module to the other, as well as to execute all process-relevant movements. This setup was chosen as trade-of between productivity throughput and machine complexity. For future applications, throughput could be increased by decoupling the functionality of product transport and process movements, as parallel processing would then be possible. But in the current development status, it is advantageous to have a sequential system, as the machine platform is both – manufacturing and experimental platform. The functionality of each module is represented by a set of commands, which is used to execute the processes as described in the "manufacturing recipe". This recipe describes the overall manufacturing process and allows direct process control and parameterization. On that basis, the overall process can be operated in very flexible way, at the same time. The manufacturing recipe can describe the whole building process of a complex part allowing for standalone operation and parts manufacturing.

Materials and process development

Material properties are one of the most aching bottlenecks of AM-technologies. This is especially true for inkjet-based processes. But for complex material arrangements, this core technology is almost indispensable. In case specific functional materials are needed, the NextFactory process chain supplements inkjet-printing with dispensing-technologies. Consequently, the market available materials give a sufficient basis for conducting and other functional materials. On the contrary, the insulating material which is needed to produce the substrate and the packaging, is an unsolved problem regarding state-of-the-art materials for 3D-inkjet printing: Especially temperature stability is by far insufficient: Looking at typical soldering processes, at least for a short time, the package has to withstand temperatures beyond 200°C. Against that, market available materials show temperature stabilities far below 100°C. A closer look on the material development itself is not subject to this paper, but to conclude the current status of development, one can say that the insulating materials are already able to fulfill most of the crucial requirements for electronic packages.

The multi material 3D inkjet-process was validated on the basis of a 3D-test-structures including insulating and silver-ink-materials. Figure 3 shows a microscope image of an SMD component (blue), which was placed in a printed cavity and embedded in UV- / heat curable glue (dark grey). It was then connected with conducting adhesive (red) to an inkjet-printed conducting track (gold).

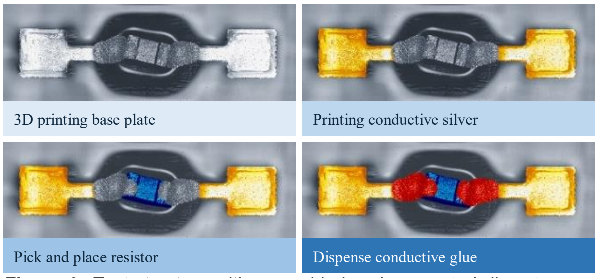

Figure 3. *Test-structure with assembled and connected discrete component on printed 3D-substrate (grey) with inkjet-printed conducting tracks (gold), SMD-resistor (blue) and dispensed CA (red)*

Conclusion and Outlook

The overall machine concept was developed and a machine- and process-module design was derived and build up. The current status proves feasibility of the overall process chain. The test-structures and trials done so far, show that the developed inkjet-printable non-conductive materials can fulfil the requirements in the desired field of application and can be properly combined with off-the-shelf materials like conducting / non-conducting glue and silver-inks. Currently it underlays an extensive period for process-trialing and – optimization. In parallel, optimization of insulating, inkjet-printable materials will be done in close interaction with process optimization.

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Author Biography

Jan C. Janhsen studied mechanical engineering in Aachen. After his Master of Engineering he started working at Fraunhofer IPA (2015). His work topics included the development of control software and automation systems for inkjet-based 3D printing machines. Since 2020, he is group manager of the division "Photopolymer-based AM Processes" in the department of additive manufacturing at the Fraunhofer IPA. The work focuses in particular on high-viscosity, functional 3D printing using piezo-based inkjet technologies.

Printing of Use-cases by Direct-to-shape Inkjet Printing with Industrial Robot

Philip Kessler, Johannes Renner, Benoît Sahli, Vincent Schneuwly, Vincent Nidegger, Gilbert Gugler, *iPrint Institute, HEIA-FR, HES-SO University of Applied Sciences and Arts Western Switzerland, Fribourg*
Florian Fässler, *Polytype AG, Fribourg, Switzerland*
Danijel Tipura, *Mabi Robotic AG, Veltheim, Switzerland*

Abstract

In the initial phase of this project, a single-colour printing system was developed to perform printing tests on 2D surfaces in different orientations and robot workspaces. These test prints were scanned by a microscope and treated by an image processing software, which allowed the statistical characterisation of the drop placement error and its different parameters. An active ink pressure control system was developed, implemented and tested to mitigate the pressure fluctuations caused by the dynamics that occur within the system. Using high-precision distance sensors, a correlation between drop placement error and robot path accuracy was proven, confirming the effectiveness of the ink pressure control. In the second phase, a four-colour printing system was developed to test high quality graphic printing and selective coating on an automotive part. This phase involved several considerations, including path generation, correcting positioning errors, ensuring stitching quality, achieving coating uniformity and implementing UV curing on 3D surfaces. The DTS workflow developed in this project was tested and improved on various use cases including automotive parts and furniture.

Introduction

Known for its adaptability, speed and accuracy, digital inkjet printing has become increasingly popular for graphic printing and coating applications. It supports a wide range of materials, including aqueous and solvent-based inks, UV-curable inks and functional substances such as conductive inks and adhesives. The technology provides precise control over coating deposition, enabling selective applications without the need for masking and facilitating the creation of intricate patterns and textures.

Digital inkjet printing has found a wide range of applications in industries such as packaging, textiles, ceramics and electronics due to its ability to produce high quality, customisable graphic prints and coatings while minimising waste and costs.

Direct-to-shape (DTS) printing takes digital printing a step further by enabling images or coatings to be printed directly onto three-dimensional surfaces such as bottles, cups and automotive parts. Typically, DTS printing uses customised printers that are designed to fit the unique shape of the object. These systems often rely on a static printing setup that moves the object to be printed and are therefore limited in their flexibility and their ability to print on large or heavy objects.

By taking the opposite approach and moving the printing system around a static object, iPrint has collaborated with MABI Robotic AG and Polytype AG to integrate a printing system with a large industrial robot and further develop their DTS workflow to improve the ability to print on large and heavy objects and to achieve a more flexible process.

Figure 1 *DTS printing system concept [1]*

Procedure

In the first phase of this study, a single-colour printing system was developed to print on a two-dimensional surface in different orientations and robot working spaces. An active ink pressure regulation system has been developed to compensate for the pressure variations caused by the dynamics to which the printing system is subjected when moved by the robot. The different samples were scanned by a microscope to determine the relative drop position errors by image processing and to show the capability of the Mabi MAX-100 robot for DTS applications. High-precision distance sensors built into the printing system provided further data on the robot's path accuracy and repeatability.

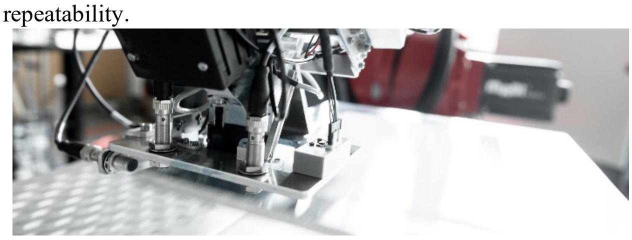

Figure 2 *single-colour printing system*

In a second phase, a four-colour printing system was developed to test the feasibility of high-quality graphic printing and selective coatings in a use-case with an automotive part. In the process, aspects such as path & image generation, position error correction, stitching quality, coating homogeneity and UV curing on 3-dimensional surfaces were addressed.

Results

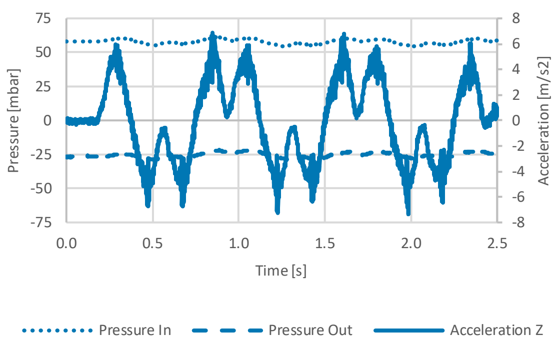

Figure 3 *Pressure and Acceleration data*

The pressure regulation tests showed a maximum deviation of 4.16 mbar in the differential pressure between the inlet and outlet of the print head at an acceleration of 7.36 m/s2. In addition, further print tests performed immediately after the accelerations showed that the additional qualitative criteria of no ink leakage on the nozzle plate and no air intake into the print head were met, thus validating the performance of the system.

Statistical analysis of the large-scale test data characterised the drop placement errors. A high correlation between the drop placement error detected by image processing and the position data generated by the laser distance sensors confirmed that the inaccuracy of the robot trajectory was the main cause of the positioning errors rather than the printing system. With the optimum parameters, an accuracy of 8 ±7.5 µm and a repeatability of ≤ 5 µm were achieved on 2D surfaces.

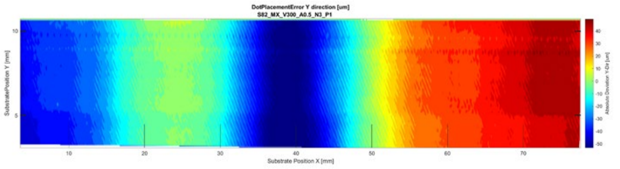

***Figure 4** Example of a contour plot of the drop placement error in Y-direction*

A prototype software was tested to generate both, path and image, and was continually improved by analysing the results. Initial printing tests on the real part, however, revealed printing errors attributable to an unacceptable deviation between the path and the real part. Manual measurements showed that the position of the real part deviated significantly from the position of the digital model. To overcome this problem, a point cloud of the real part was generated by scanning the part with a laser distance sensor built into the print module. This point cloud was then used to generate a new shape in CAD software, and the path and image generation was repeated. This significantly improved the printing results.

A further test, in which lines printed on the 3D surface were scanned, the error of these lines measured and then applied as a correction, resulted in an improvement in accuracy from +/- 140 to +/- 80 um.

Although there is room for improvement, the print quality achieved is very satisfactory for the first tests. The prototype system has proven its ability to perform the first practical applications.

Outlook

The overall results achieved in this project are very promising. A key topic for the future is to further optimise the path and image generation process towards an industrialisable solution. Furthermore, a solution for measuring the real part and correcting the path and image is needed. Finally, pre- and post-processing on the 3D surface needs to be further investigated and optimised.

References

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Author Biography

Philip Kessler studied mechanical engineering, specialising in plastics technology and lightweight construction, at the University of Applied Sciences of Western Switzerland in Fribourg. He is currently writing his thesis as part of the Master of Advanced Studies in Industry 4.0 at the Zurich University of Applied Sciences. He has worked for the iPrint Institute for 5 years and is responsible for mechanical engineering, platform development and management of industrial projects

Introduction of "GELART JET" technology: Expanding Graphic Painting based on valvejet technology

Ryo Idehara; RICOH Digital Painting Company,Ltd. ; Machida City, Tokyo/Japan:

Abstract

Ricoh Digital Painting Co., Ltd. is a venture company that has provided new value and solutions with unique technology and products. This time, we will introduce an example of a system configured by combining multiple types of GELART JET heads and special ink. We hope this presentation will serve as a valuable resource to enable all of you to connect the potential of our innovative GELART JET technology for your own applications.

Basic architecture and functional characteristics of "GELART JET" Nozzle

Our GELART JET technology is based on the power of compressed air, precise actuator control and optimal flow path design that enable us to acquire precise droplet control required for graphic printing. The basic structure of GELART JET is very simple as shown in Figure 1. We can control the jetting timing and size of droplets by simply controlling the opening time of the needle by embedded actuators.

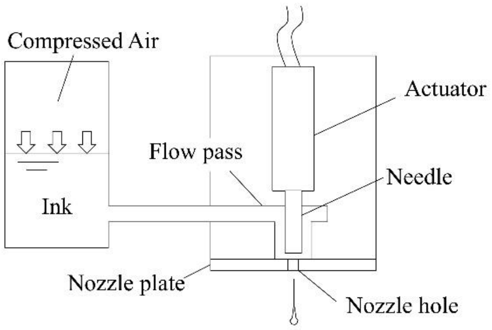


Figure 1. Basic structure of GELART JET

Figure 2 shows the actual droplet size and droplet speed ejected by a certain head. It can be seen that the droplet size increases with the valve opening time. It can also be confirmed that the droplet speed maintains a high value regardless of the open time. This property makes it possible to realize images with high tonality even with wide gaps by changing the size of the droplets.

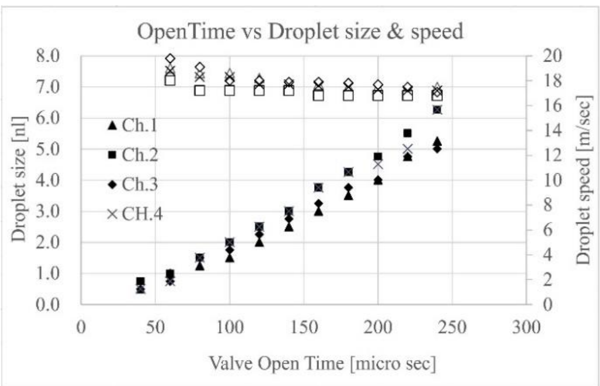


Figure 2. Droplet characteristics of GELART JET

Another feature is its ability to handle high viscosity. In particular, GELART JET can handle thixotropic liquids. Figure 3 shows datas of some paint that could actually be jetted. Since GELART JET uses the power of compressed air, we think that the viscosity of the paint that begins to move in the flow path decreases rapidly, reaching a viscosity that can be discharged near the nozzle.

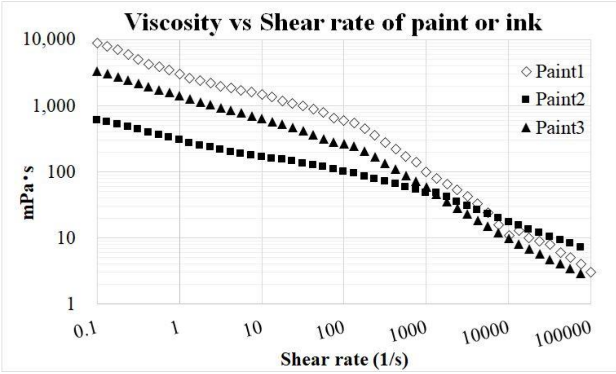


Figure 3. Viscosity data of paints GELART JET could jet

Introduction of some GELART JET Head nozzles

We have a lot of type nozzles. In this paper, we will show a head with 8 nozzles that is closest to an inkjet head. This head is a type that uses piezo elements. Values shown in Figures 2 and 3 are the result using this head.

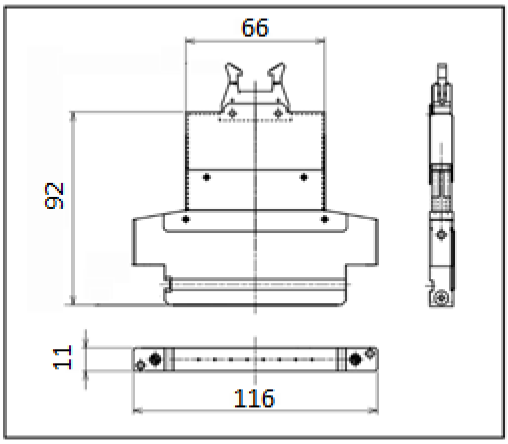


Table 1. Specs(8 Nozzle head)

Number of Nozzle	8 (7.694mm pitch)
Max. Frequency	3.3 kHz
Driving Voltage	72 V
Air pressure	0.45 MPa
Weight	450 g

Introduction of examples of our system products

Auto Body Printer is a direct decoration system for trucks and buses. It is characterized by being able to print on uneven vertical surfaces in a short time. This system is very similar to common inkjet systems. It has scanning mechanisms in the horizontal and vertical directions as well as in the gap direction. It is possible to print one side of a track in approximately 4 hours. (Figure4.)

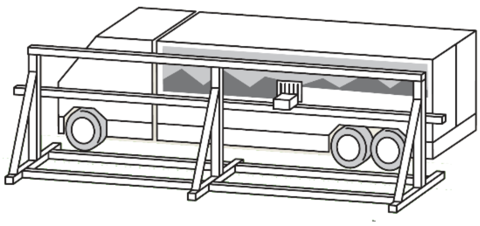


Figure 4. Auto Body Printer

Direct Lettering system is a system that decorates LPG gas cylinders with information such as filling deadlines. In order to support a lot of prints per day, it can print one of information in about 45 seconds using ultra-large droplets. This system seems like a kind of single-pass system. (Figure 5.)

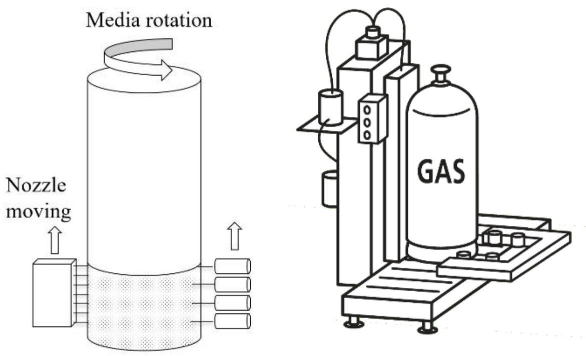


Figure 5. Direct Lettering System for LPG cylinder

The tire printer can be said to be an example of our technology demonstrating multiple effects. It is not easy to obtain paint that can adhere to tire sidewall and reproduce the desired color. Our GELART JET nozzle can deal with a variety of paints, so we were able to greatly shorten the search process.

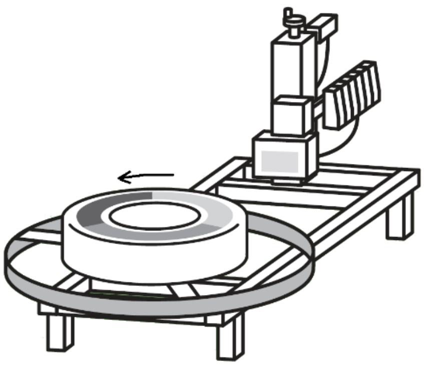


Figure 6. Tire printer

Single-pass systems have a wide range of applications. Since the GELART JET head is able to jet a large amount of liquid, it can enable the analog paint process to digital one. We have received many inquiries about whether it can be used to improve coating efficiency or progress the coating value.

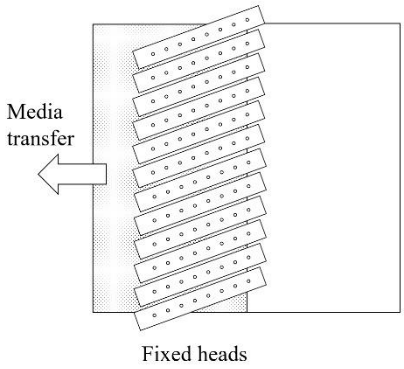


Figure 7. Single pass system

As shown in this document, we have developed and provided several unique systems. However, in addition to that, we have also been conducting tests and providing specialized equipment to meet the requests of various customers to jet paint.

In the future, we will expand our lineup of easy-to-use module products and continue to evolve to meet your digital needs.

Author Biography

Master in mechanical engineering at Osaka University Graduate School of Engineering Science (1999). Since then he has worked in the Technology Division at Ricoh in Kanagawa, Japan. He has developed many types of printers, including electrophotographic and inkjet printers. He is on the Board of RICOH Digital Painting Company,Ltd.

Transforming Industrial Manufacturing: Harnessing the Potential of Ultra High Viscosity Jetting for Functional Printing

Ramon Borrell; Quantica GmbH; Berlin, Germany

Abstract

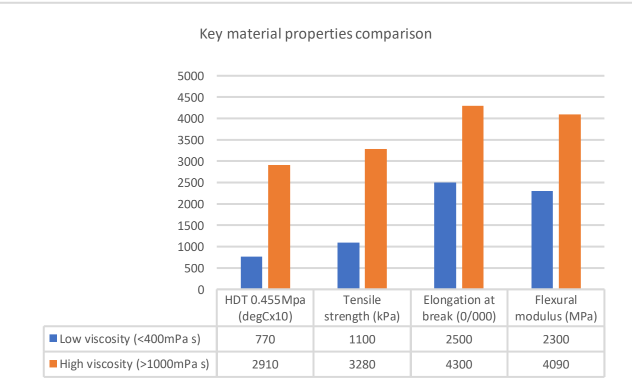
Please include a brief abstract of this paper. Avoid using figures or equations in the abstract. For details of specific styles (heads, captions, equations, etc.), see the proceedings paper template.

Overall Document Guidelines

The potential for transforming industrial manufacturing lies in the utilization of jetting ultra high viscosity fluid, merging the scalability, flexibility, and digital printing capabilities of inkjet technology with the superior properties of functional materials.

Capability to jet ultra high viscosity fluids by drop on demand inkjet well beyond state of the art was first announced in 2021 by Borrell et al. At the time only small printheads with limited commercial capabilities had been built and tested, but a tentative specification for a commercial printhead was anticipated. For the past two years substantial progress has been made in optimisation of the underlaying actuator technology, enabling jetting up to 380mPa s in lab conditions, close to 10,000mPa s at 20 C. The commercial spec however has been set at 250mPa s when using Newtonian fluids. The new technology has been named Novojet.

The ability to produce novel parts and applications of interest for science and industry lies in the properties of the materials that can be jetted. The superior capabilities of materials with higher viscosity have been verified by comparing fluids formulated for conventional inkjet, thus with viscosities at jetting well below 100mPa s, with existing commercial materials conceived for alternatives processes and therefore not being limited by such viscosity. All the materials have been proven to successfully jetted with Novojet. The fluids compared were intended for operation at elevated temperatures, to provide high strength, high elongation (flexible), or high stiffness. Results show substantial superior performance for the higher viscosity fluids between ~2x and ~4x over those formulated for conventional inkjet.



Beyond mechanical properties, other materials for functional applications have also been jetted. Notably, a diluted copper paste with 71% content by weight of copper nanoparticles intended for low temperature sintering, an ultra high surface tension fluid in the form of metal alloy liquid at room temperature (730mN/m), high dielectric index suspensions for radio frequency applications, and low toxicity, biocompatible materials for multiple products.

Printhead specifications

Novojet 1 Printhead specifications

Nozzle count	96
Rows of nozzles	1
Native nozzle pitch	1.27 mm
Dimensions (LxDxH)	145 mm x 18 mm x 25 mm
Nozzle exit diameter	60 um
Drop volume	25 pl – 600 pl
Fluid viscosity range	1 mPa s – 250 mPa s
Operation temperature setting range	15 C – 90 C
Jetting Frequency	8 kHz
Minimum Life	All spec met after 3 10^{10} drops per nozzle
Guaranty	1 year with certified fluids
Fluid flow type	Full back of nozzle recirculation
Fluid surface tension	20 mN/m – 750 mN/m
Nozzle plate	PI

Applications

Each set of materials enables specific specialized applications. A Novojet OPEN 3D printer was announced in November 2023 intended for R&D investigation on materials and printing for Additive Manufacturing, whether 2D or 3D. That printer will be shipped with a set of three compatible materials for exploration of the capability of the technology a combining properties, and it consists of a support material, a flexible material and a rigid material, all based on UV curable photopolymers. Higher performance material sets are currently being evaluated for high performance mechanical and electrical parts, such as connectors and engineering parts. A broad range of materials for medical use are currently being evaluated for dental indications and hearing aids. Finally work has started in developing applications for the electronics industry in the fields of manufacturing of displays, PCBs and semiconductor products.

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Author Biography

Ramon Borrell received a MSc in Industrial Engineering (1987) and a MSc on Automotive Business (1993) from Universitat Politècnica de Catalunya in Barcelona. He held a number of technical and management positions developing large format inkjet printers at HP. In 2007 he was appointed R&D Director of Xaar plc in Cambridge, England where he led the development of the printhead portfolio including the 5601 printhead featuring Thin Film Piezo MEMS for industrial printing. In 2020 he founded borrell.uk Technology Management aimed at helping companies globally with their technical, business and strategic developments. He joined Quantica as CTO in 2021, talking on the management of R&D activities. He is a Director of IS&T.

A new printhead generation that breaks barriers of inkjet technology in terms of resolution and ink viscosity

Patrick Galliker; CEO Scrona AG; Zürich, Switzerland

Abstract

A new type of ultra-high resolution inkjet printhead will be presented, its guiding principles of electrohydrodynamic (EHD) ejection and how it can be applied in the area of functional printing, particularly in semiconductor/electronics and display markets. As the core differentiation factor the EHD process will be elaborated and how it can help break barriers in viscosity and resolution. In comparison to traditional inkjet technology, EHD does not create pressure inside the nozzle which is prone to heavy flow resistance and viscous dissipation but instead relies on a pulling-mechanism, where the force required for droplet generation is directly formed inside the ink itself, with the benefit that all energy is created exactly where it is required and in a focused manner that enables ejection of droplets that are substantially smaller than the nozzle itself.

Overall Document Guidelines

Electrohydrodynamic (EHD) Printing has long been known as a potentially superior printing technology compared to conventional inkjet. Back in the 80's, EHD was explored for graphical applications by major players but has long since been abandoned. Beginning of the century, new activities have emerged mainly in relation to high-value industrial applications like printed electronics. The problems that keep the technology from becoming industrially relevant remain the same though. EHD printheads so far have not been manufacturable with large nozzle counts, mainly because of cross-talk issues, unbearably high driving voltages as well as general long-term stability challenges.

At Scrona, the first MEMS-based EHD printheads have been created that eliminate all these problems at once. Scrona's new EHD printheads contain nozzles at a density that can be more than five times higher than that of modern piezo-driven inkjet heads and they can be individually operated with less than 100V which makes them compatible with massively scaled driving electronics. A main success factor behind Scrona's printhead lies in an optimized arrangement of electrodes to separate two key processes that so far have not been properly decoupled from each other. In previous attempts of electrohydrodynamic printheads, particularly with capillary-based printheads, voltage was applied between the nozzle and the substrate. The resulting electric field filled the whole room from nozzle to substrate. Importantly, however, the ejection process itself is only sensitive to the electric field environment in immediate proximity to the nozzle. The field strength in this area needs to be very high to overcome liquid surface tension, depending on nozzle size up to values in the order of 10^8 V/m. The exact magnitude of the electric field has a profound effect on the printing behavior, but the electric field at the same time is strongly dependent on the distance to the substrate, so the process becomes highly sensitive to fluctuations in the printhead-substrate distance [1]. To keep voltage levels in sub-kV range, while still obtaining ~10^8 V/m of field strength, the distance between printhead and substrate generally needs to be on the order of tens of micrometers, which further attenuates the distance fluctuation problem. Lastly, as the electric field spans the whole room between substrate and printhead, it is easily understood that neighboring nozzles will have a strong influence on each other, since the non-uniform nature of the electric field forming around the nozzle will also influence the flight path of the droplets (see Fig. 1). This is due to the fact that droplets carry electrical charge and due to their small sizes, they are much more sensitive to the electric fields than they are to gravity [2].

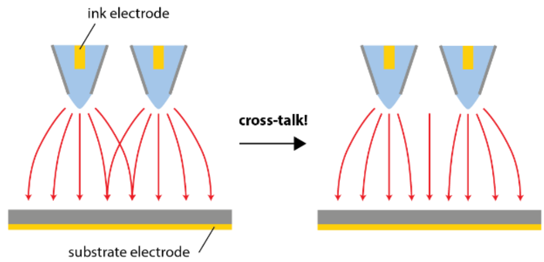

Fig1.: Graphic illustrating the cross-talk of electric field if two EHD nozzles move close to each other. Yellow bodies illustrate the electrode, one of which is individually controllable inside each nozzle and one is globally situated below the substrate.

In Scrona's printheads these problems can be resolved by effectively splitting the electric field into multiple regions that can all be separately controlled. Essentially, electrodes used to eject droplets are directly formed inside the printhead. Those electrodes are formed in very close proximity to the nozzles which allows for low voltage stimulation. In addition, the different electrodes can be effectively shielded from each other by a common shielding electrode. The shielding electrode essentially marks the end surface of the printhead that faces the substrate. Hence, the area between printhead and substrate is not influenced by the inhomogeneous electric field formed at the nozzles but instead formed highly homogeneous like that of a plate capacitor between two flat surfaces. This means that if droplet are exiting the printhead through small openings in the shielding electrode they are guides straight down onto the surface (see Fig. 2). In this way, there is no requirement anymore to keep the distance between printhead and substrate small, since the droplet acceleration process follows a straight trajectory and can be controlled completely independent of the droplet ejection process. With Scrona's printheads it is therefore able to place the sub-micron droplets created from multiple nozzles onto the substrate at a precision in the 100nm range, even if the nozzles are as close as 0.1mm spaced from each other and even if printhead and substrate are 1mm spaced.

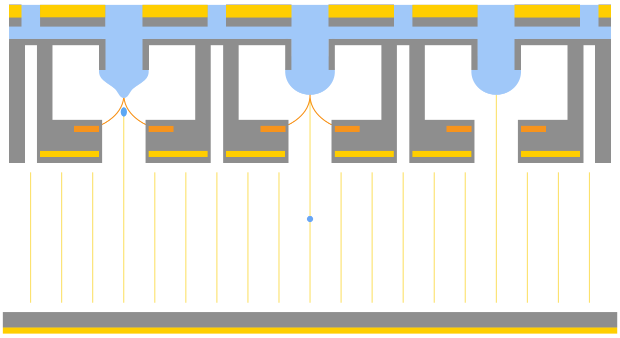

Fig2.: MEMS-type EHD printhead with all yellow bodies representing global electrodes. The orange electrode in comparison is individually controllable and can be used to create a strong electric field towards the ink inside the nozzle. This field, however, is shielded by a global shielding electrode at the bottom-surface of the printhead. This global shielding electrode, at the same time, creates a uniform field to the substrate that drives droplets straight down.

Besides the optimized electrode design, Scrona's MEMS printheads also offer the opportunity to integrate more complex microfluidic control. Capillary-type single nozzle printheads essentially drive ink in a dead-end way towards the nozzle, while in MEMS printheads it is possible to incorporate microfluidic channels for ink recirculation, similar to those used in advanced inkjet printheads.

On top of that, Scrona's proprietary manufacturing concepts in combination with the unique possibilities of the EHD process, allow nozzles to be manufactured at strongly variable size, without much design input. An easy-to-obtain increase of the nozzle size essentially converts the printheads into high-viscosity dispensers that can eject inks of 10'000cps at droplet sizes similar to those that conventional inkjet heads obtain with inks of only 10cps.

References

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[2] SB. Quang Tran et al., "Polymer-based electrospray device with multiple nozzles to minimize end effect phenomenon". J Electrost., 68(2), 138–44 (2010).

Author Biography

Patrick Galliker is CEO and co-founder of ETH spin-off company Scrona. Patrick studied Nanosciences at University of Basel and got his PhD at the laboratory of Prof. Dimos Poulikakos at ETH Zürich. At ETH Patrick also received a Master in Advanced Studies in Management, Technology and Economics. Patrick has raised more than 10 Million Swiss Francs in equity funding and received multiple recognitions, including a Guinness World Record for the smallest inkjet printed color image.

The Possibilities for Printhead Manufacturers of Next Generation Electroforming

Dave Dekker, Nicolas Hildenbrand, and Michel Duits, Veco Precision (the Netherlands)

Abstract
Electroformed nozzle plates have long been a common sight within inkjet printheads. Veco Precision has over 40 years' experience in this field and now introduces new possibilities using advanced lithography electroforming.
Veco is a world-leading manufacturer of micro- precision parts. It serves the world's most innovative, hi-tech companies from industries that demand high quality and precision.
To meet customers' specifications and demands, Veco has developed high standards of performance in Electroforming. This technology allows a powerful combination of precision and economical production; for high volumes and prototypes, standard and custom-made products.

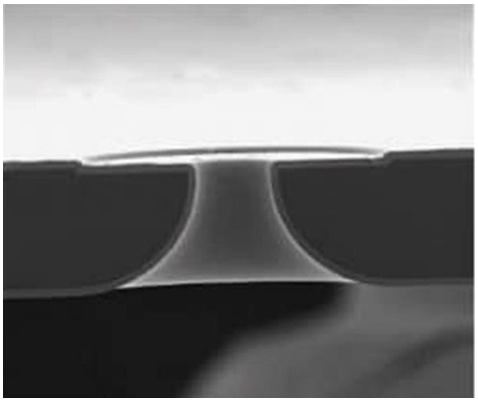
Figure 1: Characteristic Electroformed nozzle cross-section

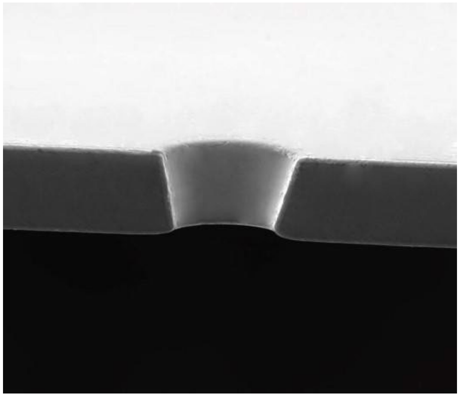
Figure 2: A conical nozzle cross-section

Recent advancements in lithographic capability have brought Veco two valuable propositions for the inkjet industry. First, increased control of the nozzle diameter can provide ±0.5µm specs within a nozzle plate, a feat previously unattainable with electroforming. Secondly is a new diversity of feasible nozzle cross sections and functional integration. While bell-mouth shaped nozzles have long been the electroforming standard, conical nozzles with different tapering have recently become a reality without sacrificing accuracy and consistency. Combining these two capabilities allows for custom-made cross sections with freedom in nozzle diameter, pitch, and nozzle plate thickness.

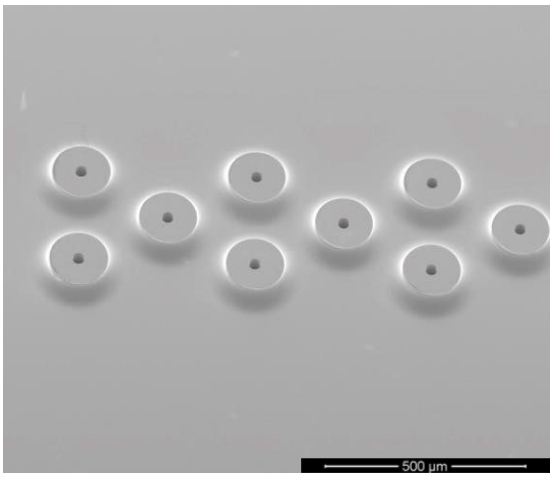

Figure 2: Protruding nozzles

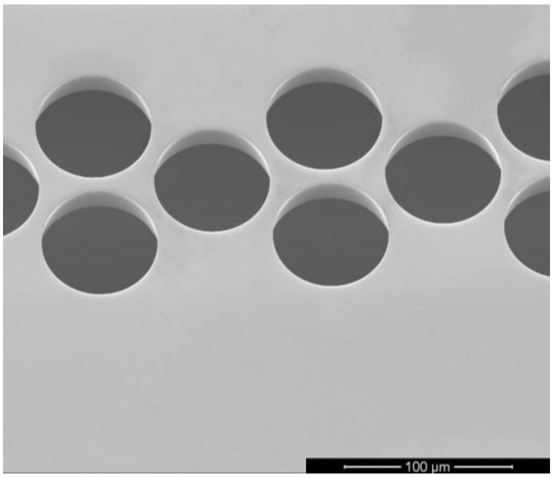

Figure 3: Densely packed conical holes

Electroforming's unique capability to stack product layers allows for glue-less functional integration within a single metal part. Integrated reflow channels do not require adhesives that deteriorate through contact with inks. Finishing the part with metal coatings can produce reliable, corrosive resistant and hydrophobic performance that lasts.

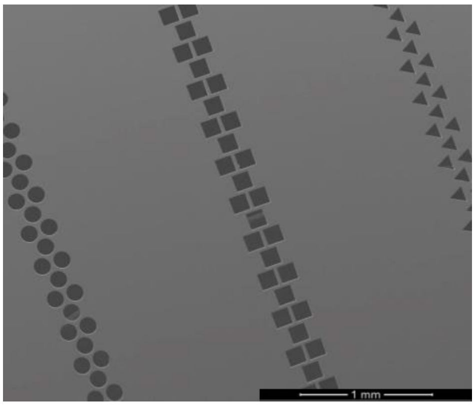

Figure 4: Freedom in nozzle shape

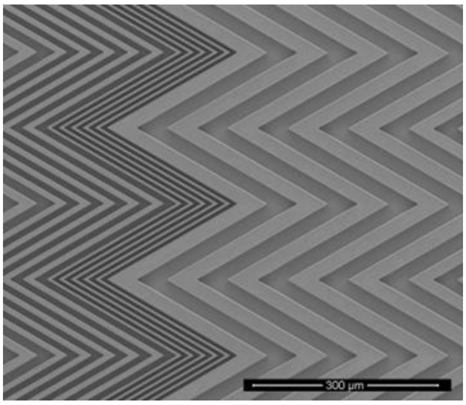

Figure 5: Freedom in channel definition for multi-layer products

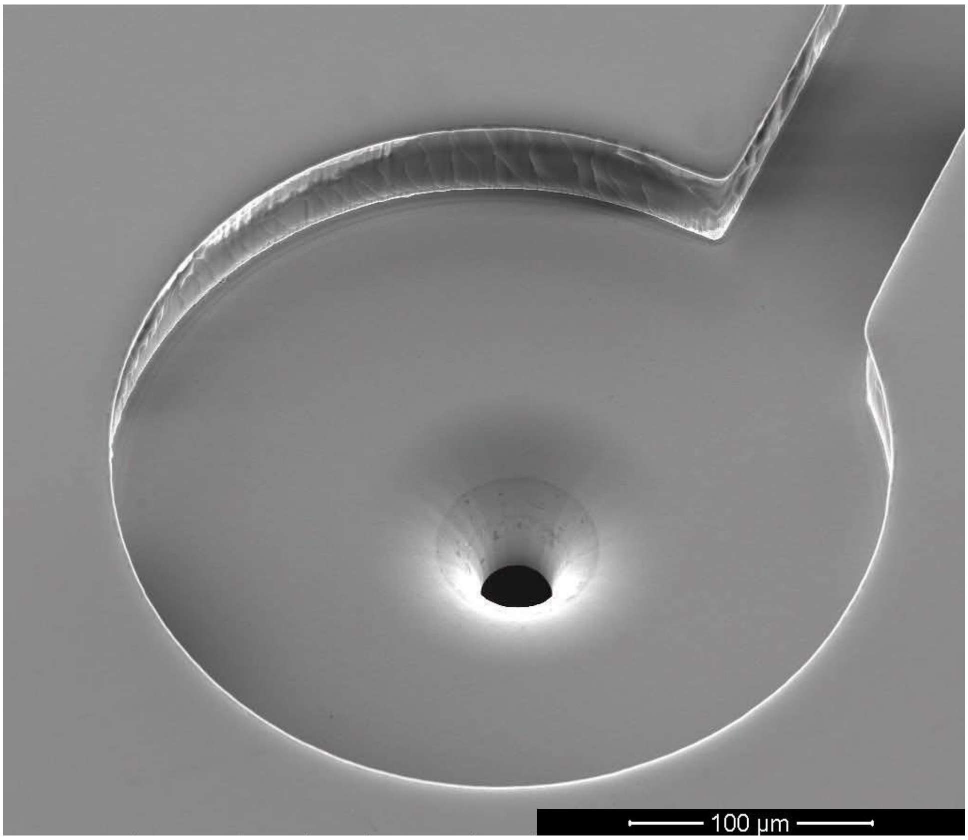

Figure 6: An ink channel integrated in a nozzle plate

The continuous advancement of lithographic and electrodeposition possibilities have allowed Veco to take the next step in electroforming nozzle plates, combining the robustness and reliability of metal nozzle plates with sub-micron accuracy, low nozzle-to-nozzle pitch and minimal spread in first-to-last nozzle pitch not previously seen in this technology.

Get an insight in Veco's toolbox for customizing the nozzle cross section, nozzle plate thickness, pitch, integrated channels and metal coatings to product specific requirements.

Innovative Fabrication of Glass Nozzle Heads, Ink Manifolds, and Nozzle Guards for Advanced Inkjet Printheads using LIDE Technology

Rafael Santos, LPKF Laser & Electronics SE , Germany; Norbert Ambrosius, LPKF Laser & Electronics SE, Germany; Aaron Vogt, LPKF Laser & Electronics SE, Germany; Roman Ostholt, LPKF Laser & Electronics SE, Germany.

Abstract

Inkjet printheads play a pivotal role in modern printing technology, demanding high precision and durability. This paper presents a groundbreaking approach to fabricating essential components of inkjet printheads by using glass as the core material, namely nozzle heads, ink manifolds, and nozzle guards. With Laser Induced Deep Etching (LIDE) technology, we achieve excellent outcomes in terms of positional and dimensional accuracy, surface quality, and functionality due to the design freedom LIDE provides.

Glass has unique properties and LIDE allows leveraging them to create high-precision glass nozzle plates with a wide range of nozzle dimensions, pitch and arrangements, in different cross-section geometries such as straight through-holes, tapered, V-shaped, and funnel-shaped. The resulting glass components exhibit exceptional chemical resistance, thermal stability, abrasion resistance, high rigidity providing mechanical stability, while also exhibiting very high transparency which could be of high interest when using UV-curable inks, for example. We demonstrate the versatility of LIDE by fabricating surface structures and through-glass structures in the same substrate and process step, allowing the fabrication of ink manifolds with complete design freedom. Our technology doesn't generate any defects and maintains all the material characteristics of glass, particularly mechanical ones, which is of particular importance for glass-based nozzle guards.

Why glass as a core material?

Glass is well known for merging several highly relevant material properties that are unique to any other category of materials. The very high thermal stability combined with high rigidity makes it a material with exceptional dimensional stability. It also exhibits a very high resistance to abrasion and does not undergo plastic deformation, which means it will only slightly and temporarily deform – i.e. no permanent deformation ever occurs. These characteristics make glass an excellent material for applications that require high dimensional tolerances even when exposed to high temperatures and/or rapid temperature variations, high pressure differentials, and direct contact with other materials. Furthermore, glass is virtually inert when in contact with several types of chemicals even at temperature, so fluids such as inks and its additives, solvents, etc., will not be altered by or cause damage to it in any way. Both the thermomechanical and the chemical properties of glass should be, therefore, of great interest for the fabrication of various components of modern inkjet printheads.

Glass also exhibits other unique and interesting characteristics that could open the door to new or improved functions of the inkjet printhead, such as its very high optical transparency which would potentially simplify the curing of UV-curable inks.

Why hasn't glass been used until now?

Despite glass' many interesting material properties, its use as a core material for advanced engineering applications has been quite limited. This is mostly due to the fact that legacy glass processing technologies commonly have severe limitations in the minimum feature dimensions and accuracy, and introduce defects such as cracks and chipping into the glass, while adding significant technological costs to a relatively low-cost material. Most of these technologies are either mechanical or laser-based, which use abrasion or ablation, respectively, to remove the glass. Both these removal mechanisms invariably generate defects that either cannot be eliminated or require several post-processing steps to alleviate their impact. Other technologies use chemical etchants which, due to the amorphous nature of glass, remove it isotropically resulting in a very limited range of structures and dimensions that can be fabricated.

The LIDE (Laser Induced Deep Etching) technology was initially developed to microprocess glass for the semiconductor packaging industry, which requires very high throughput and cost-effective processing with extremely low yield loss due to errors or defects. LIDE surpassed its objectives by also providing a wide design freedom enabling its use in essentially any industry that would benefit from the introduction of glass, such as the inkjet industry.

Where can glass be used?

As previously mentioned, glass exhibits a set of material properties that can be highly advantageous relative to legacy materials in well-established parts and applications in the inkjet industry. For example, the high dimensional stability and inertness can make it ideal to fabricate nozzle heads particularly when using LIDE's capabilities. Refer to Fig. 1 and 2 for examples of protruding and co-planar nozzles.

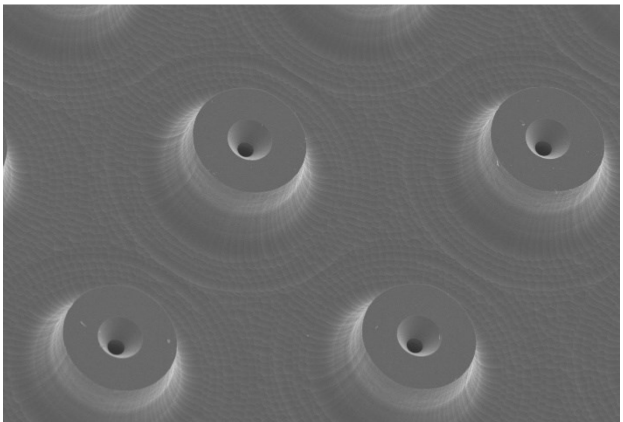

Fig. 1 - SEM micrograph of 10 µm diameter microholes in protruding mesa-like structure.

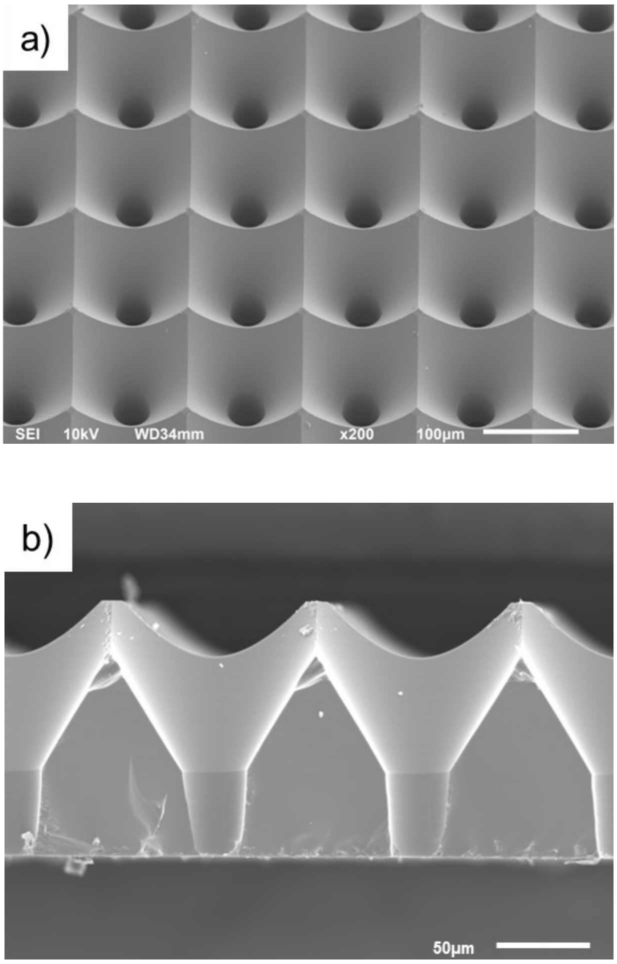

Fig. 2 – SEM micrographs of tightly spaced funnel-like microholes fabricated in glass using LIDE: a) top-view and b) cross-section view.

LIDE can also very precisely define depth-limited structures with any surface geometry and dimensions. This capability can be used to generate channels that guide the ink to the nozzles in the same glass substrate, such as in Fig. 3. These channels can be generated with varying depths and widths, in essentially any dimension and with a very high design freedom: geometric and meandering channels are feasible, and manifolds can be created while connecting them to through-glass structures such as nozzles.

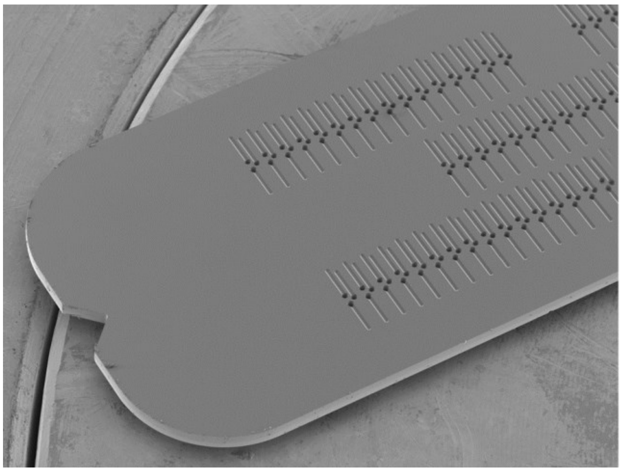
Fig. 3 – SEM micrograph of part containing microfluidic ink manifolds connected to micro through-holes.

While the excellent mechanical properties of glass, such as its high rigidity and resistance to abrasion, particularly when free of defects, make it an excellent material to fabricate nozzle guards (Fig. 4), LIDE can, within the same process step, also generate a round chamfer on the part perimeter and increase its durability.

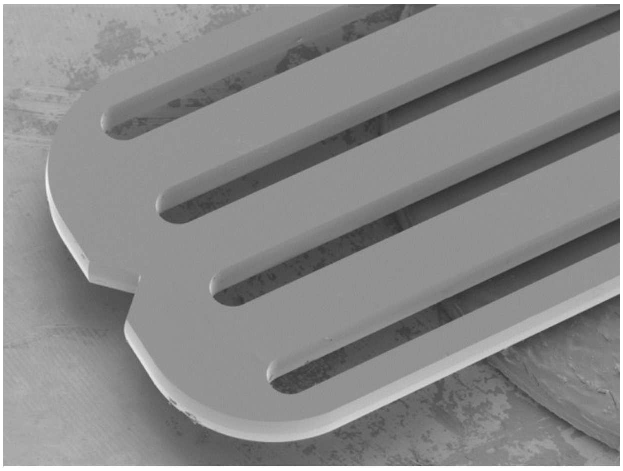
Fig. 4 – SEM micrograph of glass part containing open cavities, to form nozzle guards.

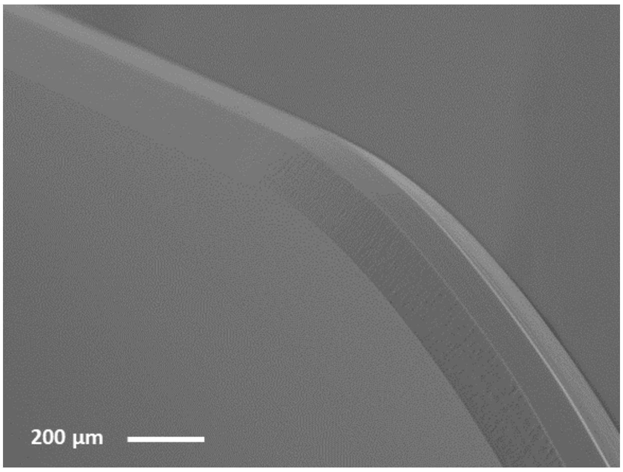

Fig. 5 – SEM micrograph of chamfered glass edge.

LIDE enables the utilization of glass to generate features and fabricate products that have been, until now, out of reach with other glass microprocessing technologies. The high positional and dimensional accuracies that can be obtained, combined with a highly cost-effective technology that manufactures such a uniquely interesting material without any defects, makes glass a highly sought-after core material for many applications, particularly for advanced microfluidic applications such as inkjet printheads.

Author Biography

After completing his PhD in Materials Engineering in 2019 in Australia, Rafael started his career outside academia in Germany, as a Process Engineer in the newly formed Vitrion division of LPKF Laser & Electronics SE, focusing on the commercialization of the LIDE technology. Shortly after, Rafael transitioned into a role in Technical Sales for LIDE, and in early 2023, assumed a leadership role as Director Technical Sales co-leading the glass manufacturing service.

Ultrafast, 3D laser micro-manufacturing of novel glass-based microfluidics

Davide Farina; FEMTOprint SA; Muzzano, Switzerland

Abstract

The present work aims to introduce the novel FEMTOPRINT® microfabrication technology, based on ultrafast laser and chemical wet etching processing, to create three-dimensional, high-precision patterns into transparent, glass materials for a wide range of applications and microdevices. Thanks to the ability to generate 3D geometries with micrometric precision, to treat surfaces to achieve optical transparency on virtually any surface topography, and to laser weld hermetically microdevices without the need of glue or adhesive, new horizons for integrated microfluidics are yet to be explored. More specifically in the inkjet industry, novel micronozzle arrays with a high degree of shape freedom and features dimensional repeatability over centimeter long substrates, within an exceptionally stable material as it is glass, can be now conceived at an industrial scale. Beyond that, the technology enables the integration of certain functional coatings to modify surface properties or the application of 3D electrodes, contributing to a new microfabrication approach suitable for a wide spectrum of microfluidic devices.

In recent years, tremendous progress in the field of ultrafast laser processing of glass has resulted in robust, industrial equipment to allow for scalable, high-throughput wafer-scale processing, competing with traditional photolithographic techniques and taking advantage of a much higher degree of geometrical freedom. Several sectors are looking at this potentially ground-breaking technology for the precision manufacturing of microfluidic devices and the industrial printing is of particular interest when looking at novel printhead and micronozzle array concepts.

The industrial printing landscape has expanded into various new domains, such as food printing, organic and biomaterials printing, and the well-known 3D printing. These domains have different printing needs, such as higher resolution, increased throughput, usage of robust and biocompatible materials, functional integration, miniaturized footprint, and precise liquid flows. To address these challenges, a new design and manufacturing approach is required that can tailor the nozzle shape to the specific properties of the inks. The FEMTOPRINT® technology can achieve this by creating micron-level features with high accuracy and repeatability, and allowing free-form internal shapes to enable a wide range of microfluidics jetting applications across the different domains.

Most of the traditional microfabrication technologies offer limited freedom in geometry (binary structures) and are often associated with MEMS materials. The goal of the novel FEMTOPRINT® technology is to broaden up the opportunities in designing more sophisticated, yet miniaturized and monolithic, microfluidic systems, where the fabrication of undercuts, of precise slopes with any angle and an angle control within 0.05° and virtually no step effects (roughness average Sa << 0.5 µm) is possible. Sub-micron accuracy on holes diameter and positioning, in addition to a laser welding process made at room temperature, without the need of glues or adhesive, enabling tight and hermetic sealing even on miniaturized elements (contact surfaces can be as small as 75 µm in width and 200 µm in depth), takes the freedom in design thinking to a new level.

Finally, glass is an exceptional material of choice thanks to its multiple properties. It's an amorphous material, insulating, biocompatible and sterilizable, inert to chemicals and mechanically and thermally stable, with outstanding optical transparency. Some specific glass families such as the borosilicate are also well known for their similar CTE with silicon materials, making them the perfect choice when laser welding needs to be applied for sealing the two materials together (often in combination with sending and MEMS-based applications).

The FEMTOPRINT® micro-manufacturing technique belongs to the so-called selective laser-induced methods that rely on a combination of ultrafast laser exposition and chemical material processing. In a first step, the desired 3D shape is patterned within the glass substrate by a focused ultrafast laser which locally modifies the material structure and refractive index, significantly increasing the etching rate in comparison with the pristine material. In the subsequent wet etching step, all the exposed material is removed. The combination of the laser writing and the etching step in relation to the overall dimensions will eventually define the minimum feature size and the shape accuracy of the resulting microdevice, which are typically of the order of a few microns or below.

Surface quality of patterned surface can reach *Sa* values below 100 nm, and such quality can be further enhanced via an additional surface processing down to $Sa \leq 10$ nm, depending on the geometrical shape under evaluation. Feature aspect ratio can be higher than 1:500 and sidewall deviation below 0.05°; minimum hole diameter can be as low as 2 µm; transparent

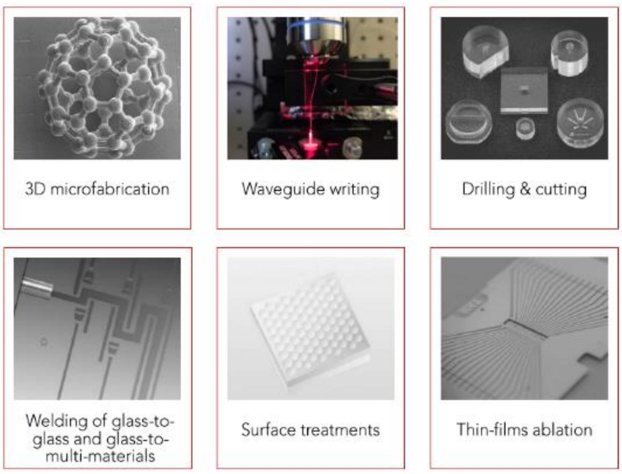

Figure 1: FEMTOPRINT® technology platform.

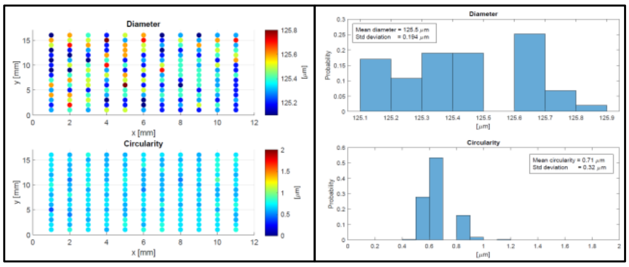

Figure 2: 2D holes array, diameter and circularity measurement over one complete device (upper) and average values over three devices (lower).

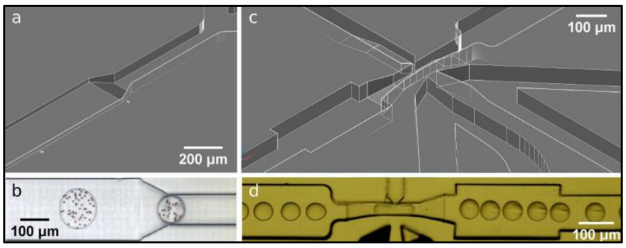

Figure 3: Droplet-trapping chip for prolonged observation and imaging [1] (Source: Courtesy of Leibniz Institute, M. Tovar).

materials can be processed up to 30 mm in bulk height, and the maximum working area is 300 mm in diameter. The FEMTOPRINT® technology is compatible with a broad range of glass materials, i.e., fused silica, borosilicate, boro-aluminosilicate, and others.

The wide breadth of capabilities of the FEMTOPRINT® platform ranges from 3D micromanufacturing (microfluidics, micromechanics, and micro-optics) to glass encapsulation and packaging via laser welding, surface ablation and polishing, optical patterning, and waveguide writing, drilling & cutting (pass-through holes), and laser ablation of thin films. Additionally, surface functionalization can be achieved with metallic and dielectric coatings.

As an example of the homogeneity and repeatability of the FEMTOPRINT® technology, Figure 2 shows measurements relative to fused silica 2D arrays of pass-through holes; target hole diameter is 125.5 µm and the inter-hole nominal distance is 1 mm. Measured diameters are narrowly distributed around the target value (standard deviation < 0.2 µm), with circularity lower than instrument resolution (± 2 µm). Moreover, holes positioning is highly precise, with errors within a single array lower than instrument resolution (± 2 µm) and a micron-level relative positioning error over multiple arrays (average 0.7 µm, standard deviation < 0.4 µm). Holes are homogenously reproduced over each complete array, and results are repeatable over multiple arrays.

The device in Figure 3 consists of a microfluidic fused silica droplet-trapping chip for prolonged observation and imaging [1]. The design features differently shaped chambers of variable depth, with ramps to observe droplet contents in flow under different channel heights, as well as to improve picoinjection. Channels overall length is 15 cm, with multi-level sloped transitions, while the over 100’000 filtering elements consist in holes with diameters below 10 µm, whereby the smallest featured diameter is 3 µm. The device presents 192 nozzles packed in a structure 25 mm in length and 4 mm in width, including all inlets and outlets, generating monodisperse droplets

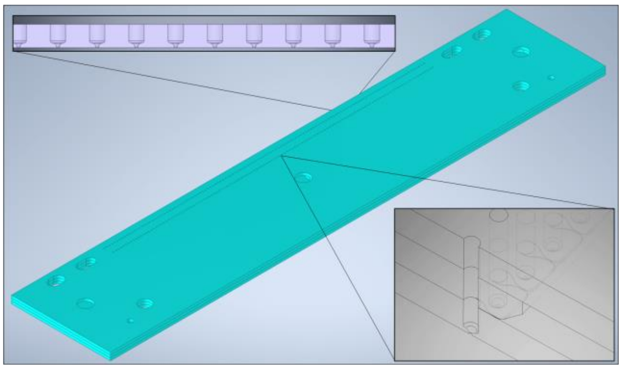

Figure 4: Fused silica printhead nozzle plate (Source: Courtesy of iPrint).

70 µm in diameter. The structure can be easily scaled to contain 1’000 nozzles in a 6.5 cm long structure.

Figure 4 illustrates a printhead nozzle plate with miniaturized curved channels connected to 256 individual nozzles. The nozzles have an entry diameter of 200 µm changing via curved shapes to an exit diameter of 40 µm; nozzles inlets feature channels 5 µm deep and 10 µm wide. Measured geometries of produced nozzle plates give highly accurate results, with maximum absolute errors of 1 µm for both entry and exit diameters of all nozzles, as well as for the dimensions of the nozzle inlets.

The excellent geometrical accuracy and surface quality, combined with a monolithic fabrication process at µm-scale resolution, grant FEMTOPRINT® technology several benefits for many different applications. For example, it allows multifunctional integration of components in a monolithic design, simplifying assembly and alignment challenges on the µm-scale level. Moreover, components can be assembled hermetically and without the need of adhesives via robust laser welding, either for glass-to-glass or for glass-to-multi-materials assemblies (e.g., SOI wafers, ceramics, and metals). Thanks to such 3D free-form manufacturing capabilities, microfluidics, micromechanics and micro-optics can be seamlessly combined. Also, the technology can leverage thermal properties of glass materials to achieve optimal thermal stability of integrated parts. FEMTOPRINT® process is maskless and doesn’t require a cleanroom environment, allowing for fast turnaround cycles during prototyping; thanks to its unique know-how and capabilities in glass microprocessing, FEMTOprint gives full support to its customers along different phases of development, from proof-of-concept to product development and wafer-scale manufacturing, delivering from single units up to high-throughput volumes.

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Author Biography

Davide Farina received his MSc in physics at Università degli Studi dell’Insubria in Como, Italy (2018). After his Master thesis in the field of natural light colorimetry, Davide worked from 2018 to 2022 for CoeLux Srl, an innovative lighting company based in Lomazzo, Italy, as part of the R&D team with focus in optical design. Davide joined the Engineering department of FEMTOprint SA in 2022 with the role of Application Engineer Optics.

A Numerical Analysis of Piezoelectric Inkjet

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Dong Kee Sohn; Research Professor, School of Mechanical Engineering, Sungkyunkwan University, Suwon, South Korea
Han Seo Ko; Professor, School of Mechanical Engineering and Department of Smart Fab. Technology, Sungkyunkwan University, Suwon, South Korea

Abstract

The jetting behavior and pressure inside the piezoelectric inkjet head was investigated using numerical methods. A computational fluid dynamics model was developed for a cylindrical inkjet head, facilitating the calculation of multiphase flow and acoustic pressure wave propagation. This developed model reliably simulated jetting and meniscus behaviors. In addition, a lumped element model was constructed to quickly predict the internal pressure and flow rate. Both numerical models demonstrated good agreement in their pressure calculation. The developed numerical models can provide practical information that is challenging to obtain experimentally and can be employed to optimize the operating conditions, such as the waveform shape.

Introduction

Drop on demand (DOD) inkjet technology can eject droplets on the scale of tens of pico-liter with high reliability and reproducibility. Therefore, a piezoelectric inkjet, a primary type of DOD inkjet, has wide applications across diverse manufacturing fields, such as publication, bio printing, display panel, printed electronics, and more. [1] With such diverse requirement, the achievement of a stable jet without jetting failure or satellite drop is essential to improve the yield in manufacturing process. [2] To analyze inkjet jetting, a comprehensive understanding of hydraulic and acoustic phenomena within inkjet head is indispensable.

In this study, numerical models were developed to simultaneously calculate both hydraulic and acoustic dynamics in the inkjet head. Numerical methods can provide important information that cannot be identified in the experiment. Most of the research to date has involved experimental visualization of the motion of the jetted droplet or the motion of the meniscus. However, the flow information inside the channel remained not accessible. Thus, researchers proposed numerical models for piezo inkjet to analyze jetting behavior according to the operating conditions. [3-5] Nevertheless, most of those models did not consider compressibility factor in their calculation. Since the acoustic pressure waves propagating within the channel induce the meniscus motion which determines the pinch off time and drop formation, it is important to include the compressibility effect in the numerical model. In prior models, pressure profiles were assigned at the inlet boundary to serve as a driving force. However, in this study, the dynamic mesh method coupled with acoustic calculation allowed for an opening condition at the inlet boundary, which facilitated a spontaneous refill process. The simultaneous computation of multi-phase flow and acoustics in the CFD model allowed the meniscus motion and drop formation representing close to the actual behavior. Moreover, a lumped element model (LEM) was also developed for quick simulation of pressure and flow rate inside the inkjet head. The LEM was modified by segmenting each flow channel to provide spatial attribute and enhance the accuracy from the Wang's model. [6]

Method

A two-dimensional axisymmetric computational fluid dynamics (CFD) model was developed for the cylindrical inkjet head, MJ-AT (MicroFab, USA), as depicted in Figure 1.
Working fluid was pure ethylene glycol with a viscosity of 15.7 cPs, and a surface tension of 47 dyn/cm. A commercial CFD tool, Ansys Fluent, was employed to simulate the inkjet dynamics with a volume of fluid (VOF) model for multi-phase flow and a dynamic mesh method for the piezoelectric actuation. With the dynamic mesh method, the linear actuator was operated in radial direction via user-defined-function (UDF), achieving constant radial expansion. The bulk modulus of ink, reciprocal of compressibility, was given in the model to involve acoustic effect. As a result, the developed model simulated from the actuation to the drop jetting including refill process of ink through the inlet conditions at the inlet boundary.

Another numerical approach, the lumped element model (LEM), was also developed to compute the internal pressure and flow rate employing an equivalent circuit model under lumped approximation. The hydraulic system of inkjet head was converted into the lumped electric system based on system dynamics theory. By Kirchhoff's law, the constitutive equations were formulated with respect to the voltage and current which are equivalent with the pressure and flow rate, respectively. MATLAB was used to solve these constitutive equations by integrating them into a state-space differential equation. The LEM calculation was completed in a few minutes, much less than the time required for the CFD simulations.

Results

The volume and velocity results, according to the operating voltage, are plotted for both the experiment and numerical simulation in Figures 2(a) and (b). The numerical results are quantitatively validated with the experimental results. The volume and velocity increase linearly with voltage, corresponding to the change in volume of the pressure chamber. In Figure 2(c), the jetting and meniscus behaviors are displayed in jetting images from the CFD simulation and visualization experiment at intervals of 20 μs. The observation of tertiary retraction in the meniscus motion indicates validity of the developed CFD model in comparison with the experimental result. This is particularly significant as models without compressibility effect only captured secondary retreat. The pinch-off and drop formation of numerical results also show good agreement with the experimental results. Figure 2(d) presents the pressure results obtained from both LEM and CFD simulation. The LEM showed good agreement with the CFD in the pressure results, thereby verifying the reliability of the lumped system. As a result, the LEM can be utilized to design the waveform or rapidly predict the jetting behavior before operating the inkjet head.

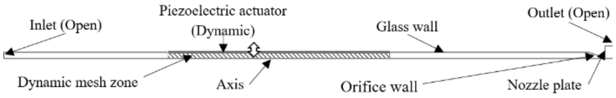

Figure 1. Geometry and boundary conditions of axisymmetric CFD model.

(a)
(b)
(c)
(d)

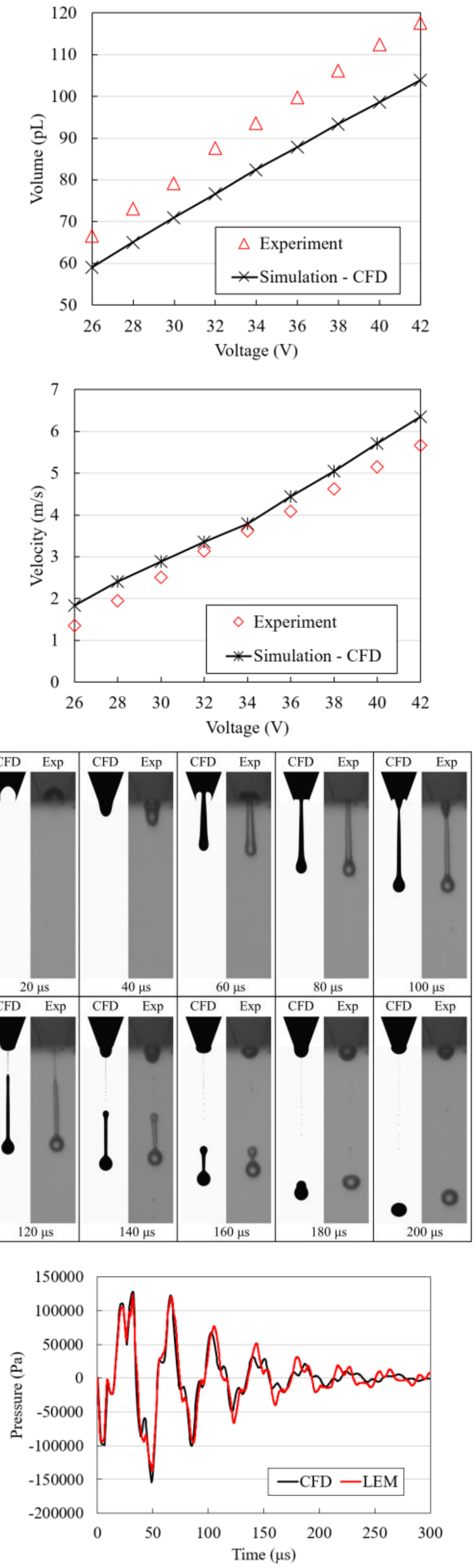

Figure 2. (a) Volume and (b) velocity results for both experiment and CFD simulation, (c) jetting images from CFD and experiment with the interval of 20 µs, and (d) pressure results from CFD and LEM over time at the center of the piezo actuation chamber.

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Author Biography

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Epson's MEMS Technology: PrecisionCore

---Development Strategy and Future plan---

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Abstract

PrecisionCore is a next-generation inkjet printing technology created by Epson. It achieves excellent image quality even as it greatly boosts print speed. In addition, it significantly expands the range of inks that can be used and materials that can be printed. PrecisionCore was created by merging high-precision MEMS fabrication processes, thin-film piezoelectric (TFP) technology, and more with Epson's inkjet technology and experience accumulated over many years.

In this presentation, we describe the strategy used to develop thin-film piezo and MEMS technologies, along with technical details, and describes how we plan to evolve in the future.

Introduction

Digital printing with inkjet in recent years has attracted attention on on-demand printing, and Inkjet are increasingly expanding the footprint in many types of industries and use cases.

Drop-on-demand inkjet printheads are divided into two main methond. One is a piezo inkjet head, which uses piezoelectric actuators to eject ink droplets. Piezo inkjet heads are superior in terms of compatibility with a wide range offluids. Another technology, thermal inkjet printhead has an advantage in terms of nozzle density, compact design , and low manufacturing cost.

Productivity and low manufacturing cost of thermal inkjet print head is due to the high number of nozzles and high nozzle density. Therefore, the key to improve Piezo print head is to increase the nozzle density; maintain the high ejection performance of each nozzle even at higher density; and achieve these two requirement with a simple, low-cost structure and process.

Development strategy and technology details of PrecisionCore

Epson has commercialized two type of piezo inkjet heads: push mode head (MACH) and bend mode head (ML-CHIPS). Due to limitations in materials and processing methods, it is not possible to achieve a high nozzle density of 180 dpi or higher for either type of head [1-3]. However, by introducing the thin film piezo technology to the combination of these heads (structure, materials, processing methods), it is possible to increase the nozzle density of piezo inkjet heads [4].

The print chips in print head are made up of three components: actuator, ink flow path, and a chip mounting structure. The development strategy and technical details is as follows. These strategies could not be achieved in the same time, so the structure was developed over 3 generations [5].

(1) Actuators (piezo elements and vibration plates) and pressure chambers
- Expensive to manufacture but has a big impact on jetting performance.
- Develop actuators with a large displacement to enable small, low-cost print chips.
- The above strategy was realized by using 1um thick high-voltage PZT using the sol-gel method and an actuator structure consisting of a minimum layer.

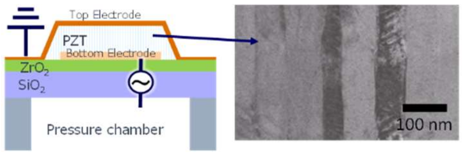


Fig.1 Schematic diagram of actuator and cross-section of pzt crystal (SEM)

(2) Ink flow paths such as nozzles and ink reservoirs
- Reduce actuator cost by fabricating ink flow paths separately from the substrate forming the actuator and then bonding them together to form print chips.
- To minimize investment and manufacturing costs, pressure chamber and ink channel plate are manufactured by Anisotropic silicon wet etching. Only Nozzle plate uses Deep RIE process to achieve circular shape nozzle

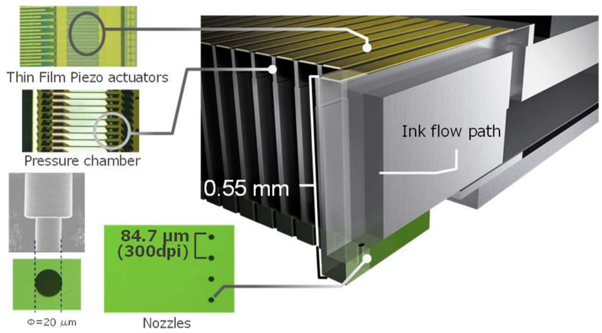
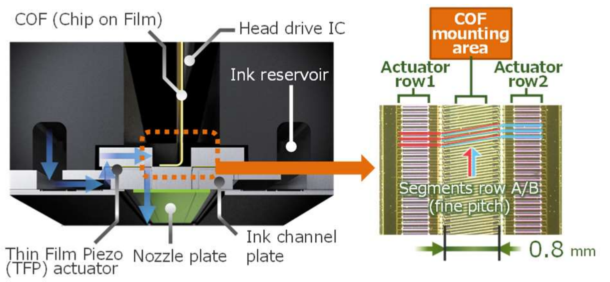


Fig.2 Si-MEMS ink flow paths

(3) Electric path for applying drive waveform (mounting structure)
- We selected the one that has the smallest footprint on the substrate forming the actuator.
- Mounting structure using high density COF can reduce the print chip size. In addition, this structure supports various ICs, depending on the application, without affecting the chip.

Fig.3 Schematic diagram of PrecisionCore Printchip and



mounting structure using high density COF.

Xaar's Ultra High Viscosity Technology: Redefining the boundaries of inkjet printing

Renzo Trip, Angus Condie, Karl Forbes; Xaar plc; Cambridge, UK

Abstract

The ability of Xaar printheads to jet high viscosity fluids for 3D applications has been known for several years. How can traditional and upcoming inkjet markets, such as ceramics, labels and direct-to-garment, benefit from a high viscosity fluid? It will be shown that Xaar's Ultra High Viscosity Technology is redefining the boundaries of inkjet printing.

Traditionally, inkjet has been limited by the range of fluids that can be jetted when compared to analogue printing techniques. One of the limitations of digital inkjet printing is the range of fluid viscosities that can be jetted, typically between 6 cP and 25 cP. Xaar's Ultra High Viscosity Technology allows fluids of up to 100 cP at jetting temperature, exceeding 1000 cP at room temperature. Behind Xaar's Ultra High Viscosity Technology are an efficient actuator, Xaar TF Technology and the ability to tune waveforms.

The ability to jet fluids with a significantly higher viscosity redefines the boundaries of inkjet. The desire to digitally print higher viscosity fluids originates from advanced applications, that are not traditionally associated with inkjet technology. In 3D printing a higher viscosity implies a wider range of material properties enabling the production of tougher or more flexible parts [1]. Together with the possibility to combine multiple materials and multiple colours inkjet presents an interesting alternative to other 3D printing techniques. Further examples of advanced applications that benefit from an increased viscosity range are automotive painting and functional fluids in the semiconductor industry.

Some of the advantages seen in 3D are applicable in 2D applications as well, for example cosmetic textures in the Décor industry, but the ability to formulate inks using higher molecular weight monomers and oligomers has further implications. An increased polymer functionality may reduce the pinning and curing requirements, and a reduced migration benefits indirect food contact applications.

An increased viscosity does also enable dispersions with a higher particle volume concentration. This benefits all ink types, including UV, oil, solvent-based and water-based inks. The ability to print whites and heavily pigmented inks allows for vibrant colours, particularly on dark substrates, for example in ceramics, direct-to-garment and direct-to-fabric applications.

The ability to increase the pigment concentration has further implications; the required laydown may reduce. A lower drop volume can increase the print speed and thus printing productivity. Furthermore, a reduction of water can significantly reduce the energy required for drying providing a more sustainable solution with a lower cost of integration and ownership.

A high viscosity fluid will interact with a substrate differently. Independent research by Swansea University – WCPC has shown that the reduced absorption of a high viscosity water-based fluid significantly improves the colour density achieved on coated and uncoated corrugated board. The reduced dot gain may allow for improved print quality, for example in direct-to-product applications. It also enables digital printing of Braille, eliminating tooling costs and reducing setup time in comparison to traditional methods such as embossing.

In summary, high viscosity enables a wider range of fluids to be jetted enabling new applications and enhancing existing applications with beneficial effect on the fluid interaction with the substrate. The benefits are improved print quality, higher productivity, reduced cost of integration, reduced energy consumption and reduced cost of ownership.

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Author Biography

Renzo Trip obtained a MSc. Degree in Applied Physics at Delft University of Technology (Delft, The Netherlands), followed by a PhD in Engineering Mechanics in 2016 at KTH Royal Institute of Technology (Stockholm, Sweden). Thereafter, Renzo joined Xaar plc (Stockholm, Sweden) as part of the Advanced Applications and Technology group, currently fulfilling the role of Principal Engineer.

Development of Effective Driving Methods for Inkjet Drop-on-Demand Jetting of High Viscosity Liquids

Takayuki Shimizu and Masakazu Hirata, SII Printek Inc. and Masanori Tamura, SEIKO FUTURE CREATION INC.

1. Abstract

Drop On Demand inkjet printheads are widely used for imaging applications and have the potential to be used in various production processes in the future. However, the upper limit of liquid viscosity that enables stable jetting is less than 20 mPa-s for most products[1]. Therefore, we investigated a method for jetting high-viscosity liquids exceeding 20 mPa-s using SII Printek's RC1536 head, which has an advantage in high-viscosity liquid jetting. As a result, we confirmed that the heat generated by the actuator contributes to the high viscosity jetting by actual measurement and simulation.

2. Experimental

Mineral oil-based liquids Sample A (126.7 mPa-s at 25°C) and Sample B (62.3 mPa-s at 25°C) were used as sample liquids. The evaluation head was a SII Printek RC1536-M model with a modified control circuit, and one row consisting of 384 nozzles (90npi) was used for observation. Furthermore, a drive waveform developed for high viscosity liquid jetting was used.

2.1 Frequency-velocity characteristics

The drive frequency was modulated to obtain drive voltages that result in a jetting velocity of 5 m/s. The evaluated liquid was Sample B, and the viscosity was changed under four conditions by heating outside the head. The results are shown in Figure 1. The higher the drive frequency, the lower the drive voltage. Converting these results to jetting velocity, the difference is 15 m/s at maximum. It also shows that the degree of change depends on the viscosity.

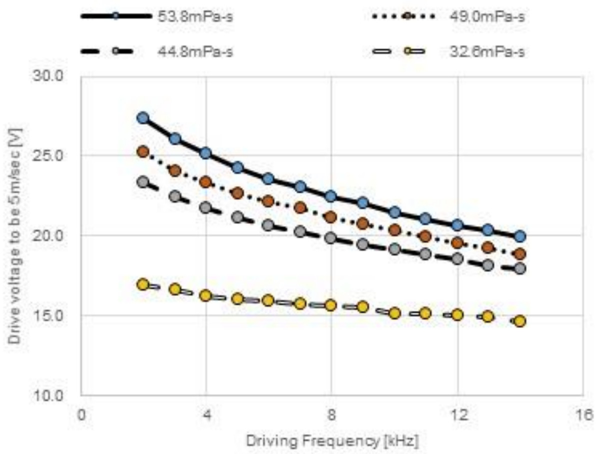

Figure 1. *Voltage and drive frequency characteristics that become 5m/s*

2.2 Measuring actuator temperature

The temperature during actuator drive was measured to confirm the cause of the velocity change effect shown in Fig. 1. While circulating liquid, the actuator was driven by inputting pulses for heating without jetting droplets. The evaluated liquid was Sample B with an initial temperature of 33.7°C. The temperature is shown in Figure 2. It can be seen that the higher the driving frequency, the more heat is generated. Therefore, it can be inferred that the heat generated by the actuator heats the liquid, which in turn lowers the viscosity of the liquid and causes the velocity fluctuation.

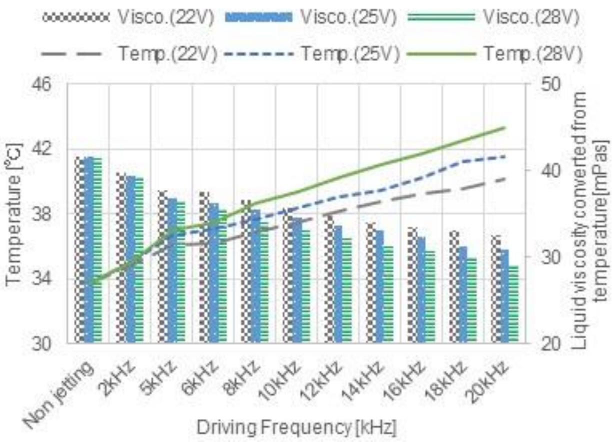

Figure 2. *Actuator temperature and viscosity calculated value*

2.3 Temperature measurement of circulating liquid and simulation

Next, the temperature change of Sample A circulating in the head was examined using thermocouples. There are five temperature measurement points in the inflow common channel that supplies liquid from the IN port to multiple actuators and five points in the outflow common channel that collects liquid discharged to the OUT port. In the common channel, liquid flow occurs along the nozzle row direction. While circulating ink, the actuator was driven by inputting pulses for heating without jetting. The temperature rise of the liquid occurred before and after inflow and outflow to the actuator, and a temperature gradient in the direction of liquid flow from the IN to OUT port was obtained.

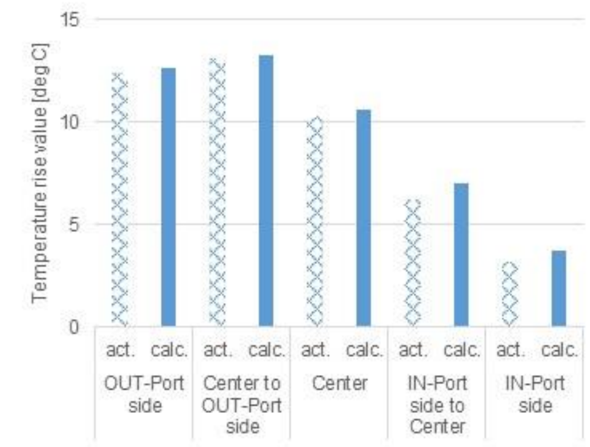

Figure 3. *Measured and simulated circulating liquid temperatures at the outflow common channel*

The same measurements were also performed for the transition from heating pulses to jetting. Simulations were also performed under the same operating conditions and compared with actual measurements. The simulation was performed using SimulationX, a multiphysics simulation software. The results are shown in Figure 3. The trend of the ink temperature is consistent with the actual measurement.

2.4 Importance Analysis of Heat Generation

Next, an importance analysis of the drive parameters that contribute to the heat generation of the actuator was conducted. For the importance analysis, random forest of scikit-learn, an open source machine learning library in Python, was used. The objective variable was the actuator temperature rise value, and the explanatory variables were drive frequency, drive voltage, circulation flow rate, and number of input pulses. The number of data is 88. The calculation results show that the contribution of drive frequency, number of pulses, and drive voltage were 0.49, 0.23, and 0.13, respectively. The higher this value, the greater the contribution to the objective variable. These results indicate that it is effective to control the number of pulses, which has a high degree of freedom to be changed, as a driving condition.

3. Examination of Heat Generation Waveforms and Verification of Effectiveness

Based on the previous confirmation, it is necessary to control the amount of heat generated by the actuator in order to align the jetting velocity. Therefore, we developed a drive method that controls the heat generated by the actuator by the number of pulses. This method enables us to flatten the effect of velocity fluctuation caused by different actuator heat generation depending on the drive frequency and print resolution.

Figure 4 shows the jetting velocity characteristics. The common driving conditions are voltage of 22 V, initial viscosity of 57.4 mPa-s, and circulating flow rate of 20 mL/min. The driving frequency for Condition 1 is 3 kHz and 45 dpi, and Condition 2 is 12 kHz and 90 dpi.

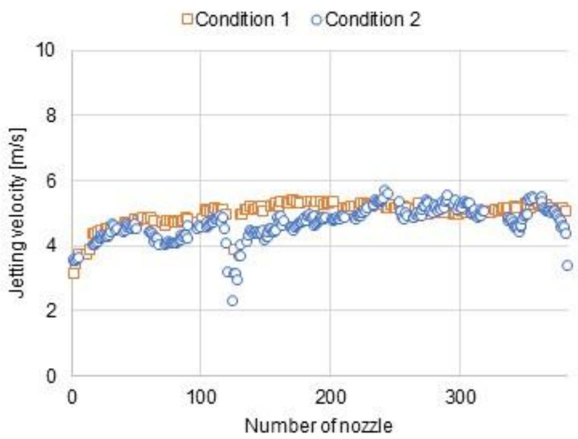

Figure 4. *Jetting velocity characteristics*

As mentioned in section 2.3, there is a temperature gradient in the direction of liquid flow, with a maximum viscosity difference of 18.7 mPa-s on the inflow side to the actuator. However, there is no velocity gradient in the direction of the nozzle row. This is thought to be due to the instantaneous heating of the liquid flowing into the actuator.

4. High viscosity "126.7 mPa-s" liquid jetting

Sample A was dispensed at 25°C using the method described above. The driving conditions are shown in Table 1. The results of time-series jetting images from the nozzle are shown in Figure 5. This result shows that stable continuous jetting was possible.

Table 1 Jetting Conditions for 126.7 mPa-s

Voltage[V]	Temperature [deg. C]	Flow rate [mL/min]	Viscosity [mPa・s]	Driving Freqency[kHz]	Print Resolution[dpi]	Jetting Nozzle number
23	25	8	126.7	6	45	96

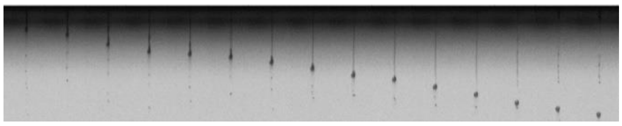

Figure 5. *Jetting image of 126.7 mPa-s liquid*

5. Conclusion

Using an RC1536 head with a modified control circuit, we investigated a high-viscosity liquid jetting method using a drive waveform developed for high-viscosity liquid jetting. It was found that the factor causing the difference in jetting velocity as much as 15 m/s depending on the drive frequency is the heat generated by the actuator. Especially for high-viscosity liquids, the viscosity change due to temperature change has a large impact on the jetting velocity. Therefore, we have shown that a high-viscosity liquid of 126.7 mPa-s can be dispensed stably by actively utilizing the heat generation and controlling the actuator's heat generation by the number of pulses.

We will continue these developments to further enhance the value of the highly regarded and widely used RC1536 head.

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Author Biography

Takayuki Shimizu received his M.E. degree in Nano-Material Systems engineering from Gunma University, Japan in 2006. He joined Seiko Instruments Inc. and worked at its operating company, SII Printek Inc.in 2006. Since then, he has been engaged in the development of inkjet ink and drive waveforms.

Masakazu Hirata received the B. E. degree in mechano-aerospace engineering and the M.E. degree in precise mechanical system from Tokyo Institute of Technology, Japan in 1999 and 2001, respectively. He joined Seiko Instruments Inc. in 2001, where he was engaged in research and development. He further joined its operating company SII Printek Inc. in 2019, where he is engaged in the development and design of inkjet printheads.

Masanori Tamura received his M.E. degree in molecular biology from Hosei University in 2011. He joined Seiko Instruments Inc. in 2011, where he was engaged in the design and development of tuning fork-type quartz crystals. From 2015, he transferred to CAE department, where he is primarily engaged in thermal fluid analysis related to inkjet heads. In 2022, due to organizational changes, his department became part of the group company, Seiko Future Creation Inc.

Fully integrated airflow visualization system for improved inkjet printing

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Abstract
Several new inkjet printing applications require high throw distances or high printing speeds. In such configurations, complex airflows occur in the gap between the printhead and the substrate, potentially jeopardizing the print quality by deviating the ink droplets. To better understand the airflow effects on the droplet's trajectories, a novel inkjet printing platform has been developed. The latter allows the full control of the different parameters, from the laser sheet intensity to the axis motion, to the fog generation, to the print head driving waveform. The system has been fully automatized and allow for large parametric study to be performed, key for unstable flows requiring for statistics.

Introduction
Driven by the digital revolution and the demand for personalized products, inkjet printing has evolved from being mainly used for graphical applications to a digital fabrication toolkit. Nowadays, functional ink drops are deposited on substrates of increasingly complex geometries (see Figure 1) [1].

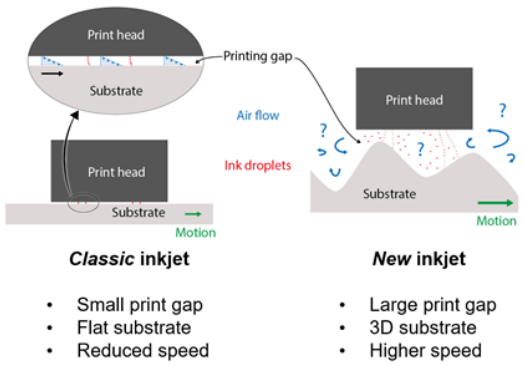

Figure 1. *Context of the project.*

As a result, the distance between the print head and the substrate is not always constant and can go up to several millimeters to avoid collisions or heat effects. This is in stark contrast with the classical working conditions of inkjet printing, where the print head is located 1-2 millimeters from a flat substrate. Furthermore, the industry is pushing for higher productivity, resulting in higher printing speeds. Today, the printing quality is dramatically compromised at higher throw distances and printing speeds by the appearance of severe drop misplacement effects.

The rationale for these undesired patterns (see Figure 2), usually referred as *wood-grain*, is the complex and unstable air flow that affects the drop trajectory for large gaps and high-productivity settings. In fact, when increasing the throw distance, the air flow produced by the jetted drops becomes increasingly important and interacts with the air flow induced by the relative motion between the print head and the substrate [2]. Furthermore, the latter is perturbed for larger gaps by external flow effects, as the transient ones induced by the varying curvature of a 3D object. Flying drops over long distances loose kinetic energy and are therefore deviated by these unstable eddy flows, eventually resulting in drop misplacement [3].

Figure 2. *Example of wood-grain effect. The printed image should be of uniform color.*

The aim of this project is to study the air flow and reduce its undesired effects on the drop trajectory to achieve higher print qualities at higher throw distances and higher speeds. To be able to visualize the airflow, a new sophisticated and versatile printing platform has been developed.

Materials and methods
A new versatile and automatized printing platform (see Figure 3) has been developed, including a dual camera system and a high-speed camera, a laser sheet generation system, a fog generation system, several possible print heads and a circulating ink supply system. Everything has been automatized and synchronized with the custom-made FPGA.

Figure 3. *Printing platform.*

Results

Beside the developed printing platform, which is a result itself, some very interesting flow visualizations could already be done and conclusions drawn. In addition to the well-known Couette and droplet-indued impinging jet flows, Poiseuille flow contributions due to pressure differences on both sides of the print head as well as inertial flow effects have been observed. The two latter contributions are mostly overlooked in the literature but can be either beneficial or detrimental to the stability of the flow [1, 4]. Furthermore, since more complex flow configurations have been studied, very interesting airflows have been identified (e.g. vortex shedding behind the print head for low confinements). The effect of the printing gap, printing speed, interleave printing, transient phenomena, have been investigated in this study.

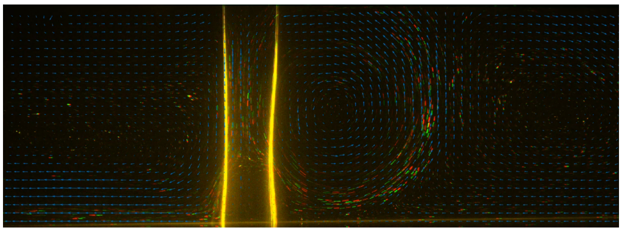

Figure 4. *Example of measured airflow field for* 0.3*m/s printing speed,* 4.5*mm throw distance and* 5 *pL droplets at 600 dpi.*

Conclusions

The key asset of the platform, where all subsystems have been developed internally, is the full control of the different parameters, from the laser sheet intensity to the axis motion, to the fog generation, to the print head driving waveform. The system has been fully automatized and allow for large parametric study to be performed, key for unstable flows requiring for statistics.

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Author Biography

Johannes Renner studied mechatronics with specialization in automation technology at the Secondary Federal College of Engineering in Vienna, and mechanical engineering as well as mechatronics at the Bern University of Applied Sciences, where he worked after graduation in 2007 as scientific assistant and later on as scientific officer for the Institute of Print Technology. In 2013 he joined the iPrint institute. Johannes has gained over 15 years of experience in applied research with the focus on inkjet technology and is contributing to many of iPrint's inkjet-related projects.

Jonas Maturo has a Bachelor's degree in Mechanical Engineering and a Master's degree in Biomedical Engineering. In 2018, he started working at iPrint, where he worked on various lab projects like designing and testing microfluidics on print heads, studying droplet aerodynamics, developing printed electronics, and investigating the transport of drop-encapsulated objects. Since 2023, Jonas has been actively involved in the family-owned business, focusing on tailored solutions in mechanical development.

Vincent Schneuwly obtained a bachelor degree in electrical engineering at the School of Engineering and Architecture of Fribourg. He then worked at iPrint while pursuing his Master's degree in Embedded Systems, that he obtained in . Vincent currently works at iPrint as R&D engineer in electronics.

Benoît Sahli holds a Bachelor degree in Mechanical Engineering from the School of Engineering and Architecture of Fribourg. After graduating in 2019, he gained experience as Mechanical Engineer in the field of hydro-electric power plant. Benoît started at iPrint as R&D Engineer in additive manufacturing, where he designed, built, programmed and tested custom 3D printers.

Yoshinori Domae studied Mechanical engineering and joined Seiko Instruments Inc. in 2006. Working in Seiko I Infotech division, he was in charge of design and development of wide format inkjet printers. After moving to SII Printek division in 2011, he was the Project Leader and Chief Designer of printhead R&D. Then he invented and designed RC1536 inkjet printhead which was disruptive new recirculation printhead for some industrial inkjet applications. After that, he moved to France where he had worked as the Technical Manager for all industrial inkjet applications in EMEA, since 2014. In 2019 he joined iPrint in Switzerland, and started his activities especially for inkjet technology and innovation.

Gioele Balestra holds a Master degree in Mechanical Engineering from ETH Zurich and a PhD from EPFL. He joined iPrint in 2019 to develop new digital deposition techniques and since July 2020 he is in charge of the applied research and educational activities of the institute and competence center.

Smart materials by Inkjet

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Abstract

There is growing interest in voxelated matter as it allows to build up tailored made surface functionalization and innovative new gradient materials. Inkjet-based printing is the only method that can create voxelated materials with high precision, digital and extremely versatile through high controlled formation of small pico-liter droplets [1, 2]. In this case the droplet will be the smallest material unit called voxel. The spatially controlled deposition allows to functionalize surfaces, build materials gradients, and combine different materials to generate printed surfaces with new features. In this way, the preparation of surfaces and coatings with a tailored functionalization and performance on demand becomes possible.

Through the vehicle of inks with different softness grades which are doped with mechanochromic additive, we have developed a multi-material inkjet platform, which allows to create gradient materials with new performance. The additive has helped to characterize this new kind of materials on one hand and on the other hand it will be the start of creating new smart materials with gradient properties by inkjet. The first drop casting tests of these two inks has proven the mechanochromism by the measurement of the ratio between the intensity of the monomer and the excimer under UV light. The intensity in the mixing zone was measured at different strain. Finally, it was proven that the hardness in the mixing zone could be defined.

Materials and Methods

Commercially available polyurethanes (PUs) with different hardnesses were dissolved in a solvent to formulate an inkjet ink. A mechanochromic additive developed by the Adolphe Merkle Institute [3, 4], which changes its fluorescence absorption and color in response to mechanical forces (elongation) was added to the ink (Figure 1). This additive is a marker and has no impact on the properties of the PU. The additive was added to the inks at low concentration (0.2-1 wt%).

Figure 1: Images taken under UV illumination of an elastomeric polyurethane/tOPV blend film containing 0.2 wt% tOPV subjected to uniaxial tensile deformation at the indicated strains

First challenge was to find a suitable solvent both for the additive and for the printhead. Compatibility tests with the RC1535 printhead were performed as described by the printhead manufacturer. Rheological properties of these inks were analyzed with a piezo axial vibrator rheometer (Tri-PAV) at high-frequency from 100 Hz to 10'000 Hz at room temperature to find suitable formulations for inkjet printing.

A standard inkjet printing platform for research was adapted to print two different PU inks at the same time with two printheads. After dropwatching and waveform optimization, two inks were selected: ink A composed of 20 mg/ml of soft35A12P PU from BASF (hardness Shore 35A) and ink B composed of 15 mg/ml of irogranA80P from Huntsman (hardness Shore 80A). Both inks were dissolved in dioxane.

Best drying conditions to obtain a good mechanochromic response without altering it had to be fixed. It was found that rest of solvent after drying didn't give any mechanochromic response. High temperatures deteriorate the mechanochromic agent.

The selected inks containing the mechanochromic additive were deposit by inkjet at room temperature on a PU substrate fixed on a heating plate at 40°C (Figure 2).

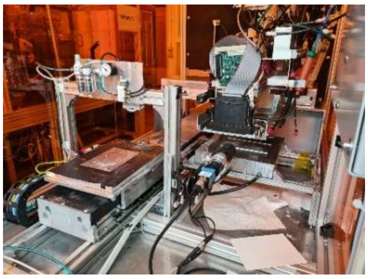


Figure 2: Inkjet printing plateform

Different printing patterns were tested, with different thicknesses (1 to 20 layers). Inkjet and dropcast samples were then dried overnight at 60°C in oven and analyzed by the Adolphe Merkle Institute. Spectroscopic analysis was performed using a microtensile tester and an optical fiber setup, as well as with a fluorescent confocal microscope (Zeiss LSM710) with a special tool developed to elongate the samples uniformly up to 100 %. The local monomer-to-excimer ratio (I_M/I_E) was measured at different elongation rates.

Results and Discussion

Drop casting deposition

First tests were performed by dropcasting of the two polymers with a pipet to show the mechanochromism. The local monomer-to-excimer ration (I_M/I_E) was measured for each polymer at different elongation rates (Figure 3). This spectroscopic analysis shows clearly the mechanochromism of the different PU inks. Harder PU exhibit higher I_M/I_E values than softer PU. We have also shown the mechanochromism with fluorescent confocal microscope analysis (Figures 4, 5 and 6). Thanks to the mechanochromic additive and the measurement of its intensity, the hardness of the blend material can be measured.

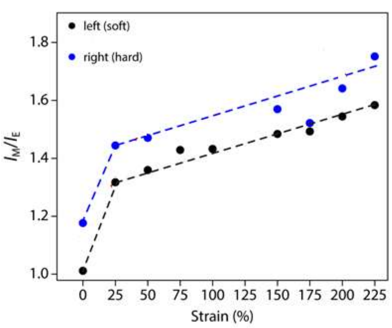
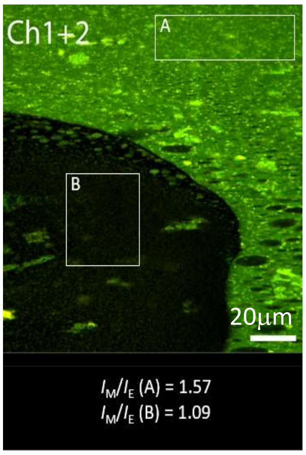


Figure 3: Intensity measurement (I_M/I_E ratio) in function of the strain on both PU inks. Ink A (hard PU) with Shore 80A. Ink B (soft PU) with Shore 35A (dropcast deposition and spectroscopic analysis)



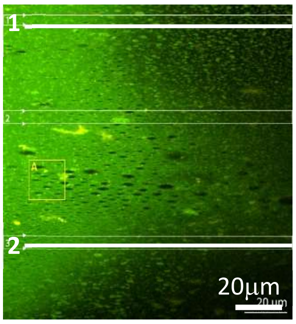


Figure 5: Confocal microscope image of a sample made by dropcasting ink A and ink B. Left side: ink A, right side: ink B

Figure 4: Confocal microscope image of a sample made by dropcasting ink A and ink B. 90% equibiaxial strain was applied to the sample before imaging

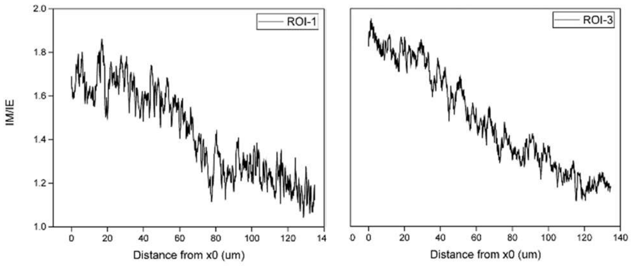


Figure 6: Intensity measurement (I_M/I_E ratio) in function of the distance along the two lines 1 (left graph) and line 2 (right graph) of Figure 4

Inkjet deposition

After having proven that the concept is working by dropcast deposition, the two PU inks were simultaneously deposit by inkjet with different patterns (Figure 7) and different thicknesses on the

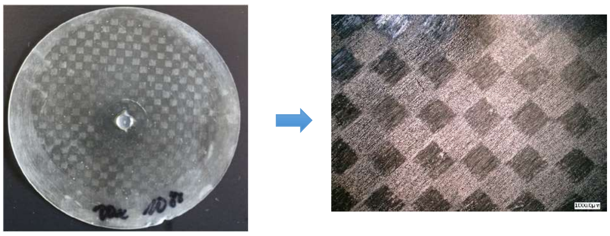


Figure 7: Inkjet printed chessboard pattern with ink A and ink B

PU substrate heated at 40°C. Difficulties appeared due to the fact that the samples were not flat enough to be able to do a good focus (impossible to do big stitched pictures due to the loss of the focal plan), leading to difficulties to find an interface between the two PU at this very high zoom. Finally, the interface found (Figure 8) was not clear enough due to printing difficulties with lots of printing satellites and dewetting issues of the hard PU during the drying. It has been impossible to perform intensity measurement on these samples.

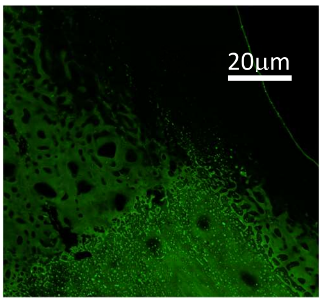


Figure 8: Fluorescent confocal microscope picture of inkjet printed inks composed of ink A (bottom right) and ink B (top left)

Conclusion

The mechanochromic additive was blended with two PUs with different hardnesses and dissolved in dioxane to create an ink that can be jetted by inkjet. The first drop casting tests by deposition of two drops of the two different inks close each other to have a mixing zone have proven the mechanochromism of the inks by the measurement of the ratio between the intensity of the monomer and the excimer under UV light. The intensity in the mixing zone was measured at different strain. Finally, it was proven that the hardness in the mixing zone could be defined. Unfortunately, difficulties appeared during the inkjet process leading the impossibility to perform these measurements after inkjet deposition due to printing inhomogeneity and issues such as ink splashing and satellite formation. Next step is to do simulations of the drop behavior and mixing to be able to predict the hardness and to be able to deposit the necessary quantities of each material to obtain the desired hardness to create materials with given hardness gradient with very high precision.

As summary, the present project is a first step to build up basic understanding on multimaterial droplet interaction for creating tailored made surfaces. It allowed us to build a dedicated inkjet printing platform, to formulate inkjet printable smart inks containing the mechanochromic additive, to prove the mechanochromism of the different polymers and to gain a deeper understanding of the requirements to achieve homogenous smart gradient material layers. Next step involves inkjet printing highly homogeneous gradient layers without substrate delamination. Once accomplished, we will analyze the collected data and results from the voxel inkjet printing process, as well as the characterization of the gradient material and surfaces, utilizing mechanochromism. These findings will enable us to further advance the process through numerical simulation and to consider other smart material like nanocomposites on demand (reactive systems) or stretchable conductive materials to be combined into new smart gradient materials.

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Acknowledgements

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Author Biography

Muriel Mauron received her master in chemical and biological engineering from the EPFL in 2007. After six dynamic years of driving innovation in inkjet photo papers at Ilford in Marly, Switzerland, Muriel joined iPrint institute. Since 2014, she has been the main person to handle primarily all bio printing projects and inkjet-related chemicals, and additionally most recently rheological analysis for almost all the iPrint project.

Combining laser engraving and UV-Inkjet printing for personalization of security documents

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Mauro Costantini, Riccardo Pogliotti, Corrado Caizzi, Rudi Bressan, *IXLA s.r.l, Romano Canavese, Italy*

Abstract

Italian company IXLA partnered with the iPrint Institute to develop a ground-breaking solution for decentralised desktop colour inkjet printing within IXLA's laser engraving machines, addressing the demand for larger colour images and innovative security features in the personalisation of security documents. The project followed iPrint's 'digital manufacturing' process, including materials analysis, ink selection and extensive testing. The resulting 'XPrint' platform, which was unveiled at the TRUSTECH exhibition in Paris in November 2023, attracted considerable interest. The collaboration facilitated the in-house development of XPrint and helped position IXLA as a leading player in the personalisation of security documents. The future plans include delivery of first platforms in 2024, ongoing work to improve processes and a focus on developing new security features by combining laser and inkjet technologies. The aim is to exploit the full potential and synergies of both technologies for revolutionary, cost-effective and easily detectable security features.

Introduction

While colour inkjet printing is already well-established on the market for centralised printing of security documents, there are only few solutions for decentralised desktop solutions. Italian company IXLA, which specialises in laser personalisation of security documents, partnered with the iPrint Institute to develop a solution integrating a relatively small inkjet printing system within IXLA's laser engraving machines.

The user-friendly system, aimed at non-specialist users, is a first in the security document personalisation market and is ready to meet the ever-changing demands of the market and the trend towards larger colour images, new innovative security features and digitalisation of security documents.

Procedure

In this project, iPrint's 'digital manufacturing' process (material, ink, pre-treatment, printing, post-treatment, platform, product) was closely followed. The initial phase consisted of a thorough examination and analysis of the materials involved in the printing process. By taking into account material properties and printing requirements, precise ink specifications were defined. Leveraging iPrint's connections with the major companies in the ink market, a wide range of potential inks were identified and acquired. Extensive ink screening, based on material compatibility and specification compliance, enabled three ink candidates to be selected for further printing tests. Methods used to assess ink performance included adhesion, Taber abrasion resistance and UV fading tests.

In a next phase, A prototyping platform was developed and assembled to streamline testing and printing of the selected inks. The platform incorporated the key components for ink deposition and curing, allowing the ink candidates to be systematically evaluated and validated. The printing process was carefully tested and optimised by fine-tuning various parameters from ink deposition to pre- and post-processing. One of the main focuses of research has been on the interaction between the laser and the inkjet technology. This phase was carried out in close cooperation between IXLA and iPrint to ensure a full knowledge transfer to IXLA.

Figure 1 *Sample showing the combination of inkjet and laser technology*

With targeted support from iPrint, IXLA used the knowledge gained to develop its own first platform, the 'XPrint'. A first model of this platform was installed at iPrint in October 2023. The primary focus is currently on long-term performance testing, optimisation of maintenance processes and the development and implementation of new features such as multi-pass printing or the integration of varnish.

Results

The inks and printing parameters were subjected to evaluation through extensive testing according to high scientific standards. These tests were designed to validate the suitability of the selected inks and processes, specifically assessing critical parameters such as adhesion, abrasion resistance and UV fading resistance. The results not only contributed to a deep understanding of the process, but also played a key role in the development of the final product.

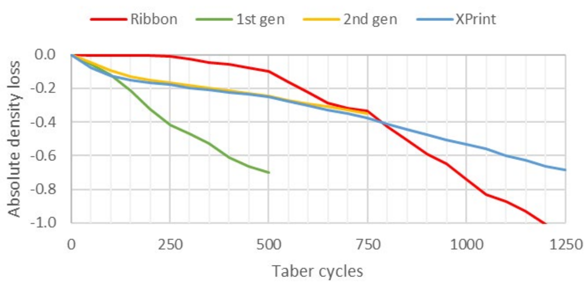

Figure 2 *Results of the abrasion resistance performance showing the improvement in performance resulting from the optimisation and a comparison with the performance of ribbon-printed samples.*

The XPrint, the result of a one-year development process, was presented to a wide audience at the TRUSTECH exhibition in Paris in November 2023, generating an exceptional level of interest and response.

Figure 3 *XPrint platform with laser personalisation engine (right) and UV-inkjet engine (right)*

Designed with a focus on user-oriented functionality, the XPrint represents a remarkable evolution in the field of security document personalisation. As the industry increasingly adopts larger colour images, integrates novel security features and undergoes digital transformation, the XPrint is positioned to play a leading role in shaping the future landscape of security document personalisation.

Outlook

As a result of the high level of interest, IXLA has already received first orders for the system, which will be delivered in response to public tenders during the course of 2024. The installation will be closely followed by iPrint, as the field experience will help to further improve the processes and the reliability of the engines.

The key success factor of this project, the exceptionally close collaboration between the iPrint Institute and IXLA, and the extensive transfer of know-how, enabled the in-house development of the 'XPrint' platform and a major step forward for the IXLA company in the market of security document personalisation.

In the future of this long-term collaboration, iPrint will not only focus on helping IXLA improve the reliability of their processes and platforms. iPrint and IXLA also share the vision developing new, innovative security features. This will involve using cutting-edge security inks, and combining the two technologies laser and inkjet to enable revolutionary, low-cost, hard-to-counterfeit and easy-to-detect security features.

The intention is not to reduce the two technologies to their main characteristics - monochrome with laser and colour with inkjet - but to exploit their full potential and synergies.

Author Biography

Philip Kessler studied mechanical engineering, specialising in plastics technology and lightweight construction, at the University of Applied Sciences of Western Switzerland in Fribourg. He is currently writing his thesis as part of the Master of Advanced Studies in Industry 4.0 at the Zurich University of Applied Sciences. He has worked for the iPrint Institute for 5 years and is responsible for mechanical engineering, platform development and management of industrial projects

Lateral Inkjet Printhead for Narrow Gaps

Marco Hölzle, Urs Lippuner, Michelle Müller, Aaron Lenherr, Raneem Achor, Katrin Albrecht, Rudolf Buser; OST – Ostschweizer Fachhochschule; Buchs SG, Switzerland

Abstract

A novel concept in inkjet technology exploits the intrinsically low design height of MEMS components. Since the nozzle is not attached at the front but laterally, drops can also be deposited in narrow gaps. Two different types of fluid displacement mechanisms have been deployed, a time controlled electromagnetic valve and a piezoelectric actuation. Thus, two types of MEMS-based printheads of only 1 mm thickness were developed and characterised with application related inks.

Motivation

Nowadays, inkjet printing is widely used as a digital material deposition technique for various complex materials. For specific industrial applications with geometrically confined spaces, the availability of commercial printheads with reduced outer dimensions is very limited. For this reason, a lateral MEMS-based printhead for very narrow gaps has been developed using two different types of fluid displacement mechanisms.

Simulation and Design Considerations

Several simulations were carried out to estimate the required dimensions to define the printhead design. It was calculated to which extent the silicon membrane bends as a function of the voltage applied to the piezo. A structure consisting of 100 µm thick silicon, 10 µm Araldite adhesive, and 200 µm piezoceramic was assumed. It was predicted that a voltage of 80 V applied to the piezoelectric actuator yields a maximum deflection of 4.01 µm (figure 1). This corresponds to a displaced volume of approx. 100 nl.

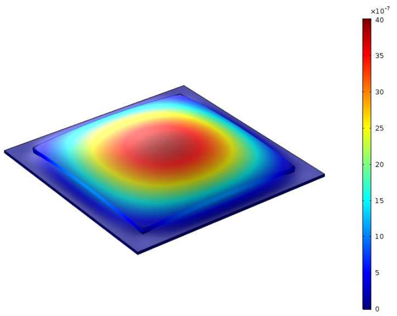

Figure 1: MEMS based piezoelectric printhead: Simulation results of a Si-Membrane displacement at 80V.

Results

Industrial microtechnology processes have been used to fabricate two different versions of the lateral printhead. The first configuration uses an external pressure source and the fast micro valve SMLD 300G from Gyger (figure 2). At 250 µs opening time of the micro valve, droplets with a volume of approx. 2 nl and a speed of 3.6 m/s were achieved. In the second configuration, a piezoelectric actuator is used to displace the fluid. The design of the channel structure is similar to the MEMS printhead using micro valve actuation. However, the channels were additionally coated with gold to reduce the surface energy (figure 3a). The pressure wave generated by the actuator diaphragm runs vertically towards the nozzle opening. Several fluids/liquids with a viscosity range between 10 - 50 mPas have been successfully jetted.

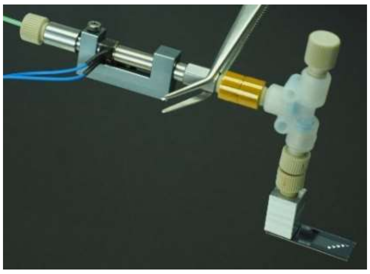

Figure 2: Final integrated MEMS printhead (bottom right) with an electromagnetic valve (top left) including fluidics.

(a) (b)

Figure 3: (a) Longitudinal section through a MEMS-based piezoelectric actuated printhead (l x w x h: 30 x 10 x 1 mm) with the ink path towards the nozzle opening and the silicon membrane visible, and (b) two single droplets ejected by piezoelectric actuation.

Conclusion

A new concept of a lateral inkjet printhead for digital printing in geometrically confined spaces such as narrow gaps has been successfully demonstrated. Conventional MEMS manufacturing technologies have been used to fabricate this only 1 mm thick printhead. Therewith, novel industrial applications for drop-on-demand technology can be addressed in the future.

Acknowledgment

Financial support from Innosuisse (grant: 28748.1 IP-ENG) for this work is gratefully acknowledged.

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Author Biography

Marco Hölzle obtained his federal certificate of proficiency as a physics laboratory engineer at the Zurich General Vocational School in 2020. Since 2021, he has been studying systems engineering part-time at OST – Eastern Switzerland University of Applied Science and works at the Institute for Microtechnology and Photonics at OST in parallel.

Recent Progress in Inkjet Monitoring based on Piezo Self-sensing

Kye-Si Kwon, Jeong Yeop Jo and Sang Hyeon Park; Soonchunhyang university, Asan, Chungnam, South Korea

Abstract

Inkjet technology, a maskless additive manufacturing process, utilizes multiple nozzles to selectively deposit ink at precise locations. This process offers significant material efficiency, minimizing waste and making it well-suited for additive manufacturing. Moreover, inkjet technology boasts exceptional throughput capabilities, employing numerous heads equipped with tens of thousands of nozzles simultaneously ejecting ink at frequencies exceeding tens of kHz. However, the reliability of ink ejection across all nozzles remains a critical challenge in implementing inkjet technology. Even after rigorous efforts, such as pre-printing vision inspections, to identify and select properly functioning nozzles, it remains difficult to actively address ejection defects that may arise during the printing process. This research project aims to develop and demonstrate a comprehensive monitoring and printing system capable of scanning tens of thousands of nozzles in real-time, effectively preventing printing defects caused by misfiring or poor ink ejection. To achieve this goal, a modularized sensing and data processing unit is developed for commercial inkjet heads. This unit is designed for seamless integration into the connection ports of commercial heads. The modular design enables the monitoring of up to 64 heads simultaneously, allowing for real-time monitoring of over 65,000 nozzles within 3 seconds. The system's effectiveness is demonstrated through simultaneous monitoring of two heads, showcasing zero-defect printing enabled by real-time classification and selection of normally functioning nozzles.

Methods and Results

Inkjet technology offers numerous advantages in additive manufacturing, but continuous real-time monitoring of jetting status is crucial due to the inherent challenge of resolving ejection defects during printing [1]. Currently, ejection defect detection primarily relies on vision inspection methods, which involve observing ejected ink using drop watchers or drop inspection on a substrate. Both methods require actual ink ejection, and when dealing with numerous heads, the process becomes time-consuming and susceptible to discrepancies between nozzle status during printing and inspection due to nozzle condition fluctuations over time.

Piezo self-sensing-based monitoring eliminates the need for additional sensors and relies solely on voltage measurements from the piezo. This method offers rapid scanning speeds due to its dependence on electrical measurements and enables defective nozzle detection using pressure waves generated by driving the piezo with low voltage, even without actual ejection for monitoring [2,3]. Moreover, the implementation cost of self-sensing is extremely low, potentially less than several hundred dollars per head if successfully commercialized.

This study presents a recently developed module capable of monitoring self-sensing signals from up to four heads. Up to 16 modules can be addressed via USB communication from a computer, enabling simultaneous monitoring of 64 heads.

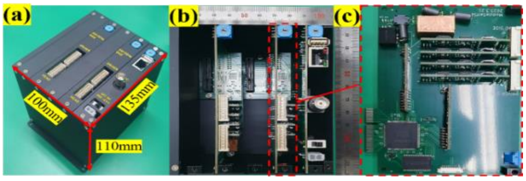

Figure 1: Module for Self-Sensing Measurement

The module comprises an impedance converter, a detection circuit, a data acquisition device, and a communication section for data transmission. A single module can measure self-sensing signals from four KM1024 RC heads. It is designed to connect directly between a commercial driver and an inkjet head using simple cabling, without requiring any modification of the existing driver and head.

For each ejection trigger, the module acquires self-sensing data at a rate of 1 MS/s (Mega Samples per second) with 80 samples. The ejection is scenario-based scanning, and the data is stored in the memory of the data acquisition system. Subsequently, the data is transmitted to the computer through communication after the entire nozzle scan is completed. The jetting trigger frequency in this process is set at 10 kHz. Since self-sensing is carried out in parallel across the four independent circuits (or many independent modules), the time required to scan 256 nozzles (corresponding to one circuit or driver) is the same as scanning all 1024 nozzles. If 64 heads are used, as many as 65,536 nozzles can be monitored simultaneously.

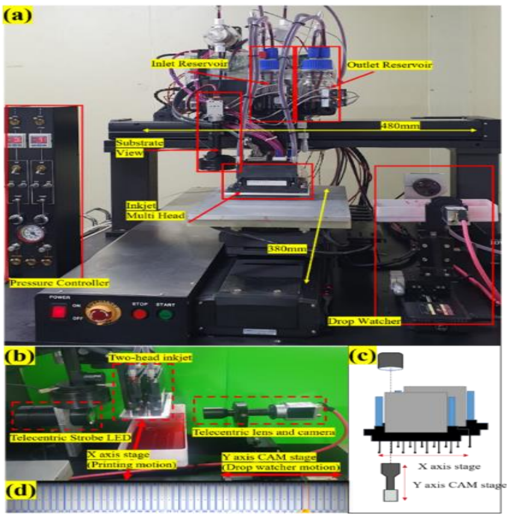

Figure 2: Experimental Setup

The self-sensing capability is demonstrated by developing an inkjet system as shown in Figure 2. System integration and algorithms were developed using LabVIEW (version 2023). Since the software was developed in-house at the research lab, it possesses various innovative functionalities based on self-sensing, allowing for the implementation of desired features as needed. The experiment utilized inkjet heads with nozzle recirculation functionality, specifically the KM1024aLHG-RC inkjet head from Konica Minolta, Japan. An in-house ink circulation system was developed in the research lab, enabling control over the pressure supplied to the inkjet head inlet and outlet. For driving the inkjet heads, a head driver (HDC-KM1024A) and printing controller (PCC2-E) from Meteor (UK) were used.

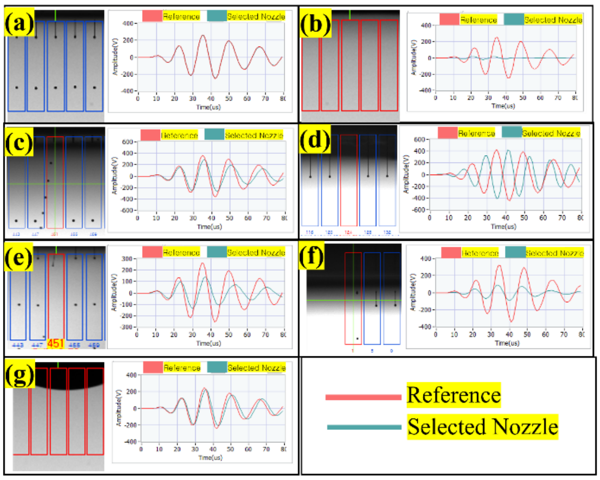

Figure 3: Experimental Results

As evident from the experimental results in Figure 3, signals from different defect causes exhibit distinct behaviors. This demonstrates that self-sensing can not only detect defects but also identify the type of defective nozzles.

Outlook and conclusions

The successful implementation of self-sensing monitoring in inkjet technology holds immense potential to address the reliability challenges often encountered in inkjet applications. By continuously monitoring the jetting status of nozzles in real-time, self-sensing can identify and classify defective nozzles, enabling proactive maintenance strategies and minimizing process costs, especially when dealing with expensive inks like QD inks. The experimental results demonstrated that scanning the entire nozzles of two or more heads required approximately 2-3 seconds, a time comparable to that of scanning a single head. This rapid scanning speed highlights the feasibility of implementing real-time monitoring in industrial settings. Furthermore, with the development of data analysis software, long-term analysis of self-sensing data can be achieved, enabling the detection of gradual process changes, such as ink degradation and head wear. This long-term monitoring capability provides valuable insights for predictive maintenance and optimization of inkjet printing processes. By analyzing the self-sensing signals, different maintenance actions, such as purging and wiping, can be tailored to the specific cause of the defect. Additionally, decisions regarding head replacement can be made based on the severity of the ejection defects, ensuring efficient utilization of resources and minimizing downtime. In conclusion, self-sensing monitoring offers a promising approach to enhancing the reliability and cost-effectiveness of inkjet technology, paving the way for its wider adoption in various industrial applications.

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Author Biography

Kye-Si Kwon (권계시) is a professor at Soonchunhyang University (순천향대학교) in Korea in the department of mechanical engineering (website: inkjet.sch.ac.kr). After his PhD, obtained from KAIST, Korea, in 1999, he was a member of research staffs in companies such as Samsung and LG electronics. He joined Soonchunhyang University in 2006 where his teaching and research is centered on inkjet-related measurement methods and system developments. In 2012, he spent one year at Palo Alto Research Center (PARC) in Palo Alto, California, as a visiting researcher. He also established a start-up company and served as CEO of PS. Co. Ltd from 2013.01 to 2017.01. He is particularly interested in developing liquid processing equipment that includes continuous inkjet, electro-spray, aerosol jet printing, high-viscosity dispensing, near-field electrospinning among others for industry and academic cooperations.

Customized design of dispersing agents and their application: improving inkjet ink reliability and performance

Nils De Vos; Project Manager ChemStream bv; Edegem, Belgium

Abstract

How to tackle the design of an (inkjet) ink? What are some of the pitfalls? Important components of the ink can be found in the dispersion, and more specifically the dispersing agent(s), and resins such as binders. These polymers can have large effects on ink stability, rheology and other important physical phenomena such as adhesion on substrates, drying of the ink etc. By applying a targeted design to e.g. a dispersing agent one can achieve much better control over the aforementioned parameters of inks.

Inkjet ink

Producing nice images, be it texts, designs, photographs and many more, requires an ink that has to tick many different boxes. Rheology behavior has to be optimally balanced to achieve high quality jetting performance and ink spreading and/or fixation on the surface while the interaction between substrate chemistry and functional components such as binders has to be optimized for good adhesion on aformentioned (non-absorbing) substrates. Additionally, stability of the ink has to be excellent to achieve a good shelf-life and consistent performance over time.

Another, often essential, part of the ink can be found in the (nano-)dispersion present. Especially for inkjet applications, a small and stable particle size is important for jetting performance (e.g. avoiding nozzle clogging) and for achieving nice color strength and gamut. The main responsible for that quality is the (polymeric) dispersing agent used to produce the dispersion.

Dispersing agent design

One of the most important questions that pop into mind is: How to tune the properties of these dispersing agents to the requirements of the final inks? As mentioned in the previous section, inkjet inks contain a lot of components, all of them interacting with each other and with the particles/pigments in the ink. Optimizing the interaction between (polymeric) dispersing agent and particle/pigment while reducing possible negative side effects on other desired requirements of the ink (such as adhesion strength) is a key question during conception of the dispersing agent.

One important (analytical) technique ChemStream applies in the customized design of these novel polymers is the Hansen Solubility Parameters. In contrast to the name, these parameters can be used for quite a lot more than simple solubility analyses and predictions [1]. ChemStream is applying this tool for characterization of particle/pigment surface by using sedimentation rate of these particles in different solvents, resulting in an interaction sphere rather than pure solubility spheres [2].

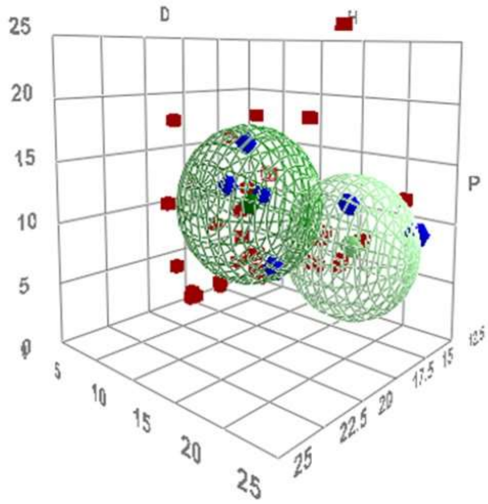

Figure 1: *Example of the outcome of a Hansen Solubility Paramater analysis on a pigment.*

The same methodology can be used to characterize other important parameters such as adhesion (interaction with surfaces), miscibility of e.g. surfactants into the ink formulation and interference with other polymers such as resins. The outcome of the Hansen analysis is subsequently transformed into a customized design of the dispersing agent. This design is further optimized in an efficient way by employing Design of Experiments, a very useful screening tool in optimizing the chemical and physical parameters of the polymer.

Customized design has several advantages. First and foremost, the stability of the dispersions can be improved by quite a large margin because, as mentioned above, the interaction and/or interference of ink components such as surfactants and binders with the pigment can be fully eliminated. This also

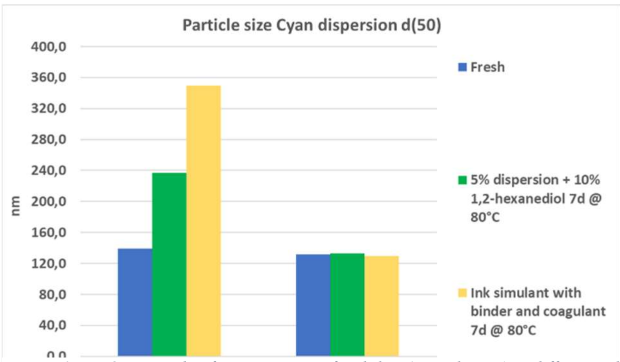

Figure 2: *Example of improvement of stability (particle size) in different ink simulants (legend on the right).*

additionally benefits ink quality a lot, reducing latency issues and improving long run performance without having to compromise on other parameters such as adhesion on the surface.

Secondly, besides using the “classical” monomers such as (meth)acrylates for the synthesis of these polymers, ChemStream is working on incorporation of different natural polymers by combining the functionalities which are inherently present in

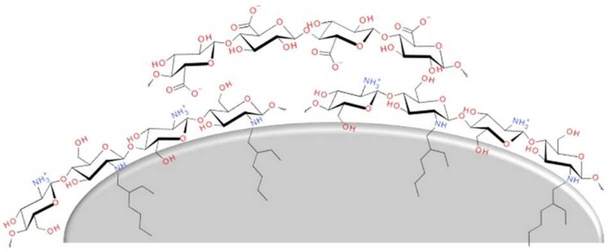

Figure 3: Encapsulation using natural polymers.

these polymers, e.g. an amine/amide function present in chitosan and chitin respectively with reduction of molecular weight without causing the loss of those functional groups. This reduction is necessary, because the molecular size of these polymers in their naturally occurring form is too big to be able to use them as dispersing agents.

This developed know-how is not only applicable in the synthesis of dispersing agents. ChemStream is extending its use into other areas. Synthesis and design of encapsulating agents in a very broad sense (not only dispersion technology), anti-scaling agents, emulsifiers and much more can be achieved, both by using “petrol”-based chemicals as well as naturally occurring components, thus increasing bio-based content and sustainability of these products and their application.

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Author Biography

Nils obtained his Master Degree in Bioscience Engineering in 2009 at Ghent University. In 2013 he obtained his PhD degree in Bioscience Engineering, organic chemistry. With a focus on ionic liquids. After his studies, Nils worked for two years at AvoRe in the field of organic chemistry and water purification methods. Nils's main interests include ionic liquids, organic synthesis, flow reactor synthesis, enzyme technology and structure elucidation. Nils joined the ChemStream team in 2016.

Printing Semiconductors Pixel by Pixel

Franziska Krieg; Avantama AG; Stäfa, Zürich/Switzerland

Abstract

In the last years the Perovskite nanocrystals (PNC) have gathered enormous attention from worldwide scientific community, due to their outstanding optical properties. High photoluminescence quantum yields in combination with narrow emission widths and high absorption coefficients are unbeatable by any quantum dot technologies. Avantama AG pioneered work on commercialization of PNCs into the display industry. This presentation will show advantages as well as challenges of using PNCs in broad variety of display technologies ranging from LCD, OLED to micro-LED with a focus on their device inclusion using additive printing technologies.

Present and Future of Displays

In times where one of the biggest challenges that humanity must face is climate change, it is of utmost importance to optimize the efficiency of energy and material use. In recent years the research directed towards lead halide perovskite semiconductors and their particularly advantageous physical properties, [1] have sparked hope in researchers, that in the intermediate future high quality semiconductors and derived devices can be produced at a much lower energy cost and using more resource efficient processes, such as additive manufacturing [2].

Lead halide Perovskites feature a property generally referred to as defect tolerance [3], that makes them efficient in photovoltaics or LEDs even in microcrystalline structures with many defects as received by low temperature solution-based deposition processes as opposed to high temperature metallurgic or high-vacuum epitaxial methods that are required for producing the currently commercial semiconductor devices. The same property allows PNCs, generally synthesized by low temperature solution methods, to outperform state-of-the-art colloidal quantum-dots- fabricated in multi-step, high temperature processes- in terms of brightness and spectral line width [4].

In displays both the increased brightness as well as the improved color resolution lead to the perceived brightness of the image to be higher at lower energy consumption [5] **Figure 1a**. Thus, the RoHS compliant, fully roll-to-roll processed color conversion sheet ava*film* reaches the same light out-put at 25% lower energy consumption compared to the best technology that is currently in the market for LCD displays (low Cd, QD light conversion sheets). Additionally, it features a 40% higher peak brightness and wider color space making it look even brighter.

While LCD is a mature technology where the simple exchange of the currently used light converters can already lead to relatively high energy savings, the future of the display industry lies in active pixel technologies. Currently, this space is filled by OLED, however, inorganic LEDs exceed OLEDs in terms of brightness by a multiple and if a combination of blue GaN LEDs with red and green PNC conversion layers **Figure 1b** are used also surpass OLED performance in terms of color purity. How much energy this novel design principle can save needs to be determined once the first prototypes are produced. Theoretically, as much as 60% of energy could be saved under ideal conditions.

The advantage of blue GaN LEDs featuring green and red PNC conversion layers compared to 3 color solid state LEDs lies in the efficiency of the red pixel, the improved color purity, as well as the much-facilitated production process that allows for monolithic production of blue LEDs and then addition of the conversion layer by additive methods such as ink-jet printing (pixel sizes >50um) or electro hydrodynamic printing (pixel size >1um, **Figure 1c**).

Inks of the ava*pix* product line are currently being tested by selected partners and have been successfully printed on

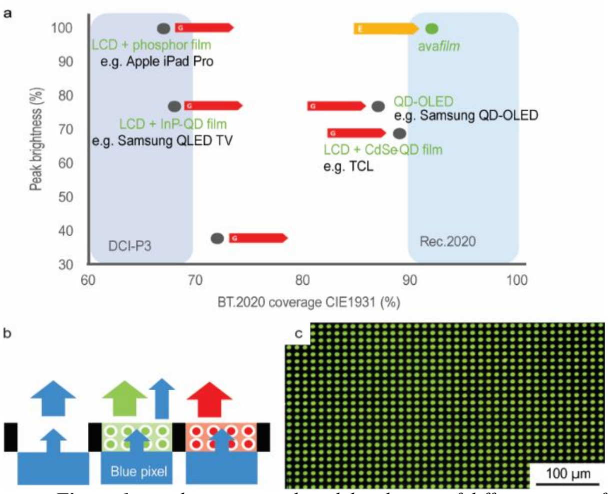

Figure 1: **a** *color purity and peak brightness of different state of the art color conversion films with their respective device efficiencies.* **b** *Schematic of pixelated color conversion with blue GaN LED and red and green PNC conversion layers.* **c** *pixel array printed by electro hydrodynamic printing 8µm pixel size 16µm pitch.*

production scale ink-jet printers. Depending on the ink formulation as much as 99% of incoming photons can be absorbed in layers as thin as 3 µm at an internal quantum efficiency exceeding 95%. The device efficiency *i.e.* electricity to light conversion of a pixel is heavily dependent on the device structure. In general, thinner layers feature better extraction efficiencies due to less losses to the pixel walls. This is a decisive advantage of PNCs over traditional quantum dots that require 2-3x this pixel thickness to reach the same absorption [6].

In conclusion, the future of display conversion materials lies in the class of PNCs applied by additive manufacturing techniques as. This will not only render the final devices more energy efficient but can also save energy during the manufacturing process and fully comply with european regulations on the use of heavy metals in electronics.

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Author Biography

Franziska Krieg received her MSc in interdisciplinary sciences from ETH Zürich in 2015. She went on to complete her doctoral studies in Chemistry in the Laboratory of Prof. Maksym Kovalenko on the topic of Lead Halide Perovskite Nanocrystals in 2020. Since 2021 she continues to improve the performance of Perovskite Nanocrystals in display applications as a materials chemist in the research and development division of Avantama AG.

Liquid Diaphragm Pumps for Controlling Meniscus Pressure in Stationary and Moving Printheads

Raphael Frey and Manuel Roos; KNF Flodos AG; Sursee, Switzerland

Abstract

Pressure pulsations and the ability of a pump to respond to pressure changes are key properties in order to control meniscus pressure in a printhead. New, specially designed liquid diaphragm pumps with integrated dampeners achieve low pressure pulsation levels so that they can be used directly to operate a statically mounted printhead. Meniscus pressure can be controlled directly with the pumps, no ink reservoir with control chamber is needed. Furthermore, if the rotary drive is replaced with a specially designed drive a pump with fast reaction velocities and low pressure pulsation levels can be obtained. Such diaphragm pumps can be used to control meniscus pressure for a printhead which is moved at high acceleration levels. No additional dampeners or active pressure compensation devices are needed.

Introduction

Ink supply systems are a key component to operate printheads in inkjet printers. The main tasks of these systems are to deliver and to recirculate ink to and trough the printhead and to maintain the meniscus pressure level in the fluid channels behind the printhead nozzles in an operative window. Different solutions exist to solve this task. In some of them the ink is exposed to air, which leads to evaporation of solvents, thus increasing the viscosity of the ink. New solutions are needed to realize airless ink supply systems. Furthermore, putting printheads onto robotic arms is a promising future application that can be used to directly print 3D surfaces such as walls or vehicles. These direct-to-shape (DTS) applications require very fast meniscus pressure control for moving printheads which usually cannot be achieved with existing solutions. Otherwise, it is risked that ink is weeping onto the nozzle plate or air is ingested through the printhead nozzles.

Diaphragm pumps with integrated hydraulic dampeners

Classical one-headed diaphragm pumps cause high pressure pulsation in the pipes which are used to guide fluid from an upstream to a downstream reservoir via the pump, for example. In order to reduce these pressure pulsations dampeners and orifices can be added. Newer types of pumps offer directly incorporated dampeners on the upstream and downstream side of the pump, as indicated in fig. 1. Such hydraulic systems can be described with mathematical expressions and abstracted by using electrical circuit symbols. The downstream part of the hydraulic system in fig. 1, for example, can be represented with the electrical circuit diagram, as shown in fig. 2. In this diagram the diaphragm pump is represented by the electrical symbol of a current source. The downstream dampener is represented by the symbol of a capacitor having a capacitance C_a. The downstream orifice is represented by the symbol of a resistor having a resistance R_o and the pipe is represented by a serial connection of a resistor having a resistance R_d and an inductor having an inductance L_d. The resistance and the inductance of the fluid column in a pipe can be

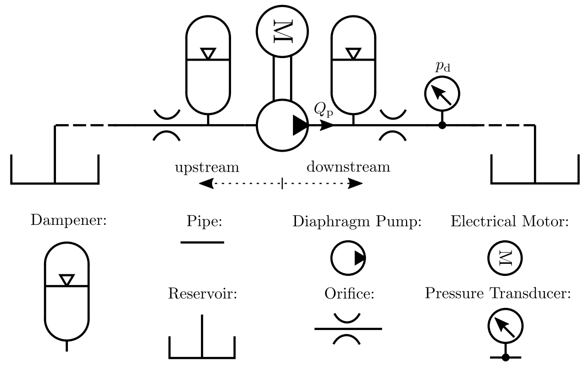

Figure 1. *Hydraulic system containing KNF smooth flow pump.*

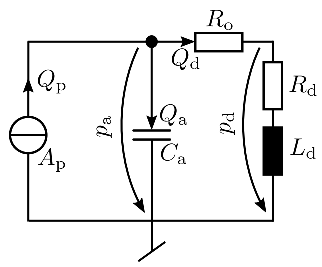

Figure 2. *Electrical analog representation of the downstream part of the hydraulic system.*

determined using the following equations:

$$R_d = \frac{128\rho\nu l}{d^4\pi} \qquad L_d = \frac{4\rho l}{d^2\pi} \tag{1}$$

, where ρ is the density and ν the viscosity of the liquid in the pipes and l is the length and d the diameter of the pipe. The resistance of the orifice and the storage capacitance of the hydraulic dampener element can be determined by means of measurements. With the known description of resistances, inductances and capacitances in the frequency domain, transfer functions can then be formed that describe how an output signal reacts in relation to a specific input signal at different frequencies. This can be easily realised, for example, for the pressure at the pump outlet $\hat{p}_d(s)$ in relation to the pump delivery rate $\hat{Q}_p(s)$:

$$H_{pQ}(s) = \frac{\hat{p}_d(s)}{\hat{Q}_p(s)} = \frac{L_d s + R_d}{L_d C_a s^2 + (R_o + R_d) C_a s + 1} \tag{2}$$

When analysing the flow rate of the pump in more detail, it can be seen that the pump flow rate is proportional to the velocity v of the working diaphragm. The two variables are coupled via the effective area A_p of the working diaphragm. In addition, the velocity of the working diaphragm can be written as the temporal derivative of the diaphragm position z. In the frequency domain, this can be expressed with the following equations:

$$\hat{Q}_p(s) = A_p \hat{v}(s) = s A_p \hat{z}(s) \tag{3}$$

If this equation is inserted into eq. 2 and a fixed eccentricity z_0 is assumed for the stroke z the following pressure is obtained:

$$\hat{p}_\mathrm{d}(s) = \frac{z_0 A_\mathrm{p} L_\mathrm{d} s^2 + z_0 A_\mathrm{p} R_\mathrm{d} s}{L_\mathrm{d} C_\mathrm{a} s^2 + (R_\mathrm{o} + R_\mathrm{d}) C_\mathrm{a} s + 1} \quad (4)$$

The corresponding theoretical and measured pressure response

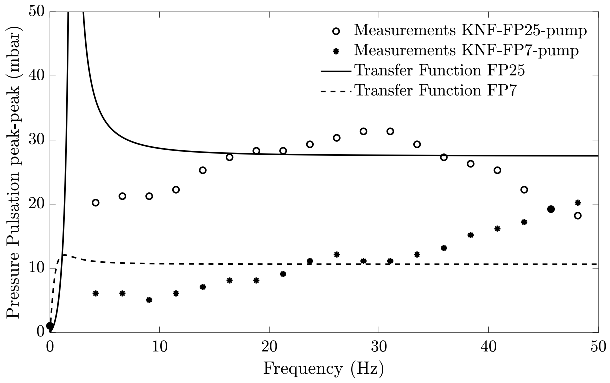

Figure 3. *KNF FP 7 and FP 25 pressure pulsation measurements and theoretical pressure pulsations.*

at the pump outlet of a system containing an KNF FP 7 or a FP 25 pump is shown in fig. 3. The theoretical pressure transfer function can be described with three characteristic ranges. For very low frequencies, the pressure pulsations are very small, but increase sharply with increasing frequency. The maximum pressure amplitude occur in good approximation at the hydraulic resonance frequency of the system. Finally, the amplitude of the pressure pulsation decreases for frequencies greater than the resonance frequency and then reaches a level that remains constant. The height of this level can be calculated as follows:

$$\lim_{s \to \infty} \hat{p}_\mathrm{d}(s) = \frac{A_\mathrm{p} z_0}{C_\mathrm{a}} \quad (5)$$

The range above the hydraulic resonance frequency, in which pressure pulsations remain constant, is the recommended operating range of the pump. As can be seen in fig. 3, the pressure measurements in this range agree quite well with the predicted pressure levels. By analyzing eq. 5 it can be observed, that the operational pressure level depends on the effective area of the working diaphragm, the hydraulic capacity of the dampener and the eccentricity of the eccentric. Therefore different options can be selected for the hydraulic capacity and the eccentricity for such pumps in order to find the desired pressure pulsation level.

Usage in ink supply systems with moving printheads

The analogy presented between hydraulic and electrical systems can be applied to more complex systems, such as an ink supply system comprising a printhead, a supply and a return diaphragm pump with dampeners, pressure sensors and the necessary pipework. Transfer functions or state space representations between input signals (pump delivery rates) and output signals (meniscus pressure and pressure drop across printhead) can be derived. These mathematical representations are needed to design controllers which allow the control of the meniscus pressure. As part of a bachelor thesis, an experimental set-up was created to investigate how a newly developed diaphragm pump with fast reaction velocities behave in an imitated ink supply system (water instead of ink, 0.8 mm Y-connection instead of printhead). In fig. 4 measurements of the printhead inlet pressure of a moving printhead are shown. Fig. 4 a) shows the pressure response for a disabled controller. At the beginning of the recording the printhead is at rest and the meniscus pressure is controlled in such a way that no water is leaving the Y-connection. Then the controller is disabled an the printhead is moved in a sinusoidal pattern with a frequency of 1 Hz and an acceleration amplitude of $1\,\mathrm{m\,s^{-2}}$. It can be seen how the acceleration of the printhead affects the printhead inlet pressure. During the printhead movement the inlet pressure is drifting slightly upwards until at 13.5 s air is ingested through the Y-connection and the experiment was stopped. Fig. 4 b) shows the pressure response for a enabled controller. The pressure disturbance caused by the movement of the printhead is regulated and meniscus pressure can be hold in a narrow band of around 2 mbar. The pressure is kept below the critical level of 11.5 mbar and no air is entering the system.

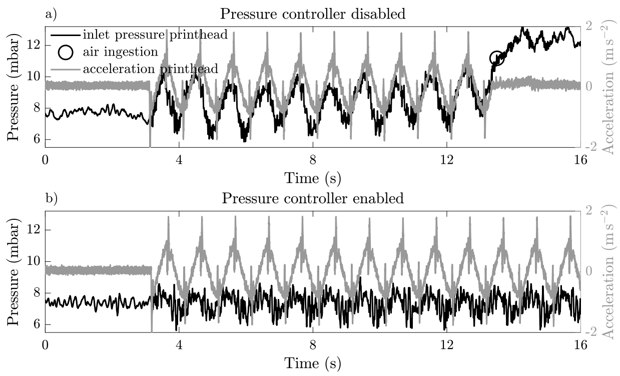

Figure 4. *Printhead inlet pressure measurements for a sinusoidally translated printhead. a) With a disabled controller, b) with an enabled controller.*

Conclusion

Important phenomena such as pressure pulsations caused by liquid diaphragm pumps in hydraulic systems can be predicted by using system theory as applied in electrical engineering.The new category of smooth flow liquid diaphragm pumps transfers liquids with a minimal amount of pressure pulsations so that a direct integration of the pumps into an ink supply system with a statically mounted printhead becomes possible.The use of a specially designed drive in combination with a diaphragm pump enables fluid delivery with low pressure pulsations and dynamic control of the meniscus pressure in a DTS system. A model of the ink supply system including pumps and printhead can be established, enabling the design of stable and robust controllers. First tests on an ink supply system imitating the behaviour of a printhead show promising results. If such pumps can be applied to control meniscus pressure in printheads they have the potential to considerably simplify the design of ink supply systems. This can lower the manufacturing costs of such systems and reduce service intensity.

Author Biography

Raphael Frey is Head of the Technology and Innovation department at KNF Flodos AG, a company which develops and produces liquid diaphragm pumps. He obtained his MSc degree in Microengineering from the EPF Lausanne (2007). After his studies he started working as a development engineer at KNF and in 2019 he finished an external dissertation at ETH Zurich in collaboration with KNF.

NOTES

AUTHOR INDEX

*No extended abstract or paper.