WELCOME TO PRINTING FOR FABRICATION 2019

I am delighted to welcome you to San Francisco, California, and the Bay area, which is synonymous with the creativity and high-tech that shapes a big portion of our daily lives, as well as the print world today. The digitalization of our world is in full swing and printing technologies are a vital part of this transformation due to their role in customized supply chains, novel and innovative manufacturing concepts, and hybrid solutions for the communication of information. Not only is printing extending out of its classical habitat to produce the function of breath-taking color on products, but it strongly enables the incorporation of electrical, optical, and mechanical functionalities into the manufacturing of industrial products. Printing processes and systems are now used to build multi-functional 3D objects and enhance sensitivity in healthcare applications.

While conventional printing techniques utilized tremendous finesse in automation to provide high quality to the shorter run-length markets, digital printing has seen tremendous innovations to increase print quality and productivity. Many of you have been part of establishing a deep understanding of the underlying building blocks and now many new areas are being enabled by exactly those techniques.

Today's printing must be seen as a system effort, as sub-processes only have a limited effect on the overall system performance and the improvements seen in the last decade can only be explained by the success of interdisciplinary research. As an example, advances in material science and nanotechnology have given rise to new families of inks that can be used to create higher color gamut, higher environmental stability, lower electrical resistance, higher charge carrier mobility, or the tailored absorption of radiation. This enables better and more functional prints or, in some applications, higher throughput as well as improved material properties in printing-based additive manufacturing processes.

At the same time, printing has matured to allow the printing of hundreds of millions of pixels (or voxels) per second, opening up new possibilities while also challenging the scope of the physical models. This drives experimentation and understanding to new horizons, and extends the role of printing and printing-inspired processes to many new engineering systems of value. The leaps made in data pipelines, machine learning, and image acquisition and processing, lets us correct for print defects, employ redundancy schemes, and adjust color values or electrical conductivity concurrently with the substrate speeds of meters per second.

At this year's conference, we will continue to highlight the astounding progress in the production of digital graphics prints and explore the frontiers of the printed fabrication world. The main foci lie in the fundamental understanding of future printing technologies that will drive the analog-to-digital conversion of applications, such as packaging where we will see how physics, chemistry, and material interaction drive the enhancements in imaging. A second key area is the production of printed textiles and non-wovens, where both ink concepts adapted to the special substrate texture and color gamut are subject to vital research. Printed electronics has had an impressive evolution in the past decade and we've seen many products incorporating printed steps as a means to increase, or even enable, functionality and reduce waste of precious materials. Lastly, the community will take a closer look at 3D printing as a whole, spanning graphical printing, the growing field of manufacturing of metallic products, and the future of tailoring materials in 3D prints.

I have no doubt that digital fabrication has made its way into our everyday life and will continue to do so. Our Late Breaking News session highlights some of the recent digital fabrication developments that may surprise you and we take a glimpse at the possible future in a special session, Frontiers in Imaging, to see where we are headed.

Lastly, I would like to express my gratitude to Executive Program Chair Teruaki Mitsuya for his knowledge, engagement, and experience in preparing this outstanding program, as well as the conference committee members and IS&T staff, who support all our efforts. I would furthermore like to thank the conference sponsors and exhibitors for supporting this platform and the exchange of scientific ideas for the advancement of the technology.

– General Chair Ingo Reinhold, Xaar plc

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Printing for Fabrication
materials, applications, and processes

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PRINTING FOR FABRICATION 2019 WEEK AT-A-GLANCE

LOCATION LEGEND

- Cyril Magnin Ballroom I/II
- Cyril Magnin Ballroom III
- Market Street Meeting Rm
- Cyril Magnin Foyer
- Room noted on ticket

SPECIAL EVENTS

Welcome Reception
Sunday 18:00 – 19:00

Colleague Connections: The Future of Digital Textile Manufacturing
Monday 17:35 – 18:30

Colleague Connections: Advances in 3D Printing Technologies
Monday 17:35 – 18:30

Evening Event: Student/Young Professionals Get Together
Monday 19:00 – 22:30

Annual Meeting of Members
Tuesday 8:30 – 8:40

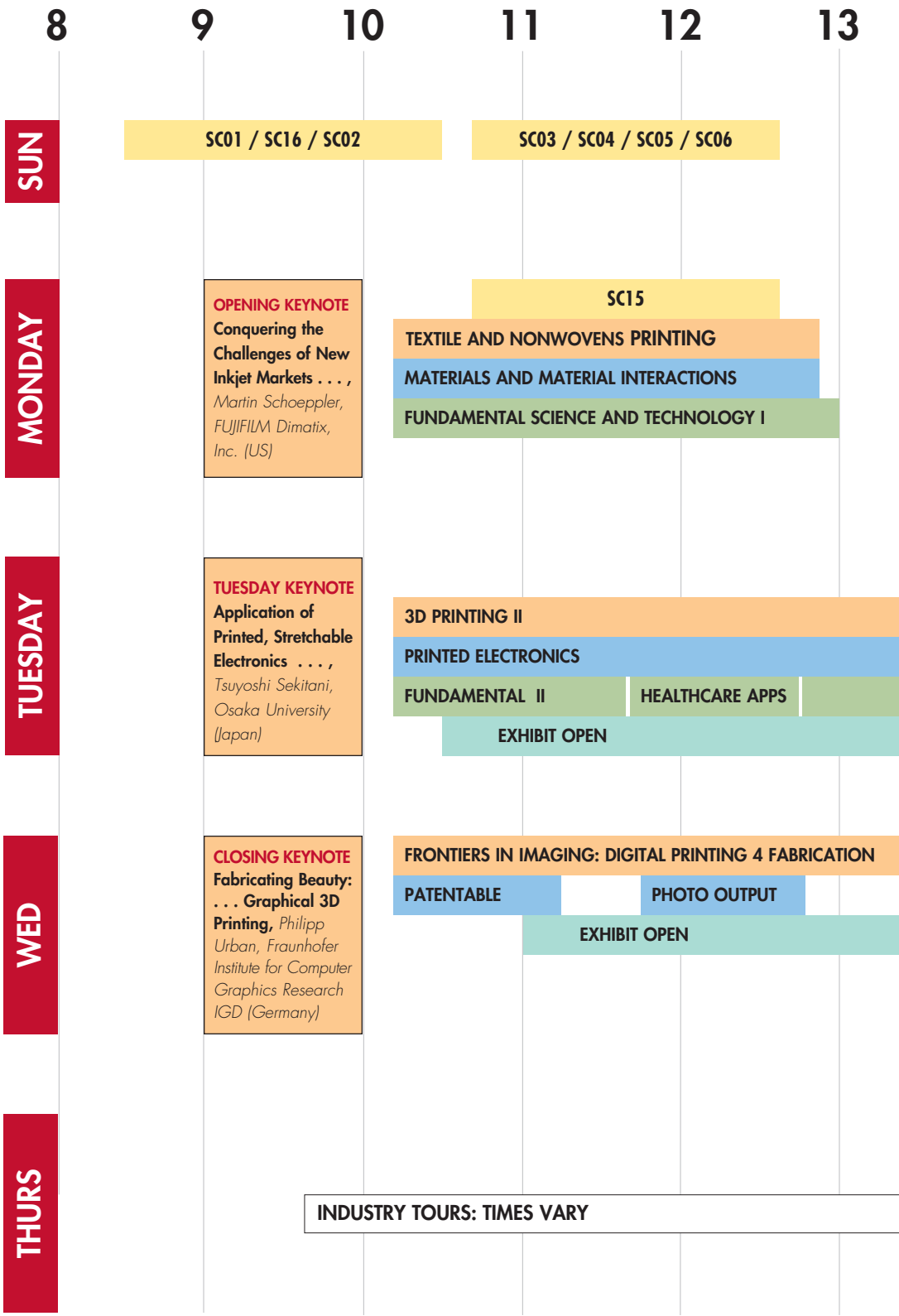
Conference Exhibit
Tuesday 10:30 – 16:00
Wednesday 11:00 – 15:00

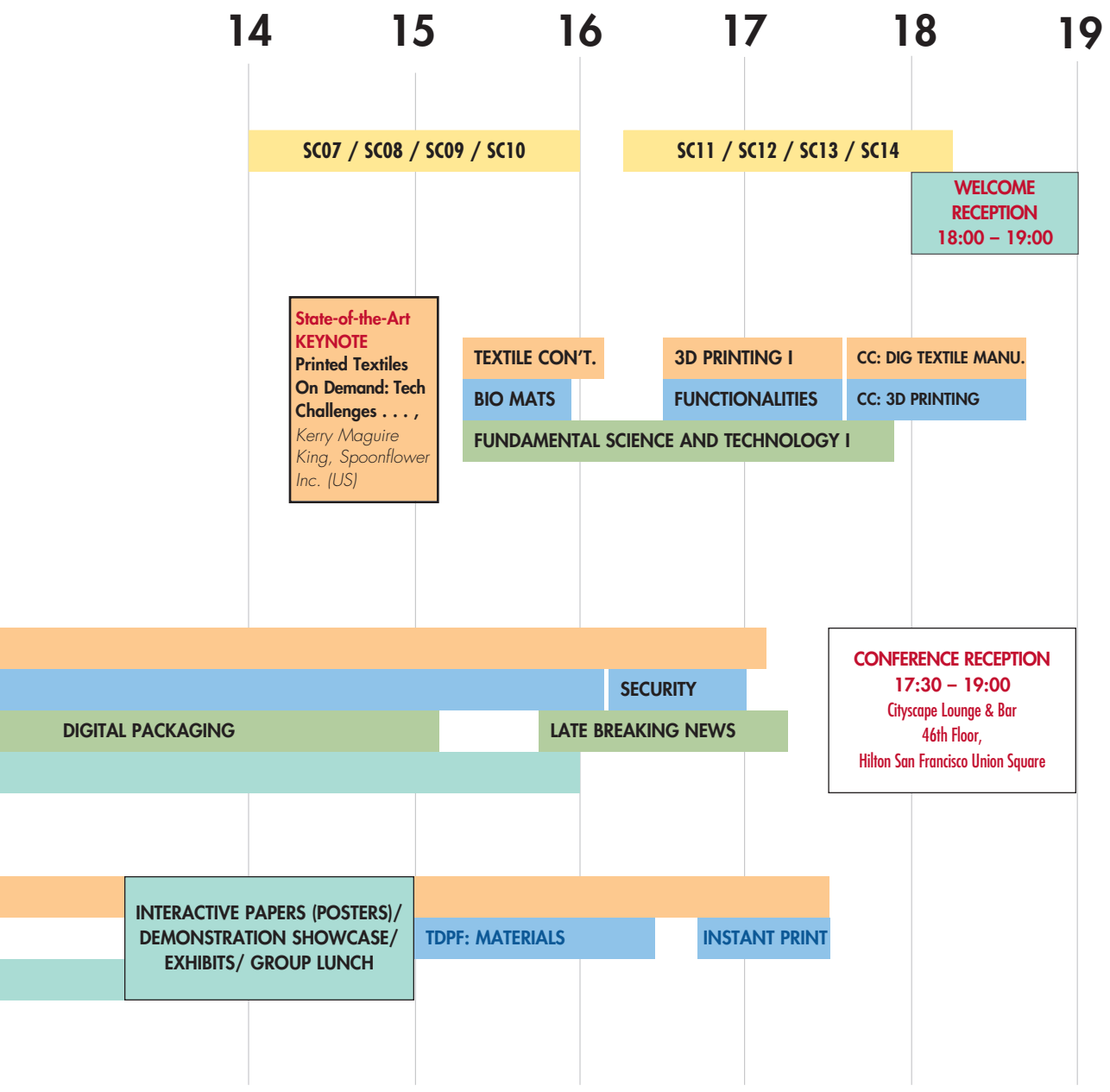
Late Breaking News
Tuesday 15:50 – 17:15

Conference Reception
Tuesday 17:30 – 19:00

Interactive Papers, Demonstrations, Exhibit, and Lunch
Wednesday 13:15 – 15:00

Colleague Connections: Industry Tours
Thursday times vary





Please note: Lunch and coffee breaks are not shown. Refer to schedule for these times.

EXHIBITOR PROFILES

ImageXpert Inc.

ImageXpert provides a complete platform for inkjet development, including automated drop-in-flight analysis, sample printing, and print quality analysis. JetXpert systems integrate printheads, drive electronics, ink supplies, and drop analysis into a single turnkey system. ImageXpert tools accelerate the development of inks, waveforms, printers, and printheads.

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Kyowa Interface Science Co., Ltd.

We are specialized in manufacturing instruments to characterize contact angle, surface tension, surface free energy, friction, and peel strength. Those are significant to evaluate the processes of printing and coating, and the finishing. Microscopic contact angle which can deposit droplet of Pico liter order is available.

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Contact: Miwa Kikuchi at m-kikuchi@face-kyowa.co.jp

Meteor Inkjet Ltd.

Meteor Inkjet Ltd. is a leading independent supplier of electronics, software, tools, and services for industrial inkjet systems. Leveraging long-standing relationships with printhead manufacturers including FUJIFILM Dimatix, Konica Minolta, Kyocera, Ricoh, Seiko Instruments, Toshiba TEC, and Xaar, Meteor eases the development effort required of printer builders and ink developers world-wide. Meteor's Printing for Fabrication exhibit showcases the most cost-effective, versatile inkjet DropWatching System on the market today.

Harston Mill, Rouston Road
Cambridge CB22 7GG
United Kingdom
+44 34 5844 0012
enquires@meteorinkjet.com • www.meteorinkjet.com
Contact: Tracey Brown at tracey.brown@meteorinkjet.com

CONFERENCE EXHIBITORS

Exhibit Hall Hours
Tuesday 10:30 – 16:00
Wednesday 11:00 – 15:00

Interactive (Poster) Paper Session, Demonstration Showcase, Exhibit, and Group Lunch
Wednesday 13:15 – 15:00

Cyril Magnin Foyer

PRINTING FOR FABRICATION 2019 SHORT COURSES

SUNDAY 29 SEPTEMBER

8:30 – 10:30

SC01: Colorants for Inkjet Applications
Instructor: Alex Shakhnovich, Cabot Corporation (US)
Track: Inkjet Materials / Level: Introductory

SC16: Electrophotography & Toner Technology — From Prints to 3D Objects
Instructor: Dinesh Tyagi, Lexmark International (US)
Track: Fabrication Technologies / Level: Overview

SC02: Technology of Textile Printing
Instructor: Enrico Sowade, Zschimmer & Schwarz Mohsdorf GmbH & Co. KG (Germany)
Track: Textile Printing / Level: Introductory/Overview

10:45 – 12:45

SC03: Fluid Dynamics and Acoustics of Piezo Inkjet Printing
Instructor: J. Frits Dijksman, University of Twente (the Netherlands)
Track: Inkjet Processes / Level: Advanced/Specialist

SC04: Practical Inkjet Ink Characterization
Instructor: Mark Bale, DoDxAct Ltd. (UK)
Track: Inkjet Materials / Level: Introductory

SC05: Industrial Inkjet: Binder-Jet, Direct-Jet 3D Printing with Inkjet: Technology Overview, Challenges, and Opportunities
Instructor: Rich Baker, Integrity Industrial Ink Jet Integration LLC (US)
Track: Fabrication Technologies / Level: Introductory

SC06: Digital Textile Printing: Inkjet Printheads, Printers, and Industry 4.0
Instructor: Ronald Askeland, HP Inc. (US)
Track: Textile Printing / Level: Introductory

14:00 – 16:00

SC07: Surface Ink Interactions and Surface Characterization
Instructor: Kock-Yee Law, Research and Innovative Solutions (US)
Track: Inkjet Processes / Level: Advanced/Specialist

SC08: Insight into New InkJet Technological Developments from Patent Literature
Instructor: Mike Willis, Pivotal Resources, Ltd. (UK)
Track: Inkjet Materials / Level: Overview

SC09: An Introduction to Digital Fabrication and Additive Manufacturing: Methods, Materials, and Applications
Instructor: James W. Stasiak, HP Inc. (US)
Track: Fabrication Technologies / Level: Introductory

NEW SC10: The Role of Software to Optimize Print Quality for Industrial Ink Jet Applications
Instructor: Simon Edwards, Global Inkjet Systems (UK)
Track: Systems Engineering / Level: Introductory

16:15 – 18:15

NEW SC11: Exploiting Physical Properties in Printing
Instructor: Travis W. Walker, South Dakota School of Mines and Technology (US)
Track: Inkjet Processes / Level: Intermediate

NEW SC12: Drying and Sintering Effects in Traditional and Functional Printing
Instructors: Tatiana Zubkova, Chemnitz University of Technology (Germany)
Track: Inkjet Materials / Level: Overview

SC13: An Overview of 2D and 3D Printing
Instructor: Kock-Yee Law, Research and Innovative Solutions (US)
Track: Fabrication Technologies / Level: Overview

NEW SC14: Machine Learning Algorithms and Applications in Printing
Instructor: Chunghui Kuo, Eastman Kodak Company (US)
Track: Systems Engineering / Level: Introductory
Prerequisite: Knowledge of linear algebra

MONDAY 30 SEPTEMBER

10:45 – 12:45

NEW SC15: Color and Appearance in 3D Printing
Instructor: Philipp Urban, Fraunhofer Institute for Computer Graphics Research IGD (Germany)
Track: Color Appearance / Level: Overview

SPECIAL EVENT

WELCOME RECEPTION

Sunday 29 September
18:00 – 19:00
Cyril Magnin Foyer

Kick off the conference by joining colleagues for a drink on Sunday before heading to dinner.

SPECIAL EVENT

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18:00 – 19:00
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Kick off the conference by joining colleagues for a drink on Sunday before heading to dinner.

TECHNICAL PAPERS PROGRAM: SCHEDULE AND CONTENTS*

KEYNOTE TALKS

Cyril Magnin Ballroom I/II

MONDAY 30 SEPTEMBER 2019

OPENING KEYNOTE

Session Chair: Ingo Reinhold, Xaar plc (Sweden)
9:00 – 10:10

Keynote sponsored by

FUJIFILM Value from Innovation Dimatix™

Conquering the Challenges of New Inkjet Markets with MEMS Printhead Technology
Martin Schoeppler, FUJIFILM Dimatix, Inc. (US)

As the world of inkjet printing expands from a focus on graphics into industrial market areas where inkjet printing can bring significantly new value to the manufacturing process, many new printhead challenges become evident during the development of these applications. These challenges can often be derived from the fact that many existing printheads were developed initially for graphics applications. Often when using an existing printhead for a new application, significant issues such as fluid compatibility, native drop sizes, productivity, fluid viscosity, and others can become apparent.

FUJIFILM Dimatix has invested significantly in the field of Silicon MEMS technology. This presentation outlines some of the key areas where Silicon MEMS can provide a solid printhead technology backbone for the growth of inkjet into industrial applications and addresses common challenges. The presentation also explores new industrial markets, their needs, and challenges to printhead technology, and its usefulness.

STATE-OF-THE-ART KEYNOTE

Session Chair: Ron Askeland, HP Inc. (USA)
14:15 – 15:05

Printed Textiles On Demand: Technology Challenges Meet Creative Opportunity
Kerry Maguire King, Spoonflower Inc. (US)

Digital printing technology is now enabling product customization and short run production within the textile industry. As a web to print business, Spoonflower illustrates the intersection of e-commerce, digital printing technology, and creative communities. Founded in May 2008, the company specializes in ultra-short run production of textiles, wallpaper, and finished home décor products. The company was conceived as a business that empowers creative individuals to design and print their own fabric. Today visitors to the website are also able to shop an extensive collection of surface designs from independent artists around the globe. Speaking from the vantage point of Spoonflower's research and development team, King shares insights into the current state of printer hardware solutions and ink chemistry that support this print-on-demand model for textiles. The presentation addresses obstacles and development opportunities related to printing systems, optimization of digital workflow, and color management considerations. She delves into the topic of customer expectations in reference to aesthetic properties and performance requirements for the textile products received and touches on evaluation methods for printed textiles. Additionally, King emphasizes the importance of product visualization and defines some of the technical requirements for supporting a customer-friendly shopping experience.

* Please note: Page numbers listed after paper titles refer to the page on which a paper is located in the full proceedings book, found digitally on the USB stick that accompanies this book.

TUESDAY 1 OCTOBER 2019

TUESDAY KEYNOTE AND TECHNICAL ACHIEVEMENT AWARDS

Session Chair: Teruaki Mitsuya, Ricoh Company, Ltd. (Japan)
9:00 – 10:00

Application of Printed, Stretchable Electronics for Monitoring Brain Activities
Tsuyoshi Sekitani, Osaka University (Japan)

This keynote introduces the research and development of printed stretchable, ultra-flexible, and ultra-thin electronic devices—made mainly of functional organic materials—and brain activity monitoring systems using these developed devices. Specifically, it discusses a new type of brain activity monitoring system, Patch-EEG. Patch-EEG is a sheet-type brain-wave sensor system (patch brain-wave sensor) that can monitor brain waves simply by attaching the sensor to the forehead. The patch brain-wave sensor has a measurement accuracy comparable to that of large medical equipment. Because it can be attached to the forehead, it has been used not only in medical applications, but also applications such as the development of products using brain waves, measurement of the quality of sleep, monitoring of brain waves during sport activities, and easy monitoring of brain activities at home.

The talk discusses the process techniques for elaborately laminating nanomaterials on ultrathin or flexible thin rubber films developed in Sekitani's lab, and the research and development of ultraflexible and stretchable electronics using original techniques. The lab has succeeded in developing a system for monitoring biopotentials by combining (1) a flexible electrode with biocompatibility and high electric conductivity, (2) a flexible thin-film amplifier to amplify very weak biosignals, (3) a Si-LSI platform with a wireless communication function, and (4) a signal processing technique to visualize signals in real time. The sheet-type wireless system has a weight of less than 20 g and a thickness of less than 5 mm. Regardless of this small size, its measurement accuracy is as high as 0.1 μV and it can monitor very weak brain waves. In addition to Patch-EEG, a brain-implant brain-activity-monitoring sensor has also been developed.

The keynote also addresses some of the remaining issues for printing technologies for next-generation bio-signal monitoring systems and outlines the leading edge of brain monitoring using these systems and their future prospects.

WEDNESDAY 2 OCTOBER 2019

WEDNESDAY KEYNOTE AND IS&T SERVICE AWARDS

Session Chair: Scott Silence, Corning Corporation (US)
9:00 – 10:00

Fabricating Beauty: The Art and Science of Graphical 3D Printing, *Philipp Urban, Fraunhofer Institute for Computer Graphics Research IGD (Germany)*

Graphical 3D printing allows the reproduction of an object's color, translucency, or gloss, in addition to its shape, boosting the design freedom in digital fabrication to tremendous heights. This talk starts with a survey of graphical 3D printing technologies, covers challenges and solutions of the digital workflow, and shows application areas in which graphical 3D printing technologies can disrupt whole industries or create new ones. The keynote concludes with a demonstration of how graphical 3D printing changed movie making, taking as an example the stop-motion animation studio LAIKA and its latest feature film "Missing Link" for which 106,000 faces were printed for replacement animation.

MONDAY 30 SEPTEMBER 2019

Keynote sponsored by

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TRACK 1

OPENING KEYNOTE

Conquering the Challenges of New Inkjet Markets with MEMS Printhead Technology

Martin Schoeppler, FUJIFILM Dimatix, Inc. (US)

9:00 – 10:00

see details page viii; Cyril Magnin Ballroom I/II

TEXTILE AND NONWOVENS PRINTING

Session Chairs: Enrico Sowade, Zschimmer & Schwarz Mohsdorf GmbH & Co. KG (Germany) and Atsushi Tomotake, Konica Minolta, Inc. (Japan)

10:10 – 16:05

Room: Cyril Magnin Ballroom I/II

10:10 **Dye Sublimation Printing with Thermal Inkjet (Focal),** *Brian Curcio, Raffaella Fior, Hector Lebron, and Alberto Ugaz, HP Inc. (US)*

The digitally printed textile market is projected to grow from $2.2 B in 2018 to $3.6 B in 2023. Macro-trends driving this growth are:

1) Changing consumer needs: speed and convenience, same day delivery, personalization, new and innovative products that focus on emotions and experiences.
2) Supplier/manufacturer changes: on demand products, agile, closer to customers, smart textiles and sustainability.

Dye sublimation is the preferred technology for polyester fabric and will account for 60% of the volume of digital textile printing in 2023. The primary applications are soft signage, home décor, sportswear, and fashion.

Key challenges for digital dye sublimation printing are:

- Color consistency—getting the same color every time
- Waste and production inefficiencies—cost of wasted materials for the typical trial and error processes in the industry, caused by lack of stability of dye sub as a technology today and how dye sub is affected by changing weather conditions, summer to winter change, etc.
- Tight delivery times—a big driver in the industry that requires products with right level of productivity and reliability (i.e. unattendedness)
- There are current gaps from normal printer OEMs in the industry

The recently introduced HP STITCH dye sublimation printer product line will be described. Features include HP SmartColor color management, ability to print on both transfer paper and direct-to-fabric, reduced cost and waste, end-to-end solution and unattended operation. Advantages and challenges of printing dye sublimation inks with thermal inkjet printheads will be discussed. (Presentation-only Paper; no extended abstract.)

10:40 – 11:20 Coffee Break — Cyril Magnin Foyer

11:20 **DTG Printers Improve Textile Quality with Innovative Pre-treatment Agent,** *Masakazu Ohashi, Ryota Miyasa, and Toshihiro Fujie, Seiko Epson Corporation (Japan)* A-1

The commercial and digital printing market has grown in recent years, placing an increased amount of attention on textile printing technology. To cater to growing consumer demand, Epson unveiled an innovative direct-to-garment (DTG) printer that could heighten the visibility of images on dark-colored garments by applying a pre-treatment agent prior to printing with eco-friendly pigment inks. Released in 2013, Epson's DTG printer drastically raised the bar for textile printing and it revealed a new challenge: The pre-treatment solution, while impactful in raising image quality, also caused fabric discoloration. In this paper, we describe the mechanics behind fabric discoloration and explain how Epson's reformulated pre-treatment solution achieves maximum vibrancy with little to no textile discoloration. (Presentation-only Paper; see Appendix for extended abstract.)

11:40 **Optimization of Pre-treatment Solution by Adjusting Thickener's Property to Fine-tune Coloring Characteristics on Fabric,** *Yoshitaka Miyajima, Eri Kuroiwa, Takuya Sonoyama, and Shuji Yonekubo, Seiko Epson Corporation (Japan)*. 1

In digital textile printing process, various factors affect printing quality on fabric. One of these factors is pre-treatment process. If this process is carried out to control chemical interactions between dyes and fabrics strictly, proper pre-treatment solution must be prepared depending on fabric types. Otherwise, high printing quality never realizes. Thus, in our previous work, we focused on pre-treatment process and investigated the impact on coloring characteristics such as optical density and ink penetration on fabric in changing thickener which was one of the key materials in pre-treatment solution to realize high printing quality. As a result, we demonstrated that using two thickeners having different chemical structures from each other was much effective to adjust above coloring characteristics on fabric depending on required printing quality. However, in this previous work, we couldn't investigate and discuss whether controlling other parameters of thickener enabled us to alter coloring characteristics on fabric flexibly. Thus, in this paper, we focused on molecular weight of thickener as a parameter to affect printing quality on fabric and investigated whether changing molecular weight was effective to fine-tune coloring characteristics on fabric or not.

12:00 **Investigation of Reactive Dye Based Ink Fixation Behavior in Digital Printing on Cotton Fabric,** *Yixin Liu, Lisa P. Chapman, Kristin Thoney-Barletta, and Stephen Michielsen, North Carolina State University (US)* A-2

Reactive dye-based printing provides excellent print quality and is used for a wide variety of printed home furnishings and apparel products. However, a high dye fixation percentage is hard to achieve for reactive digital printing. The purpose of this study is to investigate the fixation behavior of reactive dye digital printing, thereby promote the ink fixation and the print sustainability of digital printing. Currently, the relationship between dye fixation ratio and fabric steaming temperature and time has been investigated. (Presentation-only Paper; see Appendix for extended abstract.)

12:20 **Effect of Fabric Hairiness and Pretreatment on Quality of Digital DTG (Direct to Garment) Printing (Focal),** *Samir Sadikoglu, European T-shirt Factory (Turkey)* 6

Direct to garment printing is expanding its presence on the textile market today due to the markets search for sustainability, print on demand, fast response, mass customization, and inventory reduction. While this type of printing in terms of quality may be enough for the promotional market, brands are still struggling with both quality and performance of the DTG prints on natural fibers, especially on dark colors.

This paper is focused on research of print quality of the digital direct to garment printing based on the fabric hairiness and pretreatment level, which are the main obstacles for quality and sustainable printing.

Open End and Ring spun yarn types of the same count 30/1 Ne are chosen. They are knitted with the same knitting parameters (stitch length and gauge) and dyed on the same dying batch. Hairiness values coming from the yarn production and fabric dying process are respectively compared. Swatches with different opacity level (25%- 50%-75% and 100%) of CMYK are printed on all fabrics with and without White underbase. In addition the effect of 3 different amounts of pretreatment are added for evaluation. The research gives the comparison of values of L lightness value (for dark colored fabrics) and S saturation value on 10 different fabric types.

The result showed that wet pretreatment processing on fabric treated with enzyme gives the best results based on L values on ring spun fabrics on both enzyme treated and untreated fabrics. Important finding is that there is a need for pretreatment optimization of Open Endfabrics while ring fabrics gave the same result on 3 different pretreatment amounts. This conclusion is valid for dark fabrics only, while there was found no significant difference for white fabrics both on ring spun and open end.

The brushed fabric (which had the highest hairiness level) gave the poorest printing results (based on L and S values measurements) showing the negative effect of hairiness value to print quality.

12:50 – 14:15 Lunch Break

STATE-OF-THE-ART KEYNOTE

Printed Textiles On Demand: Technology Challenges Meet Creative Opportunity

Kerry Maguire King, Spoonflower Inc. (US)

14:15 – 15:05

see details page viii; Cyril Magnin Ballroom I/II

TEXTILE AND NONWOVENS PRINTING (continues)

Session Chairs: Enrico Sowade, Zschimmer & Schwarz Mohsdorf GmbH & Co KG (Germany) and Hirotoshi Terao, ALPS Electric Co., Ltd. (Japan)

10:10 – 16:05

Room: Cyril Magnin Ballroom I/II

15:15 **JIST-FIRST Replication of Screen-Printing Fabric via Ink-jet Textile Printing,** *Ming Wang, Lisa Chapman, Marguerite Moore, and Minyoung Suh, North Carolina State University (US)* 15

Digital textile printing (DTP) is fast, flexible, and relatively inexpensive for sample printing, and can be applied quickly in response to consumer demand. The aim of this two-stage research was to analyze the potential of DTP to replace traditional screen printing for a specific textile product. In Stage One, an optimal DTP workflow was established. The workflow included determination of the colorant and substrate combination, color calibration, CAD file, and the necessity of pretreatment. In Stage Two, a visual assessment instrument and protocol were established to evaluate the acceptance of replicated ink-jet printed fabric. The visual assessment and protocol were designed to evaluate the acceptance of the ink-jet printed sample to fully replicate the screen-printed sample via seven measured aspects. These seven aspects include: perceived color difference, lightness difference, overall color,

COLLEAGUE CONNECTIONS: THE FUTURE OF DIGITAL TEXTILE MANUFACTURING

Monday, 17:35 – 18:30: Cyril Magnin Ballroom I/II
Moderator: Ron Askeland, HP Inc. (US)

Please join us for an interactive discussion with thought leaders from academia and industry. Topics include digital textile printing, functional textiles, Industry 4.0, and the Internet of Things.

scale, line quality, visual texture, and overall appearance. Data gathered from the visual assessment was then analyzed and compared using SPSS statistics software. The results indicate that DTP demonstrates a significant potential alternative for traditional screen printing.

15:35 **Mastering Ink Droplet Absorption on Textiles Using Primer,** *Helmuth Haas, CHT Group (Germany)* A-3
With the advent of robust print heads and subsequently high-speed scanning machines direct-to-fabric printing became common practice in major textile mills around the world. Having mastered a manifold of engineering challenges while transitioning from paper to textile substrates the industry is still struggling with the complexity of the textile process chain. Currently, the implications of process variables on digital print processes are rather poorly understood. This is partly due to missing methods that cast light on critical ink-substrate interactions. Within this talk we show results we obtained with our high-speed camera with various inks and substrates and discuss the role of primer in digital textile printing. (Presentation-only Paper; see Appendix for extended abstract.)

15:55 **Development of New Inkjet Ink for Leathers (Interactive Preview),** *Naoto Shimura, Masaki Kudoh, Hiroki Nakane, and Masahiro Kido, Ricoh Company, Ltd. (Japan)* 25
In industrial printing, digital printing which can handle a large variety of substrates has been demanded. Digital printing employing inkjet system using UV ink has been adopted to print images on variations of substrates, but UV-ink contains Volatile organic compounds (VOC). Aqueous-ink is relatively VOC-less but can't handle a variety of substrates. We solved these problems by developing new aqueous resin ink. The aqueous resin ink has high durability on leathers and the compatibility to variations of substrates.

16:00 **Development and Evaluation of Digital Denim Technology (Interactive Preview),** *Ming Wang, Lisa Chapman, Lori Rothenberg, Minyoung Suh, and Blan Godfrey, North Carolina State University (US)* A-4
Denim, a woven cotton fabric, is a trend driven substrate used throughout the world in multiple consumer markets. As a profitable fashion fabric, denim can be classified according to texture, weight, finishing method and surface effects. The consumer demand for novel and different denim surface appearance leads to extensive research and development in finishing application efforts by companies. Although widely consumed and very popular, one drawback to denim is that the finishing and manufacturing processes are energy and water intensive and can cause environmental hazards as well as generation of pollution through water waste, particularly at the finishing stage. Textile ink-jet printing has the potential to replicate some of the coloration and finishing techniques of traditional denim fabric, without the negative environmental impacts. The benefits of textile ink-jet printing, such as quick response, ability for customization, and relatively low pollution, water, and energy usage may make this a viable production process for novel denim fabrics.

To explore the potential for ink-jet printing to replicate the coloration and finishing techniques of traditional denim fabric, a two-phase research project was conducted. In Phase I (P1), the Principal Investigator (PI) conducted a comparative analysis of traditional versus digitally reproduced denim, and a market analysis to explore and determine the potential new markets for digital denim. A comprehensive literature review, and data collected from personal interviews with industry experts, enabled a comparative analysis of the benefits and challenges of traditional vs. ink-jet-printed denim, assisted in determining the types of denim and finishing effects that were best suited for reproduction by ink-jet printing, and helped to build a new market model for digital denim.

Based on information gleaned in Phase I, outcomes for Phase II of the research were the establishment of an optimal standard production workflow for digital denim reproduction (including color and finishing effects), development and validation of a standard assessment protocol, and an expert visual assessment evaluating the consumer acceptance of the replicated denim. (Presentation-only Paper; see Appendix for author bios.)

16:05 – 16:25 Coffee Break — Cyril Magnin Foyer

Session sponsored by

RICOH

3D PRINTING I

Session Chairs: Travis W. Walker, South Dakota School of Mines and Technology (US) and Yasuaki Yorozu, Ricoh Company, Ltd. (Japan)

16:25 – 17:35

Room: Cyril Magnin Ballroom I/II

16:25 **3D Printed Electronics with Multi Jet Fusion (Focal),** *Jarrid A. Wittkopf, Kris Erickson, Paul Olumbummo, Aja Hartman, Howard Tom, and Lihua Zhao, HP Inc. (US)* 29

3D printed electronics (3DPE) is an enabling technology that has the potential to allow for the advanced track and traceability of every 3D or additively manufactured (AM) part; enable communication and sensing by an individual part; and remove geometrical limitations for electrically active devices which can directly take on the final product form factor. Additionally, AE solutions attempt to allow for faster prototyping for conventional circuit designs. HP's Multi Jet Fusion (MJF) technology is a powder-based 3D printing technology that enables the production of high mechanical performance polymer parts at high speeds and reduced costs. At HP Labs, the advanced capabilities of the MJF platform have been researched. We have developed a process for 3D printed electronics. This allows an ink-jettable conductive agent (CA) to be utilized with the MJF process to build conductive traces, vias, and contacts anywhere within or on a printed part during the 3D printing process.

16:55 **Application Kaizen for FDM 3D High Temp (500°C) Hotend,** *Hideo Taniguchi, KHR Center (Japan), and Jiro Oi, KHR Center (US)*. 34

As the FFF/FDM 3D fabrication process becomes more accepted and popular in industry, the demand for products with higher anti-abrasion capability, higher durability as well as the ability to withstand higher temperature is growing fast. The materials for this type of product are known as "super engineering plastic" and materials such as PEEK and TPI are the examples.

Due to the high temperature requirements, the existing hotends which are made for lower temperature materials like PLA and ABS are not capable to handle the material. A revolutionary new concept hotend for high-temperature usage in the range of 300 °C to 500 °C has been developed specifically designed for the super engineering plastic materials.

The new hotend is compact in size and the thermal capacity is small accordingly compared with the conventional units, but it can follow the precise temperature requirements and fine adjustments as needed. Unlike the others, this hotend does not need a large cooling system (either forced air or liquid coolant) to prevent the heat creep on the cool end of the extruder. It is more energy efficient and eco-friendly as it heats when it is needed. Also, thanks to the size and weight, multi-nozzle device will be feasible in the near future.

With the new design improvement and ability to monitor-control the hotend temperature more accurately, it is much more clogging-resistant of filament material than existing or even our own previous year's hotend.

17:15 **Robotic Ceramic Paste Extrusion for Industrial Prototyping and Production,** *David Huson, University of the West of England (UK)* 38

Ceramic additive layer manufacture employs a range of different technologies including ceramic paste extrusion, powder/binder jet, and UV and daylight cure ceramic loaded resins. Each of these technologies has its own set of advantages and disadvantages.

This paper investigates the possibilities of using a robot multi-axis system to enhance the capabilities of a ceramic paste extrusion process.

COLLEAGUE CONNECTIONS; CONCURRENT EVENTS

Colleague Connections: The Future of Digital Textile Manufacturing

17:35 – 18:30

see details page xiii, Cyril Magnin Ballroom I/II

Colleague Connections: Advances in 3D Printing Technologies

17:35 – 18:30

see details page xvii, Cyril Magnin Ballroom III

EVENING EVENT

Student/Young Professionals Get Together

19:00 – 22:30

Join others for a night of fun in downtown San Francisco; meet in the lobby of the Parc 55 by hotel registration desk at 19:00.

TRACK 2

OPENING KEYNOTE

Conquering the Challenges of New Inkjet Markets with MEMS Printhead Technology

Martin Schoeppler, FUJIFILM Dimatix, Inc. (US)

9:00 – 10:00

see details page viii, Cyril Magnin Ballroom I/II

Keynote sponsored by

FUJIFILM Value from Innovation Dimatix™

MATERIALS AND MATERIAL INTERACTIONS

Session Chairs: Omer Gila, HP Inc. (US) and Norio Nagayama, Ricoh Company, Ltd. (Japan)

10:10 – 12:50

Cyril Magnin Ballroom III

10:10 **How Carbon's Digital Light Synthesis is Enabling Digital Manufacturing of Polymeric Products (Focal),** *Matthew Menyo, Carbon (US)* A-5

Carbon, the world's leading Digital Manufacturing Platform, is reinventing how polymer products are designed, engineered, manufactured, and delivered towards a digital and sustainable future. This talk will outline how Carbon's innovations in software, hardware, and molecular science overcome traditional limitations in the additive manufacture of polymeric products and showcase industry-leading digital manufacturing solutions.

Despite industry advances, traditional approaches to additive manufacturing force trade-offs between surface finish and mechanical properties. In contrast, Digital Light Synthesis™ technology, enabled by Carbon's proprietary CLIP™ process, is a breakthrough technology that uses digital light projection, oxygen permeable optics, and programmable liquid resins to produce parts with excellent mechanical properties, resolution, and surface finish. Digital Light Synthesis™ produces consistent and predictable mechanical properties, creating parts that are solid on the inside.

The heart of the CLIP™ process is the "dead zone"—a thin, liquid interface of uncured resin between the window and the printing part. Light passes through the dead zone, curing the resin above it to form a solid part. Resin flows beneath the curing part as the print progresses, maintaining the "continuous liquid interface" that powers CLIP™.

Conventional 3D printed materials often exhibit variable strength and mechanical properties depending on the direction in which they were printed. Digital Light Synthesis™ parts behave consistently in all directions. The resolution and gentleness of our process—where parts aren't harshly repositioned with every slice—make it possible to exploit a range of materials that have surface finish and detail needed for end–use parts.

Traditional additive approaches to photo polymerization typically produce weak, brittle parts. Carbon overcomes this by embedding a second heat-activated chemistry in our materials. Once a part is printed with CLIP™, it's baked in a forced-circulation oven. Heat sets off a secondary chemical reaction, allowing the incorporation of industrially recognized chemistries such as polyurethanes, epoxies, and cyanate esters. This results in high-resolution parts with engineering-grade properties and durability.

With Carbon's ground-breaking Digital Light Synthesis™ technology and broad family of programmable liquid resins, manufacturers can unlock new business opportunities such as mass customization, on-demand inventory, and previously impossible product designs. The Carbon Platform allows customers to build uniquely differentiated products while reducing waste and speeding time to market. (Presentation-only Paper; see Appendix for author bio.)

10:40 – 11:20 Coffee Break — Cyril Magnin Foyer

11:20 **The Effect of Different Relative Humidity and Temperatures of Coated Paperboards on Inkjet Print Quality,** *Katriina Mielonen, Sami-Seppo Ovaska, and Ville Leminen, Lappeenranta-Lahti University of Technology (Finland)* A-6

The effect of different relative humidity and temperatures of coated paperboards on inkjet print quality was studied. It is known that HPS-coated substrates have unique inkjet printability with dye-based inks and too high SB-latex content can make the coating heterogeneous. In this study we have investigated how different storing conditions (humidity and temperature) and pre-heating of dual-polymer coated samples effect on print quality e.g. print density and ink adhesion of dye-based ink. It was noticed that print density was not dependent on storing temperature suggesting good stability of the ink, but some staining in ink adhesion test for dual-polymer coatings were noticed. (Presentation-only Paper; see Appendix for extended abstract.)

11:40 **Thermal Effects of Contact Angle in Polymeric Powder for 3D Printing,** *Katrina J. Donovan[1, 2], James Stasiak[3], and Willie E. Rochefort[1]; [1]Oregon State University, [2]Dragon Materials, LLC, and [3]HP Inc. (US)* A-8

Three-dimensional printing (3DP) is a diverse, unique, and developing technology. The advent of 3DP has invigorated research into metamaterials, synthetic composite material that produce properties generally not found in natural materials, requiring further studies into understanding the fundamental properties of these materials. 3DP is a fabrication process that designs an object from the bottom up in an additive digital designing process. Polymeric powder bed technology that would operate by blading a layer of heated polymeric powder, dispensing fluidic agent into the upper most powder layer to bind the powder, or using a laser to sinter the powder. This process is repeated layer by layer, and in a step-wise process.

Fundamental approaches by our group have been developed and previously presented. The technique proposed builds from prior knowledge and introduces a systematic approach to studying thermal effects of microfluidic flow in polymeric powder beds. (Presentation-only Paper; see Appendix for extended abstract.)

12:00 **Development of Safety and Low Energy Curable Monomer,** *Masahide Kobayashi, Mitsunobu Morita, Takashi Okada, Takenori Suenaga, and Soh Noguchi, Ricoh Company, Ltd. (Japan)* A-10

Low molecular weight acrylic monomers are widely used for UV curable materials which are classified as hazardous materials. Methacrylate monomers are relatively safe materials but tend to require high curable energy. It is issue to achieve both curability and safety. We solved these problems by developing new UV curable monomer. (Presentation-only Paper; see Appendix for extended abstract.)

12:20 **The Optical Properties of the Woodburytype—An Alternative Printing Technique based on a Gelatine/Pigment Matrix,** *Damien Jon Leech, Walter Guy, and Susanne Klein, University of the West of England (UK)* 42

The Woodburytype is a 19th century photomechanical technique, producing high-quality continuous-tone prints that use a mixture of pigment and gelatine as a relief print, in which the variation in height of the print produces the tone and contrast. We propose a phenomenological optical model for the process based on Kubelka-Munk theory that considers the ink formulation, the print height, and the substrate surface in order to provide the ideal combination of printing depth and contrast.

12:40 **Engineering Ag Particle Based Inks to Improve Electrical and Sensing Properties of Conductive Composites (Interactive Preview),** *Mei-Chee Tan, Singapore University of Technology and Design (Singapore)* A-11

The general approaches to print nanometals during additive manufacturing are: (1) printing of nanometal-matrix composite and (2) intermittent printing of matrix structures and nanometals. The development of versatile chemical processes to address key challenges faced in creating highly conductive composite and metal-coated matrices. For example, incompatible interfacial chemistries between poly(dimethylsiloxane) (PDMS) and polyacrylic acid (PAA)-modified Ag nanoparticles led to poor Ag dispersion and incomplete PDMS curing. Using a single-step Ag surface modification process, the PDMS composite was cured at higher Ag loadings exceeding percolation threshold with improved conductivities. To create highly conductive metal-coated matrices, low temperature fusion of nanometals are required. The underlying size and surface effects on the chemically-induced fusion is presented. Using this chemically-induced fusion of nanometals, highly conductive metal-coated polymeric lattices were fabricated. (Presentation-only Paper; see Appendix for extended abstract.)

Please note: This author is not able to present during the Interactive Paper Session on Wednesday. He will stand by his poster to discuss its content during the Tuesday morning coffee break.

12:45 **Synthesis of Carbon Dots Ink by Cellulose Nanofiber via Microwave Method (Interactive Preview),** *Donghao Hu, Kuan-Hsuan Lin, Mikio Kajiyama, and Toshiharu Enomae, University of Tsukuba (Japan)* A-12

Carbon dots (CDs) ink with an average diameter of 7.86 nm with a narrow distribution were synthesized by using 4,7,10-Trioxa-1,13-tridecanediamine (TTDDA), and tetramethyl-1-piperidinyloxy oxidized cellulose nanofiber (TEMPO-CNF) via microwave method. During the whole procedure, TTDDA acted as an acylating agent and passivator. Presumably, TTDDA underwent oxygen-acylation process, where O=CN-R groups were formed from N-H groups. (Presentation-only Paper; see Appendix for extended abstract.)

12:50 – 14:15 Lunch Break

COLLEAGUE CONNECTIONS: ADVANCES IN 3D PRINTING TECHNOLOGIES

Monday, 17:35 – 18:30: Cyril Magnin Ballroom III
Moderator: James Stasiak, HP Inc. (US)

Join other scientists, engineers, and technologists in an interactive discussion about the future of 3D Printing. Topics include novel materials including polymers, metals, and biological materials, innovations in 3D printing processes, digital fabrication and manufacturing, and applications.

STATE-OF-THE-ART KEYNOTE

Printed Textiles On Demand: Technology Challenges Meet Creative Opportunity
Kerry Maguire King, Spoonflower Inc. (US)
14:15 – 15:05
see details page viii, Cyril Magnin Ballroom I/II

PRINTING BIOLOGICAL MATERIALS

Session Chairs: Alexander Govyadinov, HP Inc. (US) and Nobuyuki Nakayama, Fuji Xerox Co., Ltd. (Japan)
15:15 – 15:55
Cyril Magnin Ballroom III

15:15 **Printable Glycosaminoglycan Graded Gelatin Methacryloyl Acetyl Hydrogels,** *Lisa Rebers[1], Kirsten Borchers[1,2], Eva Hoch[1], Sandra Stier[2], Veronika Schönhaar[2], and Achim Weber[1,2]; [1]University of Stuttgart and [2]Fraunhofer-Institute for Interfacial Engineering and Biotechnology IGB (Germany)* 48

Hydrogels are considered as appropriate scaffold materials for cell encapsulation. This is due to their high water binding capacity similar to the native extracellular matrix. However, the equilibrium degree of swelling of simple hydrogels is related to the cross-linking degree of the hydrogels and thereby not freely adjustable. We decoupled the correlation of equilibrium degree of swelling and cross-linking density by chemical modification of the biopolymer gelatin and sophisticated hydrogel formulations. These formulations contained different amounts of chemical modified glycosaminoglycans, genuine components of native extracellular matrix of cartilage. We created glycosaminoglycan-graded hydrogels by layer-wise dispensing three hydrogel precursor solutions on top of each other. We investigated the viability of the encapsulated chondrocytes 28 days after printing and evaluated the production of newly synthesized extracellular matrix.

15:35 **SynJet: A Novel Chemical Dispensing Platform for High-throughput Reaction Screening and Optimization,** *Jason D. White, SRI International (US)* A-13

The process to yield the highest-quality complex chemicals important in daily life is currently constrained to a cottage industry of experts that typically use manual procedures that are painstaking, repetitive, time-consuming, and expensive. We seek to democratize this industry with the confluence of chemistry, modern inkjet dispensing technologies, robotic automation, and instrumented analytics.

Our platform, SynJet, incorporates the HP D300e dispenser, which we demonstrate can handle important chemical solvents. We integrated press-fit vials of our own design into a full reaction platform capable of sealing, heating, and analyzing chemicals with minimal human intervention. The efficiencies gained using our platform have sped up the process to identify the optimal reaction conditions that are translatable to scale-up and flow processes. (Presentation-only Paper; see Appendix for extended abstract.)

15:55 – 16:35 Coffee Break — Cyril Magnin Foyer

PRINTED FUNCTIONALITIES

Session Chairs: Gerd Grau, York University (Canada) and Teruaki Mitsuya, Ricoh Company, Ltd. (Japan)
16:35 – 17:35
Cyril Magnin Ballroom III

16:35 **Temperature Control for Direct Thermal, Three Color, Single-Pass Imaging,** *Brian Busch, Zink Holdings (US)* A-15

We present developments in temperature control of a direct thermal printer required to achieve three color single pass printing on Zink™ media.

In a direct thermal printer the printhead heats up over the course of the print. Depending on the size and shape of the heatsink, this temperature change can be dramatic. A model-based Thermal History Control (NIP18 2002) has proven remarkably efficient and accurately compensates for this change by reducing the energy applied to the heating elements of the printhead as it heats up.

In a 3-color direct thermal medium such as Zink™, each color has a different sensitivity to the printhead temperature. This is a property of the structure of Zink Media, where each color is in a separate layer, buried at a separate depth underneath the surface of the structure, and each color has a separate activation temperature. If each color were activated in a separate print pass, this could all be dealt with using the model-based thermal history control mentioned above. But activating all three colors in a single pass also requires compensating for each color's unique sensitivity to the energies applied to the other two colors within the same pixel.

We call this the "cross-sensitivity" of the colors to each other. We present a method of calibrating and compensating for this effect, along with results of the correction algorithm. The cross-sensitivity is found to depend not only on the color, but also on the print speed, LPI, and even the details of the heating pulse pattern. (Presentation-only Paper; see Appendix for author bio.)

16:55 **How to Print a Rainbow,** *Susanne Klein, Carinna Parraman, and Louis Voges, University of the West of England (UK)* 52

In the 21st century, methods for translating additive colours as seen on screens (Red Green Blue (RGB)) into subtractive colours (Cyan Magenta Yellow Black (CMYK)) for industrial print are based on 4-colour halftoning. CMYK are so called process colours, used for printing on opaque substrates, from paper to glass and metal, when photomechanical reproduction is desired. These reproductions surround us, from images in books and magazines, on packaging to prints on clothing, homeware, and advertising banners. Additive RGB colours are traditionally used in transmittance, i.e. in backlit applications, for example in mobile phones, laptops, tablets, etc. SpectravalTM pearlescent pigments produced by Merck open the possibility of RGB, i.e. additive, colour printing on opaque substrates. We present here a characterization of the optical features of these effect pigments and discuss print applications.

17:15 **Inkjet Printing of 3D Optics for Individualized Illumination Systems,** *Erik Beckert, Falk Kemper, Sabrina-Jasmin Wolleb, and Maximilian Reif, Fraunhofer Institute for Applied Optics and Precision Engineering (IOF), and Soenke Steenhusen, Fraunhofer Institute for Silicate Research (Germany)* 56

Additive manufacturing of optical components is one of the most challenging aspects in rapid prototyping, as optics demands not only excellent surface shape and roughness parameters for the outer geometry of the printed part, but also pose stringent requirements for the homogeneity of the printed bulk material. The paper presents an approach to inkjet print optical volumes, using the specific hybrid polymer ORMOCER and an optimized, multi-layer inkjet printing process to achieve shape deviations <20 µm PV, surface roughness in the range of <50 nm and a transparency of the printed bulk volume >95 %.

COLLEAGUE CONNECTIONS; CONCURRENT EVENTS

Colleague Connections: The Future of Digital Textile Manufacturing
17:35 – 18:30
see details page xiii, Cyril Magnin Ballroom I/II

Colleague Connections: Advances in 3D Printing Technologies
17:35 – 18:30
see details page xvii, Cyril Magnin Ballroom III

EVENING EVENT

Student/Young Professionals Get Together
19:00 – 22:30
Join others for a night of fun in downtown San Francisco; meet in the lobby of the Parc 55 by hotel registration desk at 19:00.

TRACK 3

OPENING KEYNOTE

Keynote sponsored by

FUJIFILM Value from Innovation Dimatix

Conquering the Challenges of New Inkjet Markets with MEMS Printhead Technology

Martin Schoeppler, FUJIFILM Dimatix, Inc. (US)

9:00 – 10:00

see details page viii, Cyril Magnin Ballroom I/II

FUNDAMENTAL SCIENCE AND TECHNOLOGY OF INKJET I

Session sponsored by

XAAR®

Session Chairs: Masahiko Fujii, Fuji Xerox Co., Ltd. (Japan); Cailin Simpson, Dynetics Technical Solutions (US); and Werner Zapka, WZA-Consulting (Sweden)

10:10 – 17:55

Market Street Meeting Room

10:10 **Ink Jet—The Pioneers of the 19th and 20th Centuries (Focal),** *Michael Willis, Pivotal Resources, Ltd. (UK)* A-16

Although the mass commercialization of ink jet technology has only taken place in the last 40 years, the physics of drop formation, electrostatic charging and deflection, vibrating nozzles, and electrostatic drop generation go back over a century. In fact the development of ink jet technology can be considered in three waves:

- a long period before the development of digital computers, when the driver was a recording technology for a wide range of applications
- as an output technology for digital computers, from early mainframes through to desk-top and portable devices, producing graphics content of all kinds for communication
- as part of manufacturing technologies, ranging from product marking and coding, ceramic tile and textile printing to the biomedical, printed electronics and additive manufacturing applications that are growing today and one day will eclipse graphics applications

This paper will focus on some examples from the first wave. There have been many previous descriptions of the early theoretical studies for ink jet but here we look at the driving forces behind the development of recording technologies using ink drops from applications that pre-date computers.

The story is a fascinating one of English Lords, transatlantic submarine cables, recorders for radio communication transmissions to the development of heart pacemakers, and alternatives to X-ray film. (Presentation-only Paper; see Appendix for extended abstract.)

10:40 – 11:20 Coffee Break — Cyril Magnin Foyer

11:20 **Analysis Technology of Residual Solvent of Printed Inkjet Ink with Near-Infrared Spectroscopy,** *Eiichi Mori, Shunichi Oohara, and Tohru Ohshima, Ricoh Company, Ltd. (Japan)* 60

Near-infrared (NIR) spectroscopy for analysis of residual solvent of printed inkjet ink on-site is newly developed. In the industry of water-based inkjet ink, heat drying process is performed after printing. However, residual solvents remain on the printed matter after the drying process, and these residual solvents affect ink-fixing properties. Gas-chromatography (GC) or gas-chromatography mass-spectrometry (GC/MS) is conventionally used for analyzing residual solvent of the printed matter. However, this method takes several days to obtain results. To analyze residual solvent on-site, NIR spectroscopy is developed, and the value can be quantitatively predicted on-site, and easily. Also, spatial resolution is improved with NIR compared with GC/MS measurement. Therefore, spatial distribution information can be obtained. Here, NIR spectroscopy for analyzing residual solvents in a short period of time, evaluating easily, and on-site is reported. Also, the relationship between residual solvent and fixing properties of the printed matter is studied in detail. The principle of measurement, and some application examples and relationships with fixing properties of the printed matter are reported in this paper.

11:40 **Study on Ink-Jetted Droplet Volume Measurement Using Surface Energy Patterned Channels,** *Dong-Youn Shin, Pukyong National University (South Korea)*. A-17

Ink-jet printing has drawn attention from display industries because of its simplicity in manufacturing display panels with pixels. However, ink-jet pixelation has raised issues such as nonuniformity in color, as shown in Figure 1, resulting from different droplet volumes from individual nozzles of an ink-jet print head. Numerous efforts have been made to precisely calibrate droplet volumes. Herein, literature-known methods to calibrate droplet volumes will be briefly reviewed and a novel method to more pre-

cisely calibrate droplet volumes will be proposed. Unlike literature-known methods, the proposed method tries to deposit a number of droplets and allow them flow through surface energy patterned channels, as can be seen in Figure 2(a). By amplifying the minute difference of a single droplet, it is predicted to precisely measure the droplet volume difference of 0.3% even with the low measurement accuracy of 1 μm, as shown in Figure 2(b), whereas the conventional method requires the optical measurement accuracy less than 25 nm for the same volume measurement accuracy. The proposed method will contribute to display industries by virtue of better color uniformity with more accurately and precisely calibrated droplets. (Presentation-only Paper; see Appendix for extended abstract.)

12:00 **Mottle Evaluation of Coated Cardboards Printed in Inkjet,** *Sandra Rosalen and Johannes Backhaus, University of Wuppertal (Germany)* 65

In this study the methods suggested in the standards ISO/TS 15311-2 / ISO/IEC 24790 and the method suggested from FOGRA (M-Score) to measure print mottle were conducted and compared with visual evaluations. The aim was to understand if one of them is more adequate for evaluation of mottle in inkjet print on coated cardboards and if pre- and post-treatments on the cardboards have an influence on print mottle.

The measurements showed that the first method has a higher accordance with visual evaluations. A second finding was that a pretreatment with primer and post treatment with IR-radiation to improve ink adhesion and drying can also reduce print mottle.

12:20 **Quantification of Evaporation, Penetration and Viscosity Increasing Behaviors of Ink Droplets after Landing on Media,** *Yoshihiro Harada, Ricoh Company, Ltd. (Japan)* 69

In inkjet imaging, in order to obtain high image quality, it is desirable to quickly solidify ink droplets on the media. In order to understand the speed at which the ink droplets solidify, the process was quantified by measurement based on the dynamic light scattering method. In addition, the phenomenon of ink penetration into media, which is one of the factors of solidification, was visualized by the method of optical coherence tomography, and the interface movement speed was quantified. These make it possible to determine whether the ink droplet behaves properly for image quality.

12:40 **Fiber Morphology Analysis for Directed-Energy Deposition Manufacturing Process (Interactive Preview),** *Cailin Simpson[1,2], Katherine Vinson[2], Ryan J. Hooper[2], and Steve Simske[1]; [1]Colorado State University and [2]Dynetics Technical Solutions (US)* 75

The structural and mechanical properties of fibers manufactured from a batch-wise directed-energy deposition process is related to the fiber morphology. Mechanical property data of a batch is determined by testing a random sample of fibers. Metrics such as edge roughness are utilized to quantify the variations in the outer edges of a fiber whose morphology is expected to be uniform. The amount of edge roughness present in a batch of fibers affects the mechanical properties of the batch. A correlation between reduced mechanical properties and edge roughness was possible through calculating edge roughness metrics programmatically for each batch of fibers. In order to automate the analysis of batches of fibers, a software tool was leveraged to gain understanding of the morphologies.

12:45 **Effect of Ink, Substrate, and Target Line Width on the Line Quality Printed Using Dimatix DMP Inkjet (Interactive Preview),** *Mihir Choudhari, Robert Eller, and Christine Heusner, Rochester Institute of Technology (US)* 79

In this research, the image quality analysis is conducted for inkjet lines printed on substrates. ISO 24790 compliant lines are designed and printed on a substrate with a drop-on-demand inkjet printer. This study analyzes three print quality attributes of line: width, blurriness, and raggedness. The research used cyan, magnetic, and standard inks to print the same design on various substrates having differences in gloss and texture. The chosen inks were measured using a rheometer to determine a viscosity range. The effects of substrate structural parameters, such as texture, finishing, weight, and ink type on line quality, are discussed. The printed lines were measured using a charged coupled device camera. The print attributes were measured, and statistical analysis was conducted. Based on this analysis, it was observed that substrate has significant effect on all the response variables. The substrate which produced best result is luster for raggedness and line width conformity and matte for blurriness. Ink has significant effect on the line width conformity and raggedness whereas there is no significant effect of inks on blurriness. There is no effect of increase in the line width on any of the response variables. A design of experiment methodology was successfully implemented to determine the effect of surface properties of the substrate and the effect of ink properties on print quality.

12:50 **Lifetime Improvement of Sol-gel PZT Thin Film Actuators: from Methodology to Reality (5601 Print Head) (Interactive Preview),** *Song Won Ko, Xaar (US), and Charalampos Fragkiadakis and Peter Mardilovich, Xaar plc (UK)* A-18

The actuator lifetime of the XAAR 5601 printhead has been improved by dopant change, seed layer optimization, composition tuning in Z-direction, etc. Also, to understand the relationship between the localized Joule heating spots and local weak regions where an early failure or thermal breakdown is more likely, three different techniques (thermal imaging using an infrared camera, thermoreflectance spectroscopy, and Raman spectroscopy) have been explored in order to investigate the temperature profile of active MEMS devices of both released and clamped PZT actuators. (Presentation-only Paper; see Appendix for extended abstract.)

12:55 **Inkjet Printing for Bio-sensor Applications (Interactive Preview),** *Yuanyuan Zhou, Oliver Broom, Dave Varty, and Wendy Newton, Ricoh UK Products Ltd. (UK)* A-19

The capability of Ricoh inkjet printheads for concise and accurate dosing for printing biological applications is presented. With the deep characterisation of biological functional fluid, an optimised reliable jetting performance has been tuned with waveform optimisation based on efficient understanding of the bio-active ingredients and fluid rheological properties. The latency effect of such a novel application has also been studied by understanding the nozzle local viscosity profile. (Presentation-only Paper; see Appendix for extended abstract.)

13:00 – 14:15 Lunch Break

STATE-OF-THE-ART KEYNOTE

Printed Textiles On Demand: Technology Challenges Meet Creative Opportunity

Kerry Maguire King, Spoonflower Inc. (US)

14:15 – 15:05

see details page viii, Cyril Magnin Ballroom I/II

FUNDAMENTAL SCIENCE AND TECHNOLOGY OF INKJET (continues)

Session Chairs: Kye-Si Kwon, Soonchunhyang University (South Korea); Brayden Wagoner, Purdue University (US); and Werner Zapka, WZA-Consulting (Sweden)

10:10 – 15:55

Market Street Meeting Room

15:15 **Stable Inkjet Printed Lines at Ultra High Resolution (Focal),** *Jinxin Yang and Brian Derby, University of Manchester (UK)* A-20

Printed line resolution (minimum width) is controlled by both droplet size and the ink/substrate interaction. A Super Inkjet Printer (SIJ) was used to produce small ink droplets using electrostatic drop generation from a Taylor cone. Stable and repeatable drop size can be achieved through control of the electrical potential, local electric field (generator-substrate separation), fluid flow rate, and actuating pulse shape. Through suitable control of these parameters we are able to produce stable parallel line structures of width 5.5 μm. The relationship between line width, drop size, and drop spacing are shown to be consistent with models for printed line dimensions developed for larger drops generated by conventional drop-on-demand devices. (Presentation-only Paper; see Appendix for extended abstract.)

15:45 – 16:25 Coffee Break — Cyril Magnin Foyer

16:25 **Fundamentals of Thermal Inkjet Technology Micropumping and its Application for Printing and Life Science (Focal),** *Alexander N. Govyadinov, Erik Torniainen, David Markel, and Pavel Kornilovitch, HP Inc. (US)* A-21

Recently, there has been a lot of interest in microfluidic lab-on-a-chip applications for life sciences, forensic, point-of-care, molecular-diagnostic, other in-vitro-diagnostic, organs-on-a-chip, environmental and other applications. Various scientific and commercial organizations explore different material sets and operational principles to forge microfluidic devices. Simultaneously, the inkjet industry is repurposing its well-developed material base and manufacturing processes for large scale fabrication of complex microfluidic systems for precision dispense, droplet manipulation, and other applications. The presentation describes our recent progress in the development of a low-cost microfluidic platform utilizing the materials and processes of the commercial thermal inkjet business. The well-established microfluidic components and jetting elements are being repurposed for pumping, mixing, valving, fluid transport, sensing, and other critical functions of complex integrated microfluidic systems. This presentation describes the operating principles of microfluidic elements, gives examples of their integration in functional devices, and discusses the potential of the inkjet technology to deliver a broad range of microfluidic applications and lab-on-a-chip diagnostic devices. (Presentation-only Paper; see Appendix for extended abstract.)

16:55 **Surface Tension Driven Meniscus Oscillations and the Effects on Droplet Formation,** *J. Frits Dijksman, University of Twente, and Paul C. Duineveld, Philips Consumer Lifestyle Technology Expert Group (the Netherlands)* 83

In a multi-nozzle piezo-electrically driven print head a large number of miniature and valveless pumps are integrated. In order to have a design with the smallest native nozzle pitch possible the pumps are placed as closely as possible next to each other. This implies that the length of the pump chamber has to be long compared to its cross-sectional dimensions in order to enable the piezoelectric actuator to generate enough volume displacement. The layout of such a pump is of the waveguide type and upon actuation waves start to travel back and forth through the pump chamber. The evolution of these waves in course of time depends on the reflection properties at the beginning and the end of the pump chamber, the beginning being the connection to the main ink supply and the end being the nozzle. The attenuation depends on the viscosity of the ink used. At the end of the nozzle a meniscus is formed. In the case the meniscus retracts over a small distance into the nozzle its curvature increases and the capillary pressure increases. This effect forces the meniscus to move back to its original position. During outflow over a small distance the same happens. With increasing outflow the curvature increases and the capillary force opposing the motion increases accordingly. The capillarity builds a kind of

mechanical spring action. This spring action together with the mass of fluid in the pump forms a mass-spring system with its own oscillatory behavior. The resonance phenomenon is the so-called slosh-mode, all the fluid contained in the pump moves in phase against the surface tension spring. For higher order meniscus modes, however, the fluid motion is confined to the very close environment of the meniscus. When the print head and the pulse are designed such that an overtone of the waveguide coincides with an axisymmetric higher order oscillation of the meniscus it is possible to make droplets that are much smaller than the standard droplet metered by the nozzle diameter. When such an overtone coincides with a non-axisymmetric mode, straightness errors may be induced. The paper will discuss an enhanced theory on higher order axisymmetric and non-axisymmetric meniscus oscillations and their possible effects on droplet formation and straightness errors.

17:15 **Jetting Very High Viscosities with Piezo-Electric Drop-on-Demand Printheads for Increased Capability of Photopolymer 3D Printing,** *Nick Jackson[1], Wolfgang Voit[2], Renzo Trip[2], and Angus Condie[1]; [1]Xaar plc (UK) and [2]Xaar plc (Sweden)* 89

The inkjet industry is constantly evolving to cater to the needs of emerging and changing markets, requiring new capabilities as well as a drive to increase productivity and reduce cost. Presented is how a new high viscosity and high productivity capability using the Xaar 1003 printhead can extend the application of inkjet for 3D printing of photopolymer materials – with improved mechanical properties and scalability, enabling inkjet to compete with the performance of other photopolymer 3D printing technologies.

17:35 **Inkjet Waveform Optimization and Print Quality Analysis,** *Paul Best, ImageXpert (US)* . . A-23

Many factors affect inkjet print quality, including printhead and substrate selection, jetting conditions, ink formulation, waveform design, and more. In this presentation, we'll examine this relationship, with a special focus on waveform optimization, and how sub-optimal waveforms affect print quality. We'll also identify and outline key print quality attributes, and how these dimensions of print quality may be quantified. (Presentation-only Paper; see Appendix for extended abstract.)

COLLEAGUE CONNECTIONS; CONCURRENT EVENTS

Colleague Connections: The Future of Digital Textile Manufacturing
17:35 – 18:30
see details page xiii, Cyril Magnin Ballroom I/II

Colleague Connections: Advances in 3D Printing Technologies
17:35 – 18:30
see details page xvii, Cyril Magnin Ballroom III

EVENING EVENT

Student/Young Professionals Get Together
19:00 – 22:30
Join others for a night of fun in downtown San Francisco; meet in the lobby of the Parc 55 by hotel registration desk at 19:00.

TUESDAY 1 OCTOBER 2019

SPECIAL EVENT

CONFERENCE RECEPTION

Tuesday, 17:30 – 19:00
Cityscape Bar and Lounge
46th Floor,
Hilton San Francisco Union Square

Join colleagues for an evening of fun, networking, and 360° stunning views of San Francisco. The Hilton San Francisco Union Square is located diagonally across the street from the Parc 55.

TRACK 1

TUESDAY KEYNOTE AND TECHNICAL ACHIEVEMENT AWARDS

Application of Printed, Stretchable Electronics for Monitoring Brain Activities
Tsuyoshi Sekitani, Osaka University (Japan)
9:00 – 10:00
see details page ix; Cyril Magnin Ballroom I/II

2019 EXHIBIT OPEN

10:30 – 16:00 Cyril Magnin Foyer

Session sponsored by

RICOH

3D PRINTING II

Session Chairs: Mark Bale, DoDxAct Ltd. (UK); Katrina J. Donovan, South Dakota School of Mines and Technology (US); and Dong-Youn Shin, Pukyong National University (South Korea)
10:10 – 12:55
Cyril Magnin Ballroom I/II

10:10 **Large Scale Metal Additive Manufacturing—System Configuration, Materials, and Challenges (Focal),** *Yashwanth Kumar Bandari, Andrzej Nycz, Brian T. Gibson, Brad S. Richardson, Mark W. Noakes, Peeyush Nandwana, and Lonnie J. Love, Oak Ridge National Laboratory (US)* A-24

Large scale metal additive manufacturing is a group of additive manufacturing (AM) technologies based on metallic wire as the feedstock and heat source as either electric arc, laser, and electron beam. Each differing heat source creates its own unique AM process. However, each AM process shares a common feature, in that a continuously fed metal wire is melted by the energy source and deposited in the form of molten metal along a predetermined path. Components are fabricated one layer at a time starting from the base plate or an already existing metal component.

High deposition rates, low material and equipment costs, and good structural integrity make large scale metal AM processes a suitable candidate for replacing the current method of manufacturing from solid billets or large forgings. This is especially the case regarding low and medium complexity parts. A variety of components have been successfully manufactured with this process, including Ti–6Al–4V spars and landing gear assemblies, aluminum wing ribs, as well as steel wind tunnel models and cones. The final properties of any fabricated component are dependent on its geometry and the metal deposition path. Basic process parameters are also a factor in determining the final properties of a deposited part. This presentation explores the system configuration of different large-scale metal AM manufacturing processes including example parts fabricated on those systems, resulting material properties, and the challenges a process must overcome in order to be widely accepted for critical applications. (Presentation-only Paper; see Appendix for extended abstract.)

Exhibit Opens at 10:30
10:40 – 11:20 Coffee Break — Cyril Magnin Foyer

11:20 **Calibration, Printing, and Post-machining Issues for Large-scale Metal Additive Manufacturing Components,** *Mark Noakes, Scott Smith, Bradley Richardson, Andrzej Nycz, and Lonnie Love, Oak Ridge National Laboratory (US)* A-25

Many (or maybe most) components created using additive processes such as wire-arc additive manufacturing or laser-wire additive manufacturing still require machining operations to make them suitable for final use. Machining may be required for a variety of reasons such as: to achieve the required surface finish, to achieve the required geometry, to manage residual stresses, to remove stress-concentration features, or to create features that are difficult in additive processes (like threaded holes). From this point of view, the additively-manufactured component may be considered a preform for later machining operations. A better-quality preform is one that considers both the additive process and the subtractive process together.

The additive preform must meet several criteria including:

1. The final machined part must be contained within the preform.

2. It must be possible to fixture the part within the machining workspace.
3. It must be possible to locate the part within the workspace.
4. The part must be stiff enough to withstand the required machining process.

Both additive and subtractive processes should be considered in the creation of the preform. This presentation describes the design and manufacture of a part, considering both additive and subtractive processes. The additive process was robotic wire arc deposition, and the subtractive process was turning on a lathe. Multiple CAD models were produced for use in the process planning. They include the intended final model, the final as-printed model, and the intended printed model. The intended printed model was built up from the intended final part by considering the inherent resolution of printing (integer numbers of bead widths), the irregularities in deposition, the allowable overhang, the machining allowance, and the part stiffness. The final as-printed model was the result of an optical scanning operation, and represented the input to the machining operation. The part was then sliced in preparation for printing. This was an iterative process as slicing/printing needs were balanced against printing and machining requirements.

One of the most challenging tasks was accurately locating the part on the build plate. In this case, for the first time, the build plate was designed to be the datum for later machining operations. The build plate was simultaneously the substrate on which the preform material was deposited, the structure by which the part was fixtured in the machine and the datum by which the part was located in the machine workspace.

Robot calibration techniques have been described in the technical literature, and sub-millimeter accuracies are common. However, until now, additive processes have not required high precision positioning of the part. Now that the preform is paired with subsequent machining, the position of the preform matters, and variations in the position of the part resulting from, for example, the uncontrolled motion of the wire exiting the torch tip (millimeters) must be taken into account.

This presentation examines the issues and solutions developed to date for the large-scale metal additive wire arc system at the Oak Ridge National Laboratory Manufacturing Demonstration Facility. (Presentation-only Paper; see Appendix for author bios.)

11:40 **Fabrication of Large-scale Ti-6Al-4V Structures using 3D Printing: Sensing, Control, and Automation,** *B. T. Gibson, B. K. Post, M. C. Borish, Y. K. Bandari, A. C. Roschli, B. S. Richardson, and L. J. Love, Oak Ridge National Laboratory; and A. Thornton and W. C. Henry, GKN Aerospace (US)*

Large-scale metal additive manufacturing (AM) techniques are garnering increased attention from manufacturers due to their potential to deliver significantly reduced costs and lead times compared to conventional methods of manufacturing. In these techniques, layered components are constructed using wire or powder as feed stock in near-net shape configurations at large-scale, providing an alternative to subtractive manufacturing techniques, in which parts originate as large billets or forgings and significant amounts of scrap material are removed. Metal AM holds the potential to significantly disrupt industries. In the aerospace industry, a driving factor toward a change in production methodology is the buy-to-fly ratio, or the ratio of weight of raw material purchased to the weight of the final component that is installed on an aircraft.

This talk will highlight the development of laser-wire based Directed Energy Deposition (DED), a type of metal AM, for the specific industrial application of aerospace component production using Ti-6Al-4V. Laser-wire based DED processes are being developed at Oak Ridge National Laboratory's Manufacturing Demonstration Facility, in collaboration with GKN Aerospace, for Big Area Additive Manufacturing (BAAM) of large-scale metallic aerospace structures with the goal of significantly reducing buy-to-fly ratios. Successful process development will require simultaneous control of geometry, material properties, and residual stress and distortion. Additionally, a significant barrier to widerspread adoption of AM technologies in the aerospace industry is part certification. A 'born qualified' approach is being taken, meaning the quality of printed components will be certified through the printing process itself. This is a challenging technique to develop that requires a multi-faceted approach of predictive process modeling, real-time multi-modal sensing and control of the printing process, and post-build characterization; further, these aspects are being correlated using machine learning and other data analytics techniques. A major focus of this talk will be real-time sensing and control of the printing process using multiple sensors and algorithms to control both geometry and thermal properties. Specifics to be discussed include interlayer geometry scanning, melt pool monitoring through infrared thermography, geometric and thermal control, and a comparison of components printed with and without active control. (Presentation-only Paper; no extended abstract.)

12:00 **Design and Digital Fabrication of Magneto-dielectric Composites for Additive Manufacturing of Gradient Index RF Lenses,** *Khalid Masood[1], Tatiana Zaikova[2], Kenyon Plummer[2], Thomas Allen[3], James Stasiak[4], Paul Harmon[3], James Hutchison[2], Albrecht Jander[1], and Pallavi Dhagat[1]; [1]Oregon State University, [2]University of Oregon, [3]Voxtel, Inc., and [4]HP Inc. (US)* 94

The fabrication of composite materials having digitally designed dielectric and magnetic properties varying on a voxel-by-voxel basis offers exciting prospects for additive manufacturing of gradient index lenses for radio frequency (RF) signals. Such lenses will, in the future, be custom printed to form application-specific beam patterns in RF communications systems such as cellular telephone, Wi-Fi, radar, and internet of things (IoT). Here we present materials and methods for the digitally controlled additive manufacturing of magneto-dielectric composites with dielectric permittivity and magnetic permeability programmable on a voxelby-voxel basis.

12:20 **3D Printing of Ethylcellulose Implants by Solvent Jetting,** *Mathieu Soutrenon, Lucie Castens Vitanov, Edward Apebende, and Fritz Bircher, iPrint Institute (Switzerland).* A-26

This project goal is to print biodegradable porous bone replacement structures made of ethyl cellulose. Ethylcellulose is a derivative of cellulose that is widely use in the food and pharmaceutical industries as a thickener or coating agent. A new additive manufacturing process and a dedicated printer were developed to print those structures. The printing process is similar to binder jetting. Instead of a binder, only a solvent is jetted on the ethylcellulose powder bed. The solvent partially dissolve the material of the powder bed to bind the particles together. The printing process was optimized using solvents and powder properties. The printed parts are porous which should facilitate cell growth in the future. (Presentation-only Paper; see Appendix for extended abstract.)

12:40 **3D Printing for Glass Casting (Interactive Preview),** *Claire Haley, Susanne Klein, Tavs Jorgensen, and Ryan Brown, University of the West of England (UK)* 100

This paper reports on research that investigates methods for streamlining the workflow for the production of small cast glass objects from 3D digital files, with a particular focus on how this workflow can be applied in jewellery manufacturing. The conventional method for lost wax casting, whilst effective, is lengthy and time consuming, could 3D printing provide a quicker and more efficient alternative? We will look at print material options for production of mould patterns together with the processes involved in converting these originals into usable moulds. The research also investigates the parameters of the casting and finishing process, in order to achieve a finished piece of acceptable quality. The study enables evaluation of viable options for processing a jewellery piece from a digitally designed model to fabrication in cast glass.

12:45 **Printing the Muses: Reimaging Digital Musical Instruments through 2.5D Printing (Interactive Preview),** *Carinna Parraman and Benedict Gaster, University of the West of England (UK)* . A-27

The objective is to explore cross-disciplinary methods of converting musical terms for tactile interfaces, thus enabling people unfamiliar in creating music to be explorative through the development of novel musical interfaces. The project involves working with designers, coders, engineers, and musicians to translate musical terms for musical composition into a taxonomy that can be then converted into a physical interface or new musical instrument, e.g., zones of patterns, textured slider bars, different heights that contain different resistance. The approach tests different print technologies incorporating 3D and 2.5D printing, and a range of materials, smells, and textures. Surfaces need to quickly recognised in different conditions (e.g., humidity, darkness), and tests a range of materials for haptic and sensory comfort. (Presentation-only Paper; see Appendix for extended abstract.)

12:50 **Additive Manufacturing with Soft TPU: Thermal Properties for Printability and Adhesion Strength in Multimaterial Flexible Joints (Interactive Preview),** *Sebnem Özbek[1], Conor G. Harris[2], Willie E. Rochefort[2], and Travis W. Walker[1]; [1]South Dakota School of Mines and Technology and [2]Oregon State University (US)* A-28

Fused filament fabrication (FFF) is a type of additive manufacturing (AM), where a thermoplastic is extruded through a heated nozzle and deposited line by line on the printing bed to form a three-dimensional geometry. In this study, "line experiments" are conducted at various nozzle temperatures, where a line is printed at 100% infill to find the mass flow rate of the filaments. The results of the line experiments that were conducted with semi-crystalline thermoplastic polyurethane blends showed that the filament can be printed at lower temperatures when compared to the manufacturer suggested temperatures. Melt temperatures and crystallization temperatures were measured via differential scanning calorimetry (DSC) to prove the complicated characteristics of the TPUs. Knowing this information, other

COLLEAGUE CONNECTIONS: LATE BREAKING NEWS

Tuesday, 15:50 – 17:15: Market Street Meeting Room
Moderator: Werner Zapka, WZA Consulting (Sweden)

Bring your knowledge of the latest technological announcements to this lively session that is a perennial favorite. See the moderator prior to the session if you'd like to present on a recent installation, implementation, or other hot topic, or just come and listen to the latest from colleagues.

filaments (e.g., ABS, ASA, PLA) were analyzed in the same manner to identify direct correlations between rheological properties, thermal properties, and printing parameters. Further investigations considered the adhesion of these materials to other common plastics, finding printing techniques that resulted in strengths of adhesion that are comparable to commercial adhesives. (Presentation-only Paper; see Appendix for author bios.)

12:55 **Surface Color Optimization of Powder-based 3D Objects based on Impregnation Process (Interactive Preview),** *Chen Chen[1,2], Xiaochun Wang[2], Guangxue Chen[2], and Jiangping Yuan[2]; [1]Shenzhen YUTO Packaging Technology Co., Ltd. and [2]South China University of Technology (China)* 105

Poor surface color reproduction and incomplete color management system are the main impeding factors for the commercialization of full-color 3D printing. In this paper, the coloration mechanisms as well as characteristics of 3D surfaces were introduced, and a variety of impregnation methods suitable for powder-based 3D printing were integrated. The 24-color cards and four-primary cubes were printed by 3D Systems ProJet 860 Pro printer to compare single-plane and multi-plane optimization effects, choose the best impregnation process and put forward a guide to improve impregnants. The results revealed that the saturation of 3D printing surface color was greatly increased and the brightness was slightly decreased after impregnation process, which reduced chromatic aberration on single-plane or multi-plane. ColorBond and transparent coating spray are the most suitable combination for powder-based 3D objects. Increasing the uniformity, transparency, and permeability of coatings is beneficial to further optimize surface colors.

13:00 – 14:00 Lunch Break

3D PRINTING II (continues)

Session Chairs: Shinri Sakai, Yamagata University (Japan); James W. Stasiak, HP Inc. (US); and Michael Willis, Pivotal Resources, Ltd. (UK)

14:00 **Application of Attribute Information of Voxel-Based 3D Data Format FAV for Metamaterials Structure Design (Focal),** *Yuki Yokoyama, Naoki Hiji, and Tomonari Takahashi, Fuji Xerox Co., Ltd. (Japan)* 109

A FAV is novel voxel-based 3D data format in which the voxels can hold attribute information such as materials, colors, modeling parameters, or physical values. FAV is expected to be used for various kinds of simulations or for modifying the design of the object based on the results of measurement data from various sensors. We applied the attribute information for designing metamaterials structure for the first time. Attribute information is registered in each voxel of 3D data by specified directional penetrate projection of two-dimensional raster data or overlaying of three-dimensional raster data. Locally modified metamaterials structure is embedded into 3D data by using a 3D threshold value matrix which represents the shape of unit of metamaterial element and digital halftone screening technology. The 3D threshold value matrix is generated for any type of metamaterials based on the existence probability of voxel arrangement of the unit of metamaterial element. With the technologies, three-dimensional physical property values' distributions can be easily converted to locally modulated metamaterials structure, which can be expected various industrial use.

14:30 **Barcodes on Non-Flat Surfaces,** *Matthew Gaubatz and Robert Ulichney, HP Inc. (US)* . . . 115

Product marking systems play a key role in many existing manufacturing systems. With the rise of 3D printing applications, there is host of new opportunities to provide object tagging capabilities directly on product surfaces. Ideally, a solution could take advantage of existing infrastructure, which in many instances is adapted to use 1D barcodes. This paper explores different mechanisms for rendering barcodes directly onto object surfaces, including the benefits and challenges associated with mapping a

1D marking onto a 3D surface v. forms of pre-compensation for perspective correction such that the marking can be interpreted as flat from certain viewpoints. Objects with circular geometry are of key interest as they highlight differences between these two approaches.

14:50 **Multi Material Wire-arc Deposition using Metal Big Area Additive Manufacturing,**
Andrzej Nycz, Mark Noakes, Chris Masuo, Niyanth Sridharan, and Derek Vaughan, Oak Ridge National Laboratory (US)
Metal Big Area Additive Manufacturing is wire-arc GMAW-based Direct Energy Deposition (DED) process. Most additive process rely on one type of material for the entire part. The change of material is possible but might be time consuming and expensive or limited to a layer by layer case. This work presents a fully computer generated (CAD to path) tool path approach where single beads can be assigned different materials. The dual head robotic system can automatically apply proper material switching on bead by bead case without loss of productivity or human intervention. The work presents the overview of the concept from the toolpath generation to material properties. (Presentation-only Paper; no extended abstract.)

15:10 – 15:50 Coffee Break — *Exhibit Open* — Cyril Magnin Foyer

15:50 **Data Analysis Approach for Additive Manufacturing Print Quality,** *Koji Dan, Yasuaki Yorozu, Ryohsuke Nishi, and Takahisa Yoshigae, Ricoh Company, Ltd. (Japan)* A-29
We developed a technology that measures the geometry and dimensions of solid objects while building and feeds it back to printing process control, in order to improve the quality of solid objects that AM machines build.

As a result, the geometric accuracy and dimensional accuracy of the built solid object are improved. Accuracy was also robust against changes in build conditions and environments. (Presentation-only Paper; see Appendix for extended abstract.)

16:10 **Printed Smart Objects,** *Kent Evans and Steven Ready, Palo Alto Research Center (US)* . . . A-30
Objects with embedded electronics are becoming increasingly ubiquitous as the demand for "smart" functionalities in everyday objects grows. Additively manufacturing such items offers exciting opportunities to free electronics from the confines of a printed circuit board and integrate electronic components in to the structure of the object itself. Combining this approach with energy-harvesting features enables the smart objects to be battery free. 3D printing of electronics within shapes requires a thorough understanding of material interactions and process parameters. The results presented here describe novel hardware, process and material solutions enabling this technology. (Presentation-only Paper; see Appendix for extended abstract.)

16:30 **JIST-FIRST The Effect of Sub-surface Structure on the Color Appearance of 3D Printed Objects,**
Matt Ronnenberg and Susan Farnand, Rochester Institute of Technology (US) 120
Relatively recent advancements in 3D printing include the ability to print with multiple materials and in multiple colors. Traditional 2D printers, which print to flat media, assume that the surface geometry has a negligible effect on the appearance. The International Color Consortium (ICC) builds profiles allowing for color communication among devices, including traditional 2D printers. The ICC does not currently have practices in place to build profiles for color 3D printers due, in part, to several unknown parameters affecting the appearance of 3D printed objects. One such unknown parameter is the surface structure. To test the effect of surface structure on the color appearance of 3D printed objects, 3D models were built digitally with goniochromatic effects in mind and then printed using a color 3D printer. Spectral radiance and bidirectional reflectance distribution function measurements of the 3D printed samples were taken and correlated with the results of a psychophysical experiment to test for changes in the appearance. It was found that surface structure does have a measurable, perceptible effect on the color appearance of 3D printed objects.

16:50 **Visualization of Biomedical Products based on Paper-based Color 3D Printing,**
Jiangping Yuan, Ling Cai, Xiaochun Wang, and Guangxue Chen, South China University of Technology (China) 128
To explore the accurate physical visualization of customized biomedical parts using the paper-based color 3D printing, taking specific surgical training tools as tested samples, a visualization workflow was proposed and discussed with relative parameters. Three keynote elements of visualization workflow were analyzed by using model transformation, printing parameters controlling and entity evaluation from given digital congenital heart disease model, digital kidney model, and digital pulmonary

model. On the basis of Cutting-Bonding Framework (3D-CBF) strategy, kidney model was divided into two subblocks and layout during printing controlling phase, to develop specific principles for practical and economic physical visualization in modern surgical training applications. Since tested specimens were all captured from real pathological models accompanied with remarkable microscopic features, all these were processed with transformation adjustment to enhance practical feasibility of paper-based color 3D printer. Considering the experiencing service of surgical training parts, the physical qualities of printed biomedical parts were focused on tensile strength and surface color authenticity. According to final results of printed surgical models, the proposed paper-based 3D printing process workflow can implement vivid visualization of tested digital models, and further shared optimization suggestions for consistent physical visualization in biomedical field.

CONCURRENT EVENT

Late Breaking News
15:50 – 17:15
see details page xxvii, Market Street Meeting Room

CONFERENCE RECEPTION

Cityscape Bar and Lounge, 46th Floor, Hilton San Francisco Union Square
17:30 – 19:00
Join colleagues for an evening of fun, networking, and 360° stunning views of San Francisco. The Hilton San Francisco Union Square is located diagonally across the street from the Parc 55.

TRACK 2

TUESDAY KEYNOTE AND TECHNICAL ACHIEVEMENT AWARDS

Application of Printed, Stretchable Electronics for Monitoring Brain Activities
Tsuyoshi Sekitani, Osaka University (Japan)
9:00 – 10:00
see details page ix; Cyril Magnin Ballroom I/II

2019 EXHIBIT OPEN

10:30 – 16:00 Cyril Magnin Foyer

PRINTED ELECTRONICS

Session Chairs: Lutz Engisch, HTWK- Leipzig (Germany); Makoto Omodani, Tokai University (Japan); and Yang Yan, Purdue University (US)
10:10 – 16:10
Cyril Magnin Ballroom III

10:10 **Printed Electronics Integrated with Carbon Fiber Composites (Focal),** *Gerd Grau, Mohamad K. Idris, and Jiefeng Qiu, York University (Canada).* A-31
Carbon fiber composites are becoming increasingly important in high-performance structural applications including aerospace or automotive due to advantages such as high strength-to-weight ratio. Structural health monitoring (SHM) to determine mechanical stresses in such complex composites is a difficult task. Here, we demonstrate the integration of printed electronics with woven carbon fiber textile composites. This will enable SHM in large structures at relatively low cost and is compatible with current composites manufacturing. The electrical conductivity of carbon fibers is exploited whilst adding other functional materials by printing to create sensing devices. Resistive carbon fiber sheet strain sensing with printed interconnects is demonstrated as well as an electroluminescent carbon fiber composite for damage detection. (Presentation-only Paper; see Appendix for extended abstract.)

Exhibit Opens at 10:30
10:40 – 11:20 Coffee Break — Cyril Magnin Foyer

11:20 **Micro-reactive Inkjet Printing of Conductive PEDOT:PSS Hydrogels,** *Mei Ying Teo, Logan Stuart, Kean C. Aw, and Jonathan Stringer, University of Auckland (New Zealand)* A-32

The ability to combine the design freedom of inkjet printing with the intriguing electrical and mechanical properties of conductive polymer hydrogels would be of great utility in areas such as tissue engineering. In this work, we present the use of simultaneous in-air micro-droplet collision and patterning (termed micro-reactive inkjet printing, or MRIJP) to form both 2D and 2.5D structures of the conductive hydrogels based around PEDOT:PSS in conjunction with an ionic liquid. (Presentation-only Paper; see Appendix for extended abstract.)

11:40 **Sustainable Substrate for Printed Electronics,** *Liisa Hakola and Elina Jansson, VTT Technical Research Centre of Finland (Finland)* 132

This paper focuses on evaluation of paper as a substrate for printed flexible electronics. The motivation for using paper as a substrate comes from its attractive recycling and composting properties. In electronics manufacturing the majority of the materials used come from the substrate (>>50%). Thereby, the use of a sustainable substrate is the first step towards sustainable flexible electronics. The next step would be evaluation and development of the other materials required, such as inks and adhesives, for minimal environmental impact. This paper presents results on evaluation of existing commercial printed semiconductor and conductor ink performance on different paper substrate grades. The ultimate goal was to evaluate the potential of semiconductor and conductor materials as part of an NFC powered electrochromic display.

12:00 **Printable 2D Conductors for Wearable Electronics Applications,** *Joshua J. Moore[1], Junru Zhang[1], Aula A. Alwattar[1,2], Fiona M. Porter[1], Nazmul Karim[1], Amani Owda[1], Alex Casson[1], Peter Quayle[1], and Stephen G. Yeates[1]; [1]University of Manchester (UK) and [2]University of Basrah (Iraq)* A-33

The fabrication of wearable electronics by inkjet printing is the focus of much research attention due to its potential in health, environmental, and performance monitoring implementable using existing, large scale printing technology. The use of graphene and other 2D material formulations in this field has potential for low cost products with a short life-span. Graphene is of particular interest, as it does not introduce any recycling issues. However the electrical resistance levels are still a challenge for many applications where current metal based solutions are acceptable.

12:20 **Image Based Quality Assurance of Fabricated Nitrate Sensor,** *Qingyu Yang, Yang Yan, Kerry Maize, Xin Jin, Hongjie Jiang, Muhammad Ashraful Alam, Babak Ziaie, George T. Chiu, Ali Shakouri, and Jan P. Allebach, Purdue University (US)* 138

Ground-based nitrate sensors have great potential in agriculture to monitor soil conditions in real time. One path to scalable mass production of inexpensive potentiometric nitrate sensors is reel-to-reel slot-die deposition of ion-selection membranes on screen-printed electrodes. However, this process produces membranes with nonuniform thickness and texture that affects sensor performance. Manually monitoring sensor quality during fabrication costs many hours and human resources. So, we developed a scalable quality assurance method that establishes the relationship between sensor performance and the captured sensor images. The relationship will help us to monitor sensor performance only based on the sensor images. It will reduce the cost of measurement. To accomplish this, we apply both traditional and deep learning techniques for sensor image processing and regression. The traditional approaches are used to detect the useful regions of sensor images. Then we use Convolutional Neural Networks (CNNs) to combine images of the sensor membrane with sensor performance metrics to rapidly predict sensor quality. Successful prediction based on noncontact imaging will help to better control the fabrication process.

12:40 **Effect of Introducing Receptive Layer to Paper Substrate in Powder Electroluminescent Device (Interactive Preview),** *Naoki Takeda, Shota Tsuneyasu, and Toshifumi Satoh, Tokyo Polytechnic University (Japan)* 144

A powder electroluminescent (EL) device is a flat light-emitting device producible only via printing process. The properties of the EL device can be improved by introducing a receptive layer into the paper substrate surface, although the underlying mechanisms of this enhancement remain unknown. Herein, this mechanism was investigated in terms of dielectric loss. The tan δ of the device prepared with the receptive layer was high compared to that obtained without the receptive layer. The slopes of the current and luminance steeply increased accompanying a decrease of tan δ. Therefore, this frequency property determines the frequency properties of the EL device.

12:45 **Study on Preparation of Organometal Halide Perovskite and Electron-transporting Layer Thin Film by Ink-jet Printing (Interactive Preview),** *Yingqun Qi, Beiqing Huang, Weimin Zhang, Zejun Lv, Sunhao Guo, and Ti Wu, Beijing Institute of Graphic Communication (China)* . . . 148

In this study, we report to prepare two-dimensional perovskite organometal halide and electron-transporting layer thin films, which are the key layers of solar cell devices by ink-jet printing method. We have developed controllable and optimal inkjet printing process for the growth of perovskite organic metal halide and electron-transporting layer thin films by varying solution properties, printing process parameters (e.g. droplet diameter, voltage, droplet spacing, printing pass), as well as substrate temperature, etc. This demonstration of preparation for organometal halide perovskite and electron-transporting layer films though ink-jet printing offers scope for applying printed electronics technology to manufacture optoelectronic devices.

12:50 – 14:00 Lunch Break

PRINTED ELECTRONICS (continues)

Session Chairs: Ingo Reinhold, Xaar plc (Sweden), and Dong-Youn Shin, Pukyong National University (South Korea)

14:00 **Image-based Non-contact Conductivity Prediction for Inkjet Printed Electrodes (Focal),** *Yang Yan, Qingyu Yang, Kerry Maize, Jan P. Allebach, Ali Shakouri, and George T. Chiu, Purdue University (US)* . . . 152

Inkjet printed electrodes based on metal nanoparticle inks represent a significant component in low cost, thin film electronics. When scaled to continuous reel-to-reel processing platforms, there is an advantage in non-contact, imaging-based methods to monitor the quality of inkjet printed structures in real time. We developed a machine learning method to predict inkjet printed electrode sheet resistance based on microscope images of the device. The method can be extended to nondestructive, uninterrupted quality monitoring many reel-to-reel thin film manufacturing applications.

Strips of silver nanoparticle electrodes are systematically printed with different inkjet print parameters such as ink drop size and drop spacing. Then, a machine learning model is trained on processed microscope images of the electrodes and experimentally measured electrode sheet resistance. The resulting model can predict sheet resistance from images of the electrode with error as small as 10%.

14:30 **The Development & Fabrication of the All Inkjet Printed Electronic Devices Using Novel Functional Materials Suitable for Various Sensing Applications in the Field of Printed and Flexible Electronic,** *Sunil Kapadia[1], Marco Fritsch[2], Ayala Kabla[3], Franz Martin Fuchs[4], Emanuel Bilbao[5], Leandro Monsalve[5], Julia Fossati[6], Kalyan Yoti Mitra[7], Askold Trul[8], Elena Agina[8], Sergey Ponomarenko[8], and Reinhard R. Baumann[1,7]; [1]Technical University of Chemnitz (Germany), [2]Fraunhofer Institute for Ceramic Technologies and Systems (IKTS) (Germany), [3]PV Nano Cell Ltd. (Israel), [4]Kerafol Ceramic Films GmbH (Germany), [5]National Institute of Industrial Technology (INTI) (Argentina), [6]Fundación Gutenberg (FGB) (Argentina), [7]Fraunhofer Institute for Electronic Nano Systems ENAS (Germany), and [8]Printeltech LLC (Russia)* . . . A-35

The technological development in the electronic & fabrication industries has drawn much attention to various deposition technologies during the last decade, especially inkjet printing technology due to its simplicity, contactless printing, deposition accuracy range in µm, High scalability, less material wastage and consumption at research scale and industrial level. In this research work, we demonstrate the fabrication of the all sheet-to-sheet (S2S) inkjet printed sensor devices using novel functional materials for various sensing applications, for example, gas, pH, humidity, and temperature sensors on flexible PEN and rigid ceramic substrates. The deposition of the conductive patterns was accomplished using a nano-particle based Pt and Ag inks, Polyaniline (PANI) based conductive polymer, cross-linked Poly (4-vinylphenol) (cPVP), and various P-type organic semiconductors using lab scale printer DMP-2831 & printheads from FUJIFILM. The novelty of the research work is the formulation of the functional inks capable of jetting through 10 pL inkjet printheads and to use printed polymer based conductor and semiconductor materials to sense different environmental conditions. Additionally, functional layers were post-treated in the oven for sintering/curing purpose. The results indicate that the top polymeric layer of a device gives an instantaneous response when exposed to various climate conditions, e.g., gas sensor as shown in Figure 1, where the drain current changes with time were measured at equal intervals to estimate the drain current decay rate. The decay rate is constant during measurements under dry air atmosphere as shown in Figure 1.but immediately starts to change at different concentrations of ammonia gas exposure as illustrated in Figure 1. Based on the results, the theoretical limit of detection (LOD) was estimated to be in Parts per billion (ppb), calculated as the ammonia concentration to which the relative τc change is at least 3 times higher than the noise level. (Presentation-only Paper; see Appendix for extended abstract.)

14:50 **Double Sided Electrodes Connection Based on Printing Method,** *Kye-Si Kwon[1], Seong-jun Kim[2], Jin-Sol Lee[1], Sun Keun Park[1], Jaeryul Yu[1], and Md. Khalilur Rahman[1,3]; [1]Soonchunhyang University (South Korea); [2]Samsung Electronics Co. Ltd. (South Korea); and [3]Comilla University (Bangladesh)* A-36

Recently, glass substrate has been widely used as a substrate for display applications. To reduce the complexity of the circuit routing, effective connection methods to connect electrodes in the opposite sides of glass are required. In order to connect electrodes in both sides of glass, we will present a direct printing method based on near field electrospinning. For this purpose, we used high viscous Ag ink mixed with high molecular weight polymer to increase connectivity of deposited ink at the sharp edges. This method is based on fast continuous jet stream and can be high throughput process for industrial applications. After double sided connection printing over the edges, we achieved average resistance per length of 0.78 Ω/mm between the two-opposite side of pads/electrodes. (Presentation-only Paper; see Appendix for extended abstract.)

15:10 – 15:50 Coffee Break — *Exhibit Open* — Cyril Magnin Foyer

15:50 **Influence of Printing Parameters on Multiwall Carbon Nanotube (MWCNT) Sensors Fabrication and Performance,** *Tatiana Zubkova[1], Dhivakar Rajendran[1], Roshan Chandru[1], Jose Roberto Bautista-Quijano[1], Rajarajan Ramalingame[1], Olfa Kanoun[1], and Reinhard R. Baumann[1,2]; [1]Technische Universität Chemnitz and [2]Fraunhofer Institute for Electronic Nano Systems (Germany)* A-38

Smart wearable devices utilized in sport industry or in health care nowadays require integration of sensors for monitoring body activity. Thin, flexible, and easy adaptable to specification sensors are of great interest. Printing techniques like inkjet or screen printing are very promising for wearable electronics. To realize sensor by printing it is necessary to have functional materials in form of paste or liquid. Printable sensing materials based on carbon nanotubes found their applications in variety of sensors.

In previous work we investigated feasibility of inkjet printing for development of temperature sensor based on multiwall carbon nanotubes (MWCNTs) on polymeric foil. Functionalized MWCNTs formed stable dispersion in isopropanol and were successfully printed on top of interdigitated silver electrodes (IDEs). It was shown, that the initial resistance of fabricated sensors were tunable in a target resistance range (1kΩ to 1MΩ) by varying number of layers, geometry of IDEs and sintering parameters. Decreased resistance of printed sensors during heating up to 80°C confirmed sensor response to temperature.

In the present work, the sensor layout was optimized. The total sensing area as well as the amount of overprints of MWCNTs dispersion were decreased keeping the limits of the target resistance range. The sensor response to temperature was analyzed in relation to the amount of MWCNTs. Additionally, we investigated the sensors reproducibility. It was found that printing parameters in combination with sequence nature of inkjet printing and solvent evaporation influenced on reorganization of MWCNTs and on sensor resistance. Encapsulation of freshly produced sensor are favorable against humidity. Ultraviolet (UV) curable inks were inkjet printed on top of sensing element as an encapsulation layer, and sensor response to temperature compared with non-encapsulated sensors.

For pressure sensor screen-printing was chosen for deposition of the polymer/MWCNT composite as a piezoresistive pressure sensing element. Resolution of the screen, threads diameter and thickness of emulsion influenced on amount of transfer material as well as redistribution of MWCNTs inside composite. As a result, sensor response to pressure was varied. Further investigation has to be carried out to investigate the source of deviation. (Presentation-only Paper; see Appendix for extended abstract.)

SECURITY PRINTING

Session Chairs: Teruaki Mitsuya, Ricoh Company, Ltd. (Japan) and Steven Simske, Colorado State University (US)

16:10 – 16:55

Cyril Magnin Ballroom III

16:10 **3D Printing Technique that can Record Information Inside an Object as Rewritable,** *Piyarat Silapasuphakornwong[1], Hideyuki Torii[1], Masahiro Suzuki[2], and Kazutake Uehira[1]; [1]Kanagawa Institute of Technology and [2]Tokiwa University (Japan)* 158

This paper proposes a new 3D printing technique that can fabricate an object in which binary information can be recorded as rewritable. A fused deposition modeling (FDM) 3D printer that has two nozzles was used. An object was fabricated by one nozzle using polylactic acid (PLA) resin, and during the fabrication, domains for information recording were formed inside the object by the other

nozzle using the same PLA resin as the object but mixed with iron powder. Since the domains contain iron as magnetic material, information can be recorded by magnetizing them by applying a magnetic field from outside the object. Binary information is expressed by the direction of magnetization of each domain. Experimental results demonstrate the feasibility of this technique. Our technique can be applied in the future to add security and tracking information in the form of magnetic information. This would be valuable in custom manufacturing.

16:30 **Advances in the Decoding of Data-Bearing Halftone Images,** *Ziyi Zhao[1], Robert Ulichney[2], Matthew Gaubatz[2], Stephen Pollard[3], and Jan Allebach[1]; [1]Purdue University (US), [2]HP Inc. (US), and [3]HP Inc. (UK)* 162

Data-bearing halftone images are an aesthetically pleasing alternative to barcodes. A frequency-based method has been proposed to determine the scale, orientation, and the location of such images. However, we find that the introduction of periodic shifting of halftone dots complicates the detection of fundamental peaks in the frequency domain. In order to analyze and solve the problem, we develop solutions based on mathematical analysis and simulation. We also perform experiments to detect the peaks in the frequency domain using camera-captured halftone images. Based on this work, a potential optimal design for data-bearing halftone images will be proposed enabling the fundamental peaks to be detected more accurately. We also provide a theoretical proof that this design is optimal.

16:50 **Lightfastness of Invisible UV Fluorescent Inkjet Printing on Anticounterfeit Document (Interactive Preview),** *Juntira Komasatitaya, King Mongkut's University and Technology Thonburi (KMUTT) (Thailand)* 168

This work had an objective to study on lightfastness property of invisible UV fluorescent inkjet printing by comparison between two formulations of inkjet inks onto 2 different basis weight of plain papers using a desktop inkjet printer. The print was invisible under white light, but be visible under UVA/blacklight. The fluorescent inkjet prints were studied their lightfastness property by exposing of blacklight for 248 hrs. The tested prints were evaluated ink fading. It was found that there was effect of ink fading on the different types of the printed papers which the heavier weight paper type had better lightfastness than that of the lower weight paper type. Furthermore, plastic film lamination on the print had capability to protect the printed from fading.

CONCURRENT EVENT

Late Breaking News

15:50 – 17:15

see details page xxvii, Market Street Meeting Room

CONFERENCE RECEPTION

Cityscape Bar and Lounge, 46th Floor, Hilton San Francisco Union Square

17:30 – 19:00

Join colleagues for an evening of fun, networking, and 360° stunning views of San Francisco. The Hilton San Francisco Union Square is located diagonally across the street from the Parc 55.

TRACK 3

TUESDAY KEYNOTE AND TECHNICAL ACHIEVEMENT AWARDS

Application of Printed, Stretchable Electronics for Monitoring Brain Activities

Tsuyoshi Sekitani, Osaka University (Japan)

9:00 – 10:00

see details page ix; Cyril Magnin Ballroom I/II

2019 EXHIBIT OPEN

10:30 – 16:00 Cyril Magnin Foyer

Session sponsored by

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FUNDAMENTAL SCIENCE AND TECHNOLOGY OF INKJET II

Session Chairs: Mihir Choudhari, Rochester Institute of Technology (US); Toru Nakakubo, Canon, Inc. (Japan); and Ingo Reinhold, Xaar plc (Sweden)

10:10 – 11:40

Market Street Meeting Room

10:10 **Simulation, Visualization, and Analysis of Drop Breakup and Coalescence in Ink Jet Printing and Drop Based Fabrication (Focal),** *Brayden Wagoner, Christopher Anthony, Pritish Kamat, Vishrut Garg, Sumeet Thete, Hansol Wee, Xiao Liu, and Osman Basaran, Purdue University (US)* A-40

Motivated by applications using inkjet technology for printing/coating, printing drugs on edible substrates for personalized medicine, and 3D printing and drop-by-drop manufacturing, we analyze drop formation/breakup and coalescence, in air and on a substrate, using high-accuracy simulation, high-speed visualization, and theory. In most applications, the drop fluids are non-Newtonian and/or viscoelastic (VE) fluids, contain surface-active additives, can be suspensions containing non-Brownian particles (of diameters of the order of tens of microns), and be processed in the presence of electric fields. Therefore, accurate computation of the dynamics of such drops requires carrying out multi-physics, multi-scale simulations where in a given simulation length scales that differ by six orders of magnitude must be spanned. By contrast, commercial codes are severely limited in that they can at best span length scales that differ by 2-3 orders of magnitude. The ability to capture phenomena occurring over such disparate length scales is essential for accurate prediction of satellite droplet formation and physics of drop merging. Additional insights into the dynamics are gained by use of slender-jet theories, including new approaches for VE fluids based on the conformation tensor formalism. In many cases, the accuracy of the simulation results are reinforced by comparison to high speed visualization experiments. In certain situations, however, experiments are indispensable as simulations are hampered by the absence of a complete theoretical understanding. An important example comes from ejection from nozzles of drops of liquids containing non-Brownian particles, which will also be highlighted during the presentation. (Presentation-only Paper; see Appendix for author bios.)

Exhibit Opens at 10:30

10:40 – 11:20 Coffee Break — Cyril Magnin Foyer

11:20 **Shear-mode Piezo Inkjet Head with Two Recirculating Paths,** *Hikaru Hamano, Taishi Shimizu, Takuma Shibata, Yasuhiko Suetomi, Kazuki Hiejima, and Yusuke Kuramochi, Konica Minolta, Inc. (Japan)* 173

A "harmonica chip," a technology unique to Konica Minolta, is characterized by low heat generation, high frequency drive, and a compact multi-row structure. Based on this technology we have developed products of thin high-resolution IJ heads such as KM1024i and KM1800i.

KM1024a-RC is a new product of Konica Minolta with an ink recirculation function added to the harmonica chip. The recirculating path has been designed to exhibit sufficient recirculation performance against pigment sedimentation and drying of ink, and also enables stable jetting.

In this report, we introduce two recirculating paths structure for the excellent recirculation performance of the KM1024a-RC, and the evaluation results of recirculation performance and jetting performance.

HEALTHCARE APPLICATIONS

Session Chairs: Atsushi Tomotake, Konica Minolta Inc. (Japan) and Min Zhao, Purdue University (US)
11:40 – 12:40
Market Street Meeting Room

11:40 **Detection, Imaging, and Quantification of DNA-based Pathogen based on Inkjet-Printed Test Strips,** *Min Zhao, Runzhe Zhang, Susana Diaz-Amaya, Li-Kai Lin, Amanda J. Deering, Lia Stanciu, George T.-C. Chiu, and Jan P. Allebach, Purdue University (US)* 177

It is known that the foodborne pathogen E.coli O157:H7 from contaminated food can cause severe disease in our bodies and even death. Therefore, the detection of foodborne pathogens in our daily diet is crucial for global public health. We have previously reported an affordable, rapid, and simple method for detecting E.coli O157:H7 that uses inkjet patterning to create functionalized biosensing test strips detecting the target organism down to 10^2 CFU/ml. In this paper, we focus on optimizing the response variations of our biosensors for detecting the same concentration of the target in two aspects: the comparison of various image segmentation methods and the optimization of the number of print layers.

12:00 **Paper-based Electrochemical Sensors: How to Converge Sustainable Electrochemical Sensors with Printing Techniques (Focal),** *Fabiana Arduini[1,2], Vincenzo Mazzaracchio[1], Stegano Cinti[1], and Danila Moscone[1]; [1]Tor Vergata University and [2]SENSE4MED (Italy)* A-41

The paper-based colorimetric assays have been widely reported in literature being cost-effective, not requiring additional components (i.e. pump) for microfluidic handling of the solution, and avoiding the sample treatment thanks to the filtering property of the paper. In the last decade, the electroanalysis has discovered the utility paper as electrode-active support, converging the reported advantages of paper with the features of electroanalysis such the high sensitivity, selectivity and the capability to work in complex matrices (e.g. coloured samples).

Herein, we described the novel reagentless and sustainable paper-based electrochemical (bio)sensors, manufactured with a simple and inexpensive approach for pollutant detection in surface water. By following three easy steps, consisting of wax patterning, paper chemical modification, and electrode screen-printing, the filter paper provides an effective electroanalytical platform to sense pollutants in standard solutions and in real samples (river water). This novel and highly sustainable configuration was designed for the determination of phosphate ions with high reproducibility thanks to the use of heptamolybdate as reagent loaded on paper and carbon black as ink nanomodifier, achieving a detection limit of 4 mM. The filter paper has been also combined with the butyrylcholinesterase enzyme (BChE) for the detection of pesticides in rivers and waste waters. The principle of this approach is based on dual parallel electrochemical measurements of butyrylcholinesterase enzyme activity towards butyrylthiocholine with and without exposure to contaminated samples. The sensitivity of this device is largely improved using a carbon black/Prussian Blue nanocomposite as a working electrode modifier. A strip of a nitrocellulose membrane, that contains the substrate, is integrated with a paper-based test area that holds a screen-printed electrode and BChE, allowing a reagent-free detection of Paraoxon down to 3 µg/L.

Beside the filter paper, also the office paper, with different rheological proprieties, has been exploited as substrate to print the electrode. An office-paper based sensor has been developed for monitoring Zn(II) in biological fluids. The printed sensor modified with bismuth film has been used to detect Zn(II) by stripping analysis with a detection limit of 25 ng/mL and a relative standard deviation of 8%. To highlight the feasibility, reliability, and easiness of the proposed electrochemical sensor, Zn(II) has been detected in serum and sweat at a physiological level (µg/mL). The sensor printed on office paper has been also combined with alcohol oxidase enzyme for the detection of ethanol in beer samples. After optimizing the analytical parameters, such as pH, enzyme, concentration, and working potential, the developed biosensor allowed a facile quantification of ethanol up to 10 mM, with a detection limit equal to 0.52 mM. Recently, we have also combined the sensor fabricated using wax printing and screen-printing technologies with a printed holder made by a 3-D printing technology. This device is able to measure the BChE activity in serum with a linear range up to 12 UI/mL and a detection limit lower than 1 UI/mL. (Presentation-only Paper; see Appendix for references and author bios.)

DIGITAL PACKAGING

Session Chairs: Ron Askeland, HP Inc. (US); Lutz Engisch, HTWK- Leipzig (Germany); and Hirotoshi Terao, ALPS Electric Co., Ltd. (Japan)

12:40 – 15:10

Market Street Meeting Room

12:40 **Methods of Tracking Unique Items through High-Volume Print & Fabrication Operations,** *Mark Abramson, Printform Corporation (US)* A-42

Keeping track of hundreds or thousands of items produced in high-velocity print supply chains is difficult or impossible without robust automation and tracking systems. The author presents four discrete methods for automated tracking of individual items in production environments with complicated print, cut, and fabrication workflows. The methods are:

1) Items with barcodes or other unique codes printed directly on the product;
2) Barcoded label or barcode printed in waste "drop" that is used in conjunction with barcode scanners.
3) Traditional work order "traveler" and physical bin to contain each unique item;
4) Hybrid batch and single piece flows where labeled cases are utilized to track an item position throughout print, finish and packing steps;

The author concludes with profitability, capacity, and throughput of each method and its impact on the supply chain. (Presentation-only Paper; see Appendix for extended abstract.)

13:00 – 14:00 Lunch Break

14:00 **Smart Packaging—How Smart are the Applications (Focal),** *Lutz Engisch, Leipzig University of Applied Sciences (Germany)* A-44

The basic tasks of packaging are protection, information, and usability in the value chain. The development in the field of active and smart packaging has significantly expanded the range of tasks. The potential of such applications lies in the digitization of the processing line and in the ability to directly measure the quality of the food. The static "best before" could be replaced by active indicators. This would make it possible to easily continue to use large quantities of food, which is wasted uselessly with the current technologies. (Presentation-only Paper; see Appendix for extended abstract.)

14:30 **How the Printing Industry will Enable More Environmentally Friendly Packaging,** *Todd Fayne, PepsiCo (US)* A-45

In the coming years, CPG companies are laser-focused on making packaging more recyclable. In the case of many rigid plastics, this is straight forward and is widely done today; however, in the flexible packaging world, while packaging is theoretically recyclable, it is neither collected nor processed by the vast majority of the recycling industry. There is a tale to be told of how ink technology has advanced to enable new flexible packaging materials and structures to be economically viable for recyclability. Additionally there are many further considerations moving forward as packaging is designed to be recycled or composted as a full-circle solution to eliminating plastics waste. The inks left behind must be designed with this in mind. What are the needs of end users and consumers as packaging changes from disposable to recycled? (Presentation-only Paper; see Appendix for author bio.)

14:50 **Methods for Optimizing Ink and Coatings for Packaging,** *Mark Bale, DoDxAct Ltd. (UK)* . . 182

We present experimental methods for the systematic study of material effects in developing water-based formulations for the optimization of print quality on non-absorbing polymeric substrates. We apply these to demonstrate the importance of materials selection, with particular focus on the competition between drop coalescence control and print head latency.

15:10 – 15:50 Coffee Break — *Exhibits Open* — Cyril Magnin Foyer

LATE BREAKING NEWS

Session Chair: Werner Zapka

15:50 – 17:15

see details page xxvii, Market Street Meeting Room

CONFERENCE RECEPTION

Cityscape Bar and Lounge, 46th Floor, Hilton San Francisco Union Square

17:30 – 19:00

Join colleagues for an evening of fun, networking, and 360° stunning views of San Francisco. The Hilton San Francisco Union Square is located diagonally across the street from the Parc 55.

WEDNESDAY 2 OCTOBER 2019

TRACK 1

WEDNESDAY KEYNOTE AND IS&T SERVICE AWARDS

Fabricating Beauty: The Art and Science of Graphical 3D Printing

Philipp Urban, Fraunhofer Institute for Computer Graphics Research IGD (Germany)

9:00 – 10:00

see details page ix; Cyril Magnin Ballroom I/II

2019 EXHIBIT OPEN

11:00 – 15:00 Cyril Magnin Foyer

FRONTIERS IN IMAGING: DIGITAL PRINTING FOR FABRICATION

Session Chairs: Teruaki Mitsuya, Ricoh Company, Ltd. (Japan); Ingo Reinhold, Xaar plc (Sweden); and Scott Silence, Corning Inc. (US)

10:10 – 17:30

Cyril Magnin Ballroom I/II

10:10 **Welcome and Introduction to Frontiers in Imaging,** *Scott Silence, Corning Inc. (US)*

10:15 **3D Printed Custom Footwear for Sports and Leisure,** *Amit Marathe, HP Inc. (US)* A-46

One of the 3D printing applications in sports and leisure is custom footwear. In sports, custom footwear can be used by athletes to prevent injuries and improve performance. In leisure, custom footwear can be used to improve fit, style, and comfort.

As more and more companies target footwear personalization in this era of Industry 4.0, it is important to create a scalable and an end-to-end platform. Such a platform should satisfy the customer's individual needs as well as create a robust ecosystem for mass customization of footwear.

This footwear customization value chain starts with accurate 3D imaging of feet, creating the biometric profile and storing biomechanical data securely while protecting data privacy. Then, using AI and other processing techniques, this data can be used to manufacture highly individualized products that include custom insoles, custom sandals, custom shoes, and accurate off-the-shelf shoe recommendations to improve fit, style, and comfort. (Presentation-only Paper; see Appendix for author bio.)

10:45 **Printed and Hybrid Integrated Wearables for Health Monitoring,** *Liisa Hakola, VTT Technical Research Centre of Finland (Finland)* A-47

Comprehensive wearable monitoring solutions for multiple environmental, biological and health variables at the same time requires ultra-compact technologies that can be modified and adapted to many sensing and monitoring purposes. Wireless connection to e.g., smartphones will advance the wearable monitoring for uses in many sectors. Printing and hybrid integration on thin and flexible substrates are enabling technologies required in these type of solutions. Another important enabler is advancements in wearable substrate technologies. (Presentation-only Paper; see Appendix for extended abstract.)

Exhibit Opens at 11:00

11:15 – 11:45 Coffee Break — Cyril Magnin Foyer

11:45 **Interactive 3D-Printed Models for Students with Visual Impairments,** *Shiri Azenkot, Cornell University (US)* A-48

Blind people face many barriers in our educational system, which lead to lower employment rates and lower projected incomes. One major barrier is access to visualizations, which are abundant in instructional materials, especially in STEM. Three-D printing presents an exciting opportunity to create tactile models that represent concepts non-visually. A wealth of 3D-printable models can already be found on the Internet (e.g., on Thingiverse.com), and 3D printers are becoming more common in libraries, schools, and community maker-spaces. However, unlike diagrams or images typically found in textbooks, 3D printed models don't have auxiliary information such as titles, labels, captions, and other annotations. As such, despite their tactile nature, their instructional power is limited compared with

SPECIAL EVENT

INTERACTIVE PAPER (POSTER) SESSION / DEMONSTRATION SHOWCASE / EXHIBITS / GROUP LUNCH

Wednesday, 13:15 – 15:00

Cyril Magnin Foyer

Meet with interactive authors, exhibitors, attendees showcasing products, and other colleagues over lunch.

visualizations. In my talk, I will present Sensables, our new learning genre involving 3D models that respond to a user's touch with multimodal annotations. I will describe our design process with blind adults and teachers of the visually impaired, and discuss key technical challenges encountered and implications for the broader printing and fabrication communities. (Presentation-only Paper; see Appendix for author bio.)

12:15 **Advanced Printed Electronics Technologies for Flexible IoT Devices,** *Toshihide Kamata, National Institute of Advanced Industrial Science and Technology (AIST) (Japan)* A-49
Flexible electronics providing H-M interface device such as display, sensor, and actuator are one of the key technologies for wide distribution of IoT electronics in the society. In order to promoting these IoT technology, device manufacturing with high performance, high productivity, and customization is required. It has been recognized printing technology has high potential to contribute such a smart manufacturing. We have developed several types of advanced printing techniques for the flexible device fabrication. They showed high resolution, high alignment accuracy, high speed, low temperature, and low damage manufacturing. By using these advanced printing technologies, we have demonstrated flexible IoT device manufacturing. We also have newly developed an evaluation method of the relation between the film device micro-structure and electronic performance. In this talk, concept of device and process design for improving the device performance and the productivity of its manufacturing will be introduced. (Presentation-only Paper; see Appendix for author bio.)

12:45 **The Expanding World of Electrophoretic Displays,** *Michael D. McCreary, E Ink Corporation (US)* A-50
New electrophoretic display (EPD) platforms have been recently developed that promise future expansion of the use of EPD technology in application categories such as full color textbooks, color signage, "blackboards", erasable graffiti walls, and variable transmission films that can enable privacy and energy saving active windows, skylights, and sunroofs. (Presentation-only Paper; see Appendix for extended abstract.)

13:15 – 15:00
INTERACTIVE PAPER (POSTER) SESSION/DEMONSTRATION SHOWCASE/ EXHIBITS/GROUP LUNCH

15:00 **Autonomous Printing: The Next Evolution,** *Chunghui Kuo, Eastman Kodak Company (US)* A-53
The commercial printing industry has experienced the digital revolution in the past three decades as the television industry. Both transformations are caused by information digitization that provides technological advantages of data portability, perfect fidelity and easy accessibility over the traditional analog processes. However, contrary to the television being a consumer product where the hardware assembly process still follows the traditional mass production manufacturing process with expensive and high-precision equipment, the digital printing technology has an embedded on-demand manufacturing process with the capability to dynamically reproduce distinct images on each intended substrate. After decades of research and development effort, the digital printing community has largely accomplished the promise of on-demand printing although it is still facing technical challenges to consistently deliver high quality printed output along the spatial and temporal domain due to stochastic characteristics of the non-contact image formation process, non-uniform imaging component degradation, irregular hardware physical and chemical properties, etc. Therefore, it is essential for researchers in the field to diagnose the root cause of these problems and subsequently identify effective solutions. Taking advantage of rapid development in computational power with ever-decreasing cost, easy accessibility of big data and smarter machine learning algorithms, we can anticipate that the next evolution path may point to "Autonomous Printing", where ultimately little to no operator interference is required from receiving a customer's order to delivering to the end-user. (Presentation-only Paper; see Appendix for extended abstract.)

15:30 **IoTs: The Emerging Cybersecurity Challenge,** *Shivaun Albright, HP Inc. (US)* A-54
Security threats are increasing at alarming rates and IoT devices are a new attack vector for hackers. These devices pose a security risk not only to your network infrastructure, but also your private information, as hackers target the weakest link on the network. Learn how to reduce the security risk by developing cyber resilient devices. This presentation will cover security development best practices and identify common cybersecurity features that MUST be included in any device to reduce the risk of an attack. It will describe defense-in-depth security protections for IoT devices to help reduce exposure points on IoT's that can be used by the 'bad guys' to steal data. (Presentation-only Paper; see Appendix for author bio.)

16:00 – 16:15 Coffee Break — Cyril Magnin Foyer

16:15 **Digital Light Synthesis™ and the Manufacture of Medical Technologies,** *Steven K. Pollack, Carbon Inc. (US)* A-55
Carbon is revolutionizing production scale manufacturing using its Digital Light Synthesis™ (DLS™) approach. DLS™ is the intersection of software, hardware, and materials to produce products at scale with otherwise un-makeable geometries and high performance properties. In this presentation, we'll describe DLS™, our approach to materials development, some applications in performance and protection in the sports, and where we see our efforts going in the enhancement of health care. (Presentation-only Paper; see Appendix for author bio.)

16:45 **3D Bio Printing of Human Lung Scaffolds,** *Pedro Mendoza Bru, 3D Systems Corporation (US)* A-56
Recent advances by 3D Systems in 3D printing and by Lung Biotechnology, PBC in tissue engineering, have opened opportunities to be able to manufacture human organs in the near future by 3D printing and cellularizing scaffolds. 3D printing of lung on a chip has augmented researchers' ability to study cell viability, attachment, proliferation, migration and differentiation of endothelial and lung epithelial cells in engineered tissues. There are many challenges to overcome in order to get the first manufactured human lung. Although 3D printing a hydrogel scaffold could be the easiest of all the challenges we face for manufacturing human lungs, still an important challenge to overcome. This talk will present the recent advances made by 3D Systems and Lung Biotechnology in printing hydrogels in 3D. (Presentation-only Paper; see Appendix for author bio and additional contributors.)

17:15 **Closing Remarks,** *Scott Silence, Corning Inc. (US)*

TRACK 2

WEDNESDAY KEYNOTE AND IS&T SERVICE AWARDS

Fabricating Beauty: The Art and Science of Graphical 3D Printing
Philipp Urban, Fraunhofer Institute for Computer Graphics Research IGD (Germany)
9:00 – 10:00
see details page ix; Cyril Magnin Ballroom I/II

2019 EXHIBIT OPEN

11:00 – 15:00
Cyril Magnin Foyer

PATENTABLE ABSTRACT IDEAS: TALK AND DISCUSSION

Session Chairs: James W. Stasiak, HP Inc. (US); Michael Willis, Pivotal Resources, Ltd. (UK); and Hiroshi Yamazaki, Yamamoto Trading Co. Ltd. (Japan)
10:10 – 11:15
Cyril Magnin Ballroom III

10:10 **New Guidelines Issued by the U.S. Patent & Trademark Office on Patenting Computer-Implemented Inventions That Broaden Patent Eligibility By Restricting Abstract Idea Determinations,** *Scott M. Slomowitz and Michael J. Cornelison, Caesar Rivise, PC (US)* . . . 187
Since the U.S. Supreme Court decision of Alice Corp. v. CLS Bank in 2014, many U.S. patents and patent applications covering computer-implemented inventions (CIIs), including software inventions, have been invalidated or rejected as being directed to "abstract ideas" which are not eligible for patenting. This decision has resulted in a plethora of issued patents in all areas of computer technology being invalidated as abstract ideas by the federal courts and by the U.S. Patent & Trademark Office (PTO) while providing little or confusing guidance to Applicants on how to avoid patent ineligible abstract idea determinations. As a result, the PTO has recently issued new examination guidelines to assist Applicants in preparing patent applications to avoid such determinations. Furthermore, the U.S. Senate is currently promulgating new patent statute legislation to clarify the requirements of patentable subject matter to ensure the CIIs are not being denied the patent protection that they

deserve. This paper will discuss the new guidelines and provide take-aways for Applicants considering patent protection on their CIIs.

Scientists and engineers in advanced technology fields are frequently involved in the patenting process and are generally aware of the basic threshold standards of novelty and non-obviousness for patenting an invention. There is, however, an equally fundamental requirement that rarely arose in patenting high tech inventions, but which has now taken center stage, at least in inventions that include software. This is the requirement that the invention be directed to patent eligible-subject matter. The Patent Statute 35 U.S.C. §101 states:

Whoever invents or discovers any new and useful process, machine, manufacture, or composition of matter, or any new and useful improvement thereof, may obtain a patent therefor, subject to the conditions and requirements of this title.

While the Patent Statute states only that a patent may be obtained for "any new and useful process, machine, manufacture or composition of matter," the U.S. Supreme Court in Gottschalk v. Benson interpreted those terms such that "(1) laws of nature, (2) natural phenomena, and (3) abstract ideas" are excluded from patent eligible subject matter. The last of these three areas, the prohibition against patenting abstract ideas, which came to include mathematical formulae in Gottschalk, is the basis for the far-ranging 2014 Supreme Court ruling Alice Corp. v. CLS Bank. That ruling, overnight, effectively invalidated thousands of patents and has already been the basis for a large number of court cases and motions to invalidate previously-granted patents; and nowhere in the Alice opinion is the term "abstract idea" explicitly defined but only "hinted at" using phrases such as "the basic tools of scientific and technological work" or "tying up the future use of these building blocks of human ingenuity". Meanwhile, patent practitioners have seen rejections of applications involving software skyrocket with the "abstract idea" concept applied even to inventions that do not mention software.

10:40 **Panel Discussion on the topic,** *led by Michael Willis, Pivotal Resources, Ltd. (UK)*

Exhibit Opens at 11:00
11:15 – 11:45 Coffee Break — Cyril Magnin Foyer

JOINT PRINT4FAB / TDPF SESSION
QUALITY AND LONGEVITY TESTING FOR PHOTOGRAPHIC OUTPUT

Session Chairs: Joe LaBarca, Pixel Preservation International (US) and Nobuyuki Nakayama, Fuji Xerox Co., Ltd. (Japan)
11:45 – 12:45
Cyril Magnin Ballroom III

11:45 **Subjective Image Quality Assessment Digitally Printed Images,** *Gaurav Sheth and Susan Farnand, Rochester Institute of Technology (US)* *A-57*
Smartphones have become ingrained in our daily activities, driving their cameras to become better with every generation. As more and more images are being taken by smartphones it has become increasingly important to assess the quality of the images taken by different phones. While many smartphone images are only viewed electronically, many images also get transformed into printed images, especially photobooks, as digital printing gets better and cheaper compared to traditional printing processes. The gap between electronic image and printed image is shrinking rapidly and it becomes important to study the transition of images from screen to paper. The main goal of this research was to perform a rank order experiment for assessing how smartphone image capture quality translates to printed images via several different digital printers. It was of interest to investigate whether the overall image quality on displays correlates well with printed image quality. The important aspect was to study was to observe if there is a loss of image quality depending on different digital printers. (Presentation-only Paper; see Appendix for extended abstract.)

12:05 **Image Permanence of Photographic Prints under LED Lighting,** *Hiroshi Ishizuka[1], Evert Groen[2], Nobuhiko Uchino[1], Yoshi Shibahara[1], and Shin Soejima[1]; [1]FUJIFILM Corporation (Japan) and [2]FUJIFILM Europe B.V. (the Netherlands)* 192
LED (Light Emitting Diode) lighting has been widely used as a major light source to illuminate photographic prints. However, the effects of LED lighting on image stability of prints are not clear. Light stability tests were carried out using some commercially available white LED lamps, and the fading behaviour was compared to the standardised Xe light testing, which simulates indirect sunlight indoors. It was clarified that fading under LED lighting is less than under Xe lighting, but it correlates

well with Xe testing regarding the order of print materials in light stability. The effects of the correlated colour temperature (CCT) and the excitation wavelength of LED lamps were also studied. As a result, it has been confirmed that the dependence on the CCT is not significant, but LED lamps with shorter excitation wavelengths are more harmful to the light stability of photographic prints. Based on these results, a guideline for determining the standard test condition for LED light stability of photographic prints will be proposed.

12:25 **Endpoint Criteria for Evaluation of Image Permanence of Photographic Prints,** *Hiroshi Ishizuka[1], Evert Groen[2], Nobuhiko Uchino[1], Yoshi Shibahara[1], Shin Soejima[1], and Wil der Kinderen[2]; [1]FUJIFILM Corporation (Japan) and [2]FUJIFILM Europe B.V. (the Netherlands)* 197

Light-fading tests were conducted for the several consumer and commercial photographic prints which were available in the current market. The print life of those photographic prints was evaluated subjectively using some sets of endpoint criteria, and also assessed visually by observers. It was confirmed that the evaluation based on the colour difference produced results that correlated well with those of the visual assessment.

12:45 – 13:15: Free Time; please feel free to join the Frontiers in Imaging session

13:15 – 15:00
INTERACTIVE PAPER (POSTER) SESSION/DEMONSTRATION SHOWCASE/ EXHIBITS/GROUP LUNCH

INTERNATIONAL SYMPOSIUM ON TECHNOLOGIES FOR DIGITAL PHOTO FULFILLMENT (TDPF) 2019

MATERIALS AND TECHNOLOGIES ENABLING QUALITY PHOTO PRODUCTS

Session Chair: Joseph LaBarca, Pixel Preservation International (US)
15:00 – 16:30
Cyril Magnin Ballroom III

15:00 **How AI is Actually Supporting the Photo Products Ordering,** *Reiner Fageth, CEWE Stiftung & Co. KGaA (Germany)*

Finding the best images on the mobile phone between all the food porn and convenience photos makes the selection process even more time consuming than it was while changing from analogue to digital cameras.

In this paper we will describe how AI based evaluations such as object detection, face recognition, finding near duplicates and convenience images can be combined also with classical algorithms and heuristics to prove the user a compelling suggestion that he or she then can easily modify. The implementation is shown on mobile phones as well in desktop and online based photo ordering solutions. Also, a search function including these tasks will be presented in order to combine these features for finding relevant images or events to be placed, e.g. in a photobook for compelling story telling. The relevance of object and person detection will be proven while re-presenting (presented on Electronic Imaging 2019 in Burlingame) a manually made evaluation of images placed in CEWE photobooks but the first time brought into this AI based feature extraction context.

The paper will also address the demand for resolution enhancement for images downscaled by social apps such as Facebook or WhatsApp. Image samples will be evaluated and shown while being processed by GAN networks.

Finally we will present first attempts to combine these results with speech recognition in order to offer beside the keyboard, mouse and touchscreen another interaction possibility with digital systems while using spoken messages such as: "Present me a photobook with images from Lara and Nadine from the last holidays on Kos in Greece". The near product-based usage of this technology is the CEWE Photo diary which will be presented as the actual use case. Text spoken will be analyzed and keywords are automatically extracted and images on linked online platforms are therefore analyzed and linked to a document containing the text and the images in a nice (of course printable) layout. *Full paper available on IS&T Digital Library.*

15:30 **The Importance of Dark Keeping Factors in Determining Overall Image Permanence of Photographs—2019 Update with Pigment Inkjet,** *Patrick W. Webber, Kodak Alaris Inc. (US)*

Traditional reporting of the image permanence of photographs has tended to primarily focus on light stability. The reality of how consumers use and store prints is that the vast majority of the print life is stored in the dark. The dark stability of traditional silver halide photographic paper was primarily driven by thermal affects. However many of the newer digital material used for photographic prints are susceptible to additional dark factors including humidity, and atmospheric pollutants can result in predicted life times being significantly shorter than reported by light stability data alone. This paper will review these additional dark factors and provide comparisons to traditional silver halide photographic paper and provide an update to the 2018 paper. Additionally the paper will include the dark factor impact on pigment inkjet on porous media photographic products. *Full paper available on IS&T Digital Library.*

16:00 **Recent History of Kodak EKATCOLOR Papers—Enabling the Photo Fulfillment Industry,** *Joseph E. LaBarca, Pixel Preservation International (US)*

The past 40 years of product development in Kodak EKATCOLOR papers has been a very interesting one. Many changes to the emulsion and imaging technologies were related to image quality, image permanence, and product performance for the photographic processing labs. Several required major changes to the processing chemistry to enable product improvements. Enabling the revolution of photographic printing technology from analog to digital was also a key driver of product changes over the past 20 years, seeing EKTACOLOR papers evolve from analog capability only, to both analog and digital capabilities. While changes to the emulsion and processing technologies may not be

directly relevant to the professional finishing lab or the end consumer, their indirect benefits of production efficiencies and reduced costs are certainly beneficial. Changes to other technologies, including imaging and paper base technologies, have a direct impact. All together these improvements have enabled silver halide photographic paper in general, and EKTACOLOR papers in particular, to provide a high volume, high quality, and low cost printing solution in the digital photography age. Additionally, improvements leading to high longevity provide the end consumer with an optimal means for long term preservation of important events in their lives. This paper will review the product history of EKTACOLOR papers from 1975 to the present, and will include technology changes and the benefits they provided to both the photo fulfillment industry and end users. *Full paper available on IS&T Digital Library.*

16:30 – 16:45 Coffee Break — Cyril Magnin Foyer

STIMULATION OF PRINTING VIA INSTANT PRINT TECHNOLOGIES

Session Chair: Joseph LaBarca, Pixel Preservation International (US)

16:45 – 17:30

Cyril Magnin Ballroom III

Group Discussion: Stimulation of Printing via Instant Print Technologies

With the advent of digital photography, hardcopy output has dropped precipitously as it is no longer required to view images. A focused effort of TDPF has been to promote the value of hardcopy as a supplement to viewing images on screen. Now, with the growth of "portable pocket printers", millennials are being exposed to hardcopy output, many for the first time. This discussion will focus on ways of leveraging these new printing technologies to expand output into premium, larger format, higher quality prints, and photo books.

NOTES

APPENDIX

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- Arabic number (1, 2, 3) indicates page on which full paper is found in the e-version of the book on the usb stick. It is also the number to use for citation of the paper.
- A-followed by an arabic number indicates the page on which the extended abstract and/or author bio of a presentation-only paper is found in this book, within the Appendix section.
- * indicates abstract only; there is no extended abstract nor proceedings paper associated with the talk.
- "tdpf" indicates this is a Technologies for Digital Photo Fulfillment talk and if there is a paper associated with the talk, it will be open access at http://ist.publisher.ingentaconnect.com/content/ist/tdpf, otherwise it is just the abstract

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