Ink-Jet Microdispensing: A Tool for Fabrication and Packaging of BioMEMS Devices

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Abstract

In the last decade, ink-jet has come to be viewed as a precision microdispensing tool, in addition to its huge success in color printing. Today, this tool is being used in a wide range of applications, including electrical & optical interconnects, sensors, medical diagnostics, drug delivery, MEMS packaging, and nanostructure materials deposition. Ink-jet microdispensing is data-driven, non-contact, and is capable of precise deposition of picoliter volumes at high rates, even onto non-planar surfaces. Being data-driven, ink-jet dispensing is highly flexible and can be readily automated into manufacturing lines. This paper will illustrate a few of the applications of ink-jet technology that are either BioMEMS packaging applications, or specific Biomedical Device manufacturing applications.

1. INTRODUCTION

Micro-Electro-Mechanical Systems (MEMS) fabrication technology has been developed primarily from large volume microelectronics manufacturing technology, which relies almost exclusively on photolithographic processes. Photolithographic processes are particularly well suited for large volume, high density fabrication of devices with low process and feature diversity. The prime example is a DRAM memory device with repetition of the same features millions of times. MEMS has successfully built on the huge microelectronics equipment and technology base, adding feature diversity by using a limited number of compatible processes.

However, MEMS is a field that by definition aims to created integrated micro-devices. If MEMS is to extend beyond the boundaries of it current successes, it must integrate many diverse functions. Integration of optical functions (Micro-Optical-Electro-Mechanical Systems, MOEMS), biological functions (BioMEMS), and /or sensor functions will require a high level of process diversity, in many cases at a low density. Thus, these integrated micro-device types are creating a dilemma by driving MEMS fabrication technology away from what photolithography does best (high density) and toward what it does poorly (high diversity).

In addition, many integrated MEMS applications use materials that are simply too expensive to be used with subtractive processes, such as photolithography, where most of the material would be wasted. With the growing investment in nano-technology, it is likely that many more interesting, but expensive materials will be created in the near future. MEMS's current reliance on subtractive processes will limit the utility of these materials in MEMS applications.

A solution to this dilemma is to THINK ADDITIVE. One additive process that has been shown to be particularly well suited to MEMS device fabrication is ink-jet printing technology.

2. BACKGROUND ON INK-JET TECHNOLOGY

Ink-jet printing technology is actually not a single technology, but a group of technologies that have a common end result: the extremely repeatable formation of small fluid droplets that can be directed to a specific location with high accuracy.

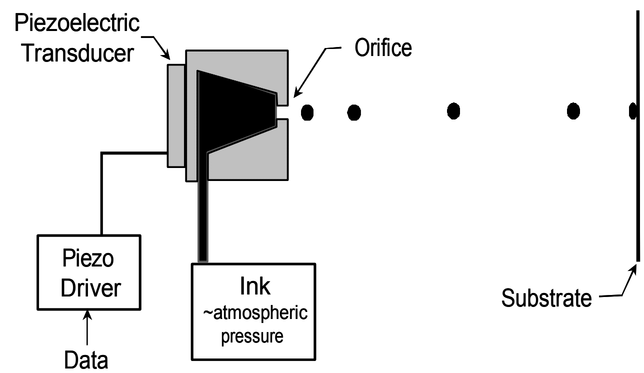

Figure 1 Schematic of a demand mode ink-jet printer.

Demand mode ink-jet technology is employed in all SOHO (small office, home office) ink-jet printers. In demand mode systems, a small transducer is used to displace the ink, creating a pressure wave (Figure 1). This pressure wave travels to the orifice [1,2] where its energy is converted to inertial energy, resulting in the ejection of a droplet. A single drop may be generated, or a group of drops at arbitrary intervals of time. Thus, the droplets are created "on demand." Demand mode droplets are usually the same diameter as the orifice diameter. Drop diameters of 15-100µm (2-500pl) can be achieved with demand mode systems, at droplet generation rates of up to 30kHz.

Figure 2 shows a demand mode ink-jet device generating 60µm diameter drops of butyl carbitol (an organic solvent) from a 50µm orifice at 4,000 per second.

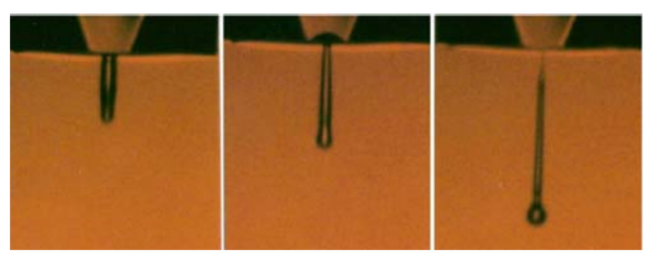

Figure 2 Demand mode ink-jet device generating 60µm drops 50µm orifice at 4kHz.

3. APPLICATIONS

3.1 DNA & Protein Deposition

Early developments in ink-jet printing of bioactive fluids [3] centered on making patterns of antibodies on membrane materials, typically nitrocellulose, that bound the antibody for use in an assay. The pattern was used as a human readable display for the assay. Over one billion diagnostic test strips ($6B value) of this type have been manufactured to date using ink-jet technology.

Miniaturizing antibody assays can increase the number of diagnostic tests conducted in parallel, increase the sensitivity of the assay, and decrease the required sample size by minimizing the amount of both the sample and expensive antibody required for the assay. The MicroSpot™ system [4] of Boehringer Mannheim could contain as many as 100 distinct reactions sites (i.e., spots) in a disposable reaction well shown in Figure 3. Figure 4 illustrates the results obtained from two different immuno-assays in the MicroSpot™ format.

Figure 3 Disposable diagnostic test that contains up to 100 tests printed using ink-jet technology

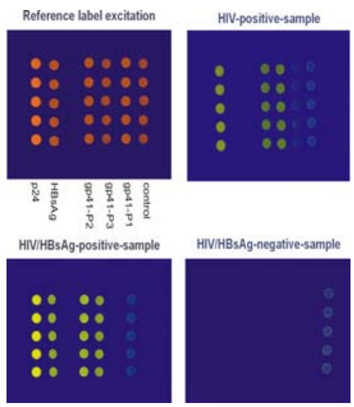

Figure 4 Immunoassay, ink-jet deposited spots ~100µm (courtesy Boehringer-Roche).

Miniaturized DNA based assays can be fabricated in the same manner as antibody based assays. Figure 5 illustrates a resequencing assay, fabricated using ink-jet deposition of oligonucleotides, for drug resistant Mycobacterium tuberculosis (Mtb).

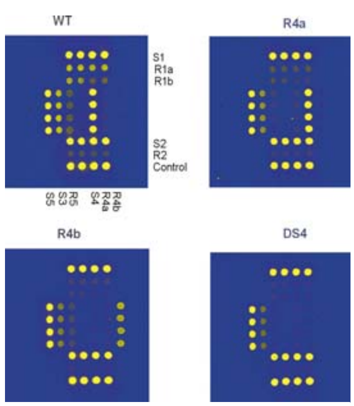

Figure 5 DNA test, drug resistant Mtb.,ink-jet deposited spots ~100µm (courtesy Boehringer-Roche).

3.2 In-Situ Synthesis

In addition to being used as a bioactive molecule deposition tool, ink-jet printing methods have been used to perform micro-chemistry, both for synthesis and decomposition. Synthesis of DNA arrays using ink-jet technology greatly decreases the reagent volumes required to create a DNA based micro-assay. For in-situ synthesis, only the precursor solutions of the four constituent bases (A, G, C, T) of DNA, plus an activator (tetrazole), are jetted. Figure 6 illustrates an ink-jet based DNA synthesis system. In addition to DNA synthesis, ink-jet methods have been used to synthesize peptides, which have the 20 naturally occurring amino acids as the building blocks.

Figure 6 Ink-jet based micro-spot DNA synthesis printer (Protogene

3.3 Biopolymers, Cells, Growth Factors, Drugs

Biopolymers are currently being printed using ink-jet methods for both tissue engineering and implantable device applications. Biosorbable polymers (PLGA) can be printed into three-dimensional structures to form scaffolds for tissue growth. Cells can be seeded into this scaffold to proliferate and create the desired tissue. Printed growth factors, possibly in complex 3-D distributions, would assist and/or direct the tissue growth. To illustrate, Figure 7 shows 1mm diameter biosorbable conduits for peripheral nerve regeneration fabricated using ink-jet methods. Nerve growth factor (NGF) is embedded in the conduit to stimulate and direct growth.

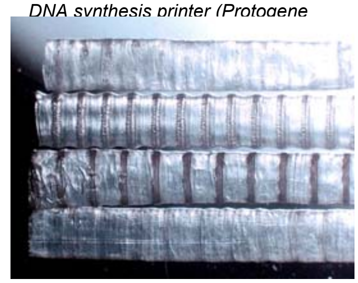

Figure 7 1mm diameter biosorbable conduits for peripheral nerve regeneration, fabricated using ink-jet printing methods. Nerve growth factor (NGF) is embedded in the conduit to stimulate direct growth.

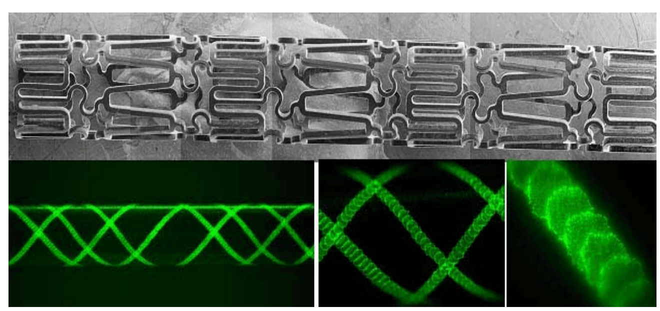

Figure 8 1.5mm coronary stent above, 100µm spots of anti-restenosis drug printed onto 1.5mm diameter polymer coated stent blank.

A recent application of high interest is coating coronary and peripheral stents with drugs and polymers using ink-jet methods.

Figure 8 illustrates a typical complex stent geometry, and the precision with which drugs can be jetted onto polymer coated surfaces.

3.4 Sensors

Chemical sensor materials can be ink-jet printed onto MEMS devices for use in clinical diagnosis, manufacturing process control, environmental monitoring, etc. A number of organizations are currently investigating MEMS cantilever and surface acoustic wave (SAW) structures coated with functionalized polymers. Fabricating the sensing mechanism and conditioning electronics in a MEMS device can lead to a low cost / high performance sensor in mass production, if a method of depositing multiple functional polymers onto the micro-scale sensing mechanisms can be found. Because these strictures are very fragile, the deposition method must be non-contact. Direct deposition onto sensing structures that are 50µm or larger has been accomplished using demand mode ink-jet technology [5]. Figure 9 shows a chemoresistor sensor array with 100µm sensor elements, used for rapid screening of functional polymers and ink-jet printing parameters. Structures 2×4µm and smaller have been functionalized by ink-jet deposition into wells that direct the polymer to the sensing structures via micro-grooves [6].

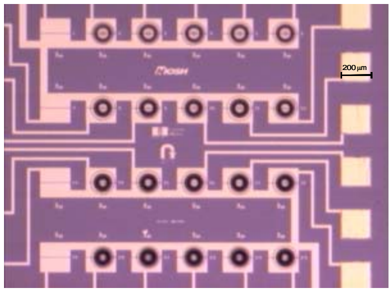

Figure 9 Chemoresistor sensor array with 100µm sensor elements, used for rapid screening of functional polymers and ink-jet printing parameters (courtesy Lee Weiss, Carnegie Mellon).

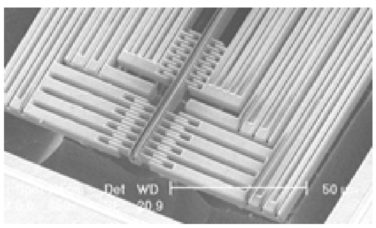

Figure 11 Submicron capacitive sensing elements that have been coated with a functional polymer by ink-jet printing into a well (not shown) and allowing the polymer to wick into the 4µm groove on the center of the sensing element (courtesy ot Gary Fedder, Carnegie Mellon).

Figure 11 shows an example of an electrostatic (capacitive) sensor structure too small to deposit a functional polymer directly onto the submicron sensing elements. Polymer has been ink-jet printed into a well, not shown in the image, so that it wicks into the 4µm groove along the center of the sensor. The polymer then wicks onto the submicron comb fingers connected to the groves that are the sensing elements.

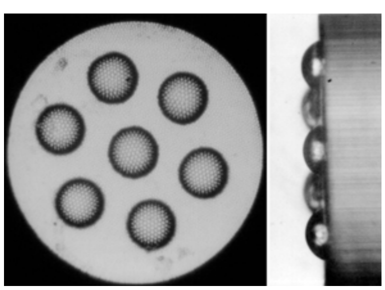

Figure 10 Array of 80µm diameter indicator elements printed on 480µm diameter fiber-optic bundle.

UV-curing optical epoxies used can be modified to be porous and doped with chemical indicators. These can then be printed as sensor array elements onto detection surfaces, such as the tips of imaging fiber bundles, providing a sensor configuration as exemplified by Figure 10.

4. CONCLUSIONS

Ink-jet printing methods have been demonstrated for a broad range of processes that are applicable to current and future MEMS applications. The additive nature of ink-jet allows for a high degree of process diversify in fabricating MEMS devices, which should allow a broad range of functionality to be included in a single MEMS device.

REFERENCES

[1] J.F. Dijksman (1984). Hydrodynamics of small tubular pumps. *Journ. Fluid Mech.* **139**, 173-191.

[2] R.L. Adams and J. Roy (1986). A one dimensional numerical model of a drop-on-demand ink jet. *J. of Appl. Mech.* **53**, 193-197.

[3] D.J. Hayes, D.B. Wallace, D. VerLee, and K. Houseman, (1989). Apparatus and process for reagent fluid dispensing and printing. *U.S. patent 4,877,745*.

[4] U. Eichenlaub, B. Berger, P. Finckh, J. Karl, H. Hornauer, G. Ehrlich-Weinreich, K. Weindel, H. Lenz, P. Sluka, and R. Ekins (1998). Microspot - A highly integrated ligand binding assay technology, *Proc., Sec. Int. Conf. on Microreaction Tech.* (New Orleans, LA), eds. W. Ehrfeld, I.H. Renard and R.S. Wegeng, The American Institute of Chemical Engineers, New York, pp. 134-138.

[5] T.E. Mlsna, S. Cemalovic and S.V. Patel (2005). Chemicapacitive Microsensors for Chemical Detection," *Proceedings of the 11th International Symposium on Olfaction and Electronic Nose – ISOEN' 2005,* Barcelona, Spain, 13-15 April, 2005, Eds. S. Marco and I. Montoliu, pp. 326-329.

[6] S. Bedair and G. Fedder (2005). Polymer Wicking To Mass Load Cantilevers for Chemical Gravimetric Sensors, Proceedings, *The 13th International Conference on Solid-State Sensors, Actuators and Microsystems*, pp. 2035-2039, June 5-9, 2005, Seoul, Korea.

Biography

Donald J. Hayes holds a BS and MS in Physics from Louisiana State University and a PhD. in Materials Science from Rice. He has over 30 years experience managing research and development of process driven manufacturing for ink-jet printers, semiconductor devices, and electronic assemblies while at MicroFab, Polaroid, Mead Office Systems, Texas Instruments, and Boeing. Dr. Hayes has been awarded 55 patents and has 3 patent applications outstanding. He is a member of the Engineering Counsel for the Eric Johnson School of Engineering at the Univ. of Texas at Dallas, a member of the Industrial Advisory Committee at the University of Arkansas and an advisor on Materials Technology Review Board, Texas State Technical Institute.

Dr. Hayes founded MicroFab Technologies, Inc. in 1984 as a research and development company focusing on applications of ink jet technology. Since then MicroFab has developed a line of Jetting Hardware and Printing Platforms. (www.microfab.com)