Printing System for MEMS Packaging

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ABSTRACT

Ink-jet printing technology is, in many ways, ideally suited for addressing a number of these MEMS device packaging challenges. The general advantages of this form of microdispensing derive from the incorporation of data-driven, non-contact processes which enable precise, picoliter-level volumes of material to be deposited with high accuracy and speed at target sites, even on non-planar surfaces. Being data-driven, microjet printing is a highly flexible and automated process which may readily be incorporated into manufacturing lines. It does not require application-specific tooling such as photomasks or screens, and, as an additive process with no chemical waste, it is environmentally friendly. In short, the advantages obtainable with incorporation of micro-jet printing technology in many fabrication applications range from increased process capability, integration and automation to reduced manufacturing costs.

Keywords: Microdispensing, ink-jet, micro-optics, MEMS, MOEMS

1. INTRODUCTION

Due to the variety of functions that need to be integrated into a single package, MEMS devices represent a major challenge to the packaging industry. A single package may contain a variety of technologies: optics, electronics, motion, chemistry, biology, etc. In some cases the package needs to be hermetic. In others, small volumes of fluid need to flow in and out of the device. Also, many MEMS packages require both optical and electrical I/O and require the fabrication of non-planar structures not readily accomplishable by photolithographic processes.

A schematic of a MEMS optical switch is shown in Figure 1. Many of the assembly and interconnect elements of this MEMS package can be created using precision microdispensing, including:

• bonding of individual optical fibers in place;
• creating the microlens array;
• chip attach with adhesive or solder;
• electrical interconnects with solder;
• deposition of getter materials;
• mechanical assembly with adhesives;
• and package sealing with solder, glass frit, or adhesives.

In this paper we will address a variety of MEMS packaging solutions based upon ink-jet printing technology, which, fundamentally, is a precision microdispensing technology. First,
the general capabilities of the ink-jet printing technology will be discussed. Next, specific hardware implementations applicable to MEMS packaging will be described. Finally, we will show results of precision microdispensing technology applied to: optical and electrical interconnects, package sealing, and other assembly processes.

2. BACKGROUND ON INK-JET PRINTING TECHNOLOGY

Ink-jet printing technology is familiar to most people in the form of desktop office printers. Actually, there is a broad range of diverse technologies that fall into the ink-jet printing category. The physics and the methods employed within this group may differ substantially, but the end effect is repeatable generation of small droplets of fluid. Only demand mode technology will be discussed in this paper, since it is the most widely applicable to MEMS manufacturing applications.

2.1 Demand Mode Ink-Jet Technologies

In a drop-on-demand ink-jet printer, the fluid is maintained at ambient pressure and a transducer is used to create a drop only when needed. The transducer creates a volumetric change in the fluid which creates pressure waves. The pressure waves travel to the orifice, are converted to fluid velocity, which results in a drop being ejected from the orifice.

The transducer in demand mode ink-jet systems can be either a structure that incorporates piezoelectric materials or a thin film resistor. In the later, a current is passed through this resistor, causing the temperature to rise rapidly. The ink in contact with it is vaporized, forming a vapor bubble over the resistor. This vapor bubble creates a volume displacement in the fluid in a similar manner as the electromechanical action of a piezoelectric transducer.

Figure 2 shows a schematic of a drop-on-demand type ink-jet system, and Figure 3 shows an image of a drop-on-demand type ink-jet device generating 60µm diameter drops of butyl carbitol (an organic solvent) from a device with a 50µm orifice at 4,000 drops per second.

Demand mode ink-jet printing systems produce droplets that are approximately equal in diameter to the orifice diameter of the droplet generator. Droplets less than 20µm are used in photographic quality printers, and drop diameters up to 120µm have been demonstrated.

2.2 Discussion

As a non-contact printing process, the volumetric accuracy of ink-jet dispensing is not affected by how the fluid wets a substrate, as is the case when positive displacement or pin transfer systems “touch off” the fluid onto the substrate during the dispensing event. In addition, the fluid source cannot be contaminated by the substrate, as is the potential during pin transfer touching. Finally, the ability to free-fly the droplets of fluid over a millimeter of more allows fluids to be dispensed into wells or other substrate features (e.g., features that are created to control wetting and spreading).

In general, piezoelectric demand mode technology can be more readily adapted to fluid microdispensing applications. Demand mode (both piezoelectric and thermal) does not require recirculation or wastage of the working fluid, as does continuous mode. It is easier to achieve small drop diameters with demand...
mode (again, both piezoelectric and thermal). It is easier to achieve lower drop velocities with piezoelectric demand mode. Piezoelectric demand mode does not create thermal stress on the fluid, which decreases the life of both the printhead and fluid. Piezoelectric demand mode does not depend on the thermal properties of the fluid to impart acoustic energy to the working fluid, adding an additional fluid property consideration to the problem.

3. PRINTING SYSTEM DESCRIPTION

3.1 Printing System Configurations
All desktop ink-jet printers have the same configuration: the printhead is translated on one axis (nominally 100 mm/s), and the paper is indexed ninety degrees to the printhead motion. For manufacturing applications of ink-jet printing technology, the substrate to be printed upon determines the machine configuration. In most cases, the substrate will be, or will be similar to a silicon wafer, a circuit board, circuit board panel, or other relatively flat, rigid substrate. In addition, manufacturing equipment using ink-jet dispensing will have setup, alignment, and control functions not generally found in desktop printers. To expand the range of materials that can be jetted, the printhead may require elevated or depressed temperature operation. Also, the substrate may need to be heated or cooled to control the pattern formed by the dispensed fluid after it has landed on the substrate. Environmental control requirements may include particle control, oxygen control, or water vapor control. Curing immediately after printing may require injection of reactive gasses or UV illumination.

Figure 4 shows a block diagram for a typical ink-jet based dispensing system. In this case, the workpiece is shown mounted onto an X-Y stage, so that the printhead assembly is stationary. A stationary printhead does not have to be designed to account for acceleration effects on the contained fluid, or the motion of service lines if a remote reservoir is utilized. Figure 5 shows MicroFab’s jetlab™ research printing platform for ink-jet dispensing application development, which is based on the system configuration of Figure 4.
3.2 High Temperature Printhead Configurations
Operation at temperatures above 150°C is usually considered infeasible for piezoelectric systems. However, MicroFab has developed the capability to operate piezoelectric demand mode ink-jet devices at up to 240°C indefinitely, at temperatures of up to 320°C for several days, and briefly at temperatures as high as 370°C.8 Both the device construction and the drive waveform utilized during operation are critical to this capability. Operation at elevated temperatures allows high viscosity polymers, solders, and other materials to be dispensed using demand mode ink-jet technology. Figure 6 shows a printhead designed for operation at up to 370°C, mounted onto a system designed for depositing onto silicon and gallium arsenide wafers. This system includes the ability to inject an inert gas around the jetting device and into the local region which is being printing on.

4. APPLICATIONS

4.1 Optical Interconnects
Ink-jet technology can be used to “write” refractive microlenses, and waveguides9 for optical interconnects. Ink-jet deposition has a key advantage over other methods in that interconnects can be fabricated directly onto optical components of arbitrary geometry.10 Refractive microlens configurations which can be printed using ink-jet processes range from convex/plano hemispherical, hemi-elliptical and square,11 to convex-convex. Arrays of thousands of microlenses have been ink-jet printed for use as free-space optical interconnects in VCSEL-based photonic switches,12 with 13,872 microlenses being printed on a single wafer. Figure 7 illustrates a section of one of these microlens arrays. The red box indicates a VCSEL / detector pair. Figure 8 illustrates an assembled smart-pixel switch containing a lens array printed using ink-jet technology.

Hemi-elliptical and square microlenses are illustrated in Figure 9 and Figure 10 where adjacent droplets are printed along one and two axes, respectively, and allowed to flow together prior to solidification and curing. The elliptical and square lens configuration could be useful in edge-emitting diode laser collimation and light-collection for detectors, respectfully.

The process for printing multi-mode waveguides is similar to that utilized for hemi-cylindrical microlenses, except that the deposited optical material must be higher in refractive index than the target substrate. Arbitrary patterns of waveguides may be printed by utilizing software which enables precise adjustment of features such as number & location of branching points, turning radii and segment lengths, as illustrated in Figure 11. Edge smoothness of the guide-substrate interface is on the order of the wavelength of the trans-
mitted light and is superior to etched waveguides. To date, waveguides have been written only with materials with unacceptably high loss, but use of low loss materials is under evaluation.

4.2 Electrical Interconnects
Solders suitable for electrical interconnects have been dispensed using piezoelectric demand mode ink-jet technology. Bumping of wafers for flip-chip assembly has been demonstrated, and both Motorola and Delphi have developed and certified bumping and assembly processes based on Solder Jet™ equipment. A sample from Delphi’s process is given in Figure 12.

Operating characteristics achieved for jetting of solders include: formation of spheres with diameters of 25-125µm; drop formation rates (on-demand) up to 1,000 per second; deposition onto pads at up to 600 per second; and operating temperatures to 320°C. The solder dispensed has been primarily eutectic tin-lead (63Sn/37Pb), but a number of other solders have been demonstrated, including high lead (95Pb/5Sn), no lead (96.5Sn/3.5Ag; indium; 52In/48Sn), and low temperature bismuth solders.

Figure 13 shows results from printing solder onto an 18x18 test coupon with 100µm diameter pads on 250µm centers. The deposited solder volume is equivalent to a drop diameter of 100µm. The resolution obtainable with ink-jet based deposition of solders is shown in Figure 14, where both bumps and towers of solder have been deposited with 25µm feature size and pitches as small as 35µm. Extension of these simple geometries into more complex shapes 3-D shapes may be possible, but will be limited by how the impacting solder drops wet the solidified drops. Figure 15 shows an example of a 3-D structure created by jetting solder.
4.4 Package Sealing and Other Assembly Processes

Adhesives for sealing and bonding can be ink-jet printed. Simple line (see Figure 16) and dot patterns can be applied. In addition, complex patterns that vary both the spatial and volume distribution of adhesive can be printed, as shown in Figure 17. The same materials can be used for spacer bumps for flat panel display assemblies. Bumps as small as 25µm in diameter and 10µm high have be created. Figure 18 shows an example of printed spacer bumps that would meet the physical and thermal (in excess of 200°C) durability requirements for flat panel displays.

In addition to jetting adhesives, 80Au/20Sn solder, or glass-frit suspended in a carrier fluid, could be dispensed in patterns as package sealants, both being subsequently reflowed. MicroFab is currently investigating jetting these two materials.

4.5 Sensors and Other Active Elements

Chemical sensor materials can be ink-jet printed onto MEMS devices for use in clinical diagnosis, manufacturing process control, environmental monitoring, etc. UV-curing optical epoxies used can 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 18.

Active optical/electronic materials printed can also ink-jet technology. Both light-emitting polymers (displays) and semiconducting polymers (low cost electronics) are currently being deposited, using ink-jet technology, by a number of organizations that are developing manufacturing methods in these areas. To construct active elements with these materials, a uniform layer of approximately 1µm must be created in a structure, and the structure must create an electric field across the polymer layer. Whether it is deposited in a spin-coating process or by ink-jet deposition, the polymer is usually suspended in low concentrations (0.5-2% by volume) in a volatile organic solvent such as xylene. After deposition, the solvent is driven off and the polymer film is left behind. MicroFab has demonstrated that feature sizes as small as...
30µm can be achieved when printing light-emitting polymer solutions onto a surface coated with hole-injection layer material. Figure 20 illustrates the spot quality and resolution that can be obtained by ink-jet printing of light-emitting polymers.

Active elements may also be biologically active, such as DNA, protein, or peptide spots. Because bioactive fluids can be fragile and expensive, they are usually not suitable for use in photolithographic or other subtractive processes. Hence, ink-jet deposition of these materials has been of interest for almost two decades.

Figure 21 shows an array of biotin labeled cytochrome C spots printed at seven concentrations. The array has been developed using a sandwich immunoassay. Visualization of the microspot sandwich immunoassay arrays was achieved by using the ELF-97. Figure 22 shows the resulting calibration curve.

Figure 23 shows the result of hybridizing a wild type M.t.b. target to an array of 100µm oligonucleotide probes spots printed on 200µm centers. A probe complementary to a drug resistant mutant strain was printed to form the letters “TB” and a probe complimentary to the wild type was printing around the letters to fill in the square array. Figure 24 shows the result hybridizing the array to the drug resistant mutant.

5.3 Surface Creation, Modification, and Activation

Materials can be printed using ink-jet technology to create or modify solid support structures to be used as attachment, synthesis, sites for bioactive and electroactive molecules; to locally control of wetting or reactivity; or to create a time release flow obstructions. Solid phase materials such as nitrocellulose (see Figure 25), methyl cellulose, sol gels, and biotinylated PLGA have been dispensed onto substrates using ink-jet technology. Chromic acid has been used to modify polypropylene and acetone to modify polystyrene (see Figure 26). Finally, cleavable linkers such as succinate, amidate have been dispensed.
SUMMARY

The capability of ink-jet printing systems to controllably dispense a wide range of materials of interest to MEMS packaging has been demonstrated. Materials dispensed include optical polymers, adhesives, solders, thermoplastics, light-emitting polymers, biologically active fluids, and precursors for chemical synthesis. In addition to the wide range of suitable materials, the inherently data-driven nature of ink-jet printing technology makes it highly suited for both prototyping and flexible manufacturing.

REFERENCES


