Opto-electronic Packaging Enabled by Direct Write Micro-printing Technology

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Abstract: With a capability of printing optical epoxy for varied microlens geometries, solders for wafer bumping and electric interconnects, and adhesives for die attach and sealing, the data-driven inkjet printing proved capable and cost effective for packaging opto-elecronic devices and components.

1. Introduction

Inkjet printing technology can reproducibly dispense spheres of fluid with diameters of 15 to 100 µm (2pl to 5nl) at rates of 0 - 25,000 per second from a single drop-on-demand (DOD) printhead. The deposition is non-contact, data-driven and can dispense a wide range of fluids. It is a key enabling technology in the development of bio-MEMS devices, displays, sensors, electrical components, and micro-optical systems. In this paper, we present the use of this technology for opto-electronic packaging, specifically printing microlenses for optical interconnects, solders for electrical interconnects, and adhesives for bonding and sealing.

2. Background of inkjet printing

Inkjet printing technology is being developed and used across a wide spectrum of optoelectronic and microelectronic manufacturing applications. A more widely used and simpler approach for smaller drop (20-100 µm), lower frequency (up to 20KHz) printing applications is DOD technology [1]. In DOD, a drop is only ejected from the device orifice when a voltage pulse is applied to a transducer. Since the fluid at ambient pressure in the device is coupled to the transducer, the acoustic waves generated by the application of an electrical pulse eject a drop from the device orifice. The DOD device produces drops that are approximately equal to the orifice diameter of the drop generator. Fig. 1 shows drops from DOD inkjet device at 2 kHz.

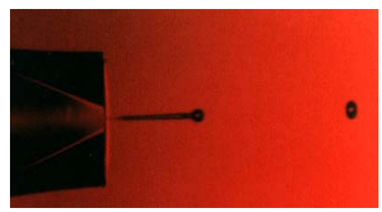

Fig. 1. Dispensing of 50 µm drops at 2 kHz.

3. Development of microlenses

UV-curing optical epoxies are a preferred class of material for microlens printing, because of their thermal and chemical durability, as compared to other optical-grade plastics, such as acrylics, photoresists, and thermoplastics. Our in-house developed MRXH-series of optical epoxy is a100%-solid formulation of prepolymers. Its viscosity can be reduced to below 40 cps at temperatures above 100°C to enable DOD printing. The dispersion curve of MRXH, along with that of other printable acrylic polymers, is given in Fig. 2. Printing the liquid prepolymer drops onto the designated locations, followed by UV-curing, forms hemispherical microlenses. The number of the drops (i.e., the volume of dispensed material) determines the lens dimension [2].

With inkjet technology, Microlens arrays have been fabricated with a diameter from50 µm to 5 mm and a lens speed (F/#) from 1 to 4. The highly uniform array has the diameter accuracy within ±1 µm and the focal-length accuracy within ±3%, as shown in Fig. 3 as an example. The printed and cured microlenses with MRXH material have passed a test at 200°C for 1

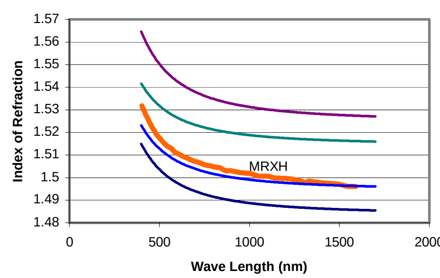

Fig. 2. Dispersion curves of refractive indices of optical polymers, including optical epoxy MRXH.

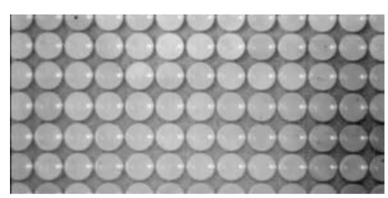

Fig. 3. Printed microlens array of 916 µm on 1 mm centers with focal lengths of 1.10±0.01 mm.

hour and have survived a 96-hour pressure pot test (120°C, 100%RH).

For efficient beam shaping and light coupling, microlens arrays have been passively or actively aligned with other components, such as VCSELs, laser diode, LED, optical fiber, etc. Fig. 4 is the integration of microlens array (250 µm diameter) with VCSEL arrays in smart pixel array technology.

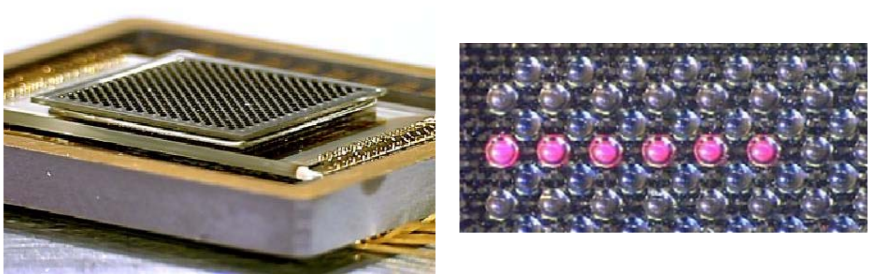

Fig. 4. Smart pixel array module (left) and printed 250 µm diameter microlens array in module with VCSELs under 6 lenslet turned on (right). (Photos courtesy of Y. Liu & A. Cox of Honeywell.)

We have also developed a wafer-level integration of micro-optics with VCSEL arrays [3]. Polymer pedestals are first formed on a VCSEL wafer through very-thick film patterning, and microlenses are then printed directly on top of the pedestals, as shown in Fig. 5. The alignment of the pedestals to the VCSELs is ensured in the photolithographic process, and the alignment of microlenses to pedestals has a self-centering nature. This micro-optical structure has been proved to have high mechanical stability. The improvement of optical performance is shown by the measured coupling efficiency from VCSELs to 50/125 multi-mode fibers. Fig. 6 shows the coupling efficiency versus axial distance between VCSEL emitting facet and fiber tip for different drop numbers in forming the microlenses. The pedestals are115 µm in diameter and 100 µm in height; the printed drop numbers are 3 to 7, corresponding to lens heights of 25, 28, 33, 36, and 38 µm. Microlenses have also been printed on the tips of single/multi mode optical fibers via glass collets to form a monolithic lensed fibers for increasing the efficiency of light coupling or collection [2].

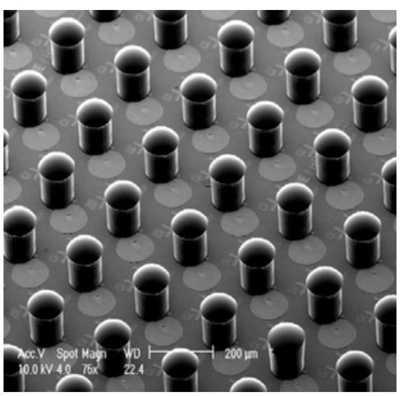

Fig. 5. Pedestal-microlens structure fabricated on VCSEL wafer.

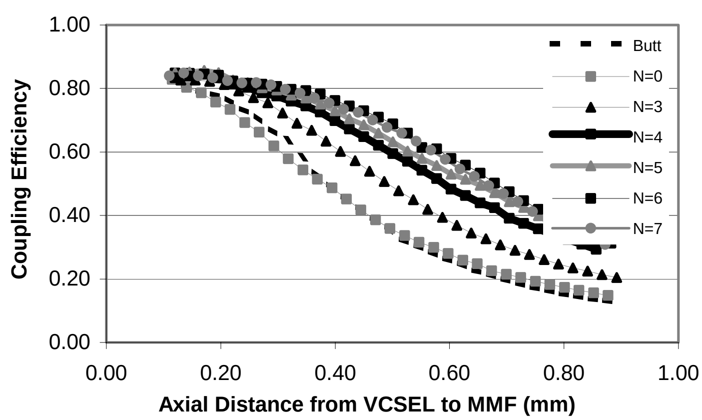

Fig. 6. Coupling efficiency from VCSEL to MMF for different epoxy drop number *N* printed on pedestals to form microlenses. Parameters are given in the text.

4. Development of electrical interconnects using SolderJet®

Deposition of small quantities of solder onto the interconnect pads of integrated circuits or chip-scale-packages is a large, rapidly growing application in electronic assembly, driven by flip-chip and other space/weight saving electronics packaging developments. Photonics assembly processes that use surface tension driven self-centering to enable alignment of optical components to <1µm are also beginning to be used. Ink-jet technology is one method to deposit solder bumps for these applications, and its use is being explored by many organizations. Demand mode solder jetting systems using both electro-dynamic and piezoelectric actuators have been developed [4]. Piezoelectric driven solder jetting developments are discussed below as exemplary of this application.

The operation of piezoelectric demand mode inkjet devices at temperatures above 200°C is one of the principle challenges in developing solder jetting technology. In addition to selecting materials, designs, and assembly processes that are compatible with these operating temperatures, unique drive waveforms have been used for piezoelectric devices at elevated temperatures.

Operating characteristics for solders dispensed using piezoelectric demand mode systems include: formation of spheres with diameters of 25-125 μm; drop formation rates (on-demand) up to 1,000 per second; deposition onto pads at up to 600 per second; and operating temperatures up 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-leads (96.5Sn/3.5Ag; indium; 52In/48Sn), and low temperature bismuth solders.

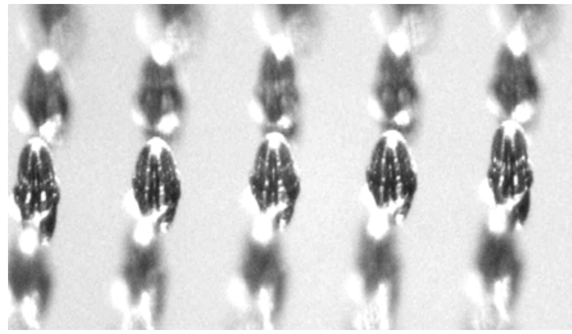

Fig. 7. 100 μm diameter solder bumps placed onto 100 μm pads on 250 μm centers at 400 per second on the MPM Solder Jet feasibility platform.

Fig. 7 shows the results of printing solder onto an 18x18 test coupon with 100 μm diameter pads on 250 μm centers. The deposited solder volume is equivalent to a drop diameter of 100 μm. Note that the bump shape shown in Fig. 7 is a consequence of rapid (<100 μs) solidification. The instantaneous droplet rate for these tests was 400 per second and the pattern was printed by rastering the substrate in the horizontal direction of the figures. An average placement error of 10 μm was achieved in these tests, which is close to the accuracy limitations imposed by the positioning and alignment systems of the platform employed. This method is continuous over the entire range of achievable volumes.

5. Adhesive dispensing

Using the same printing techniques, various adhesives have been printed onto substrates for both die attach and the bonding of optical elements using optical adhesives. Either UV or thermal curing is used after the printing. Fig. 8 shows patterns and lines printed with inkjet technology. The polymer dispensing has also been used to form uniform spacers for the packaging.

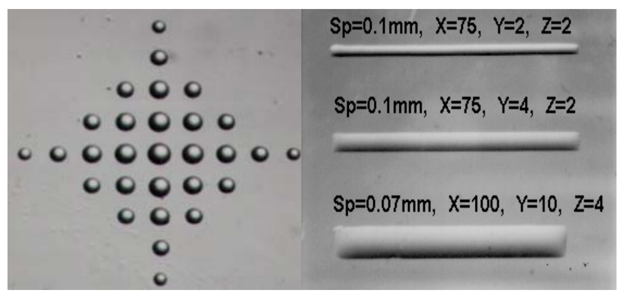

Fig. 8. Printed adhesive pattern with spot size ranging from 80 to 200 μm (left); printed thermoset epoxy lines (right).

6. Conclusions

The capability of inkjet printing technology to print optical polymers for microlenses, solder for solder bumping and adhesives for die attach and package sealing have all been demonstrated. This direct-write method provides opportunities both for significant cost reductions in existing components and for new component and device configurations.

7. References

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