Picoliter Solder Droplet Dispensing

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A device based on ink-jet printing technology was used to produce and place molten solder droplets, approximately 25-125μm in diameter, onto substrates. The advantages of an ink-jet based system are direct production of metallic objects, no post-cure, low cost, and the repeatability and resolution for small feature sizes. This paper describes the device, the supporting hardware, and experimental procedures. Results show that bump size can be varied by placing in quick succession, multiple droplets as well as by resizing the device and by altering the signal.

Introduction

The technology that was developed for forming droplets of ink in printing has been applied, over the past several years, in the dispensing of materials during the manufacture of microelectronics (see References). This work has resulted in the development of print heads that can, at elevated temperatures, deliver precise amounts of molten solder with exacting positional control.

This paper presents the results of forming bumps of solder using ink-jet printing technology. Initial applications for solder droplet dispensing include the bumping of chips for flip-chip bonding and tape-automated bonding (TAB), the bumping of substrates for TAB or fine pitch surface mounting, and the repair of solder joints. Potential applications include the formation of metal layers, reinforcement of metal joints, and the freeform fabrication of metal parts.

Description of the Droplet Generator

The device that was used to dispense the liquid solder is based on early ink-jet print heads. A schematic of this droplet generator is shown in Figure 1. The end of the 0.75 mm diameter tube is formed into an orifice of approximately 50 μm. The other end is attached to a fluid supply. Fluid at essentially ambient pressure fills the glass tube, and surface tension prevents the fluid from leaking out of the orifice. A tube-shaped piezoelectric crystal is adhesively bonded to the outer diameter of the glass. The assembly is mounted in a protective shell.

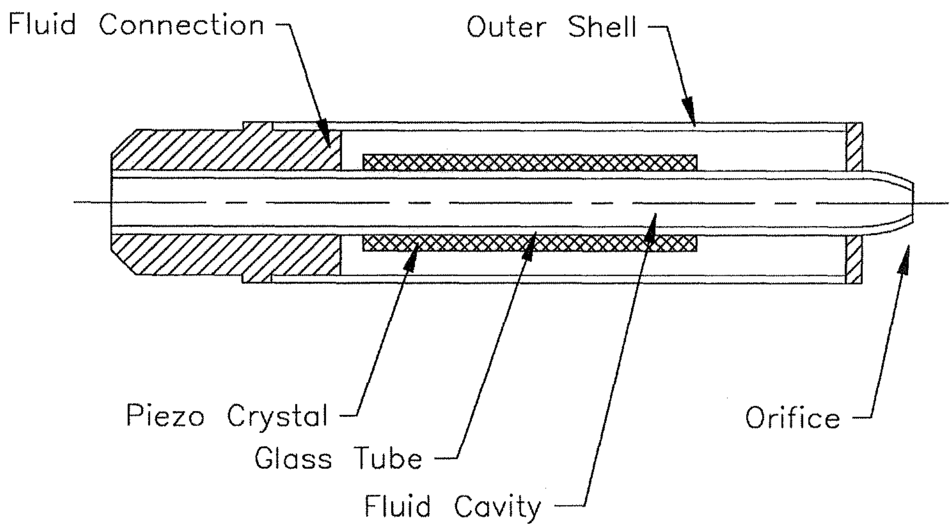

Figure 1 - Schematic of droplet generator.

When a voltage is applied to the piezoelectric crystal, the crystal squeezes the glass tube and entrained fluid. A voltage pulse causes, in the fluid, transient pressure waves which travel toward the orifice. The pressure wave ejects a small drop of fluid from the orifice. The size and velocity of the ejected droplet is determined by the shape and construction of the device, the fluid properties, and the shape and duration of the applied voltage pulse. Typical droplet volumes are ~100 picoliters and typical ejection velocities are from 1 to 5 m/s.

This design is called "drop-on-demand" because drops are formed only when a voltage pulse is applied. Other ink-jet designs use a pressurized stream to form droplets continuously. These "continuous" mode devices require hardware to deflect unwanted droplets away from the target and into a gutter for recirculation or disposal. Although the continuous type can form droplets at higher rates than the drop-on-demand type, the deflection and recirculation hardware complicates matters.

Prototype Liquid Metal Printer

The printing system used in this study is shown in Figure 2. The system was designed to provide oxide and contaminant-free molten solder at a controlled temperature to the droplet generator. The solder was melted in the upper-reservoir, where the dross/impurities could rise to the surface while the molten solder was gravity fed to the main reservoir. Teflon coating of the reservoir and the nitrogen environment prevented oxidation/degradation. The ink-jet device was also housed in a controlled heater. Patterns were formed by dispensing droplets raster style onto a copper substrate, which was mounted on an x-y stage.

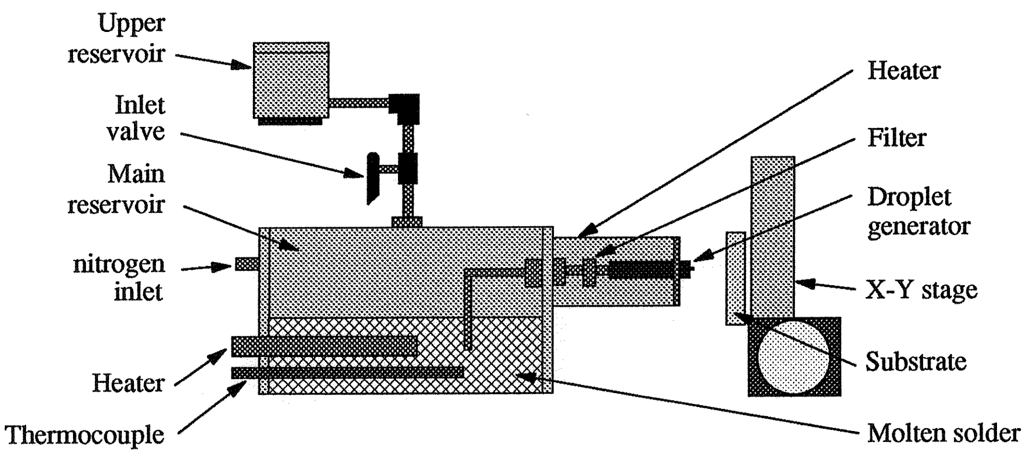

Figure 2 - Schematic of liquid metal printer.

The solder selected for this study was Indalloy-58, a low melting temperature eutectic solder. A eutectic solder composition was selected because it directly transitions from liquid to solid without an intermediate solid/liquid phase. The melting point of Indalloy-158 is 70°C, and the composition is 50 Bi, 26.7 Pb, 13.3 Sn, 10 Cd.

Test Patterns

Using a single drop per location, an array of 60 µm diameter bumps on 200 µm centers was produced and is shown in Figure 3. Multiple droplets (2-10) per location were dispensed at a rate of 500 droplets/second to produce larger bumps, up to 160 µm in diameter, on 200 µm centers (Figure 4).

At the dispensing rate used in these tests, the solder droplets dispensed onto a single site merge into one another before they solidify, forming a single, large bump. If sufficient time for cooling is allowed between consecutive droplets dispensed onto the same location, the individuality of the droplets can be maintained, and a three-dimensional structure created.

Moreover, since solidification is due to phase change, no further cure is needed.

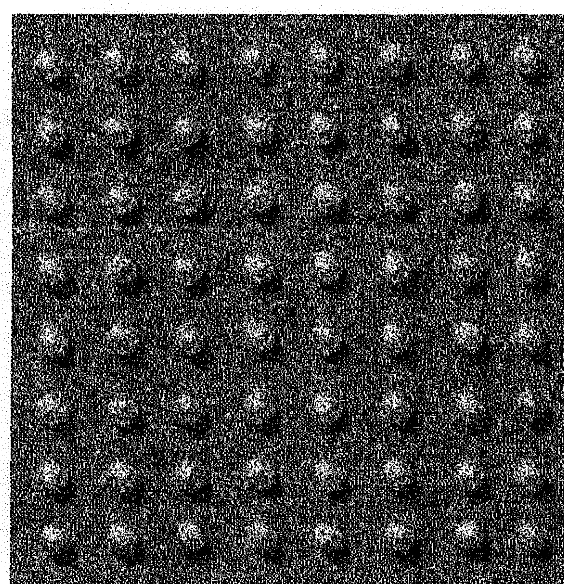

Figure 3 - 60 μm diameter bumps of Indalloy-158 deposited on 200 μm centers on copper using drop-on-demand dispensing.

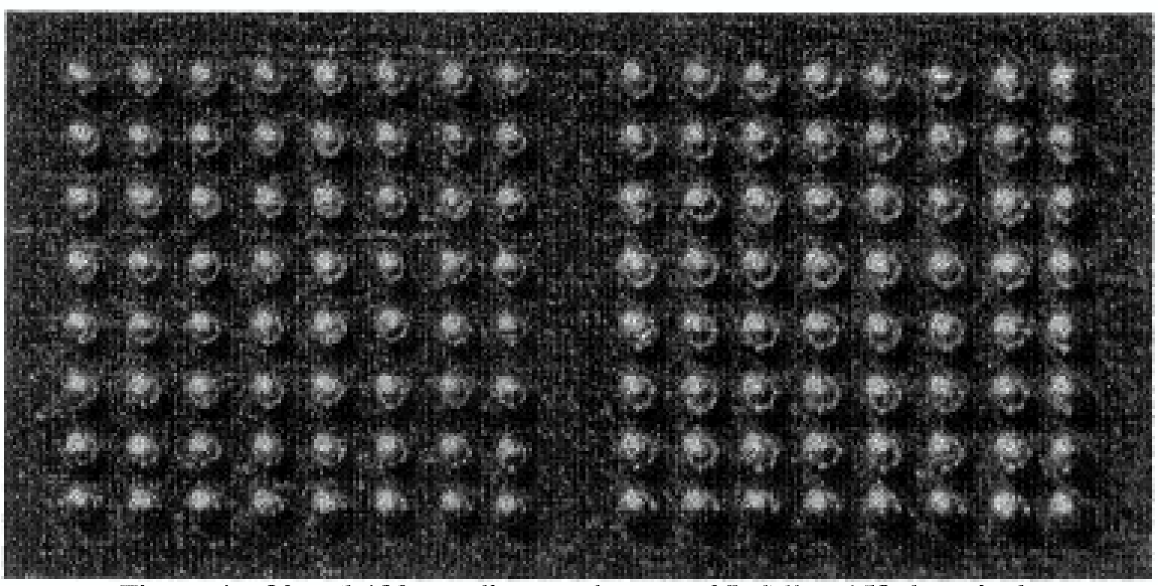

Figure 4 - 90 and 120 μm diameter bumps of Indalloy-158 deposited on 200 μm centers on copper using drop-on-demand dispensing.

The photo of Figure 5 is evidence of the flexibility, control and resolution of the solder bumps.

Conclusion

The ability to dispense molten solder droplets, as small as 60 μm in diameter, in a controlled manner, to create reproducible solder bumps has been demonstrated.

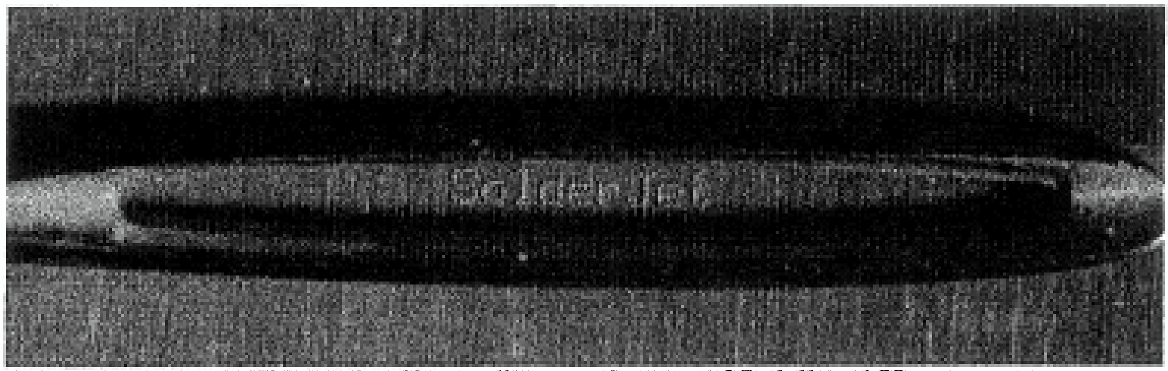

Figure 5 - 60 μm diameter bumps of Indalloy-158.

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