Low-Cost Display Assembly and Interconnect Using Ink-Jet Printing Technology

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Abstract

Ink-jet printing methods may be utilized for efficient micro-deposition of solder bumps, spacer balls and adhesive sealant/bond lines in the manufacture of display panels. Advantages realized by this approach include data-driven, low-cost, high-speed, non-contact and environmentally friendly processing.

Introduction

Manufacturing technologies are being driven toward further automation, miniaturization, and reductions in costs, cycle times & environmental impact, so ink-jet printing methods are becoming increasingly attractive material micro-dispensing alternatives in a wide variety of applications. Advantages offered by the ink-jet printing method include low-cost, precise control of dispensed volumes, data-driven, *in-situ*, processing, and environmental friendliness. As a non-contact deposition method, this technology may also be employed to print on non-planar and curved surfaces.

Two differing approaches are utilized for piezoelectric (verses thermal) micro-jet printing of materials for manufacturing applications. In “Continuous, Charge & Deflect” ink-jet printing technology [1], a stream of fluid ejected from the orifice of a pressurized fluid chamber is broken up into droplets by the application of pulses to a transducer bonded to the chamber. The droplets are electrostatically charged and deflected, as needed to hit or bypass a moving target substrate. This method offers advantages when high speed coverages of relatively large areas are required, since droplets up to 0.5 mm in diameter may be produced at rates up to 1 MHz. A more widely utilized approach for smaller droplet (20-100 µm), lower frequency (to 10 KHz) dispensing applications is the “Drop-on-Demand” (DOD) technology [2]. In this type of ink-jet printing system, a droplet is only ejected from the device orifice when a voltage pulse is applied to a transducer coupled to the fluid at ambient pressure. The inherent temporal and spatial stability of the DOD micro-drop formation process is clearly illustrated in the one-second exposure of Figure 1**,** where the stroboscopically illuminated image of an ejected droplet is actually the superposition of 2000 droplets.

Materials dispensed by DOD ink-jet printing processes have included: (a) solder for placing bumps for flip-chip and ball-grid-array [3-5] and towers (vias) for chip-scale packages [6]; (b) epoxy for micro-optics fabrication [7]; (c) adhesive patterns for component bond-line patterns [8]; (d) dielectrics for component over coating and conformal capacitor fabrication; and (e) a variety of filled polymer systems for the printing of components such as resistors, micro-optical detector elements and organic polymer light emitting diodes (OPLED) [9,10].

Objectives

The overall objective of this work is to develop ink-jet/micro-jet processes and platforms for use in fabrication of displays, both active elements (or-

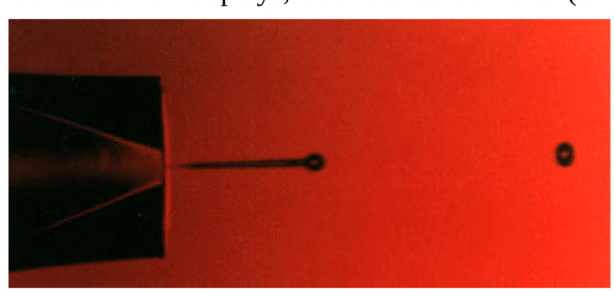

Figure 1. Generation of 50 µm droplets by DOD microjet at 2 kHz.

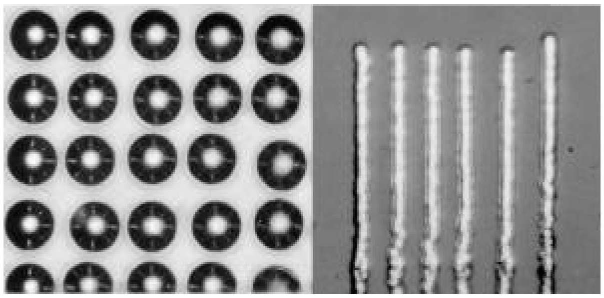

Figure 2. Printed array of 24 µm diameter solder bumps (left) and 25 µm wide, 400 µm high solder towers (right).

ganic light emitting polymers and phosphors) and passive elements (spacers, sealants and electrical interconnects). This paper will focus on passive element printing, including solder bumps for IC driver electrical connection, polymer spacers, and adhesive bond/sealant lines.

For solder bump printing, the technical development objectives are now focused on increasing speed and placement accuracy. In addition to speed and accuracy objectives, spacer bump and adhesive bond/seal line printing involve also the challenges of optimizing the fluid formulations for meeting the applications requirements, while keeping within the rheological constraints imposed by the DOD micro-jetting process. For example, printed and cured polymer spacer bumps in LCD displays must exhibit height uniformity to better than a micron, along with high levels of compressive strength and thermal stability. Likewise, printed and cured polymer sealant lines must be highly adherent to the bond surfaces and thermally stable against out-gassing or leaking at elevated processing temperatures.

Results

<u>Solder Bumping</u>

Of the three micro-jet printing applications for panel display manufacturing addressed here, only the "Solder-Jet" technology has advanced to the point of commercialization. Tin/Lead (63/37) solders have been printed at 220EC in both the continuous and drop-on-demand mode, and as both step-and-repeat and fire-on-the-fly processes. The size and shape of a printed solder bump depends on the number and diameter of droplets deposited at the target site and on the temperature of the substrate. For Sn/Pb solder, no flux is needed to achieve good adhesion to gold or clean copper substrates, and

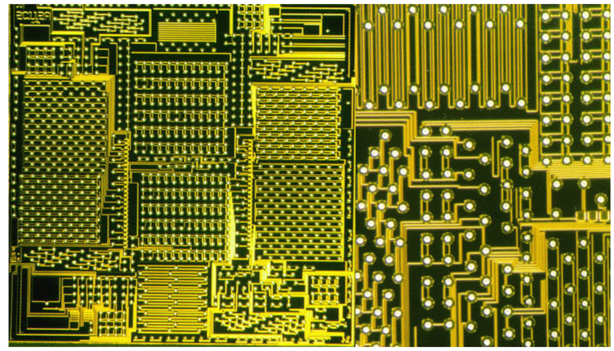

Figure 3. Portions of microprocessor test vehicle with 1,440 printed with 60 µm solder droplets at 100% yield.

adhesion to aluminum has been demonstrated with a doped Sn/Pb formulation. Indium-based solders have also been used for printing patterns of bumps directly onto ITO substrates.

In the DOD mode of solder-jetting, the diameter of a droplet formed by a device of a given orifice size may be modulated over a two-fold range by adjusting the device-driving waveform. By reducing the print head device orifice size, solder bumps as small as 24µm have been printed, and 3D towers-vias fabricated, as shown in Figure 2, with a step-and-repeat printing process. The use of this process in microelectronics manufacturing is illustrated in the photographs of Figure 3, where 1,440 microprocessor test vehicle pads were bumped at 100% yield utilizing the step-and-repeat solder printing platform shown in Figure 4.

In the fire-on-the-fly process, the substrate stages raster back and forth in the two horizontal-plane

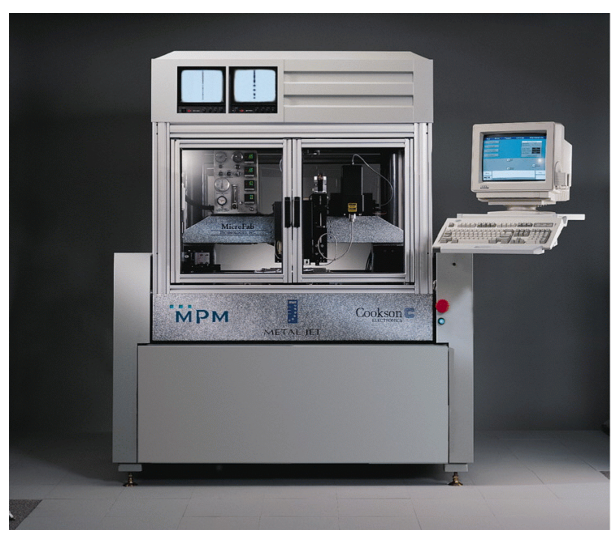

Figure 4. MPM demand-mode solder printing (Metal-Jet®) demonstration platform.

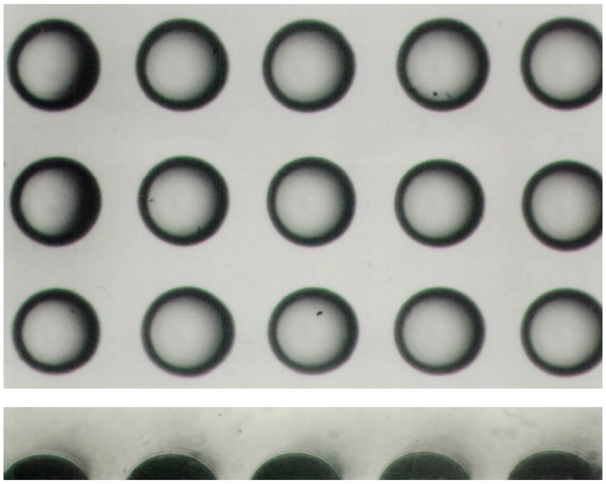

Figure 5. *Array of 95 µm diameter, 34 µm high, printed microlenses (spacer bumps), in substrate plane (top) and in profile (bottom).*

directions without stopping, while the print head ejects droplets continuously, but in the drop-on-demand mode. Data on target pad locations is entered via a CAD file, and the machine vision system automatically registers the file with substrate fiducials. With the fire-on-the-fly solder jetting platform currently in manufacture by MPM/Speedline and based on MicroFab's print head, wafer and chip pad bumping speeds in excess of 400 bumps per second have been demonstrated.

<u>Polymer Spacer Printing</u>

The high-temperature DOD dispensing process for printing UV-curing polymer elements for applications such as display spacers is very similar to that for solder bumping, so the same platform, with multiple print heads for different materials, may be used for both steps. UV-curing optical epoxies which are currently being used for printing microlens arrays, such as that pictured in Figure 5, would meet the physical and thermal (in excess of 200EC) durability requirements for panel display spacers. Arrays of hemispherical microlenses as small as 40µm in diameter have been printed in our laboratory, which is within the size range currently usable for display manufacture. We believe that the printing of 25µm diameter, 10µm high polymer spacer bumps is possible with this technology. In addition, the printing of microlens arrays could be directly utilized to advantage in the manufacture of projection displays and of some backlighting configurations in panel displays.

For spacer printing, the key parameter to control is the height of the deposited droplets, which is deter mined by droplet volume and the degree of spread ing which occurs on the substrate prior to solidification and curing. The DOD printing process produces droplets of diameter close to that of the print head orifice and provides volumetric control over dispensed droplets to better than 2%. The spreading of deposited material may also be precisely controlled by the use of low-wetting coatings on the target substrates to provide specific contact angles and, additionally, by varying substrate temperature to adjust fluid viscosity prior to solidification. Adjustment of spacer bump height may also be achieved by utilizing *in-situ* UV-flash between depositions to increase bump aspect ratio, as illustrated by the photo of Figure 6.

<u>Sealant/Bond Line Printing</u>

The printing of adhesives for sealing and bonding of LCD cells could be accomplished quite efficiently by the ink-jet printing method. For materials requiring dispensing at temperatures less than 140EC, either single-jet or array-type print heads may be used, depending on throughput requirements. In all cases the line patterns would be printed from data files and aligned to substrate fiducials. The width and height of the cross section of each printed line is determined by the specified spacings of the deposition sites and number of droplets deposited per site, as seen in Figure 7.

Conclusions

We have developed the basic technologies of ink-jet printing of metals and polymers for potential use in flat panel display manufacturing, via automated deposition of solder and spacer bumps, LCD cell sealant/bond lines, and microlenses. High speed production printing stations are currently available for solder bumping, and could readily be modified for polymer printing. The industrial impact of the

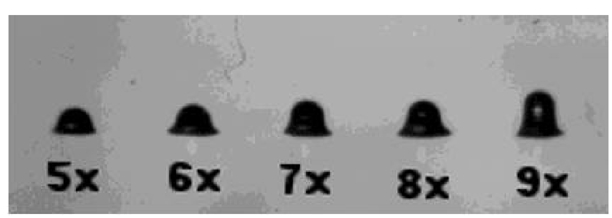

Figure 6. *Increasing printed epoxy spacer-bump / microlens height by UV-flash after each of the indicated total number of 50µm droplets.*

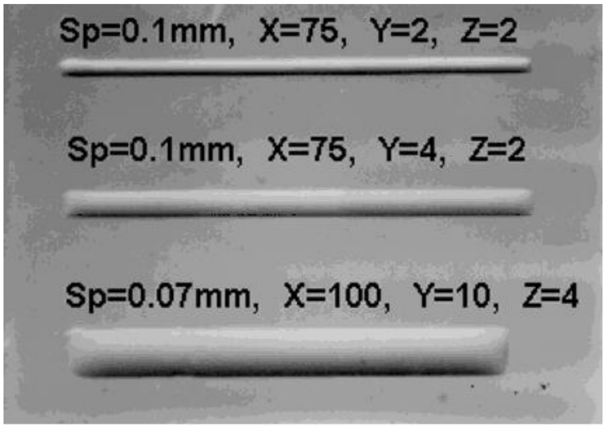

Figure 7. *Printed bond lines (top is 300µm wide) made by deposition at 125EC of 60µm droplets of thermoset epoxy, where site spacings (Sp), number of sites in horizontal (X) & vertical (Y) directions in substrate plane and number of droplets per site (Z) are as indicated.*

use of ink-jet printing technology in the assembly and electrical interconnect of displays could be substantial. Advantages would accrue in the areas of: (a) reduction in cost and increase in the flexibility of manufacturing, due to the data-driven and additive-material-application aspects of the technology; (b) enhancement of process integration: and (c) reduction in environmental impact.

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