Solid-State Sensor and Actuator Workshop '98, Hilton Head Island (1998).

DEVELOPMENT OF AN INNOVATIVE FLIP-CHIP BONDING TECHNIQUE USING MICROMACHINED CONDUCTIVE POLYMER BUMPS

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ABSTRACT

Using micromachining techniques with thick photoresists, an innovative conductive polymer flip-chip bonding technique that achieves both a low processing temperature and a high bumping alignment resolution has been developed and characterized in this work. By the use of UV-based photolithography with thick photoresists, molds for the flip-chip bumps have been patterned, filled with conductive polymers, and then removed, leaving molded conductive polymer bumps. After flip-chip bonding with the bumps, the contact resistances measured for 25 µm-high bumps with 300 µm x 300 µm area and 400 µm x 400 µm area were 35 mΩ and 12 mΩ, respectively. The conductive polymer flip-chip bonding technique developed in this work shows a very low contact resistance, simple processing steps, a high bumping alignment resolution (± 1 µm), and a lower bonding temperature (~170 ^{o}C). This new bonding technique has high potential to replace conventional flip-chip bonding technique for sensor and actuator systems, optical MEMS, OE-MCMs, and electronic system applications.

INTRODUCTION

In recent years, the use of flip-chip bonding technology has grown in many packaging schemes. This is due to the advantages of improved reliability, lower costs, and higher I/O density in less packaging space. Flip-chip bonding is preferred for the mounting or inverting of photonic devices, where input/output coupling is required for optical waveguides or optic fibers, as shown in Figure 1 [1, 2]. In developing flip-chip bonding technique for sensor and actuator systems, optical MEMS, or optical interconnections, most difficult problems usually come from precision bumping alignment and bonding temperature. The conventional solder bump technology provides a quite good bumping alignment, but it has several drawbacks from its high soldering temperature and several depositions of metal layers.

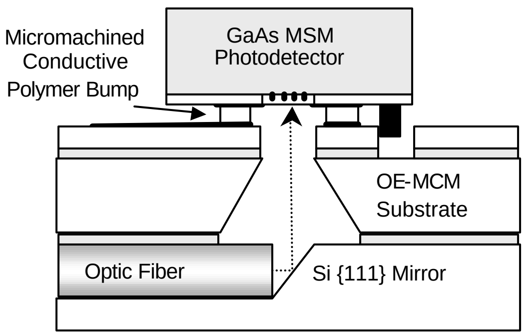

Figure 1. *Schematic diagram of an optical I/O coupler by the use of flip-chip bonding technique using micromachined conductive polymer bumps.*

Nowadays, it is possible to buy conductive polymers tailored for specific electronic packaging applications from commercial suppliers [**3**]. These conductive polymers are most often made using a silver flake fill in a polymer matrix. Since conductive polymer requires a low bonding temperature as well as fairly simple processing steps, the conventional solder bonding technique is being challenged by conductive polymer flip-chip bonding technique [**3**]. However, currently available screen printing techniques for the conductive polymer bumps have quite a crude bumping alignment resolution because the printer offers registration accuracies of ±10 µm.

This paper describes a new approach to address the problems which can be caused by the solder bonding technique and the screen printing-based polymer bonding technique, such as high bonding temperature and poor bumping alignment. Using micromachining techniques with thick photoresists, an innovative conductive polymer flip-chip bonding technique that achieves both a low processing temperature and a high bumping alignment resolution has been developed and characterized in this work.

TEST ASSEMBLY DESIGN

A conductive polymer bump sandwiched between the flip-chip and substrate has a certain amount of so-called contact resistance. This contact resistance is obviously an important parameter that impacts the behavior of devices, if flip-chip bonding is involved in their packaging. Quantitative determination of the contact resistance in ohms can be evaluated by using a four-terminal method.

Figure 2 shows test structures to characterize the electrical properties of the micromachined conductive polymer bumps. The first mask is used to define contact pad lines and terminal electrode pads for passing a current and reading a voltage drop through a

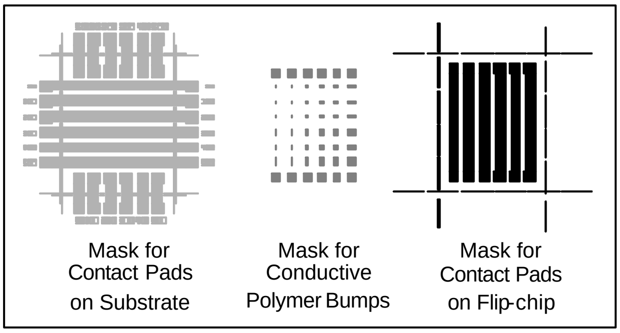

Figure 2. *Three-mask set of test structures to evaluate the electrical properties of the thermoplastic conductive polymer bumps by using a four-point terminal method.*

Solid-State Sensor and Actuator Workshop '98, Hilton Head Island (1998).

conductive bump sandwiched between the flip-chip wafer and the substrate. To align with a diced flip-chip, a set of guidelines is included in the mask. The second mask contains the rectangular patterns with various sizes for thick photoresist bump-holes on the flip-chip wafer. The third mask is designed to define contact pad lines for bumps on the flip-chip wafer and guidelines for the dicing saw.

FABRICATION

Figure 3 summarizes fabrication steps of the micromachined bumps by employing thick photoresist bump-holes as molding patterns. Initially Cr/Au contact metal pad lines and pads for the conductive polymer bumps were formed by lift-off on silicon dioxide layer, which servers as insulation layer [Figure 3(a)]. Thick photoresist was patterned for bump-holes. High aspect ratio and straight side-wall patterns are very important because they are

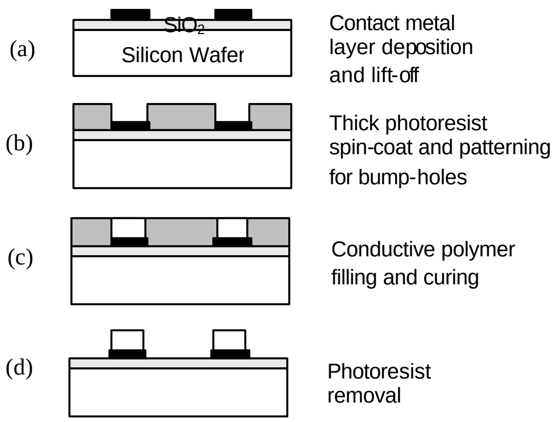

Figure 3. *Summarized fabrication steps for the formation of conductive polymer bumps on contact metal pads.*

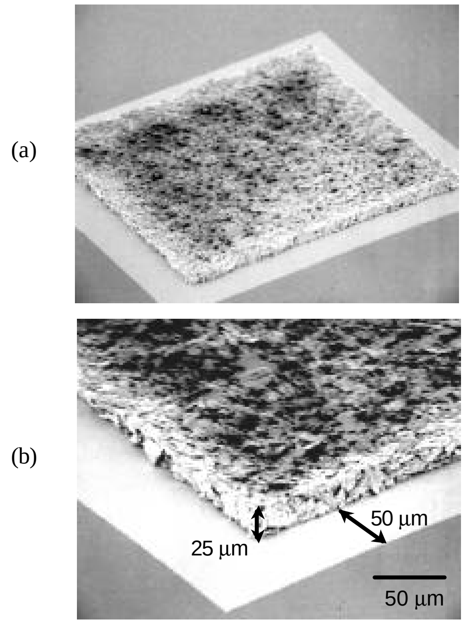

Figure 4. *SEM photographs: (a) a 25-mm-high conductive polymer bump (400 mm x 400 mm) on gold contact pad (500 mm x 500 mm) and (b) close-up view of the corner of a 25-mm-high bump.*

crucial for the molding of conductive polymer bumps [Figure 3(b)]. After the lithography, thermoplastic conductive polymers were applied into the bump-hole patterns. Excess materials were immediately scraped off by a sharp blade or rubber pad [Figure 3(c)]. The wafer was cured in convection oven of 120 ^oC for 15 minutes. Due to the different curing conditions between the patterned thick photoresist and the conductive polymer filling in the bump-holes, the photoresist can be dissolved away leaving the conductive polymer bumps on the contact metal pads. After the removing of photoresist, the wafer was cured in convection oven of 150 ^oC for 1 hour, to achieve a better conductivity for conductive polymer bumps [Figure 3(d)]. Figure 4 shows a micromachined conductive thermoplastic polymer bump with a thickness of 25 µm and an area of 400 µm x 400 µm on a 500 µm x 500 µm gold contact pad.

CONDUCTIVE POLYMER FLIP-CHIP BONDING

Figure 5 illustrates the flip-chip bonding technique using thermoplastic conductive polymer bumps. Thermoplastic conductive polymers (Epo-Tek K/5022-115BE) used in this work possess the property of melting or re-wetting when heated to a specific temperature (150 ^oC). After substrate is pre-heated to approximately 20 ^oC above the thermoplastic polymer melting temperature, a diced flip-chip is flipped, aligned and contacted onto it. The thermoplastic bumps then melt or re-wet onto the conductor pads of the substrate. The mechanical and electrical bonds are established as the substrate cools below the melting temperature of the

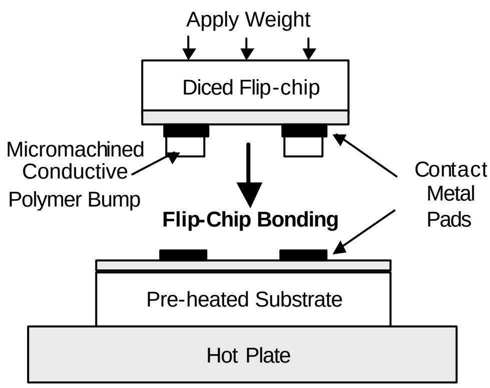

Figure 5. *Schematic illustration of an innovative flip-chip bonding technique using micromachined conductive polymer bumps.*

thermoplastic materials. To enhance the mechanical bonding strength, a small amount of pressure is applied by placing a weight on the chip.

Figure 6(a) and (b) show a flip-chip wafer before the formation of bumps and after the formation of bumps with 100 µm x 100 µm, 200 µm x 200 µm, and 300 µm x 300 µm squares on contact metal pads. The micromachined bumps have their *flat surface* morphology as shown in Figure 4, instead of *mountain peak* morphology when they are usually formed with screen printing technique [3]. Each bump was uniformly micromachined on the contact pads with a thickness of 25 µm.

To test thermoplastic conductive polymer flip-chip bonding arrangement, a flip-chip wafer with bumps and a substrate with a gold metal layer were used. During the bonding on a hot plate, the thermoplastic bumps melted onto the gold layer of the substrate. As the substrate cooled below the melting temperature of the thermoplastic materials, the mechanical and electrical bonds were established. To simply test the mechanical bonding strength and

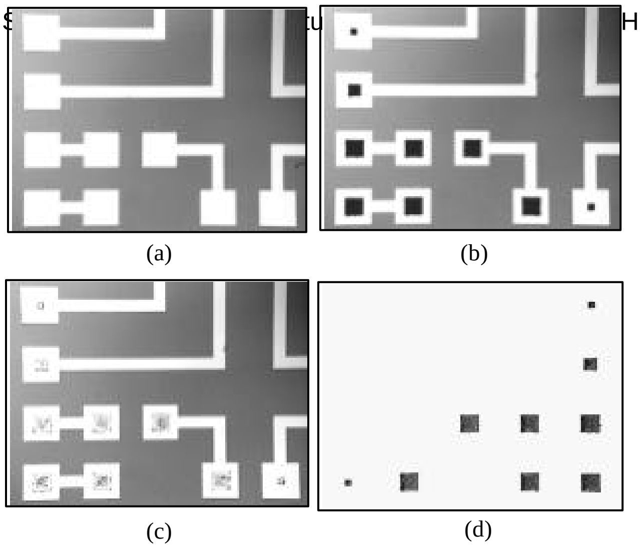

Figure6. Microphotographs: (a) a flip-chip wafer before formation of bumps on contact metal pads; (b) the wafer after formation of bumps with 100 mm x 100 mm, 200 mm x 200 mm, and 300 mm x 300 mm areas on contact metal pads; (c) the wafer with bumps left after separation of the testing assembly; and (d) a substrate with bumps left after separation of the testing assembly.

the bonding status, flip-chip bonded assembly was separated into individual wafers. The bumps were left on the side of the substrate [Figure 6(c)] as well as the flip-chip wafer [Figure 6(d)].

EXPERIMENTS

A schematic diagram of a flip-chip bonding for the contact resistance measurement using a four-terminal method is illustrated in Figure 7(a). In a four-terminal structure, a bump is sandwiched between two metal pad lines crossing each other. A constant direct current is made to flow through two of the contacts from each end of the metal pad lines, and the voltage across the other two contacts is measured with a high-impedance-voltmeter. An equivalent circuitry of the four-terminal method to measure the contact resistance of $Bump_2$ is shown in Figure 7(b). Current is forced between contact pads 1 and 2, and the voltage is measured between contact pads 3 and 4. There are two voltage drops between pad 1 and pad 2. The first is between pad 1 and upper pad B and the second is between upper pad B and pad 2. A high-impedance-voltmeter used to measure the voltage, V_{34}, allows a negligibly small sensing current, I_{SENSE}, to flow between pads 3 and 4. Hence, the potential at the pad 3 is essentially identical to that in the upper pad B. V_{34} is solely due to the voltage drop across $Bump_2$, known as R_2. The contact resistance of $Bump_2$ is

$$R_2 = \frac{V_{34}}{I}, \qquad \textbf{(1)}$$

where it is simply the ratio of the voltage measured to the current applied. The contact resistance as defined here is the total resistance through $Bump_2$, which includes the bulk resistance of the bump and the two contact resistances between the metal pad B and bump.

Figure 8 shows the actual flip-chip, substrate, and their assembly used for the contact resistance measurement. White rectangles shown in Figure 8(a) are the micromachined thermoplastic conductive polymer bumps on the gold contact pad lines. The two bumps on each end of the individual contact pad lines are used as conducting bumps, like R_1 and R_3 in Figure 7, to be connected with

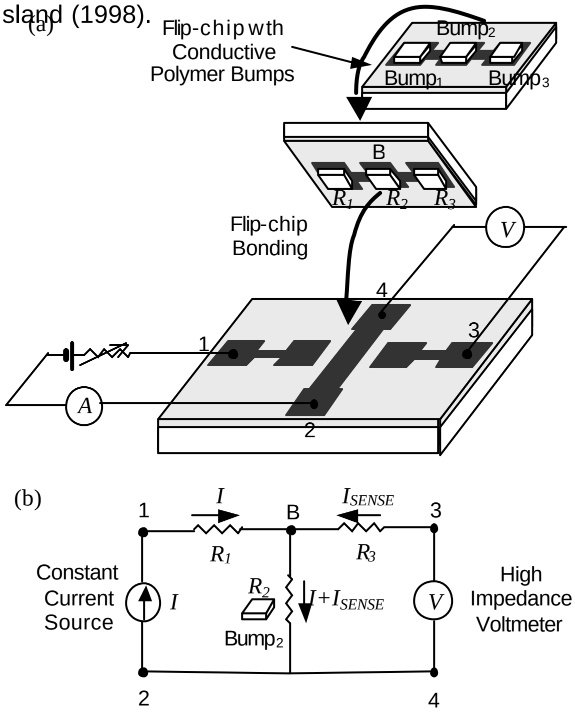

Figure 7. *Four-terminal method: (a) Schematic view of contact resistance measurement and (b) equivalent circuitry of a four-terminal method to measure the contact resistance of $Bump_2$.*

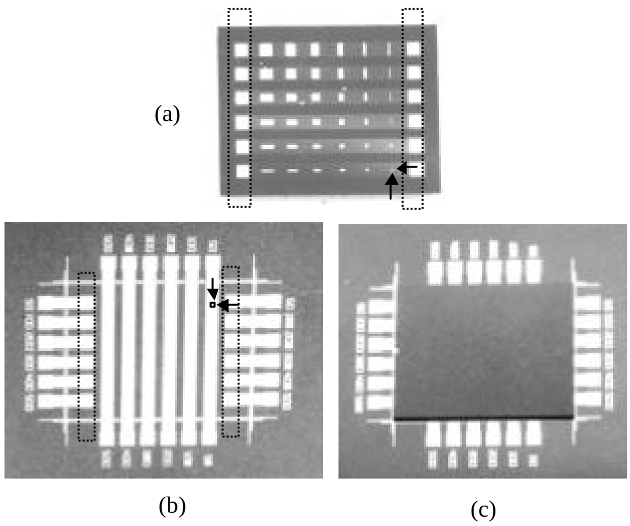

Figure 8. *Photograph of actual: (a) flip-chip; (b) substrate; and (c) their assembly used for the contact resistance measurement of the thermoplastic conductive polymer bumps.*

the probe pads on the substrate. Figure 8(b) shows the substrate with the other set of contact pad lines, guidelines to aid the alignment, and the numbers to indicate the dimensions of bumps sandwiched between metal pad lines on the chip and substrate. For example, a 50 µm x 50 µm bump is in the lower right hand corner of Figure 8(a). This bump will be centered on the intersection of the arrows in Figure 8(b). Figure 8(c) shows their flip-chip assembly used for the contact resistance measurement.

RESULTS AND DISCUSSION

The I-V characteristics measured for 25 µm-high bumps with various sizes are shown in Figure 9. The voltage drop is measured as the constant direct current is forced through the bumps up to 50 mA. The slopes of the I-V graphs are linear with different driving currents. The contact resistances measured for 25 µm-high bumps with 400 µm x 400 µm, 300 µm x 300 µm, 200 µm x 200 µm, and 100 µm x 100 µm area were 12 mΩ, 35 mΩ, 75 mΩ and 122 mΩ, respectively. The linearity of I-V curves

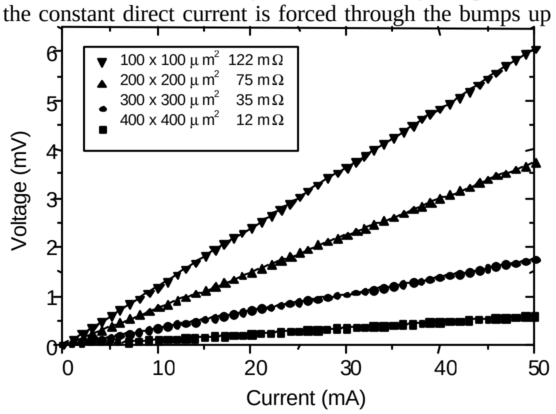

Figure 9. *I-V characteristics measured for 100 um x 100 um, 200 um x 200 um, 300 um x 300 um, and 400 um x 400um bumps.*

In principle, the contact resistance decreases as a function of contact area for square contacts. Figure 10 shows the trend as a function of the contact area. The specific contact resistance, defined as contact resistance multiplied by contact area, for the micromachined conductive polymer bumps was on the order of ~10^{-5} Ω-cm^2. In the case of metal-semiconductor ohmic contacts, contact resistance with usual specific contact resistance of ~10^{-5} Ω-cm^2 and 300 µm x 300 µm area is ~11 mΩ [5]. The resistance reading of 35 mΩ measured for a bump with 300 µm x 300 µm area are comparable with these of the ohmic contact and also with those of screen-printed bumps [3].

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CONCLUSION

Using micromachining techniques with thick photoresists, an innovative conductive polymer flip-chip bonding technique that achieves both a low processing temperature and a high bumping alignment resolution has been developed and characterized in this work. The conductive polymer flip-chip bonding technique developed in this work shows high potential to replace conventional flip-chip bonding technique for sensor systems, optical MEMS, OE-MCMs, and electronic system applications [**1**], since the technique allows a very low contact resistance, simple processing steps, a high bumping alignment resolution (± 1 µm), and a lower bonding temperature (~170 °C).

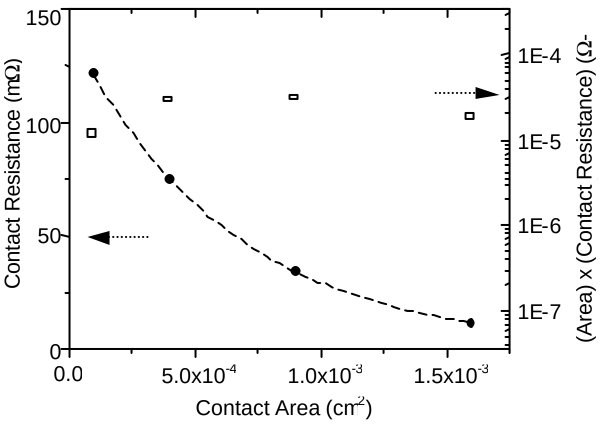

Figure 10. *Contact area dependence of contact resistance (closed circles) and area times contact resistance dependence of contact resistance (open squares).*

ACKNOWLEDGMENT

The authors wish to thank Richard H. Estes in Epoxy Technology, for donating the conductive polymer materials and technical support. This work was partially supported by a DARPA grant under contact number AF-F30602-97-2-0102.

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