BATCH TRANSFER OF LIGA MICROSTRUCTURES BY SELECTIVE ELECTROPLATING AND BONDING

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ABSTRACT

A flip-chip, batch transfer process for LIGA microstructures has been demonstrated by selective electroplating and bonding. The bonding process is achieved by filling electroplated nickel in the gap of two bonding substrates, a LIGA and an IC (Integrated Circuit) chip. The electroplating solution is set at a temperature of 50°C and with current density of 68.3 A/m^2. It is found that a total electroplating time of 80 minutes is required for the completion of the bonding process and that all the targeted LIGA microstructures are bonded and transferred to the IC substrate. Experimentally, a LIGA gripper based on the principle of self-heating and thermal expansion is successfully transferred and operated. When a maximum input current of 1.6 A is applied, a displacement of 90 μm is observed. This flip-chip assembly process enables a new class of integrated electro-mechanical manufacturing for microelectromechanical devices.

INTRODUCTION

Batch transfer of microstructures with microelectronics is an important manufacturing process, especially for processes that are not IC compatible such as LIGA and EDM. Without the integration with microelectronics, microstructures fabricated by these processes may have very limited functions. Previously, efforts in the area of batch assembly have been reported, such as solder bump bonding [1], conductive polymer bumps [2], and diffusion bonding [3]. These processes aim to provide reliable electro-mechanical integration such that micromechanical structures can have multiple functions. However, drawbacks can be identified in these processes, including integrity of the solder bump bonding, degradation of polymer bumps, and high temperature processing requirement for diffusion bonding.

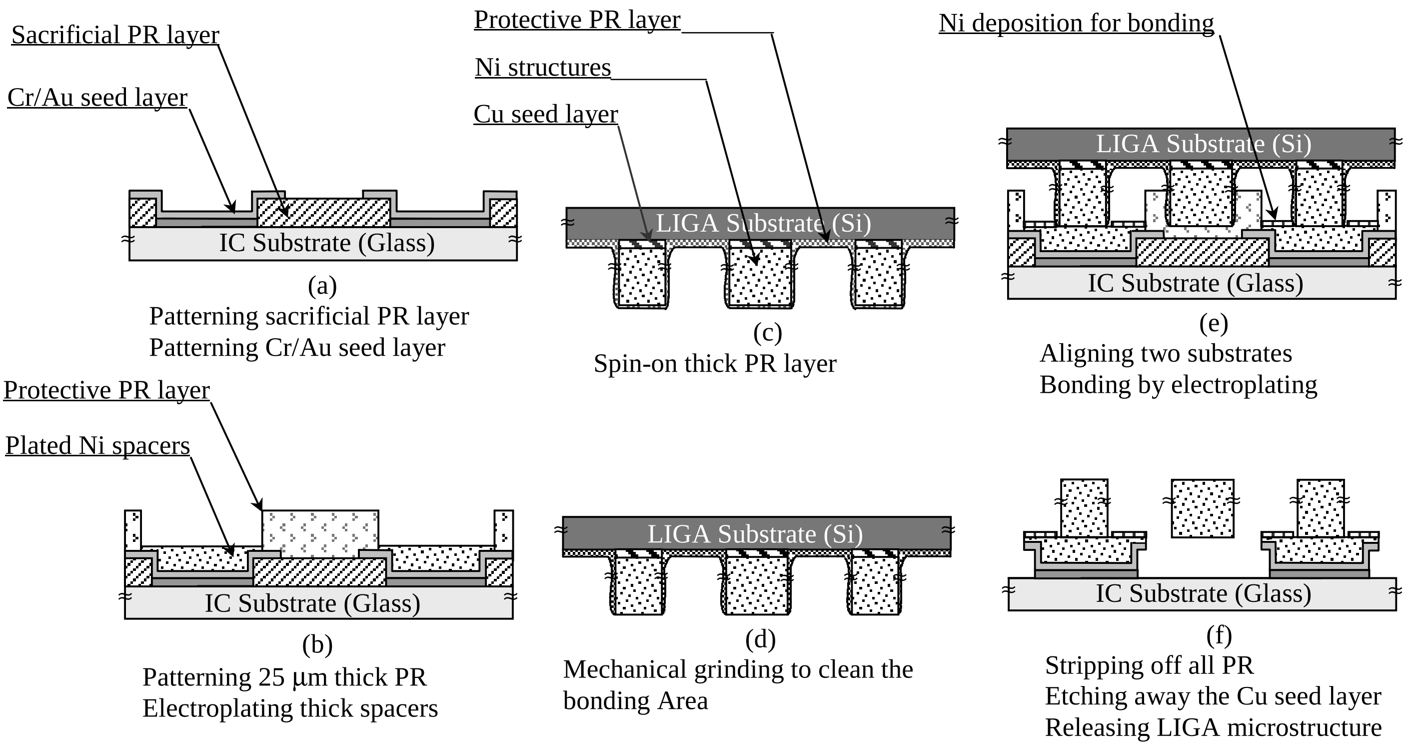

Fig. 1: The fabrication sequence.

In order to address some of the aforementioned problems, a new batch assembly process based on flip-chip, electroplating and bonding is explored and demonstrated in this work. The advantage of the proposed process is low-temperature processing, reliable bonding and batch processing. The electroplating process takes place at a low temperature and the flip-chip bonds are found to be strong. Therefore, mechanical microstructures fabricated by LIGA or other means can be directly integrated with microelectronics, including CMOS, massively and in parallel by the new process.

FLIP-CHIP BONDING PROCESS BY ELECTROPLATING

A schematic diagram of the flip-chip, batch-assembly process is shown in Fig. 1. Two substrates, one has LIGA microstructures and the other has microelectronics, are to be assembled. In this demonstration example, a Pyrex glass is used as an IC (Integrated Circuit) substrate and an LIGA substrate fabricated by the MCNC foundry service [4] is used as the substrate with micromechanical structures. The glass substrate is coated and patterned with 500Å chromium and 2000Å gold as the bonding pads on the IC substrate. A 2.7µm thick sacrificial photoresist is coated and patterned to open the bonding pad area. Another 500Å chromium and 2000Å gold layer is deposited and patterned as the conductive seed layer. Figure 1(a) applies after these processes. A 25µm thick, protective photoresist layer, which prevents any unwanted electroplating deposition in the later electroplating step, is then coated and defined. A layer of 5µm thick nickel is then selectively deposited on the bonding areas as spacers (suspension gap) as illustrated in Fig. 1(b).

The second substrate where LIGA microstructures are fabricated on is coated with 5000Å thick photoresist to protect the sidewall of the LIGA structures as illustrated in Fig. 1(c). The photoresist on top of LIGA microstructures are removed by mechanical grinding using a regular planar grinder with a 1200 grit sand paper. This process is necessary to open the bonding area as shown in Fig. 1(d). Both substrates are now aligned under an optical microscope, pressed together and put into nickel plating bath. Electroplating process at 50°C, current density of 68.3 A/m^2 is conducted for 80 minutes to complete the bonding as shown in Fig. 1(e). After the bonding process, acetone is used with ultrasonic stripper to strip off all photoresist. The copper seed layer that holds the LIGA microstructure with the original LIGA substrate is now etched away by using copper etchant and the whole process is complete as shown in Fig. 1(f).

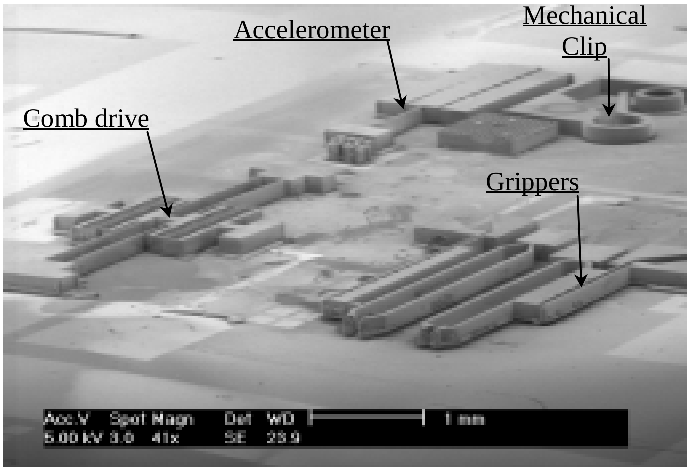

Fig. 2: Overview of flip-chip bonded LIGA microstructures on glass substrate.

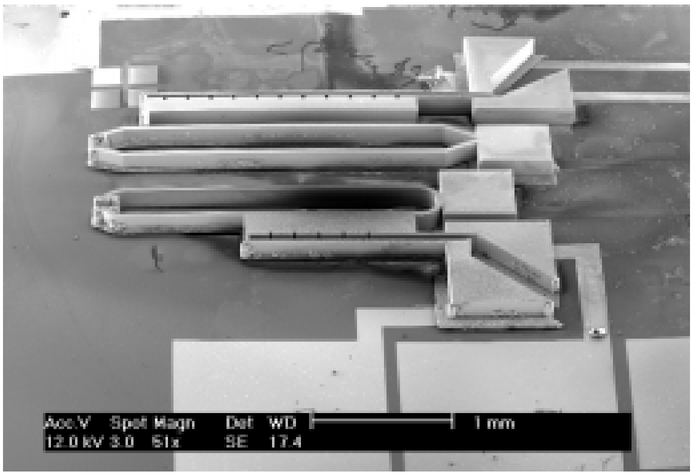

Fig. 3: The close view micrograph of two LIGA grippers and bonding pads.

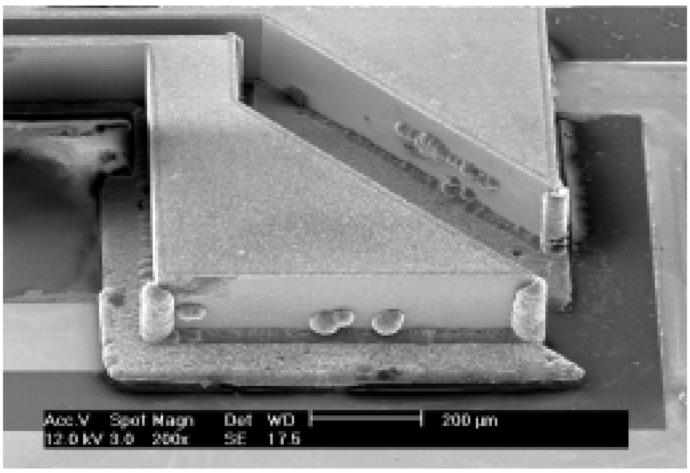

Fig. 4: The close view SEM micrograph showing the bonding interface of the bonding anchors.

Figure 2 shows the SEM microphoto of several assembled LIGA microstructures, including two microgrippers, one comb-drive, one accelerometer and one mechanical clip. The total transferred device area per die is about 0.6mm x 1.1mm. Figure 3 shows two microgrippers, which are suspended above the substrate with a gap of about 5µm. These LIGA grippers have arm length of 2700µm. They are designed to be actuated by means of thermal actuation [5, 6], width of 40 µm and thickness of 200 µm. Because of the selective electroplating bonding process, the anchors are fixed on the substrate but the microstructures are suspended above the substrate. A close view SEM microphoto in Fig. 4 reveals the bonding interface, where the newly electroplated nickel filled the gap between the LIGA microstructure and the IC substrate. Due to the leakage problem in the protective photoresist, some extra deposited nickel as irregular bead shapes appear on the sidewall of these structures.

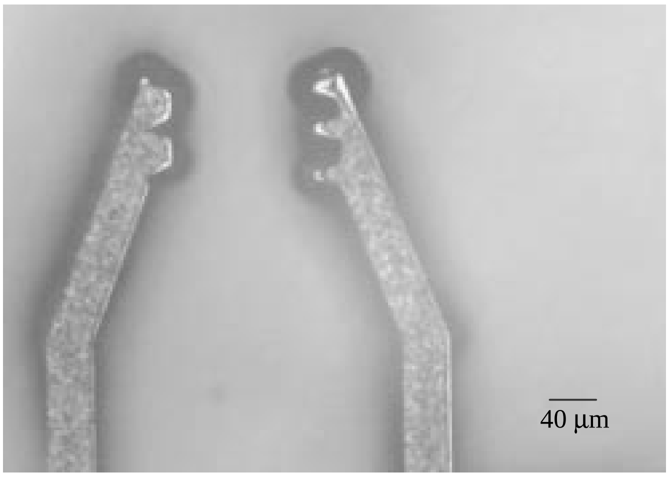

Fig. 5: The tips of the LIGA gripper before applying input power.

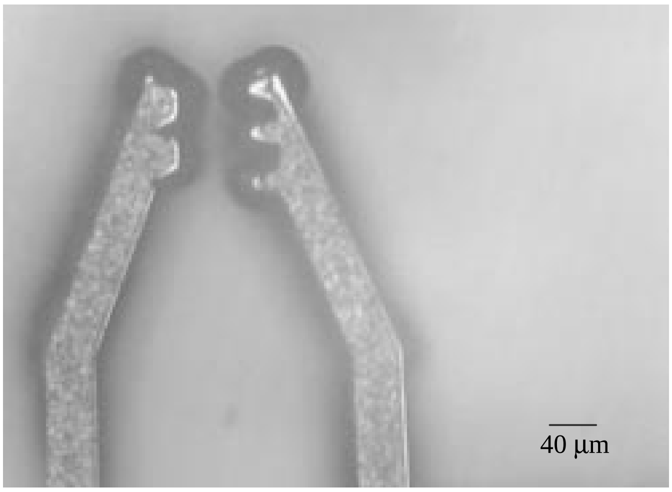

Fig. 6: The tips of the LIGA gripper after applying a 1.6A input electrical current.

EXPERIMENTAL RESULTS

After testing all the bonded microstructures, only the microgrippers are functional. Both microaccelerometer and comb drive are not operational in this first demonstration due to the excessive electroplating between small gaps that shorted the circuit. Before an electrical current is put through the thermal microgripper, the gripping distance has design the value of 150µm as shown in Fig. 5. After an input current is put into the actuator, the gripper can be closed as shown in Fig. 6. A current versus displacement (at the tip of the microgripper) is recorded in Fig. 7. The current-displacement curve shows exponential increment as the input current is increased. The maximum power consumption of the LIGA microgripper is about 3.93 W at 1.6 A. At that point, the movement of the gripper was 93 µm and the device failed due to high temperature effects at the bonding interface.

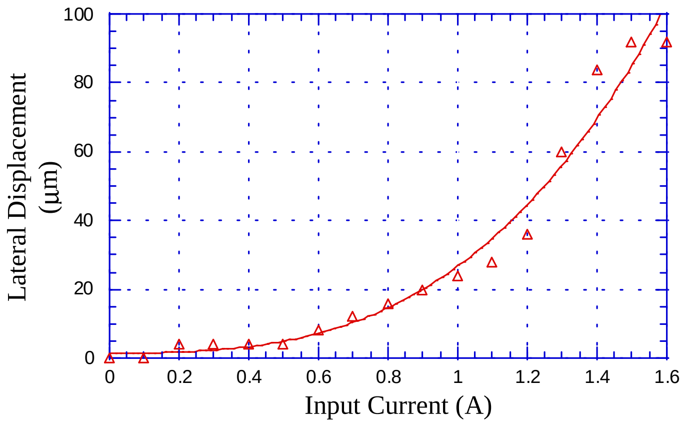

Fig. 7: Experimental results of lateral displacement versus the input current for the thermal actuator.

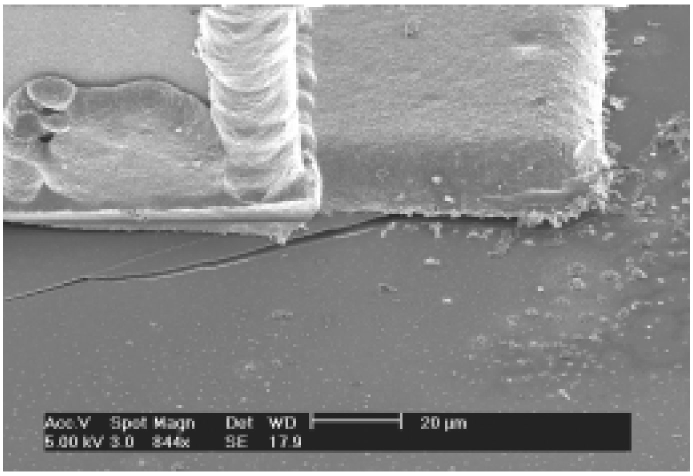

Fig. 8: The SEM microphoto showing cracks appeared at the glass substrate close to the anchor of the LIGA gripper after the test.

Figure 8 shows the cracked glass substrate after testing when the microgripper is driven at an extremely high current of 1.6 A. The crack is probably resulted from the thermal expansion mismatch between nickel and glass when the thermal actuator is heated.

DISCUSSIONS

The batch transfer process via electroplating as demonstrated has a few engineering challenges, including design rules for flip-chip bonding, the protection of the sidewalls and non-bonding parts from unwanted electroplating, the integrity of the bonding interface and the responses of the assembled microgripper.

Design Rules for Flip-Chip Bonding

The flip-chip bonding process requires alignment between two chips. In order to account for misalignment, the bonding pads on the IC substrate should be larger than the bonding area on the LIGA microstructure. Currently, the alignment process is performed by human hands and under an optical microscope; the design rule for possible misalignment is 20 μm. Larger bonding pads on the IC substrate also help the electrolyte to flow and diffuse to the bonding interface. Moreover, to prevent short circuitry due to excessive electroplating, the minimum distance between any two bonding pads is twice of the alignment error, which is 40 μm in our experiment.

Excessive Electroplating

Because the bonding process is achieved by electroplating to fill gaps between two conductive materials, electroplating is easy to occur on parts that do not welcome any excessive deposition. This intrinsic drawback of the process is alleviated by spin-on protective photoresist to prevent the excessive electroplating (Fig. 1(c)). After this protection process, the bonding area on the bottom of the microstructure is opened by a planar grinding process as shown in Fig. 9. Although the sidewalls of LIGA microstructure are now covered by a thin layer of photoresist, it is difficult to assure good conformal coverage on the open corners. Furthermore, corner areas generally have stronger electrical field than those flat surfaces such that excessive deposition is commonly found at the corners of the microstructures. A second source of excessive electroplating is on the surface that went through the grinding process but is not the bonding area as those comb fingers shown in Fig. 9. These surfaces have to be protected during the bonding process to prevent excessive electroplating. The thick protective photoresist coating in Fig. 1(b) can help solving the problem but is not a perfect solution.

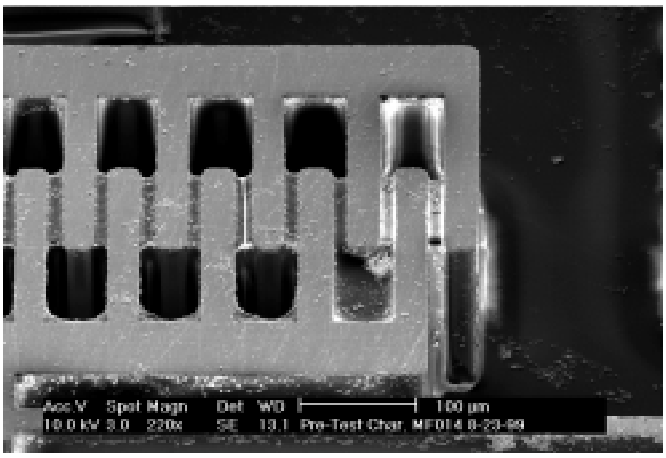

Fig. 9: The SEM microphoto of the surface of the LIGA structure after the protective PR coating and grinding process.

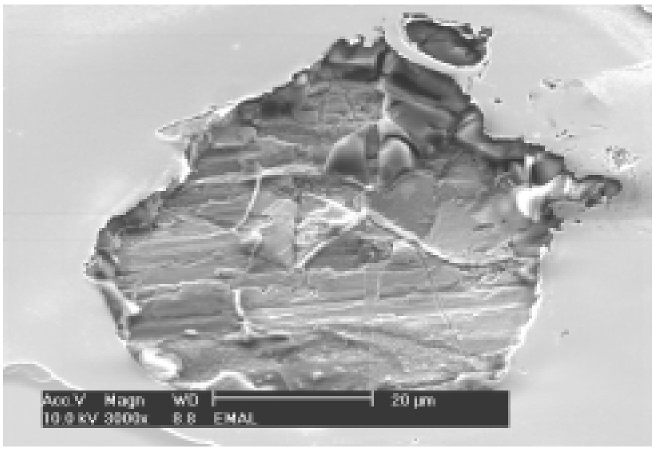

Fig. 10: The SEM microphoto showing the peeled-off bonding interface on the LIGA microstructure.

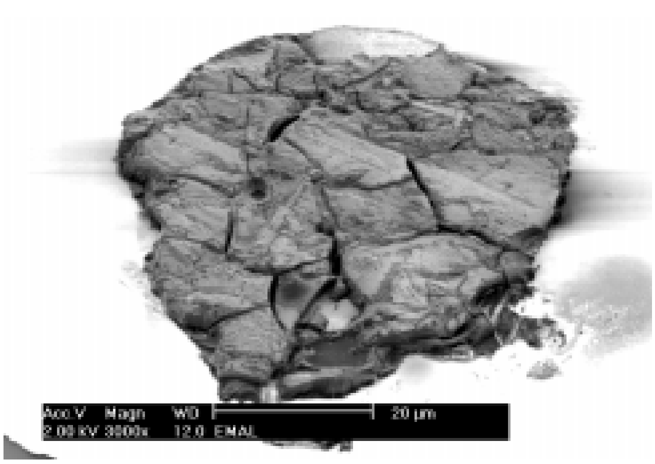

Fig. 11: The SEM microphoto showing the peeled-off bonding interface on the glass substrate.

Bonding Interface

Figure 10 and 11 are two SEM microphotos showing the microstructures and glass substrate after forcefully breaking the bond. The thickness of the bonding nickel layer is about 5 μm and cracks are found with random orientations and sizes. Although the mechanism about the formation of the crack is not known, it has been reported that electroplating conditions such as the pH values, electrical current density and preferential growing planes may contribute to these cracks [7, 8, 9].

In the flip-chip assembly process, electrolyte has to be able to diffuse into the bonding gaps for reaction. Low diffusivity could reduce the nickel ion to reach the interface area that is far away from the edges of the bonding pads such that the bonding area and the quality of the bond may be affected. In order to improve the diffusivity, pulse electroplating [10] is suggested to provide the relax time required for the diffusion of nickel ion.

The Performance of LIGA Microgripper

These LIGA microgrippers have high-aspect-ratio such that they are expected to deliver large force when compared with thermal actuators fabricated by surface-micromachining processes. However, the driving current is extremely high for these microgrippers because their resistance is very low. In our experiments, the estimated resistance of the LIGA microgripper is 0.03 Ω at room temperature and the contact resistance between the probe and the contact pad can be as high as 1.3 Ω. Therefore, under a high input current, most of the energy is consumed at the probe-pad contact. Figure 12 shows the melting of the probe-pad contact after operation under a high current. Even under this high temperature, the integrity of the bonding seems to remain fine.

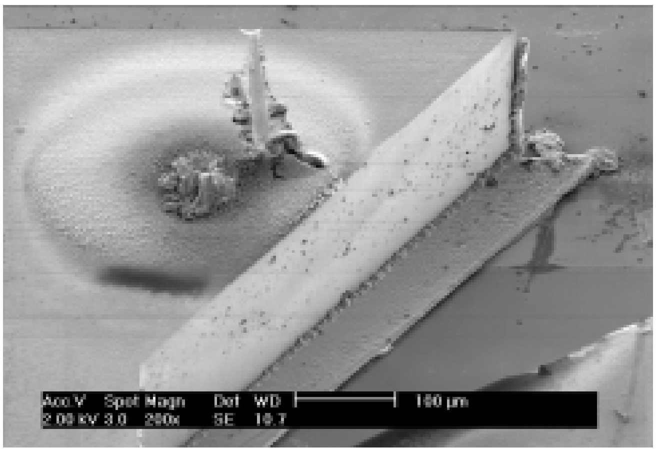

Fig. 12: The SEM microphoto showing the melted anchor and the probe-pad interface under a high input current.

The operation of the LIGA microgripper depends strongly on the temperature effects. Electrical resistivity, Young's modulus, and thermal expansion coefficient of nickel are all temperature-dependant. Due to the lack of material database of these properties, the theoretical characterization of the performance of these LIGA microgrippers is very difficult and meaningless until better understanding of temperature effects are investigated.

CONCLUSIONS

LIGA microstructures have been successfully batch transferred to a glass substrate by means of bonding via electroplating. Nickel electrolyte is chosen as the demonstration example in this work. The transfer-bonding process occurs at a 50 °C with a current density of 68.3 A/m^2 and completes in 80 minutes. Several LIGA microstructures are successfully transferred in a single run of process with strong bonding at the interface. Experimental results show that the LIGA microgrippers are operative and a maximum displacement of 93 μm is achieved under an input current of 1.6 A. As such, this flip-chip assembly process enables a new class of integrated electro-mechanical manufacturing that have potential applications in both MEMS and mesoscopic systems.

ACKNOWLEDGEMENTS

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