

HIGH YIELD BATCH PACKAGING OF MICRO DEVICES WITH UNIQUELY ORIENTING SELF-ASSEMBLY

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ABSTRACT

We demonstrate a high yield wafer level packaging technique for micro devices on the basis of uniquely orienting self-assembly with 2mm square diced silicon parts. Each silicon part has one hydrophobic thiolated gold face and one circular peg, offset from the center of mass, on the opposite face. A receptor site on an alignment template has a circular trap hole. The whole assembly process consists of five major steps: (1) bulk parts are oriented to face the same direction; (2) parts are palletized onto the alignment template; (3) parts are one-to-one distributed to receptor sites; (4) parts self-align to receptor sites with a unique in-plane orientation; (5) parts are bonded to a chip carrier template. The experimental results indicate that step 1-4 have yields close to 100%. We skip step 5, a well-established process widely used in the IC industry. This packaging strategy can be applied for any shape of silicon or non-silicon parts, and the assembly mechanism itself imposes no upper limit on the size of the assembly templates.

1. INTRODUCTION

Surface mount technologies are widely used to package device chips ranging from several hundred micrometers to several centimeters onto chip carrier templates (CCTs). Placement of a chip with accurate position and correct orientation is the key requirement for all surface mount technologies. Currently there are several assembly techniques which can place parts accurately: (1) robotic assembly systems use pick-and-place methods to deliver parts in serial processes [1]; (2) fluidic shape-directed self-assembly assigns parts to complementary trenches in parallel [2]; (3) capillary-driven self-assembly assembles parts to receptor sites via adhesive droplets in parallel [3-5]. Serial robotic assembly is not suitable to assemble a large volume of parts; neither the shape-directed assembly nor the capillary-driven self-assembly can provide a unique in-plane orientation for a part with rotational symmetries. To flip-chip bond a rectangular chip with multiple interconnect pads, the chip should be assembled with a unique in-plane orientation so that correct electrical connections to a CCT can be achieved. In addition, mass production of microelectromechanical systems (MEMS) requires batch packaging for lower costs and faster product throughputs.

Here we present a novel self-assembly strategy to batch package microchips with a unique orientation. This wafer level packaging process has the following five major steps: (1) organize randomly oriented bulk parts to face the same direction and spread in a single layer; (2) palletize the parts onto an alignment template (ALT); (3) distribute the parts one-to-one to receptor sites; (4) align the parts to a unique in-plane orientation; (5) bond the parts to a CCT by wafer level flip-chip bonding. We demonstrate step 1-4, and skip step 5, a well-established process [6-8] in the IC industry.

2. FABRICATION

Square diced silicon parts (side length 2mm) are used to demonstrate this packaging technique. We fabricate the parts from a 4-inch single side polished (SSP) silicon wafer with the following steps: (1) spincoat photoresist AZ4620 on the polished side and lithographically pattern AZ4620 to cover only circular peg areas (0.3mm in diameter); (2) deep reactive ion etch (DRIE) the polished side for about 20 minutes to form the protruding pegs with 45 μ m height; (3) spincoat photoresist AZ1512 on the rough side and lithographically pattern AZ1512 using double side alignment (ABM IR aligner) to cover the circular areas directly opposite to the pegs; (4) sputter deposit a layer of TiW/Au (50/800 \AA) on the rough side; (5) strip all the photoresist together with TiW/Au on it in acetone, then rinse the wafer in IPA and DI water, and dry it with a N₂ gun. Finally the silicon wafer is mechanically diced into 2mm square parts (Fig. 1a). The opening in the gold layer marks the position of the peg on the other side.

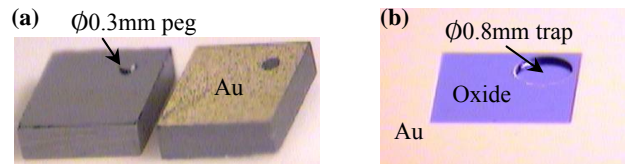


Fig. 1. (a) Top and bottom views of the 2mm square silicon parts. (b) A 2mm square receptor site on the ALT.

An ALT with an array of 168 receptor sites is fabricated from a 4-inch oxidized SSP silicon wafer (thermal oxide thickness is about 3900 \AA) with a DRIE process and a lift-off process. Patterning of the receptor sites on the polished wafer surface is accomplished with the following steps: (1) spincoat AZ4620 and pattern it to expose only the circular trap areas (0.8mm in diameter), then completely remove the exposed oxide in a buffered oxide etchant (BOE) with an etching rate of about 600 $\text{\AA}/\text{min}$; (2) DRIE the wafer for 20 minutes to form 60 μ m deep traps, and then strip AZ4620; (3) spincoat AZ1512 and pattern it to cover only square receptor site areas and sputter deposit 50/800 \AA TiW/Au; (4) strip AZ1512 and lift off metal in acetone. A receptor site is shown in Fig. 1b.

Surface treatment is applied to the silicon parts and the ALT to prepare them for the assembly process. First, the parts and the ALT are soaked in Nanostrip for half an hour, and then rinsed with DI water. The Nanostrip oxidizes the silicon surfaces and removes photoresist residues from the gold surfaces. Second, the parts and the ALT are soaked in a 0.1mmol alkanethiol CH₃(CH₂)₁₁SH solution (alkanethiol diluted in ethanol) overnight. The gold surfaces become hydrophobic after adsorbing a self-assembled monolayer (SAM) from the alkanethiol solution. Now each silicon part has only one hydrophobic thiolated gold face, and all the

other faces are hydrophilic silicon oxide. The receptor site area is hydrophilic silicon oxide, and its background is hydrophobic thiolated gold surface. Finally, the parts and the ALT are dried respectively with heating on a 120°C hotplate and blowing N₂.

3. PALLETIZING PARTS

Initially bulk parts are randomly oriented, and we develop an agitating process to orient all the parts to face the same direction with their pegs before palletizing. The 2mm square silicon parts can float on a water surface because surface tension is enough to balance their gravitational forces. For a smaller part with side length L and thickness t , surface tension ($\propto L$) is even more significant compared with the gravitational force ($\propto L^2 \times t$). We put the 2mm square silicon parts in a beaker and submerge them with water, and then shake the beaker on an orbital shaker (Model 513500, Cole-Parmer) to tilt the water surface (Fig. 2) so that some parts are exposed to air. The water surface tension drags and floats the exposed parts. After 1 minute shaking, most of the parts float, and all floating parts have their thiolated gold faces upwards (the only stable state on an agitated water surface) and stay together in a single layer to minimize potential and interfacial energies.

A carrier wafer (CWF) is used to pick up the floating parts and palletize them onto an ALT. The CWF is a 3-inch pyrex wafer coated with hydrophobic fluorocarbon polymer PFC802 (Cytonix Corp., MD, USA) on one side. When the CWF is inserted vertically into water, the water surface bends downwards near the hydrophobic PFC802 surface, hence the floating parts are attracted to the water valley near the PFC802 surface to minimize their potential energies. When the CWF continues to enter the water, the parts adhere to the CWF firmly (Fig. 3a) due to significant capillary forces caused by trapped air bubbles underneath them. After all the floating parts stick to the CWF, the CWF is withdrawn completely from water, and above 98% parts keep sticking to the CWF due to capillarity of the residual water on the hydrophilic part surfaces. Finally the CWF is turned over the ALT (Fig. 3b) on a 120°C hotplate, and then the parts are released to touch the ALT with their pegs when the water evaporates. The CWF is brought very close to the ALT to preserve the face orientations of all the parts during the releasing.

4. TRAPPING PARTS

We utilize orbital shaking to move the parts around on the ALT. The experimental setup is shown in Fig. 4: the ALT is attached to an orbital shaker platform, and the top Petri dish defines the moving range for all the parts. Orbital shaking produces centrifugal forces which are evenly distributed across the shaker platform. The centrifugal forces are proportional to the square of the shaking speed and should be large enough to overcome sliding friction for the parts to move around. The 2mm square silicon parts start to move at a shaking speed of about 150RPM.

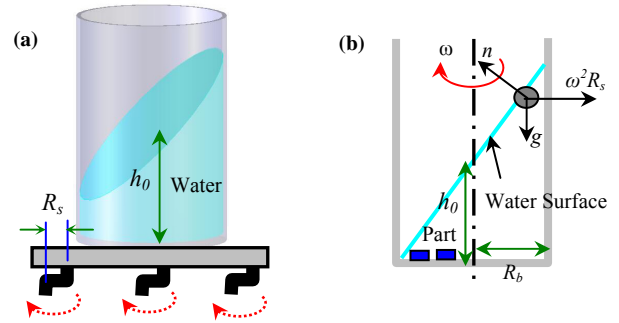


Fig. 2. Water surface tilted by orbital shaking (the centrifugal force induced by orbital shaking is horizontal and evenly distributed): (a) tilted plane surface; (b) rotating water surface at the minimum shaking speed to expose the parts to air: the vector sum of normal force n , gravity g and centrifugal force $\omega^2 R_s$ on a finite element of the tilted water surface is zero, so that the slope of water surface is $h_0/R_b = \omega^2 R_s/g$, thereby $\omega = \sqrt{g h_0 / R_b R_s}$.

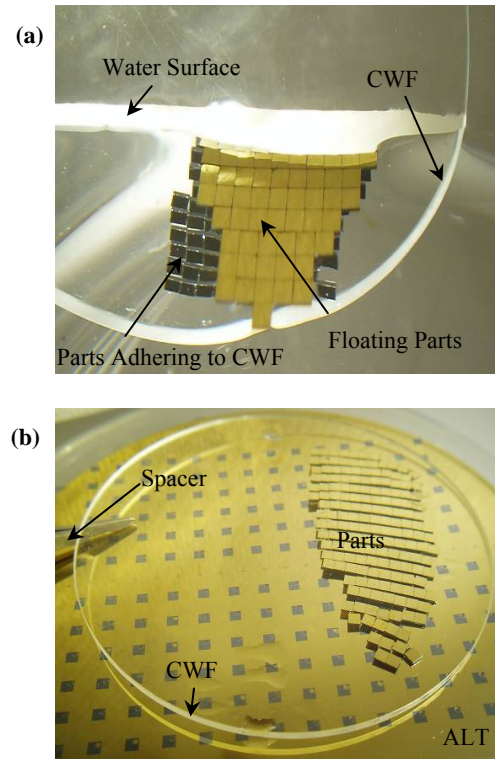


Fig. 3. Palletizing the floating parts onto a 4-inch ALT via a CWF: (a) a 3-inch pyrex CWF is inserted into water, and floating parts stick to the hydrophobic PFC802 surface; (b) the CWF is turned over the ALT to release the parts.

The moving parts are anchored by the traps of the receptor sites. The four corner receptor sites are blocked by the top Petri dish, and the remaining 164 receptor sites are open to receive parts. We perform four trapping experiments without and with 10%, 20%, 30% redundant parts (Fig. 5). During the first 10sec, the shaking speed is 200RPM, and the trapping yield (number of occupied receptor sites / 164) reaches about 80% for all 4 cases. A slow shaking speed for

the first 10sec avoids parts flipping due to violent collisions among the crowded parts. After that, the shaking speed is raised to 250RPM. With most of the parts anchored to the uniformly distributed receptor sites, a higher shaking speed causes the remaining free parts to move faster to get trapped, and no part flipping has been observed for all the 4 cases. After 3 minutes shaking, 99% of the receptor sites are occupied.

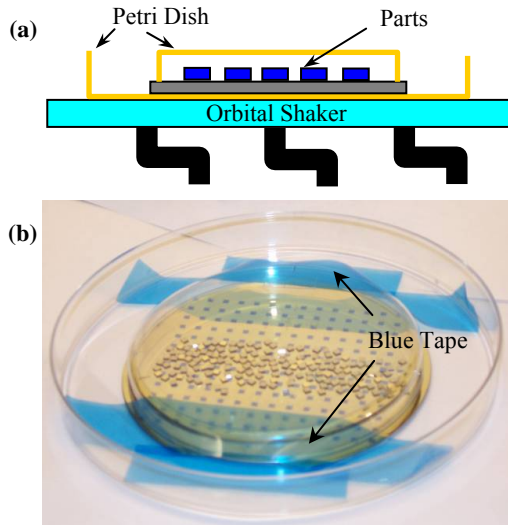


Fig. 4. An experimental setup for parts trapping: (a) a schematic side view; (b) a top view snapshot.

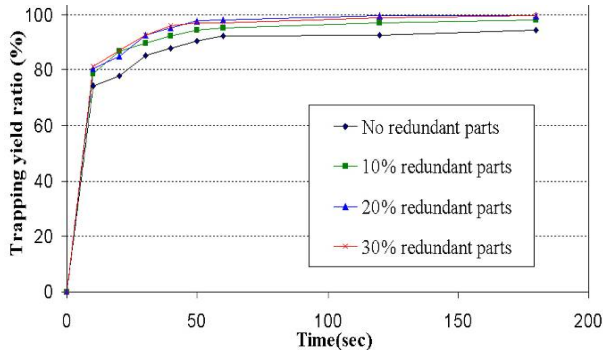


Fig. 5. Experimental results for the orbital shaking assisted trapping without and with redundant parts.

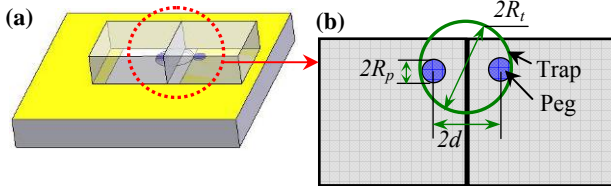


Fig. 6. One-to-one registration design rule: (a) two neighboring parts compete for one receptor site; (b) for one receptor site to trap one part, the following relation should be satisfied: $2R_t < 2d + 2R_p$, where d is the smallest possible distance between two adjacent pegs.

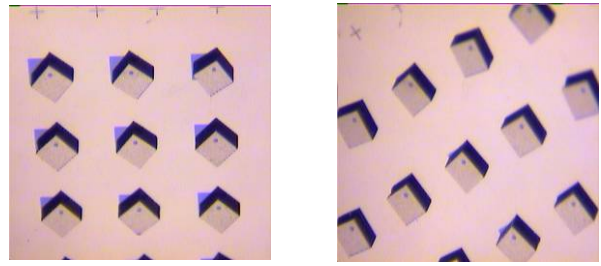


Fig. 7. Rough alignment of the parts by gravity induced torques when the ALT is tilted in two different orientations. The right figure aims for exact alignment to the receptor sites.

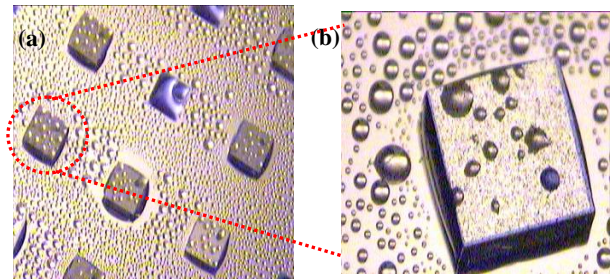


Fig. 8. Precise alignment by condensing water steam: (a) droplet-wise condensation on hydrophobic surfaces, film-wise condensation on hydrophilic receptor sites; (b) zoom-in view of one part, the water continuously covers the hydrophilic sidewall.

We introduce a layout design rule to guarantee one-to-one registration, i.e., one receptor site is exclusively assigned to one part. The circular trap has a greater diameter than the circular peg, which makes parts trapping easier and faster. But the trap should have an upper limit to avoid anchoring multiple parts. An appropriate geometric constraint shown in Fig. 6 guarantees that one receptor site is occupied with only one part.

5. UNIQUELY ALIGNING PARTS

We first roughly align the anchored parts towards a unique in-plane orientation using gravity as the driving force. On a tilted ALT, the free parts slide away, and the anchored parts tend to rotate about their pegs until the minimum potential energy is achieved, when the centers of mass are directly below the peg centers (Fig. 7). Friction blocking the rotation of the parts is relieved with a slight knocking on the edge of the ALT. This alignment is rough because of three factors: (1) the tilt orientation of the ALT is roughly controlled; (2) friction from the ALT prevents exact alignment; (3) the layout design for the parts and the receptor sites defines the exact alignment when the pegs are concentric with the traps. The maximum translational misalignment is the difference between the radii of the peg and the trap, which is 0.25mm. The maximum rotational misalignment we observe is about 18° .

Capillary-driven self-alignment can produce accuracy down to sub-microns [5], so we introduce capillary forces to minimize the misalignment of the previous gravity driven

assembly. The ALT with anchored parts is placed in a water steam environment, where water forms droplet-wise condensation on hydrophobic surfaces and film-wise condensation on hydrophilic surfaces (Fig. 8). The hydrophilic sidewall of the parts is continuously covered with water. The sidewall water enters the capillary gaps between the parts and the hydrophilic receptor sites, and then lubricates the parts so that they can self-align to the receptor sites to minimize total interfacial energies. Finally water is evaporated when the ALT is placed on a hotplate (Fig. 9).

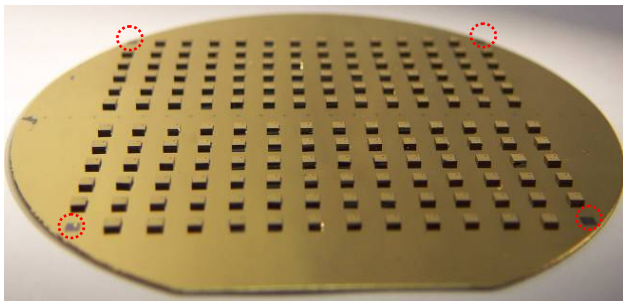


Fig. 9: 164 silicon parts self-aligned on a 4-inch ALT. 4 receptor sites at the corners are not occupied because the top Petri dish blocks them during the trapping step (Fig. 4).

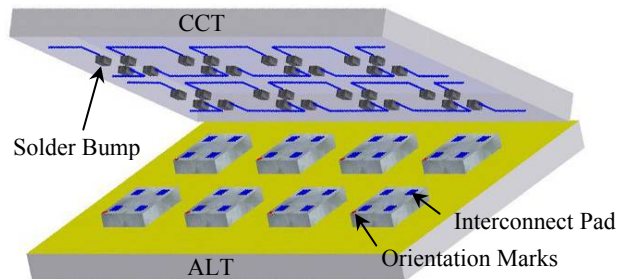


Fig. 10: Wafer level flip-chip bonding (a well-established process in the IC industry) scheme for the mounting of uniquely aligned microchips onto a CCT with electrical circuits.

6. FINAL BONDING

We use dummy silicon parts without any functional circuit or interconnect pad for the previous steps, therefore here we only propose a wafer level flip-chip bonding for the last step to assemble functional microchips. The flip-chip bonding can be achieved via solder bumps deposited on the CCT (Fig. 10) or a layer of anisotropic conductive film [7]. In order to face orient functional chips on an agitated water surface with high yield, the interconnect pads should be also hydrophobic (e.g. thiolated gold), and the hydrophobic background of receptor sites and interconnect pads can be, e.g., octadecyltrichlorosilane (OTS) SAM coated silicon oxide or meshed (for electrical isolation among pads) and thiolated gold.

7. CONCLUSIONS

We demonstrate a wafer level packaging technique with its major process steps for flat microchips on the basis of peg-in-hole and gravity driven self-alignment mechanisms. Our packaging strategy has several major advantages: (1) it is a complete process to correctly assemble randomly oriented bulk parts; (2) it is a batch process suitable for a large number of parts; (3) it can handle any shape of silicon or non-silicon parts because the peg offset from the center of mass can be fabricated with additive patterning techniques such as SU8 casting on almost any solid surface; (4) the hydrophobic faces (used as bonding faces with interconnect pads for functional chips) of the parts are quickly and uniquely oriented with a 100% yield; (5) the alignment template (ALT) is used for aligning of parts without bonding, thus reusable; (6) the ALT can be easily expanded to larger sizes because orbital shaking, which is the only required agitation during the assembly, introduces centrifugal forces evenly across the shaker platform; (7) all the parts are assembled with a unique in-plane orientation; (8) all the process steps have high yields close to 100%. With a reusable ALT, multiple batches of parts can be assembled, which is very useful for integration of multiple components into hybrid micro systems.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

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