Micro-Scale Self-Assembly Via Capillary Forces

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Micro-scale self-assembly is an attractive future manufacturing paradigm for continued miniaturization and increased functional microsystem integration. Conventional pick-and-place methods become increasingly difficult as component sizes shrink from millimeter to nanometer scales. Capillary forces have been shown to induce sub-micrometer precision in alignment across a 200 mm wafer [1]. These forces are also useful for assembly and alignment of much smaller components from a variety of micro- and nano-fabrication processes. With capillary forces from a molten alloy or solder, regions of heated, liquefied solder act as binding sites to provide capillary forces and provide both mechanical and electrical connections. We have demonstrated the utility of such an approach, shown in Fig. 1 and reported in [2], producing filled-to-available binding site yields in excess of 97%. Others report similar results [3, 4].

Despite these successes, the size scale of electrical contacts has been limited by molten alloy degradation and intermetallic compound growth. A novel approach presented here is the use of two alloys to decouple mechanical and electrical connection processes (Fig. 2), allowing smaller and potentially higher quality electrical contacts. The use of a second alloy allows the benefits of a modern flip-chip or ball-grid-array solder-reflow process where the alloy is reflowed just long enough to form electrical contacts. Figure 3 shows initial self-assembly results, where we reflowed alloy 2 at 230 °C for 30 seconds, following assembly at 180°C in a glycerol/HCl environment. The resulting electrical connections measured $3.9 \pm 2.8\ \Omega$ for the 10 μm diameter part contacts, corresponding to a 160 times higher conductance-per-unit-area over other published values for self-assembled electrical contacts [2, 3].

We are also pursuing the self-assembled, three-dimensional (3-D) circuit architecture shown in Fig. 4. Figure 4 also shows a collection of released microparts, and in the final paper we plan to show the self-assembly of these parts into 3-D structures and test their electrical connectivity.

References

[1] M. R. Tupek and K. T. Turner, "Submicron aligned wafer bonding via capillary forces," *Journal of Vacuum Science & Technology B,* vol. 25, pp. 1976-1981, 2007.

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[4] H. O. Jacobs, A. R. Tao, A. Schwartz, D. H. Gracias, and G. M. Whitesides, "Fabrication of a cylindrical display by patterned assembly," *Science,* vol. 296, pp. 323-5, 2002.

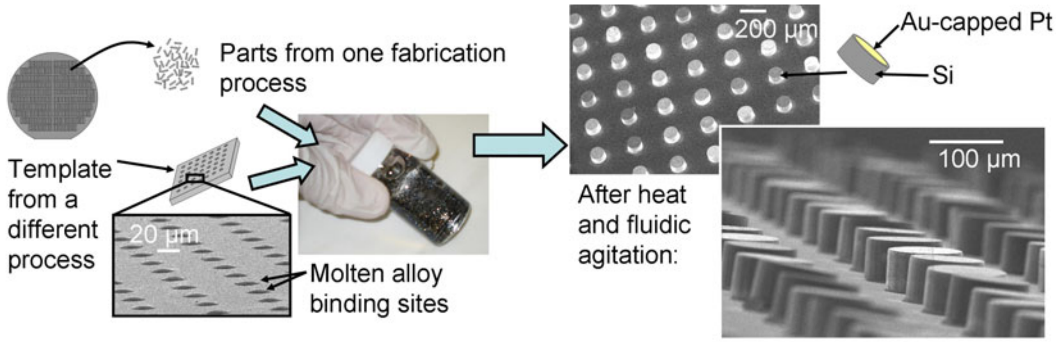

Fig. 1: Description of our heterogeneous integration approach based on self-assembly via molten alloy capillary forces. These results and additional details are reported in [2].

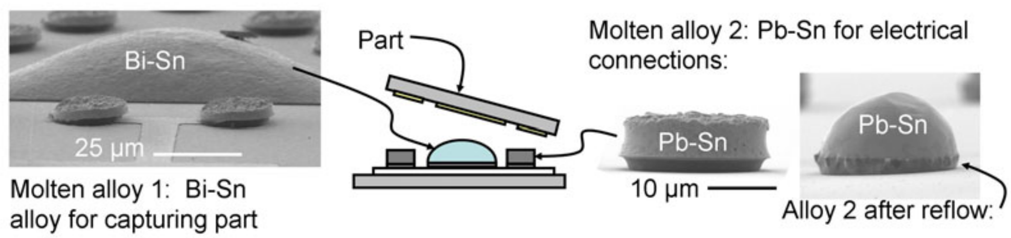

Fig. 2: An approach using two molten alloys to decouple the mechanical and electrical connection self-assembly processes.

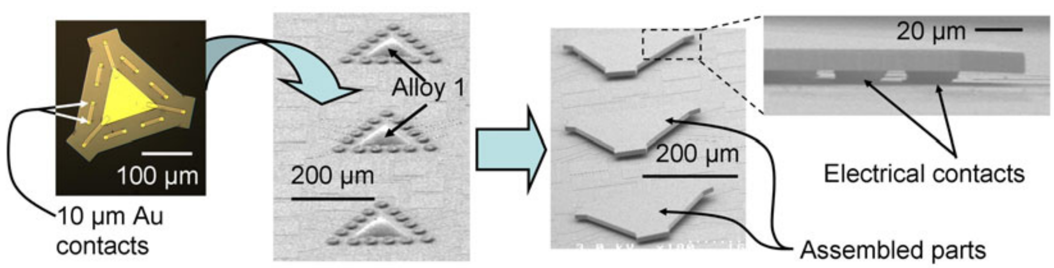

Fig. 3. Initial results of the two-alloy self-assembly process, which improved the electrical conductance by over two orders of magnitude.

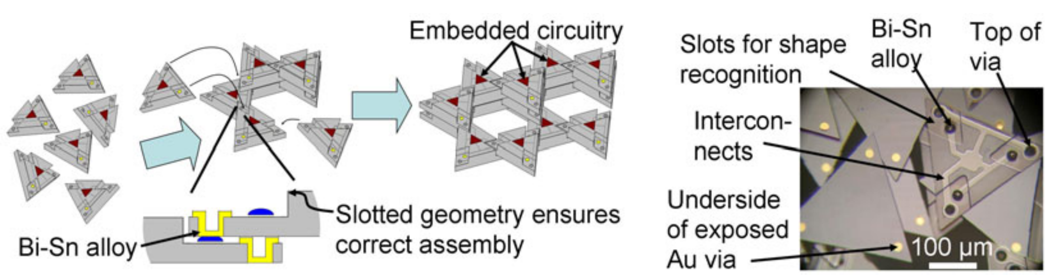

Fig. 4. Schematics and microscope images showing current work on three-dimensional (3-D), self-assembling circuits.