Programmed Self-assembly of Microscale Components Using Biomolecular Recognition

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With the advent of molecular electronics, single electron devices, nanoelectromechanical sensors (NEMS) and other nanoscale components, the near future will see a requirement to assemble onto a common substrate systems that are much smaller than conventional robotic pick-and-place systems can accommodate. This necessitates a new integration paradigm. An ideal assembly method for such small devices is one that can handle many parts in parallel, integrate devices made from incompatible processing technologies into a single platform (heterogeneous integration), and be able to position parts in planar, nonplanar and/or 3D geometries.

Selective adhesion based on biomolecular recognition is one approach to achieving such assembly. Examples of selective binding include complementary DNA strands, antibody-antigen pairs or certain protein-ligand combinations. The protein avidin and the B-vitamin biotin have one of the strongest protein-ligand binding interactions known. We have employed this highly specific binding to selectively self-assemble micron-scale model 'nanochips' (silicon microtiles) onto lithographically programmed locations on a substrate. This is analogous to the assembly of integrated circuits onto a printed circuit board, but with the potential for many of the ideal assembly characteristics described above.

Thiol-based self-assembled monolayers (SAMs) were used to functionalize target gold pads on substrates and gold-coated microtiles with avidin and biotin, respectively. The viability of the concept and the binding capabilities of the SAMs used were initially tested by self-assembling functionalized gold nanospheres onto complementarily functionalized pads. Reasonable assembly yields (up to 5% of all nanospheres assembled) and high selectivity (up to 260:1 ratio of nanospheres on the pads vs the silicon substrate) were simultaneously demonstrated.

Square silicon microtiles with widths of 5, 25, and 100 μm were fabricated as model test devices for programmed assembly. They were fabricated from silicon-on-insulator (SOI) substrates by underetching the buried SiO_2 layer so that only a narrow pillar is left supporting the device, as shown in Figure 1. A gold layer on the top silicon face of the device layer allows for functionalization of that face with a biotin SAM. After functionalization, the microtiles can be released into solution by bath ultrasonication, breaking the pillars. Once in solution, the microtiles self-assembled onto avidin-functionalized gold pads by cycles of stirring and settling. Figure 2 demonstrates a high selectivity and high yield assembly of 5 μm square microtiles onto a gold pattern. Figures 3 and 4, respectively, show 5 μm and 25 μm square microtiles self-assembled onto square gold pads of the same respective sizes, also using the avidin-biotin interaction. The yields of these trials have not been as high as trials where the target gold features are larger than the tiles used, but very high selectivities of up to 9:1 have been achieved thus far.

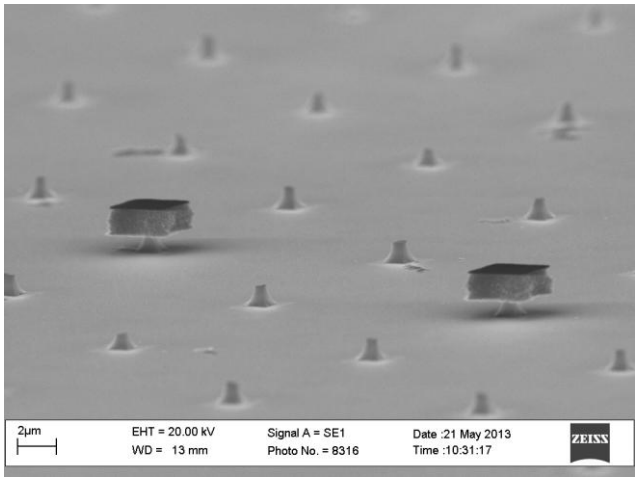

Figure 1: Silicon microtiles held in place by narrow underetched SiO_2 pillars. Although two microtiles remain, most of the microtiles on this substrate were released into solution by bath ultrasonication to break the pillars. The two that remain demonstrate a typical pillar width where almost all of the microtiles on the substrate will be released.

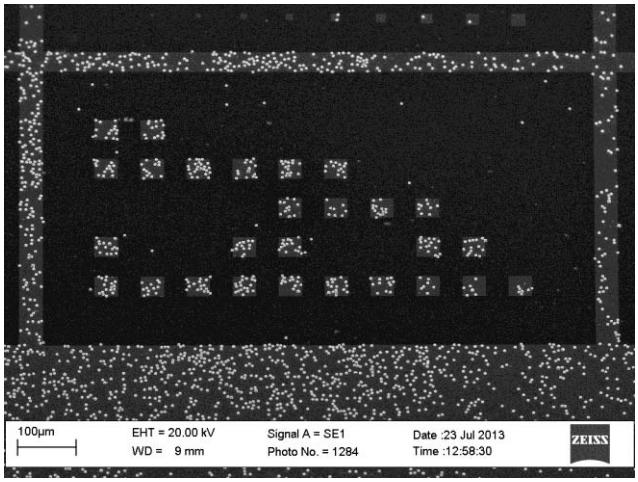

Figure 2: 5 µm wide square silicon microtiles (white) that have been self-assembled onto the gold patterned surfaces (grey) of a silicon substrate (black) using the avidin-biotin interaction. A very high attachment yield of microtiles and selectivity to gold over silicon attachment were achieved.

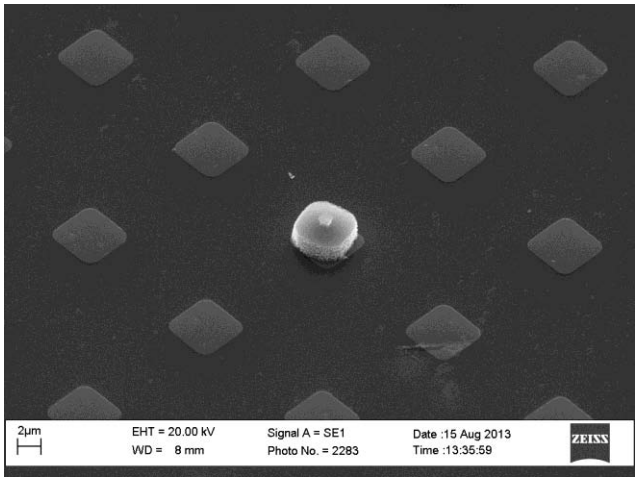

Figure 3: A 5 µm wide square silicon microtile that has self-assembled onto a 5 µm wide square gold pad. Tiles bind 'face-down', showing the underside and the broken pillar.

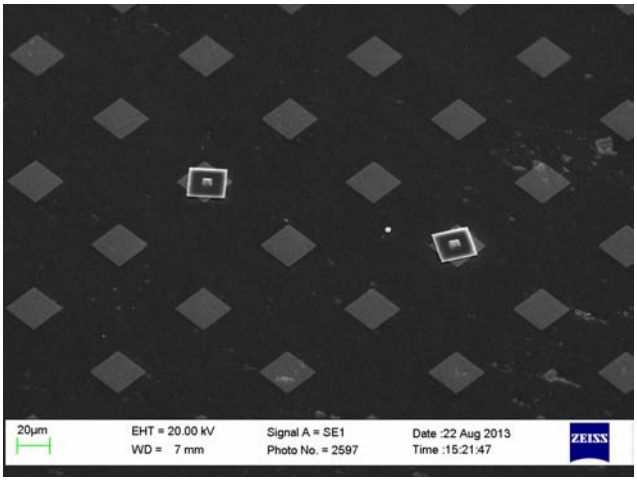

Figure 4: Two 25 µm wide square silicon microtiles that have self-assembled onto 25 µm wide square gold pads. Orientation control may be achieved by pad shape and annealing.