Perfecting Si and Metal Nanostructures Using Guided Self-Perfection by Liquefaction (G-SPEL)

Qiangfei Xia[1] and Stephen Y. Chou
NanoStructure Laboratory, Department of Electrical Engineering,
Princeton University, Princeton, New Jersey 08544

Removing the fabrication defects generated in conventional nanofabrication is crucial to further shrinking of nanostructures. Previously we have proposed and demonstrated a new approach -- self-perfection by liquefaction (SPEL) [1, 2], to repair fabrication defects (e.g. edge roughness, sidewall angle, etc) in semiconductor or metal nanostructures using selective, ultra-fast melting and liquid flow driven by surface tension and other boundary conditions. Here, we present further demonstration of a new variation of SPEL, where the self-perfection is guided by a flat plate, which is placed over the nanostructure-to-be-perfected and initially has a gap with the structure (Fig. 1). We observed, for the first time, that in the Guided SPEL, the silicon and metal nanostructures rise up on their own to reach the top plate, leading to a self-reshaping that not only has smooth edges, but also vertical sidewalls, flat tops, narrower width (~45% of original) and higher height (>210%) (hence >450% aspect ratio improvement).

Figure 1 shows more details of the G-SPEL process for Si and metal nanostructures. First, a flat fused silica plate is placed above the nanostructures-to-be-repaired with a gap (the gap is controlled by microfabricated spacers between the substrate and the plate). Then, a laser pulse of 308 nm wavelength and 20 ns pulse width is shone through the fused silica plate and melts the nanostructures for hundreds of nanoseconds, depending upon the laser fluence.

For Cr lines, after G-SPEL (a single laser pulse of 406 mJ/cm^2 fluence), both the edges and sidewalls are smoothed, the tops are flat, and the original linewidth of 280 nm and height of 62 nm become 130 nm and 130 nm, respectively (Fig. 2), offering a factor of 215% in narrowing of the linewidth and 210% increasing of the height (hence 450 % in aspect ratio). The line edge roughness (root mean square) was reduced from 13.5 nm to 4.7 nm -- ~300% improvement.

For Si nanostructure, after G-SPEL (a single laser pulse of 400 mJ/cm^2 fluence), the Si pads of 90 nm by 100 nm and 50 nm high (Fig. 3a) become cylinders of 78 nm diameter, 73 nm high (150% of original height) (Fig. 3c) with smooth and vertical sidewalls and flat tops. In comparison, in open-SPEL, where no flat plate is used as a control boundary condition, the final structures were semi-spheres (rather than cylinders) of 85 nm diameter and 62 nm high (Fig. 3b). The fact that the structure height rise in G-SPEL is more than that in O-SPEL indicates an attractive force between the nanostructures and the plate.

We believe G-SPEL offers a new way to repair defects and control critical dimensions and topography of nanostructures, and should have broad applications in improving the fabrication of devices for nanoscale electronics, photonics, magnetic memory, and biotechnology.

[1] S.Y. Chou and Q. Xia, EIPBN'05, Orlando, FL, May31-June 3, 2005.
[2] Q. Xia and S.Y. Chou, EIPBN'06, Baltimore, MD, May30-June 2, 2006.

[1] Email: qxia@princeton.edu

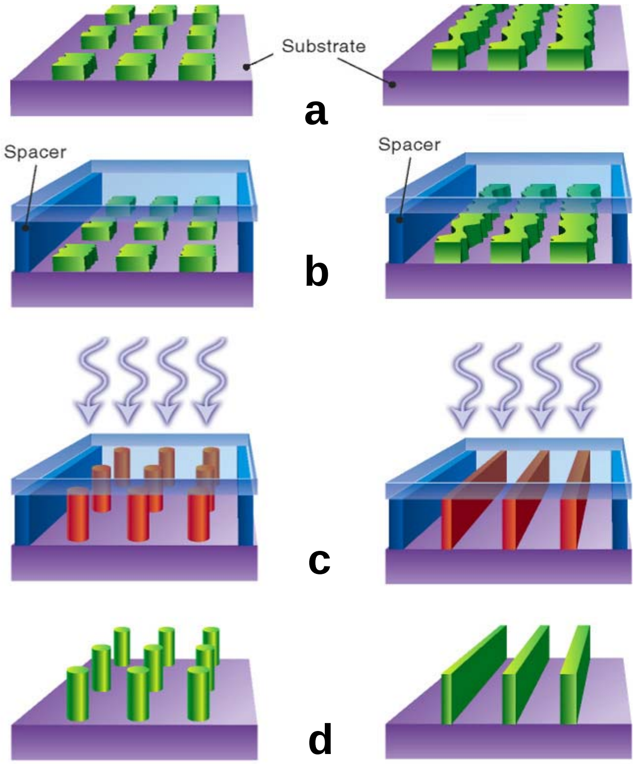

Fig. 1 Principles of guided self-perfection by liquefaction (G-SPEL). (a) Defective nanostructures on a substrate, (b) a flat plate is placed above the nanostructures with a distance (controlled by spacers), (c) a single laser pulse melts the structures and molten material self-rise to the top plate in 100's ns, (d) after re-solidification, new nanostructures have smooth and vertical sidewall, flat top, narrower linewidth, and taller height (higher aspect ratio).

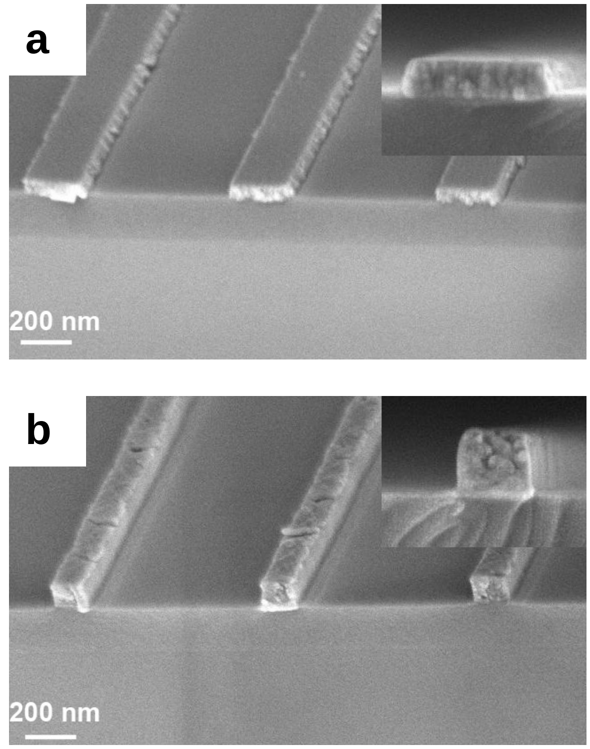

Fig. 2. G-SPEL of Cr lines. (a) The as-fabricated Cr lines of 280 nm wide, 62 nm high on a substrate (220 nm thermal oxide on a Si wafer). (b) After G-SPEL with a single laser pulse of 406 mJ/cm^2, the Cr lines were turned into 130 nm wide, 130 nm high.

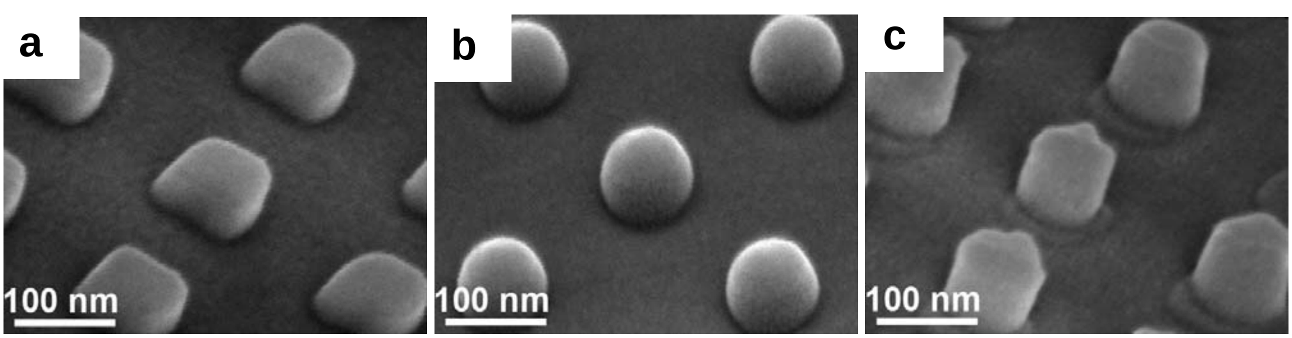

Fig. 3. G-SPEL of Si dots. (a) As-fabricated 50 nm high Si pads of 90 nm by 100 nm on 200 nm thick SiO_2. (b) With open-SPEL, the dots were turned into round dots of 85 nm in diameter and 63 nm high. (c) With G-SPEL, the Si pads were turned into cylinders of 78 nm in diameter and 73 nm high, with smooth and vertical sidewall, and flat top. The laser fluence used in both (b) and (c) was 400 mJ/cm^2.