Self-assembled templates guide growth of nanostructures on a silicon substrate

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Lines of bismuth, just 1.5nm wide, can be used as templates for fabricating the nanowires and nanocluster arrays that could eventually make up nanoelectronic devices.

To build next-generation nanoelectronic devices—composed of switchable molecules, carbon nanotubes, and so on—arranging and interconnecting the nanoscale components creates a significant challenge. The problem arises when trying to fabricate features just a few nanometers wide across an entire device. Conventional or top-down lithographic techniques are reaching their limits at 65nm. Direct-writing techniques, such as electron-beam and scanning-probe-microscope lithography, can theoretically write lines one-atom wide, but these techniques do not scale up to patterning across an entire substrate, such as silicon (Si). To address these issues, many bottom-up techniques based upon the assembly of nanostructures are currently being developed.

Next-generation devices could be built by arranging naturally nanoscale components—such as carbon nanotubes or preformed metal nanoclusters—on a surface. This can be done using self assembly. Some surface reconstructions, for instance, create metallic one-dimensional atomic structures, and anisotropic strain can be used to grow epitaxial nanowires that run with the crystalline orientation of the substrate. In my nanoline-template method, self-assembled bismuth (Bi) nanolines act as atomic-scale templates across an entire sample: these do not require direct writing and allow a variety of materials to be deposited.

Figure 1 shows Bi nanolines on Si(001), where the 001 indicates the orientation of crystals in the substrate. Annealing these materials at up to 600°C creates 1.5nm-wide Bi nanolines, which have no kinks or defects and grow longer than 1μm. These are described in more detail in an upcoming review article. Crucially, the Bi nanolines are passive to attack by atomic hydrogen (H). Consequently, the background Si can be masked, which leaves the Bi nanolines clean to act as preferential adsorption sites.

Deposition of metal shows a strong preference for adsorption onto the template, with no adsorption occurring on the background H:Si. Indium, as shown in Figure 2, interacts strongly with the Bi, forming long, flat, epitaxial islands. Silver, on the other hand, forms nanoclusters (see Figure 3). At 300K, the silver nanoclusters reach a peak size of about 0.55nm, which might represent an icosahedron of 13 atoms. At 400K, clusters up to 4nm high have been formed, and the upper limit has not been reached.

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In summary, conventional patterning techniques do not work on the single-nanometer scale. Nonetheless, my Bi-nanoline templates can guide the fabrication of indium or silver nanostructures. The deposition of other metals—including aluminum, cobalt, gold, iron, palladium, and platinum—is being investigated. Furthermore, this method could potentially be used as a template for other structures, such as fullerenes or prefabricated nanoclusters, which would greatly expand potential applications.

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References


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