## High-Throughput FIB-Less Fabrication of Metallic Nanopillars Reduces Tapering and Extends Lower Diameter Limit

$Ga^{+}$-induced damage to the microstructure and a nonuniform stress and strain distribution are serious concerns raised by the conventional focused-ion beam (FIB) milling approach used to fabricate nanomechanical testing specimens for uniaxial compression and tensile testing. M.J. Burek of the University of Waterloo and intern at the California Institute of Technology (Caltech) and J.R. Greer of Caltech, however, have designed a FIB-less fabrication process that is absent of $Ga^{+}$ ion damage, greatly reduces pillar tapering (and the associated strain-gradients), and can produce nanopillars with a wide variety of microstructures and diameters as small as 25 nm. In contrast to the FIB milling procedure, the researchers create arrays of gold and copper nanopillars by first patterning polymethylmethacrylate (PMMA) using electron beam lithography and then electroplating into the template. Burek and Greer state that this high-throughput process, which is capable of fabricating hundreds of pillars simultaneously, can be extended to a wide variety of electroplatable systems.

As described in the January 13 issue of *Nano Letters* (DOI: 10.1021/nl902872w; p. 69), the researchers created nanopillar arrays by first evaporating a Ti adhesion layer and then a Au seed layer onto Si substrates. The substrates were then spin coated with a PMMA resist layer, which was subsequently baked, exposed according to a specifically created pattern by using an electron beam lithography system, and developed. Metal electroplating was next used to fill the resist template, and finally, the PMMA resist was stripped away with acetone. In the case of nanopillars for tensile testing, brief overplating of the metal resulted in a cap on the top of the pillar that could be used in combination with a set of micrgrips. Without using ion bombardment, this lithographic approach allows full, automated control over the pore size and spacing of the resist. Furthermore, pillars with diameters much smaller (down to 25 nm) than those possible with the FIB technique can be readily fabricated. In addition, so long as the PMMA resist thickness closely matches the intended nanopillar height and the resist is not under or over exposed, the nanopillars are virtually taper-free (Figure 1). Depending upon the solution chemistry, by altering the applied dc current or using a reverse pulse current (ac) during the electroplating process, nanopillars with single, bi-, or tri-crystal; polycrystalline; or nanocrystalline microstructures can potentially be fabricated, as the researchers demonstrated for Cu nanopillars.

Without the additional complexity of ion-damage effects and strain gradients, the researchers said that this fabrication technique "brings the nanoscale plasticity community closer to the desired goal of investigating unique deformation mechanisms operating in nanoscale crystals."

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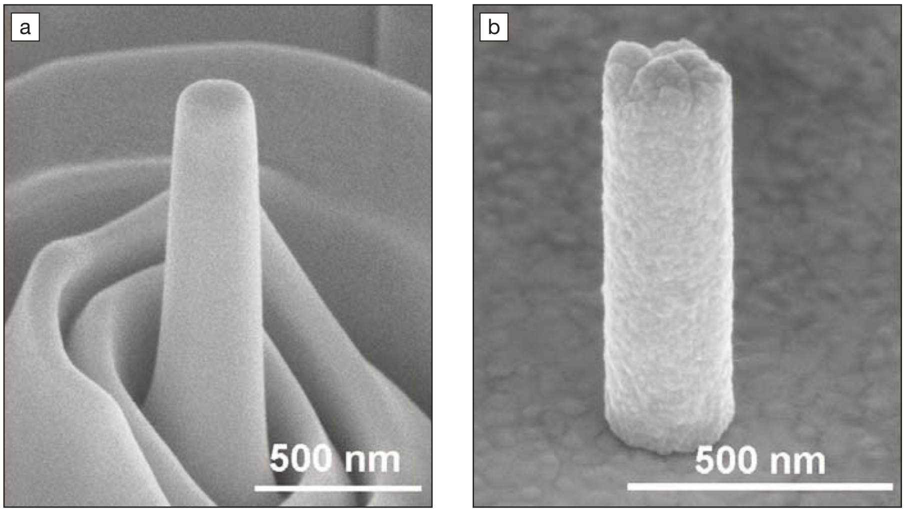


Figure 1. Scanning electron micrographs of Au nanopillars of 250–300 nm diameter. A clear reduction in pillar tapering is observed between Au nanopillars prepared by (a) the focused-ion beam milling and (b) FIB-less fabrication method. Reproduced with permission from *Nano Letters* **10** (1) (2010) 69; DOI: 10.1021/nl902872w. © 2009 American Chemical Society.