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Maskless Fabrication of Highly-Ordered Periodic Nanopillars using FIB and Bitmap Control

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Nanopillars have many potential applications, *e.g.*, in making biochips for DNA separation, fast genome sequencing analysis and producing photonic crystals. The form of lithography used in the semiconductor industry, optical projection lithography (OPL), can be used to produce feature sizes below 100 nm. However, a pattern must be first created on a mask, a large and heavy (over 1000 kg) and very expensive reduction lens has to be used to project the image of the mask onto a Si wafer, and high quality photoresist is needed to record the projected image. To achieve nanoscale precision, a variety of resolution-enhancement techniques have to be employed, including phase-shift masks, off-axis illumination, and optical proximity-effect correction. The cost of a set of masks for producing a chip can be well over US$2 million. The difficulty, time, and prohibitively high cost associated with designing and repairing a mask makes OPL unsuitable for exploring innovative applications of nanostructures. We demonstrate that FIB can be controlled effectively using bitmap to provide a one-step maskless nanofabrication tool for making micro- and nanoscale pillars (Figs. 1-2). In principle, the technique can be extended to make other nanostructures such as nano-gratings and nano-wells for various useful applications.

Focused ion milling was carried out using FEI Quanta 200 3D SEM/FIB dual beam workstation. The Ga^+ ion energy, incident angle, dwell time, and beam overlap were fixed at 30 keV, 0º, 3 µs, and 50% in all the experiments, but the beam current was varied from 10 pA to 5 nA to study its effect on the milling process. Ion beam diameter increases with beam current, so it is generally preferable to use small current for making nanoscale structures, but too small a current would entail too long a beam sputtering time. Our results show that 30 pA is a suitable current for making nanopillars at reasonably fast rate.

It is possible to induce self-organized surface patterns by ion beam sputtering [1-2], but lack of external controllability and lack of pattern regularity are the major problems with the self-organized approach. For "writing" highly-ordered periodic patterns directly, either the XY stage or the focused ion beam has to be programmed for patterned movement. We find it more convenient to control the beam movement for patterning in a small area (*e.g.*, 20 µm by 20 µm), though moving stage might be better for patterning much larger surface. For the purpose of controlling the beam, we used Photoshop software to prepare bitmaps with periodic black dots in white background. Fig. 1a shows a bitmap with arrays of circular black dots of 20 pixels in diameter. When the pixel size was scaled to 20 nm, the feature size was defined as 400 nm with a period of 800 nm. As shown in Fig. 1, the arrays of pillars produced on Si(100) wafer are in good agreement with the defined values of dimensions. When the pixel size was scaled down further, highly ordered arrays of nanopillars were produced on Si(100), as shown in Fig. 2. It should be pointed out that formation of the nanoscale structures is not only due to "direct writing" of FIB. Ion induced diffusion and material-ion beam interaction play an important role in controlling the shape and size of the pillars. For example, we found it much more difficult to produce nanopillars on InP(100) than on Si(100).

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[3] Wei Zhou would like to thank FEI for sponsorship and thank Dr. Jens Greiser and Mr. Andy Ong of FEI for helpful discussion.

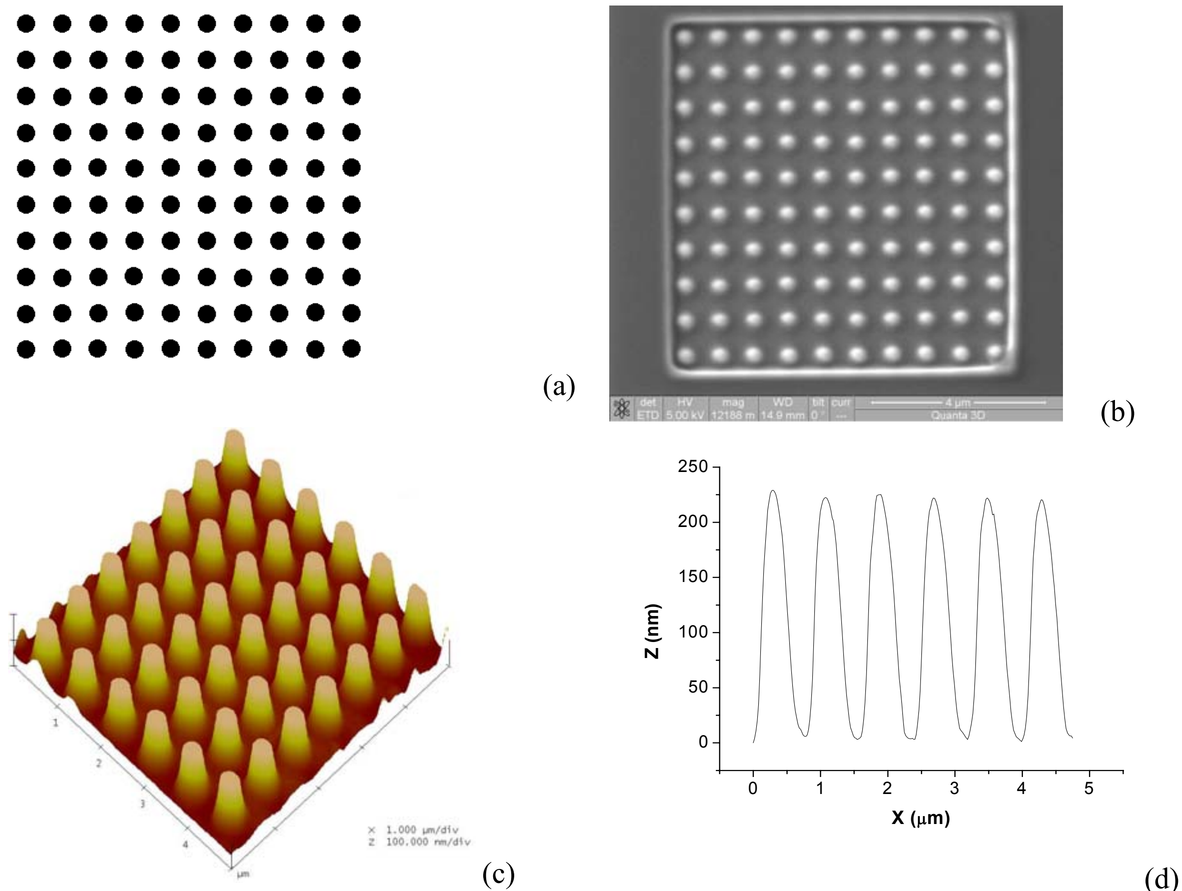

Fig. 1. Maskless fabrication of periodic micropillars using FIB. (a) Bitmap file used. (b) SEM image of arrays produced on Si(100) wafer. (c) 3D-AFM image of the micropillars. (d) AFM line profile across 6 pillars.

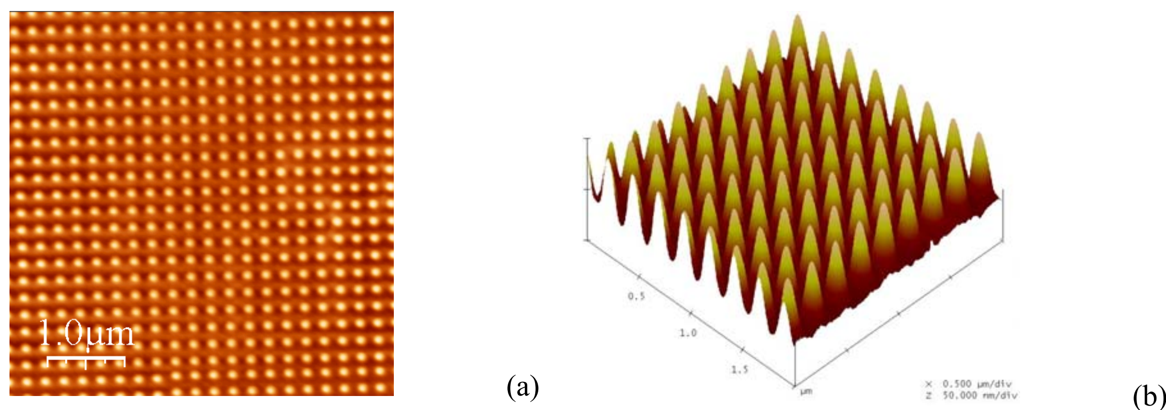

Fig. 2. One-step maskless fabrication of highly-ordered periodic nanopillars on Si(100) using FIB and bitmap control. (a) 2D-AFM image. (b) 3D-AFM image.

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