Novel Nanostructure Fabrication Method Combining Silicon Doping with Focused Ion Beam and Cryogenic Deep Reactive Ion Etching

N. Chekurov, K. Grigoras, A. Peltonen, S. Franssila and I. Tittonen
Helsinki University of Technology, *PO Box 3500, FI-02015 TKK, Finland*

We present a novel and rapid process for fabricating silicon nanostructures with the lateral dimensions of less than 50 nm and the height-to-width ratio of higher than 15. The process consists of only two steps. First we directly pattern a silicon substrate using a focused gallium ion beam (FIB) and then etch the structures using a SF_6/O_2 – based cryogenic deep reactive ion etching (DRIE). The gallium doped silicon serves as a mask during the etch step producing the desired structures.

The main benefits of this arrangement are a high writing speed and an advanced control over the wall profile. To form an adequate surface masking layer for producing structures up to 10 μm in height, only a moderate gallium dose of 10^{16} cm^{-2} is required. Compared to the direct or gas assisted milling, the speeding in the processing time is several orders of magnitude. A separate DRIE step provides an excellent way to control the wall profile and enables aspect-ratios up to 1:15, making it even possible to create dense arrays of high-quality structures (Figure 1).

In demonstrating the method we used an ion energy of 30 keV, producing a 30 nm deep doping layer. With the doping concentration of higher than 10^{16} cm^{-2} the whole treated volume becomes etch-resistant. One of the ways to utilize this feature is to use anisotropic etching to form free standing structures (Figure 2).

The process was realized using a Helios Nanolab 600 dual beam system (FEI Company) for the local gallium implantation and a Plasmalab System 100 reactor (Oxford Instruments) for etching. The maximum achieved resolution was 20 lines μm^{-1} and the smallest masked feature size was around 40 nm. The selectivity between the gallium doped ($3 \cdot 10^{16}$ cm^{-2}) and untreated silicon is estimated to be higher than 1000, allowing etching the structures that are higher than 80 μm without mask erosion.

Another advantage of the FIB-DRIE fabrication method is a very short processing time. A single component of arbitrary configuration within 10×10 μm^2 writefield can be produced in under two hours. This includes patterning the component at maximum resolution, writing large 150×150 μm^2 bonding pads and etching. The etch rate is c.a. 2 μm/min, so the typical etch time is well under 10 minutes.

This fabrication method can directly be utilized for prototyping purposes in plasmonics and metamaterials research and with some additional processing for nanomechanical networks and quantum structures.

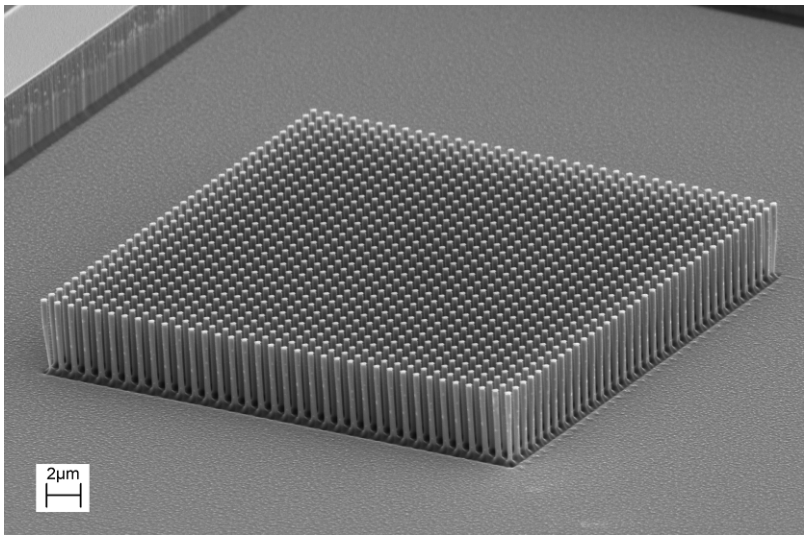

Fig 1: 4 µm high pillars 280 nm in diameter, forming a 36 by 36 – matrix, fabricated by a FIB gallium masking and cryogenic DRIE etching.

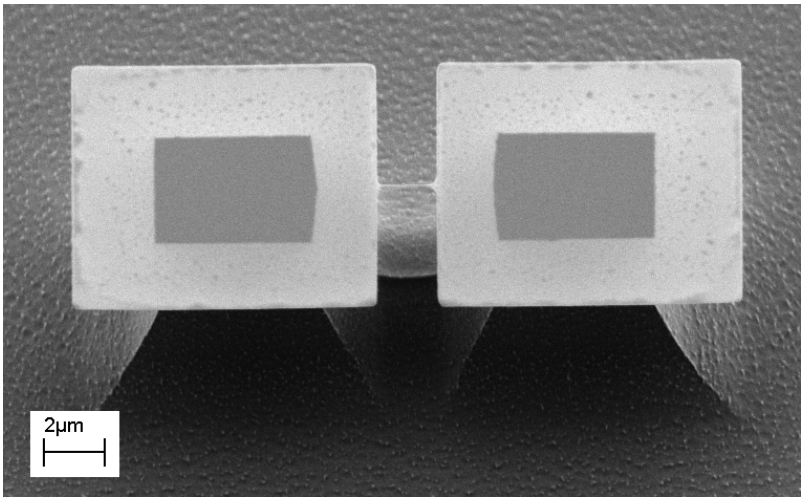

Fig 2: 20 nm wide, 30 nm thick and 2 µm long freestanding silicon nanowire produced by Gallium implantation and isotropic plasma etching.