Nanolithography Using Transferrable Membrane Mask For Unconventional Substrates

Luozhou Li[a,b], Igal Bayn[a,b], Ming Lu[c], Chang-Yong Nam[c], and Dirk Englund[a]
[a]*Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Cambridge, MA 02139*
[b]*Department of Electrical Engineering, Columbia University, New York, NY 10027*
[c]*Center for Functional Nanomaterials, Brookhaven National Laboratory, Upton, NY 11973*
ll2670@columbia.edu

The ability to define patterns in a nanometer scale is a corner stone of modern nanotechnology. The patterns, whose critical dimension falls into sub-100-nm range, are usually written in a resist by electron-beam lithography and then transferred onto a substrate of interest via additional processing (etching or lift-off). This approach, while being commonly accepted and producing unparalleled results in “classical” microelectronic materials such as silicon (Si) and gallium-arsenide, cannot be implemented in many novel and emerging material systems due to their small sample size, insulating properties and non-planar surface morphology. A wide variety of potential applications, such as quantum photonics[1,2] and fiber-integrated photonics[3], require high-resolution patterning in those materials. One of those applications are quantum photonic devices fabricated on 200-nm-thick diamond membranes. Generally it is hard to produce uniformly flat diamond membranes over 100-µm-scale. Also, it is not preferred to process small diamond membranes with wet processing, such as resist coating, development and acid etching, due to the difficulty in sample handling. In addition, the realization of high-quality photonic devices on them requires nanometer precision, which is difficult to achieve by direct electron-beam lithography due to the limitations discussed above.

Here we introduce a reliable lithographic technique with sub-10-nanometer resolution, which makes use of the most mature Si-based lithography technologies to a wide variety of unconventional materials. The technique uses micro-PDMS sphere attached on a tungsten tip or bulk PDMS to transfer silicon membranes onto desired substrate, e.g. diamond, gallium phosphide and silicon carbide, followed by anisotropic dry etching to transfer the pattern onto the substrate (Fig. 1a and 1b). Tone-reversal pattern transfer has also been demonstrated by the additional metal deposition, followed by a mask removal step between mask transfer and dry etching (Fig. 1c and 1d). The substrate could be of arbitrary shape, and as an example, we implemented this technique on fiber

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[1] M. Loncar and A. Faraon, MRS bulletin **38**, 144-148 (2013).

[2] W. F. Koehl, B. B. Buckley, F. J. Heremans, G. Calusine and D. D. Awschalom, Nature **479**, 84-87 (2012).

[3] D. J. Lipomi et al., Nano Lett. **11**, 632-636 (2010).

ferrule for fiber-integrated applications (Fig. 2). The presented approach meets the requirements of many patterning applications by offering high alignment accuracy and multiple mask use without electron beam irradiation on the substrate.

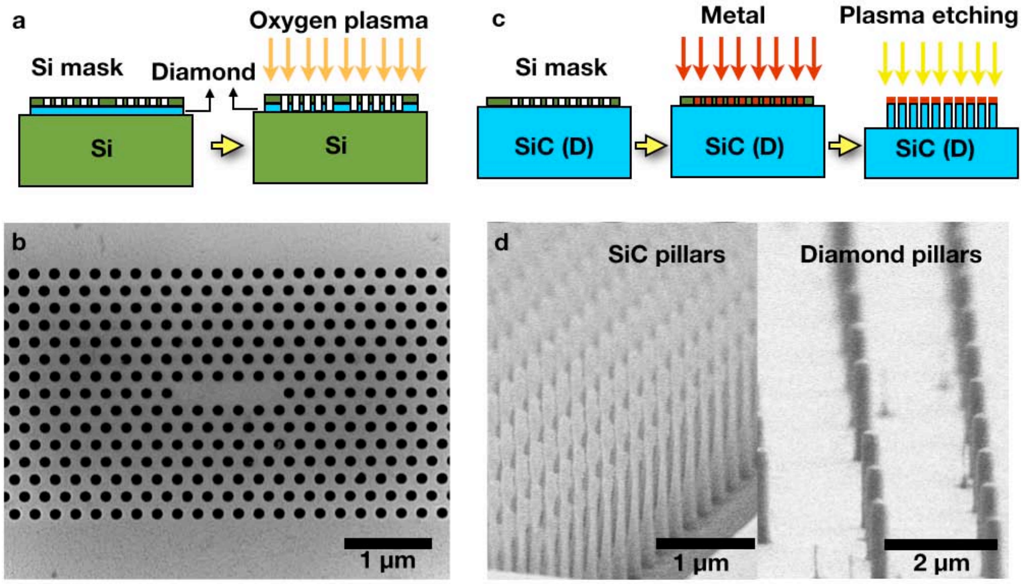

Figure 1: Silicon membranes as robust etch masks: a, Fabrication schematics of a silicon membrane (green) directly used as the etching mask for diamond photonic devices (blue). b, The resulting photonic crystal cavity in diamond. c, Fabrication schematics of tone-reserved pattern transfer with the addition of metal deposition and silicon membrane removal steps between silicon membrane transfer and dry etching. d, The resulting SiC and diamond nanopillar arrays after the tone-reserved pattern transfer.

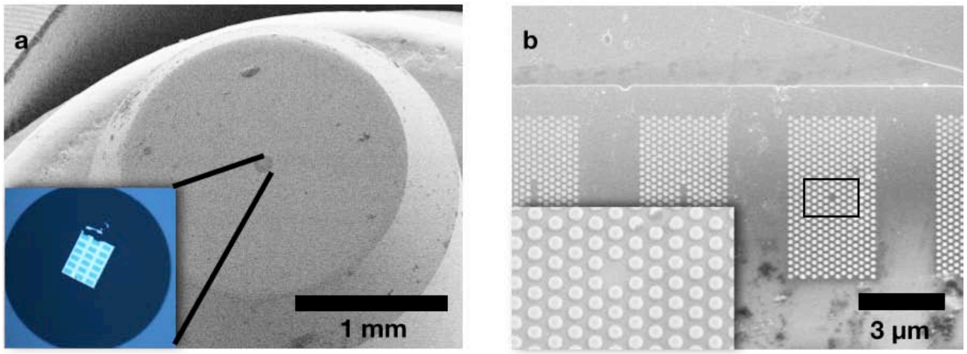

Figure 2:Examples of fiber-integrated applications: a, A silicon membrane with photonic crystal cavity array was transferred on fiber ferrule. The inset image shows an enlarged view of photonic crystal cavity arrays on the fiber core. b, Metal dot arrays were inversely transferred on fiber ferrule. The inset image shows an enlarged view of the region denoted by the black rectangle.