Fabrication of single-crystal diamond nano-slabs for photonic applications

Luozhou Li, Edward H. Chen, Matthew Trusheim, Jonathan S. Hodges, Dirk Englund
Columbia University, New York, NY 10027
ll2670@columbia.edu
Ming Lu
Center for Functional Nanomaterials, Brookhaven National Laboratory, Upton, NY 11973

Production of photonic nanostructures in diamond membranes for interactions between embedded color centers, such as negatively charged nitrogen vacancy (NV^-) centers, with confined optical modes are nearly within reach of current fabrication techniques. Demonstration of such regimes in light-matter interactions would secure diamond as a viable platform for quantum information processing[1]. The advent of optically thin membranes in other semiconductor materials has enabled the development of a variety of nano-photonic devices. However, a remaining challenge concerns the growth of high-quality, single-crystal diamond membranes on lattice-matched substrates.

Here, we introduce an approach to fabricate thin, tall slabs of diamond by vertically etching a single-crystal diamond plate that is commercially available (Fig. 1). These diamond nano-slabs can then be mechanically removed from the bulk diamond plate for further processing, so that the plate may be reused after polishing for nano-slab fabrication. To produce slabs that are nearly vertical and deep enough to accommodate micro- and nano-photonic devices, we have developed a new process that alternates between plasma etching and mask deposition steps, similar to the Bosch process used in deep reactive ion etching. This process enables vertical nano-slabs with aspect ratios (height: thickness) of about 50, including 200-nm-thick slabs that are 10 μm tall (Fig. 2). We mechanically separate the nano-slabs from the parent bulk diamond, and implant NV^- centers (Fig. 3a). Spin-echo experiments[2] indicate that the NV^- centers in the nano-slabs exhibit very long spin coherence times that approach 100 μs, which is comparable to high-quality bulk diamond. When necessary, we thin the nano-slabs using plasma etching to the desired thickness. These above-mentioned dimensions are suitable for a range of nano-photonic devices. In particular, we pattern two-dimensional photonic crystal cavities into them using focused ion beam (FIB)[3]. We also confirm that the material properties of nano-slabs produced using only plasmas etching processing are indistinguishable from the parent bulk diamond using Raman scattering characteristic (Fig. 3b).

---

[1] A. Igor, A. Greentree, and S. Prawer, Nature Photonics, 5(7), pp.397-405 (2011).
[2] J. Hodges, L. Li, M. Lu, E. Chen, M. Trusheim, S. Allegri, X. Yao, O. Gaathon, H. Bakhru, and D. Englund. New Journal of Physics, 14(9):093004, 2012.
[3] J. Riedrich-Moller et al, Nat Nanotechnology, 7(1):69-74, Jan 2012.

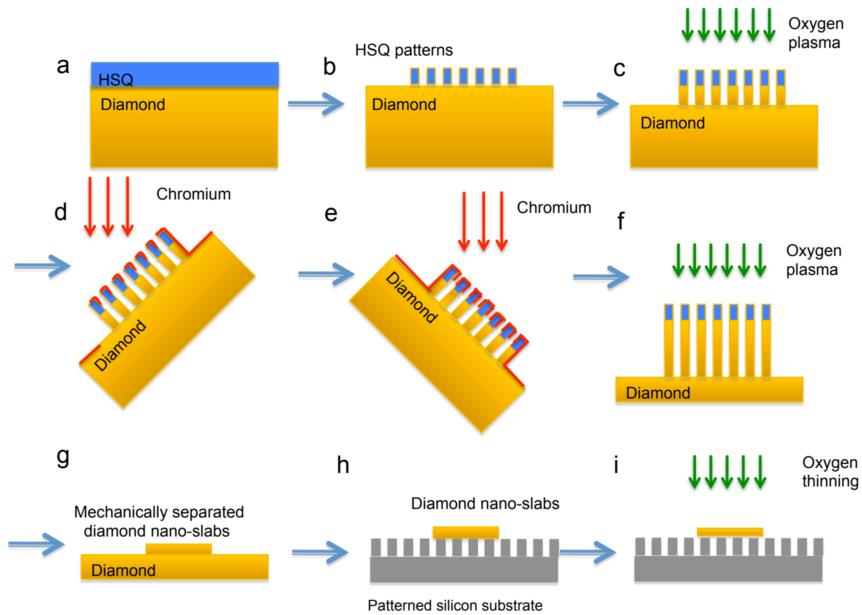

Figure 1: Fabrication procedure. (a) e-beam resist coating; (b) e-beam lithography and development; (c) initial oxygen plasma etching of diamond; (d) and (e) Cr deposition at an oblique angle; (f) continued oxygen plasma etching of diamond; (g) mechanically separated diamond nano-slabs from diamond; (h) diamond nano-slabs transferred to a patterned silicon substrate; (i) further thinning of diamond nano-slabs with oxygen or chlorine plasma etching.

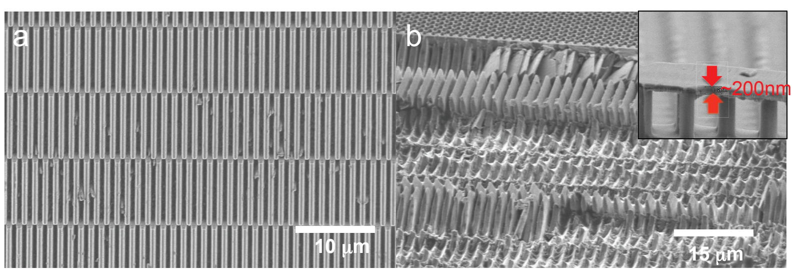

Figure 2: Scanning electron microscope images of diamond nano-slabs (a) before and (b) after mechanical separation. The inset image shows one diamond nano-slab transferred onto patterned silicon substrate and thinned with plasma etching to ~ 200 nm.

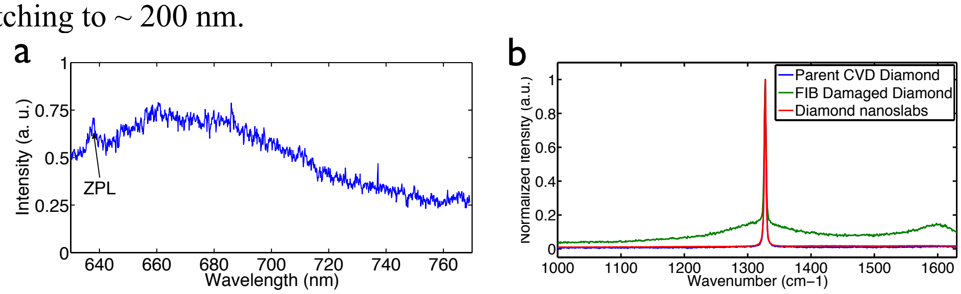

Figure 3: (a) Spectrum of fluorescence from one NV^- center in the fabricated nanoslabs clearly showing the presence of the zero-phonon-line (ZPL) at 637nm. b) Raman scattering spectra from parent diamond, FIB damaged diamond and fabricated diamond nano-slabs showing the quality of nano-slabs is distinguishable from parent diamond.