Free-standing nanoscale mechanical and photonic devices fabricated in single-crystal diamond

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A variety of nanoscale photonic, mechanical, electronic, and optoelectronic devices require scalable thin film fabrication. Typically, the device layer is defined by thin film deposition or growth on a substrate of a different material, and optical or electrical isolation is provided by the material properties of the substrate or by removal of the substrate. For a number of materials this planar approach is not feasible, and new nanofabrication techniques are required to realize complex nanoscale devices.

Recently, we have developed a three dimensional fabrication technique, illustrated in Figure 1 (a), based on anisotropic plasma etching at an oblique angle to the sample surface[1]. This 'angled-etching' was achieved using a standard reactive ion etcher, by housing the sample inside a Faraday cage to shield it from electromagnetic fields. One such Faraday cage design is a triangular structure shown schematically in Figure 1 (b). The triangular design allows for angled-etching in two simultaneous directions, as illustrated in Figure 1 (c). As a proof of concept, this angled-etching methodology is used to fabricate free-standing nanoscale components in bulk single-crystal diamond, including nanobeam mechanical resonators, optical waveguides, and photonic crystal and microdisk cavities. Figure 2 displays SEM images of such prototype devices.

Initial characterization of single-crystal diamond nanobeam mechanical resonators, shown in Figure 3 (a,b), revealed resonance frequencies in the ~ 1 to 10 MHz range, with mechanical Q-factors on the order of 10^4 recorded in high vacuum. Measurements of single-crystal diamond nanobeam photonic crystal cavities (Figure 3 (c,d)) revealed modes in the telecom wavelength range, with optical Q-factors as high as ~ 20 000. Potential applications of the fabricated devices range from classical and quantum photonic devices to nanomechanical-based sensors and actuators[2].

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[1] M. J. Burek *et al.*, Nano Letters **12**, 6084 (2012).

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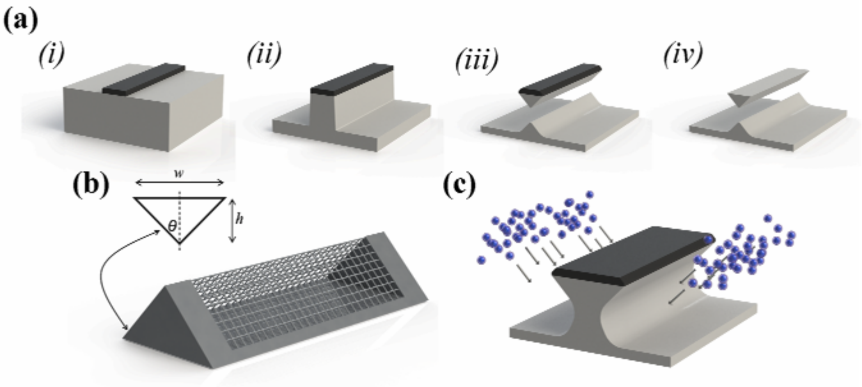

Figure 1: (a) Angled-etching fabrication schematic: (i) an etch mask was defined on the substrate, (ii) the etch mask pattern was then transferred into substrate by top down plasma etching, (iii) angled-etching is then employed to realize suspended nanobeam structures, (iv) residual etch mask is removed. (b) Schematic of triangular prism Faraday cage design with inset showing the relationship between etch angle and nanobeam apex. (c) Illustration of angled-etching from two directions accomplished with the triangular prism cage design.

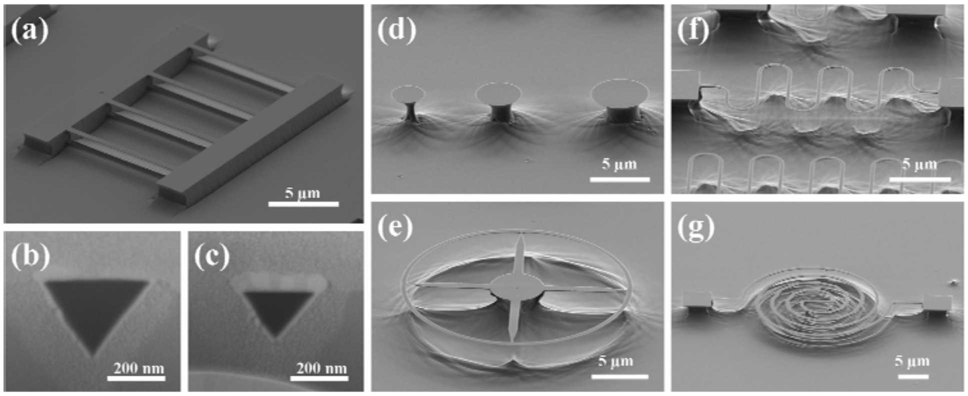

Figure 2: SEM images an array of (a) suspended ~ 500 nm wide solid diamond nanobeams and FIB cross-sectioned (b) ~ 350 nm and (c) ~ 250 nm wide diamond nanobeams. SEM images of (d) ~ 3 μm to ~ 5 μm diameter undercut microdisks; (e) ~ 500 nm wide nanoring structure; and (f) ~ 500 nm wide curved and (g) ~ 750 nm wide spiral nanobeams. SEM images taken at a 60° stage tilt.

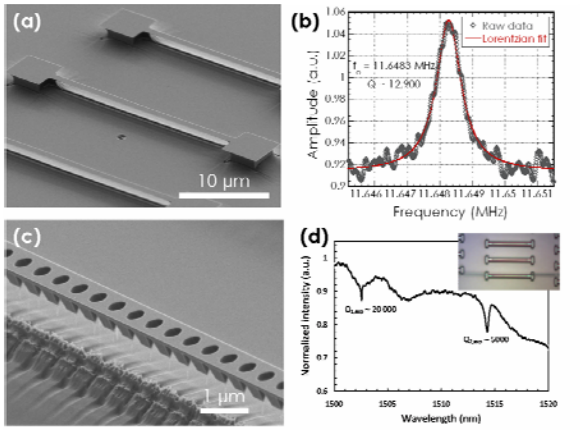

Figure 3: (a) SEM image of an array of diamond nanobeam mechanical resonators and (b) high resolution mechanical spectrum. (c) SEM image of fabricated diamond nanobeam photonic crystal cavity and (d) optical transmission spectrum indicating two cavity modes.