Nanoscale patterning of Niobium Nitride thin films for superconducting metamaterials

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Superconducting nanostructures are of growing interest for their unique properties and potential applications in advanced quantum and electronic devices. This work presents the fabrication and characterization of nanopatterned niobium nitride (NbN) nanowires and films, developed as a platform for top-down superconducting metamaterials. Emphasis is placed on refining electron beam lithography and resist processing to achieve reliable, high-resolution patterning in epitaxial NbN thin films on sapphire.

A negative-tone HSQ lithography process was optimized, and multiple development techniques were evaluated, including 25% TMAH at room temperature and at 50 °C, as well as salty development. Grid-patterned nanowires with a 70 nm pitch and superconducting wire widths down to 22 nm were successfully fabricated, as shown in the SEM micrograph in Fig. 1 and the TEM micrograph in Fig. 2. Various proximity effect correction strategies were employed to improve pattern fidelity. In addition, square-millimeter-scale nanopatterned superconducting films with a 100 nm pitch were fabricated using a positive-tone ZEP resist process, as shown in Fig. 3. These films enable future THz spectroscopy studies of superconducting behavior in nanostructured films.

Structural and dimensional characterization using SEM, AFM, and TEM confirms the fidelity of the patterned features. These results establish a robust process flow for fabricating nanopatterned epitaxial NbN films and nanowires suitable for top-down superconducting metamaterials.

Acknowledgements
This work was funded in part by the Defense Sciences Office (DSO) of the Defense Advanced Research Projects Agency (DARPA) (HR0011-24-9-0311). AS and EB acknowledge support from the NSF GRFP, DM from the Alan McWhorter fellowship, and DJP from the MathWorks Engineering Fellowship. This work was carried out in part through the use of MIT.nano's facilities.

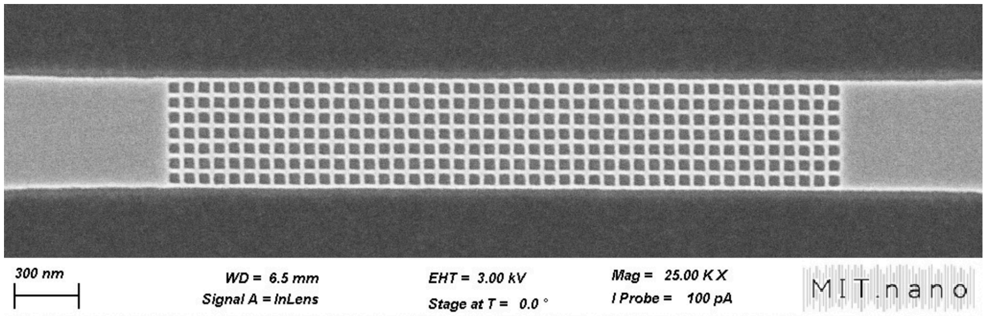

Figure 1: SEM micrograph of a nanopatterned NbN nanowire: the square pattern has a 70 nm pitch. The sample was etched with RIE to transfer the pattern to the underlying NbN layer, and was later coated with 2 nm of Au for SEM imaging.

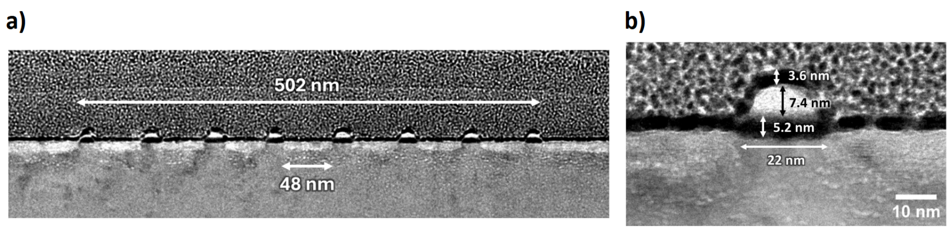

Figure 2: TEM micrographs of a cross-section of a nanopatterned NbN nanowire:
a) The nanowire across its full width, showing 8 separate subwires. The region of highest electron transparency is the HSQ mask, with the NbN layer beneath it.
b) A single subwire with layer thickness measurements: the Au coating is 3.6 nm, the remaining HSQ mask is 7.4 nm, and the NbN sub-wire is 5.2 nm thick and 22 nm wide.

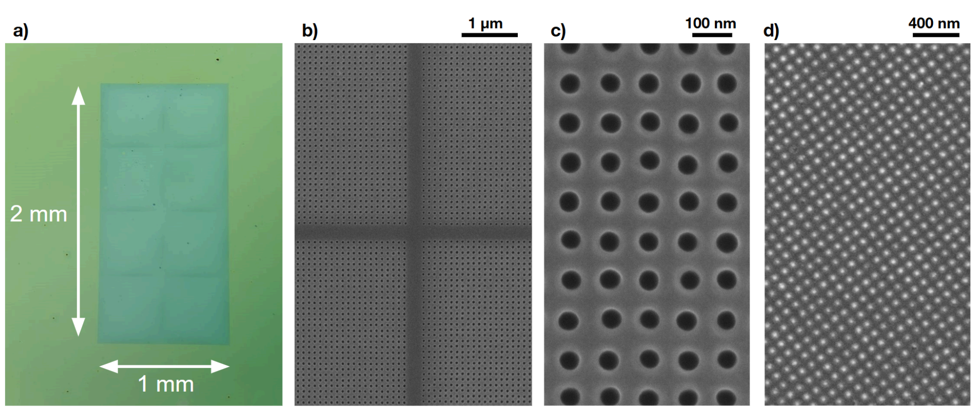

Figure 3: Large area exposure of a NbN film: a) optical image of a 2 mm × 1 mm patterned area, b) SEM micrograph of the intersection between four stitched fields, c) magnified SEM of a portion of the nanopatterned area, and d) SEM of the nanopatterned NbN film after resist stripping.