Fabrication of Microwires on Reduced Indium Tin Oxide Nanoparticle Thin Films

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Technologies such as quantum networks require circuit architectures that put optical modes on-chip with superconducting microwave electronics [1]. However, such circuits are frequently limited by absorption of the optical field in the superconducting electronics, which can degrade the performance of both the optics and the superconductor. Although fine-tuning the geometry of the circuit can decrease optical absorption in the superconductor, the absorption could be further reduced if the electronics were made of a superconductor that was transparent to visible light.

Indium tin oxide (ITO) has previously been studied as a transparent conductor with a low carrier concentration and a high mobility. ITO has been shown to superconduct with a transition temperature tunable by carrier concentration [2], which in turn can be linked to concentration of oxygen vacancies [3]. We electrochemically reduced ITO and examined the potential of the resulting material for fabrication of transparent superconducting electronics. Notably, reduced ITO forms a low-oxygen nanoparticulate thin film on top of the original surface, as confirmed by an XPS depth profile. Carrier concentration and morphology of the nanoparticle layer were found to be both critical to film performance and highly dependent on properties of the original ITO film. Additionally, we studied two different methods of patterning the reduced film: direct patterning of the reduction and ion beam milling. We compared the performance of microwires patterned by these methods.

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[2] A. Alievet al., “Reversible superconductivity in electrochromic indium-tin oxide films,” Appl. Phys. Lett. 101, 252603, 2012.
[3] N. Mori, “Superconductivity in transparent Sn-doped In_2O_3 films,” J. Appl. Phys. 73, p. 1327-1338, 1993.

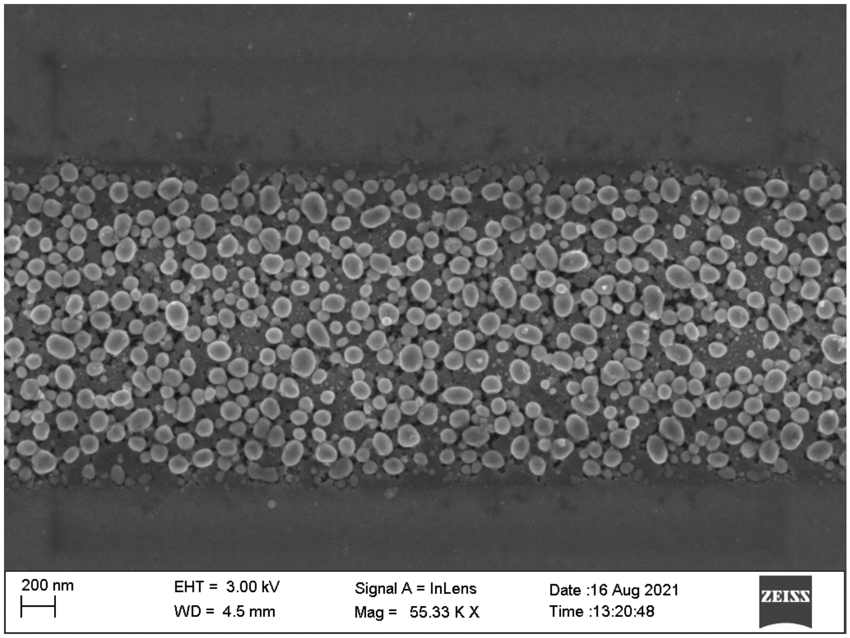

Figure 1: Directly patterned microwire: Direct patterning of the reduction results in a wire with a clean delineation between the masked ITO (sides) and the reduced ITO (bright particles in center). The above wire was designed to be 2 μm wide, and the final result measures about 1.9 μm edge-to-edge. Reduction was performed with 95 μA of current for 50 s over an exposed area of 6.6×10^{-2}cm^2, totaling about 72 mC/cm^2. Later experiments showed this to be near the optimum value of charge transferred to maximize transition temperature.

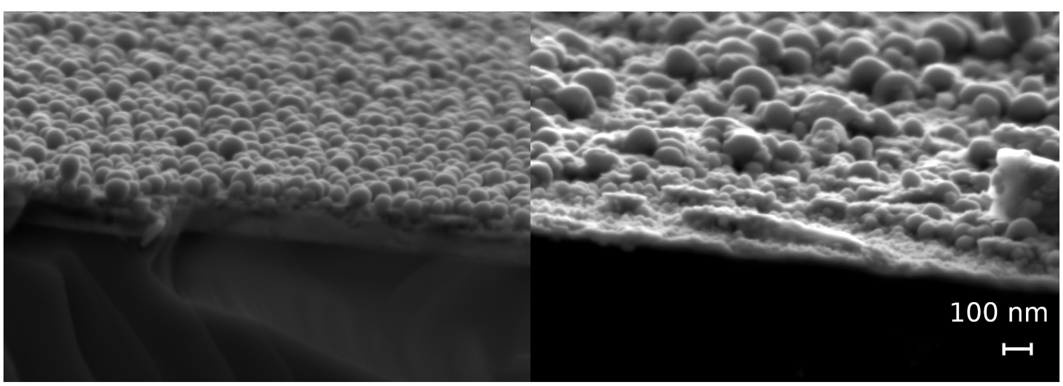

Figure 2: Morphologies of the nanoparticle thin film: (Left) SEM cross-section of an ITO film reduced by about 90 mC/cm^2 with a transition temperature of 1.8 K. (Right) SEM cross-section of an ITO film reduced by about 108 mC/cm^2 with a transition temperature of 1.4 K. Note the difference in morphology: the film on the left is fairly uniform, while the film on the right has begun to develop random larger nanoparticles.