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Superconducting Nano Wire Josephson Junction Fabricated using a Focused Helium Beam

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Introduction and motivation

Traditionally superconducting circuits made from high transition temperature superconductors (HTS) are patterned using an argon ion mill. HTS materials are extremely sensitive to processing and degrade easily. Chemical etching can only be used on large features to tens of microns. Dry etching with isotropic argon ion milling is required for smaller feature sizes, however, overheating of the material by ion milling causes deoxygenation which in most cases transform the superconductor into an insulator. Therefore, the critical dimension for dry etching is limited to a few microns. Although recently there are advancements in fabricating nano wires with an argon ion mill by using protective layers in the milling process. A simple yet well controlled method to reliably pattern nano scale features and reduce the Josephson junction dimension are essential for superconducting circuits.

Methodology

We propose a novel method of patterning superconducting circuits by local modification of the superconducting material. Since $YBa_2Cu_3O_{7-\delta}$ (YBCO) undergoes a superconducting-insulator transition when irradiated with high energy ions, it is possible to modify the electrical properties of the material with disorder. Instead of removing material, we create disorder in the material with a finely focused helium ion beam (FHB) so that it locally converts the material to an insulator. This creates an insulating barrier without generating excess heat that damages the material. Josephson junction was placed in each nano wire

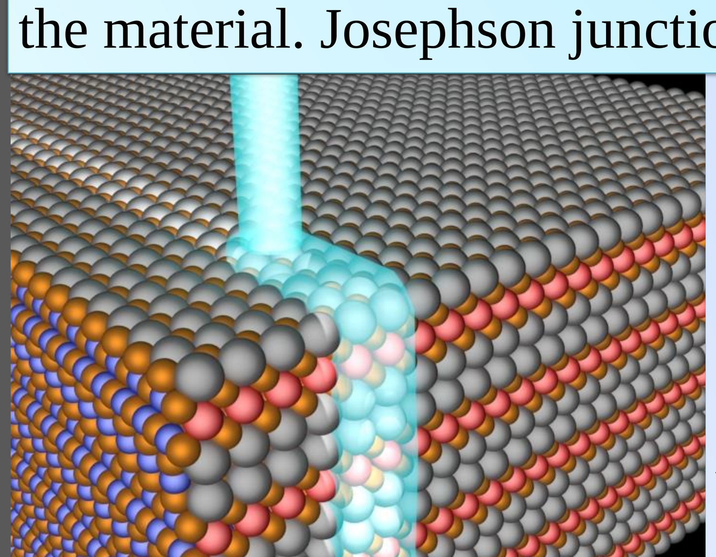

Figure 1. A schematic showing a helium beam creating disorder in $YBa_2Cu_3O_{7-\delta}$ crystal. The beam size is on the order of YBCO unit cell and creating disorder in a few nanometer wide range.

to create nano junctions. Therefore, the FHB can create and modify the dimension of the Josephson junction. In addition, the product of critical current and normal state resistance (I_CR_N) of Josephson junctions is a good metric for measuring the nano wire width.

Experiment

For our experiment, test samples were prepared by patterning 4 μm wires with standard photolithography and broad beam ion etching from 30-nm thick YBCO films grown on sapphire. Nano wires were made by creating insulating barriers by irradiation to narrow down the 4 μm wires (Fig. 2). The nano Josephson junction in the middle of the wire also helped to precisely determine the wire [3].

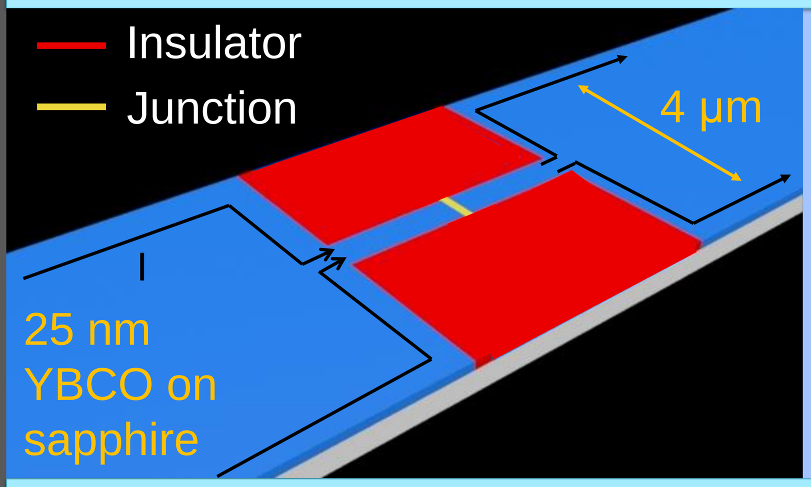

Figure 2. Schematic representation of a direct write nano wire. A 4 μm YBCO wire was narrowed down to 250 nm with insulating barriers (red lines). A Josephson junction was inserted in the middle of the wire with a lower dose (orange line).

Measurement of the Josephson junction parameters, maximum super current (I_C) and voltage state resistance (R_N), allow us to accurately determine the wire width. To create the sample we first used a dose of 6×10^{16} He^+/cm^2 to write a Josephson junction, and then the dose was increased to 2×10^{17} He^+/cm^2 to write the insulating barriers that define the nano wire. Three test samples were made with wire widths of 500 nm, 250 nm and 50nm, and a control sample without narrowing the wire (4 μm).

Results and conclusion

Current-voltage characteristics of the samples were measured in a vacuum cryostat inside of a liquid helium dewar at 4K. Figure 3 shows the results for different width junctions. All of the junctions have an I_CR_N product of about 400 μV. We expect the I_CR_N product should be a constant. This implies that material properties in the wire remained the same and that there

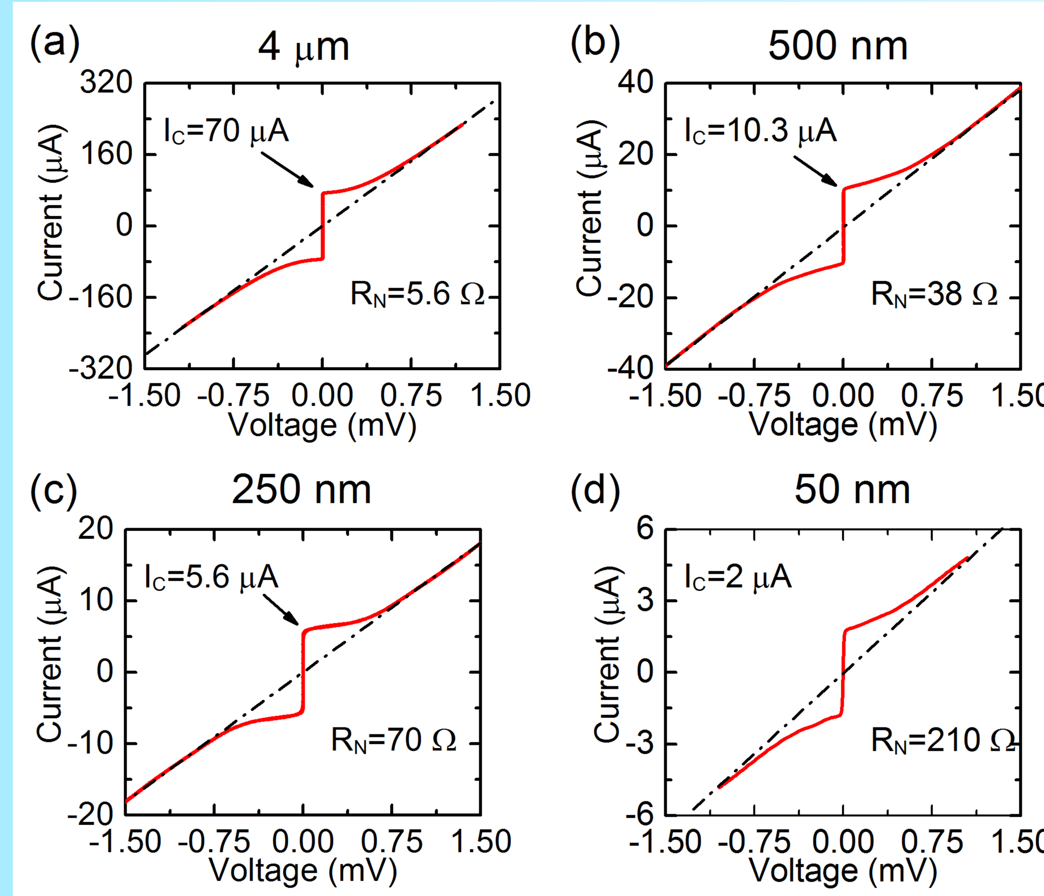

Figure . Current-voltage characteristics of YBCO Josephson junctions 4.2 K with wire widths of 500 nm, 250 nm, 50 nm, and 4 μm. The red lines are the measured data and the black dashed lines indicate extracted R_N.

was no thermal damage. Furthermore, R_N are 70, 38 and 5.6 Ω, which scale inversely proportionally with the width $\left(\frac{1}{R_N} \propto w\right)$. I_C for the junctions are 5.6, 10.3 and 70 μA, which scale proportionally with the width $(I_C \propto w)$ as it should. These results provide strong evidence that the current only flows through the nano filament, and that we were successful in direct writing of nano junction in nano wires.

This new technology provides an improvement in patterning HTS and enables fabrication of high density nano scale superconducting circuits and interconnects.

Reference

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Acknowledgement

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