Focused Helium Beam Fabricated Superconducting Devices

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In this talk, we will present a novel technique to fabricate Josephson junctions and the junction properties in several materials that were previously difficult to process.[1] This technique uses a focused helium ion beam (FHB) of 0.5 nm to irradiate and create disorder. Electrical transport data suggest the critical dimensions are less than 3 nanometers. (Fig. 1) The helium ion irradiation from the Orion Nanofab has energy of 30 keV. Therefore, our superconducting thin films are typically approximately 30 nm to ensure the ions completely penetrate the thin film. By adjusting irradiation dose we can control the disorder that modifies the material superconducting properties to create Josephson junctions. In particular, we have demonstrated a continuous transition from a superconductor-normal metal-superconductor (SNS) type junction to a superconductor-insulator-superconductor (SIS) type junction in Y-Ba-Cu-O. The product of junction critical current (I_C) and normal state resistance (R_N) of FHB Josephson junction reached 1 mV, primarily from the increase of R_N, because barriers created by FHB are very well defined and have higher resistivity than the prior art.

It is also possible to create junctions in metallic superconductors such as MgB_2 and iron-based materials, for example, Co-FeAs. However, the dose required for the more metallic material is about an order of magnitude high than oxides like Y-Ba-Cu-O and the junctions are generally SNS junction. From the demonstration of fabricating Josephson junctions in different material systems suggest this technique is applicable to any material that is sensitive to disorder.

The FHB irradiation can also be used to pattern circuits. By irradiating with a higher dose, we can directly define insulating regions with FHB. The disorder process is much less aggressive than ion milling which is the conventional patterning method. Therefore, the heat generated during etch process that can deoxygenate the Y-Ba-Cu-O films is reduced. This significantly reduces the patterning feature sizes that was previously limited to about a micron. We have demonstrated superconducting oxide nanowires with sizes as small as 25 nm

[1] Cybart, S.A., Cho, E.Y., Wong, T.J., Wehlin, B.H., Ma, M.K., Huynh, C. and Dynes, R.C., 2015. Nano Josephson superconducting tunnel junctions in YBa2Cu3O7–δ directly patterned with a focused helium ion beam. *Nature nanotechnology*, *10*(7), pp.598-602.

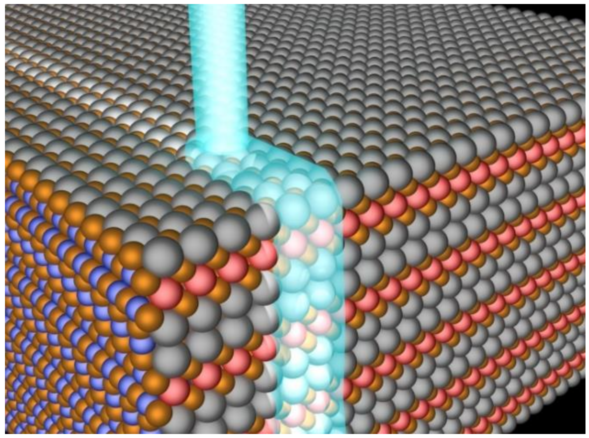

Figure 1: A schematic of Y-Ba-Cu-O crystal irradiated with a focused helium beam, the size of the beam and the crystal are to scale. The light gray region on the crystal show where we believe the disorder occurs.