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Nano Josephson Superconducting Tunnel Junctions Direct-patterned in Y-Ba-Cu-O with a Focused Helium Ion Beam

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Functional oxide materials are very sensitive to disorder and many transition from metal to insulator as disorder increases. This phenomenon has been used for many years to fabricate Josephson junctions in cuprate high-transition-temperature (T_C) superconductors like $YBa_2Cu_3O_{7-\delta}$ (YBCO). In this approach, ion irradiation is used to selectively disorder a nanoscale region of material between two superconducting electrodes, that serves as a Josephson barrier. Historically, the barriers created in this manner have been tens of nanometers in length which only allowed for the creation of superconductor-reduced-T_C-superconductor-superconductor junctions. We have reduced the length of the Josephson barriers to just a few nm by using a 500 pm diameter focused beam of helium ions. The smaller length of these barriers allows us to change the properties continuously from reduced T_C superconductor to normal metal, to insulator as a function of irradiation dose. We present data for several Josephson junctions fabricated in this manner using controlled doses. Our results are well-described by the Blonder, Tinkham, Klapwijk model (BTK) for microscopic electrical transport at an interface between a superconductor and a normal material. This model uses a single parameter related to barrier strength (irradiation dose in our experiments) and can describe current-voltage characteristics for barriers ranging from a strong barrier, such as an insulator in a tunnel junction, to a weak barrier like a normal metal. In the case of a strong barrier (a tunnel barrier) the only transport mechanism for Cooper pairs is direct Josephson tunneling whereas in the case of weaker barriers both tunneling and Andreev reflection occur. This technique could provide a reliable method for the realization of reproducible high-T_C Josephson junctions. I will present details of the technique and analysis of the results.