'Y-Ba-Cu-O nano SQUIDs fabricated with a focused helium ion beam'

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Nano-scale superconducting quantum interference devices (SQUID) are important for ultra-low noise, high-resolution magnetic sensing as well as high-speed, low-power, single flux quantum superconducting digital logic. Several processes have been developed for these types of devices fabricated from conventional metal low-transition-temperature superconductors. However, achieving reproducible nano-scale features in high-transition temperature superconductor (high-T_C) electronics has been very challenging due to the very high anisotropy and sensitivity to crystalline defects that these materials exhibit. Recently, our group developed a technique for direct-write patterning of high-T_C oxide thin films using a focused helium ion beam, that demonstrated the scaling of high-T_C circuit feature sizes down to the nano-scale [1] and the ability to create high-quality micro-SQUID magnetometers [2]. Here we present the use of this technique to create even smaller nano-scale SQUIDs with pick-up loops as small as 10 × 10 nm. The SQUID is defined entirely by helium ion irradiation from a helium gas field ion source focused to a sub-nm diameter. The irradiation converts the superconductor to an insulator, and no material is milled away or etched. In this manner, the device is created entirely within the plane of the film. SQUID properties such as critical current, dynamic resistance and inductance can be precisely controlled to optimize performance. Electrical measurements reveal large (0.8 mV) modulation voltages with applied magnetic field and we measure a white noise level below 1 $\mu\Phi_0/\mathrm{Hz}^{1/2}$. We will present how the electrical properties are affected by scaling and discuss the limits and potential for this emerging technology.

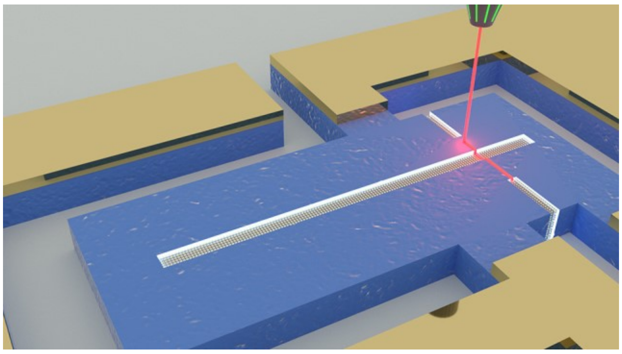

Figure 1. Depiction of direct write patterning of a high-T_C ceramic nano-SQUID using a helium gas field ion source. In this method, no material is milled, but rather converted from superconducting to insulator by defects introduced into the crystal lattice.

[1] *Superconducting nano Josephson junctions patterned with a focused helium ion beam,* E. Y. Cho, Y.W. Zhou, J. Y. Cho, and S.A. Cybart, *Appl. Phys. Lett.* **113**, 022604 (2018); https://doi.org/10.1063/1.5042105.

[2] *Direct-coupled micro-magnetometer with Y-Ba-Cu-O nano-slit SQUID fabricated with a focused helium ion beam*, E. Y. Cho, H. Li, J.C. LeFebvre, Y.W. Zhou, R. C. Dynes, and S.A. Cybart, *Appl. Phys. Lett.* **113**, 162602 (2018); https://doi.org/10.1063/1.5048776