YBaCuO Nano-SQUIDS Fabricated by Focused Helium Ion Beam Direct Writing

Department of Electrical and Computer Engineering, Shane Cybart, Hao Li, and Ethan Cho

E-mail: cybart@ucr.edu

Superconducting electronics have been substantially boosted by recent research progress in superconducting quantum computing and cryogenic energy-efficient computing. Scaling down the features size of basic superconducting devices such as Josephson junctions and superconducting quantum interference devices (SQUIDs) is essential to make the technology competitive with CMOS devices. Nanoscale SQUIDs as highly sensitive magnetic sensors has also attracted a growing research interest for the past several years, for applications in detection of bio-functionalized magnetic nanoparticles, readout of spin-based quantum information, direct observation of nano-magnetism and nanoscale studies of superconductivity.

In this work we have successfully fabricated several YBCO nano-SQUIDs with loop sizes of 400 nm by 400 nm, with 200-nm wide Josephson junctions using focused helium ion irradiation. The electrical properties of cuprate superconducting films can be locally tuned from superconducting to insulating by introducing controllable oxygen displacements by using a 32-keV focused helium ion beam (FHIB). The small spot size of 0.5~nm, enables sub-10~nm writing of circuits directly into the plane of a thin film without etching of any material. This technique is free of chemical contamination, and a process that can be scaled down to nanometers. The electrical characterization of these nano-SQUIDs in a systematic investigation showed that large voltage modulation up to millivolts with applied field over a wide range of temperatures from 4 Kelvins up to 50 Kelvins. In comparison to micro-SQUIDs, the nano-SQUIDs fabricated by FHIB have larger critical voltages and modulation voltages. The voltage modulation of typical FHIB nano-SQUID is 0.5 mV, which is about ten of times larger than that of low-T_C SQUIDs. The large amplitude of voltage signal, allowed for direct measurement of the magnetic flux noise of which was determined to be 300 $n\Phi_0/Hz^{1/2}$ by using a low-temperature low-pass filter, SR560 preamplifier and HP spectrum analyzer.

YBCO nano-SQUIDs has been successfully fabricated by using FHIB and characterized over a large temperature range which show a great improvement in electrical proprieties. Higher resistances and smaller feature sizes enable novel device in nanoscale geometries. This demonstration of YBCO nano-SQUIDs could open up new applications in high-T_C energy-efficient quantum flux parametron (QFP) logic, high density cryogenic memory, and other high performance circuits.