Nanotechnology for High-temperature Superconductor Electronics: Large-Scale Two- Dimensional Arrays of Y-Ba-Cu-O Josephson Junctions

Shane Cybart, Ethan Cho, Travis Wong and R. C. Dynes
University of California San Diego, Department of Physics, La Jolla, CA, 92093, USA

E-mail: scybart@ucsd.edu

March 3, 2014 (HP71). Since the discovery of high-temperature superconductivity almost three decades ago, researchers have tried to develop scalable and reliable Josephson junctions capable of operating at or above 77 K and possibly cooled by a simple cryocooler. It was soon realized that this was a difficult task, in part because of the anisotropic nature of the electronic properties of the cuprate materials and the very short coherence length. Despite this challenge, some successful junction technologies emerged. Junctions formed by a superconducting bridge straddling a grain boundary of a bi-crystal substrate[1] have been shown to have high products of the critical current and resistance, $I_c R$ (a figure of merit for Josephson junctions) but are not very uniform from junction to junction and difficult to layout in complex geometries. Ramp junctions are more uniform but the process is complicated, not readily scalable and relies on interfaces with the cuprates [2]. Another technique developed in the early 1990's involves using ion irradiation to create local disorder in a superconducting bridge by ion implantation through a mask prepared by nanolithography [3]. This technique has been mostly overlooked by researchers due to small $I_c R$ values of the junctions and limitations in nanolithography.

Recently, a great deal of progress has been made in the ion damage junction process by scaling up the number of junctions per circuit to generate the higher voltages desirable for superconducting electronics [4-5]. An array shown in Figure 1(a) was constructed that consists of 5225 series segments of 6 parallel SQUIDs.

For this study, we chose to build an array containing SQUIDs with different loop areas in a scheme first proposed by Kornev et al.[6] In this method, different loop areas are selected to provide individual voltages v_n that oscillate with frequencies that when combined form a triangle wave. Consider the following Fourier series of a triangle wave as a function of magnetic field B, written in terms of the relevant SQUID parameters, $V = v_n \sum_{n=1,3,5,\ldots}^{\infty} \frac{1}{n^2} \cos \frac{2\pi B_n A}{\phi_0}$. The loop areas A of the SQUIDs in the array are a sequence of odd integer values A, $3A$, $5A$, ... and the number of SQUIDs having each of these areas forms the ratio 1: 1/9 : 1/25, ... For our array we used just the first three terms of this series.

Plots of modulation voltage *versus* magnetic field for a current-biased device are shown in Figure 2 for temperatures of 34 K and 43 K. A peak amplitude of ~35mV was observed at 34 K. The small SQUID areas chosen in this case result in a magnetic field periodicity of ~50 μT that is many orders of magnitude greater than that of typical single SQUID devices. This yields more dynamic range when operating this device as a magnetometer for applications without feedback electronics. The latter complicate the circuitry and also reduce the bandwidth of SQUIDs from GHz to MHz. The very large modulation voltage provides a field sensitivity of approximately 1000 V/T.

This study demonstrates the value of Josephson junction arrays fabricated by ion irradiation and nanolithography. We believe this is just a first glimpse of the potential devices that can be constructed using this technology.

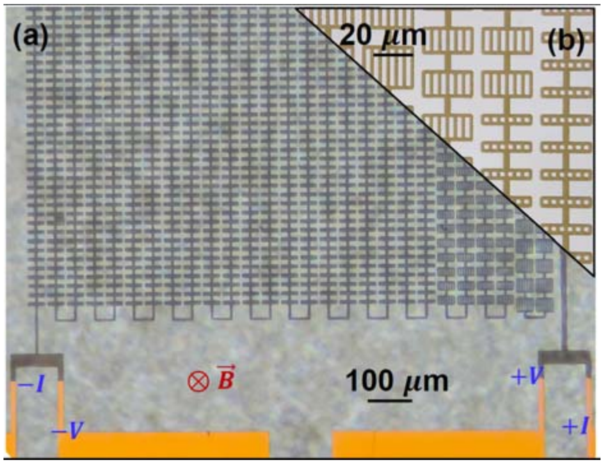

Fig. 1(a). Optical microscope photo of a 2D SQUID array with a meander geometry. The array consists of 5225 segments connected in series with each segment containing 6 SQUIDs in parallel for a total of 36,575 Josephson junctions. **(b).** The inset shows a magnified view of the array.

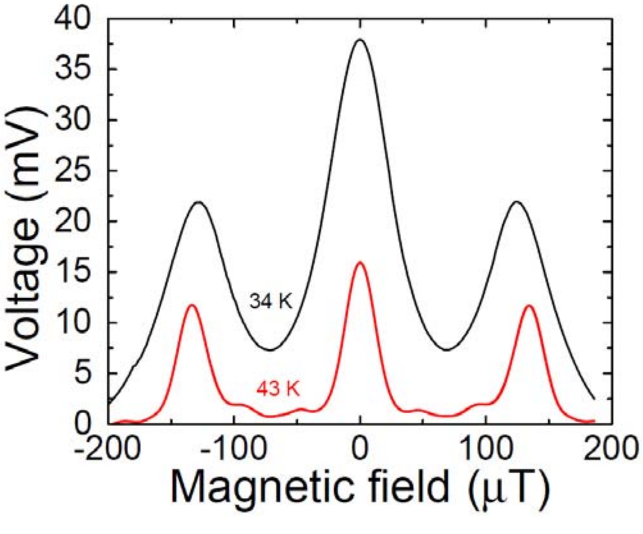

Fig. 2. Voltage as a function of magnetic field for a DC biased 2D Josephson junction array. The sensor can be used without flux-locked loop electronics for greater bandwidth and has a large dynamic range with an upper field limit of approximately 50 μT while maintaining a high transfer factor greater than 600V/T.

References

[1] P. Chaudhari, J. Mannhart, D. Dimos, C. Tsuei, J. Chi, M. M. Oprysko, M. Scheuermann, Phys. Rev. Lett. 60, 1653 (1988).
[2] J. Gao, W. Aarnink, G. Gerritsma, and H. Rogalla, Physica C 171, 126 (1990).
[3] S. S. Tinchev, Supercond. Sci. Tech. 3, 500 (1990).
[4] S. A. Cybart, S. M. Anton, S. M. Wu, J. Clarke, and R. C. Dynes, Nano Lett. 9, 3581 (2009).
[5] S. A. Cybart, E. Y. Cho, T. J.Wong, V. N. Glyantsev, J. U. Huh, C. S. Yung, B. H. Moeckly, J. W. Beeman, E. Ulin-Avila, S. M. Wu, and R. C. Dynes, Appl. Phys. Lett. 104, 062601 (2014).
[6] V. K. Kornev, I. I. Soloviev, N. V. Klenov, and O. A. Mukhanov, Supercond. Sci. Tech. 20, S362 (2007).