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High I_cR_n Products and Hysteretic Behavior of YBCO/Au/YBCO Josephson Junctions

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We have developed a method for eliminating the excess conductance in YBCO/Au/YBCO step edge junctions. This fabrication procedure results in I_cR_n products of 7.8 mV at 4.2 K and 0.18 mV at 77 K. The dc-SQUIDs showed a flux noise of 3×10^{-5} $\Phi_0/\sqrt{Hz}$ at 77 K with a 1/f noise knee at 1 Hz. Underdamped junctions can also be made with this fabrication technique. This may allow for the fabrication of relaxation oscillation SQUIDs operating at 77 K.

1. INTRODUCTION

One type of high T_c Josephson junctions that has exhibited low noise in SQUIDs are the SNS (YBCO/Au/YBCO) step edge junctions.[1] An undesirable feature of the standard fabrication procedure for these junctions is that the gold covers large areas of the YBCO electrodes. This creates an unnecessarily large shunt conductance that reduces the I_cR_n product. Previously, the excess conductance was reduced by etching the excess gold away.[2] We have developed an alternative method for eliminating this excess conductance. An insulating layer is deposited between the YBCO and the Au. This fabrication procedure results in a dramatic improvement in the I_cR_n product (7.8 mV at 4.2 K and 0.18 mV at 77 K). The high I_cR_n product translates into improved device performance. Using these junctions, we have fabricated SQUIDs with a flux noise of 3×10^{-5} $\Phi_0/\sqrt{Hz}$ at 77 K, with a 1/f noise knee at 1 Hz. In addition to higher I_cR_n products, it is possible to make these junctions underdamped. This means that the junctions have a hysteretic current-voltage characteristic. Underdamped junctions are essential for certain applications such as high-T_c relaxation oscillation SQUIDs.

2. FABRICATION

In this paper two types of junctions will be described. One is the standard YBCO/Au/YBCO step edge junctions (type *A*), and the other is the YBCO/Au/YBCO junctions with the insulating layer to reduce the shunt conductance (type *B*). Schematic drawings of these two junction types are shown in Fig. 1. To separate the two superconducting electrodes, the YBCO is ablated at an angle over a step in the substrate. This interrupts the YBCO at the step. To make type *A* junctions gold is then ablated from another angle so that the gold covers the step and makes contact to both YBCO electrodes. To make type *B* junctions, a thin $SrTiO_3$ layer is ablated at the same angle as the YBCO. The substrate is then rotated and gold is ablated as for the type *A* junctions. Because the $SrTiO_3$ is ablated at an angle, it does not deposit at the YBCO/Au interfaces where the supercurrents flow. The critical current densities in the two types of junctions are the same. The resistances of the type *B* junctions, however, are much higher than the type *A* junctions. Details of the fabrication process were described previously.[3]

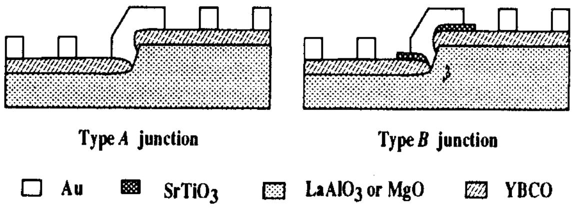

Fig. 1. Schematic drawings of the two types of YBCO/Au/YBCO step-edge SNS junctions.

3. RESULTS AND DISCUSSIONS

The junctions could be well described by the RSJ model with thermal noise. Clear Shapiro steps were observed at temperatures up to 85 K. The type *A* junctions are not hysteretic while the type *B* junctions can be either hysteretic or nonhysteretic depending on the resistance and the capacitance of the $Au/SrTiO_3/YBCO$ overlap regions. The I-V characteristic at different temperatures for a non-hysteretic type *B* junction is shown in Fig. 2. For both types of junctions, the critical current densities were nearly the same ($J_c \sim 5\times10^3$ A/cm^2 at 77 K) and the resistance was temperature independent. The resistance of the type *B* junctions was about 15 times greater than that of the type *A* junctions and

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roughly scales with the junction width (and hence area). The high R_n values result in high I_cR_n products. The type *A* junctions have a I_cR_n product of 0.01 mV at 77 K and 0.4 mV at 4.2 K while the type *B* junctions have I_cR_n products of 0.18 mV at 77 K and 7.8 mV at 4.2 K. If we assume that the effective area of the junction is the film thickness times the patterned width of the junction, then the contact resistance for the type *B* junctions is 2 - 12 Ω-μm^2. This value is close to the values reported by Ekin *et al.*[4] for clean (or *in situ* deposited) YBCO/noble-metal interfaces. The resistance of the junctions is dominated by this contact resistance.

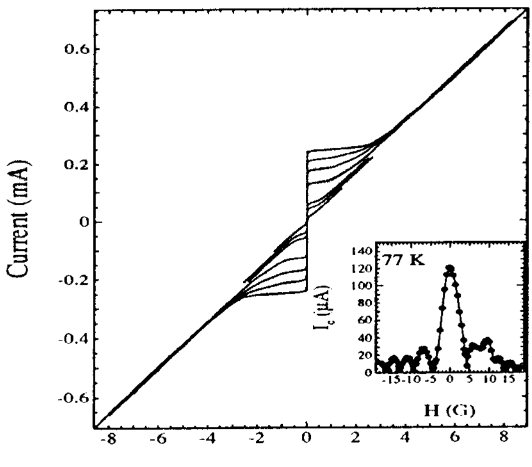

Fig. 2. The current-voltage characteristic of a 3-µm-wide junction at 4.2 K, 20 K, 30 K, 40 K, 60 K, 70 K and 77 K. A magnetic field diffraction pattern for a 10-µm-wide junction at 77 K is shown as an inset

Dc-SQUIDs were made using both type *A* and nonhysteretic type *B* junctions. The SQUIDs are composed of two 5-, 10-, 15- or 20-μm-wide junctions with SQUID loop areas of either 100 or 300 μm^2. The voltage modulation peak to peak with applied magnetic flux at 77 K was 1-2 µV for type *A* SQUIDs and 3-7 µV for type *B* SQUIDs. Noise measurements were performed in an open loop. The voltage noise spectral density $S_v^{1/2}$ was about 0.6 nV/$\sqrt{Hz}$ at 77 K for both type *A* and type *B* SQUIDs. The flux noise spectral density, $S_\Phi^{1/2}$, is given by $S_\Phi^{1/2} = S_v^{1/2}/(\delta V/\delta\Phi)$. For the type *B* SQUIDs the flux noise is lower than that of type *A* SQUIDs because of the larger flux-voltage conversion. The minimum flux noise spectral density, is about 80 $\mu\Phi_0/\sqrt{Hz}$ for the type *A* SQUIDs, and 30 $\mu\Phi_0/\sqrt{Hz}$ for the type *B* SQUIDs. The knee of 1/f noise is between one and a few Hz. This noise is comparable to the results obtained from a commercial niobium dc-SQUIDs at 4.2 K. Theoretically, one expects the energy resolution to be $\varepsilon = 9k_BTL/R_n \approx 4\times10^{-31}$ J/Hz, where the inductance of SQUIDs, *L*, was estimated to be about 80 pH. The experimental energy resolution for the type *B* SQUIDs was $S_\Phi/2L = 2.4\times10^{-29}$ J/Hz. For this SQUID, $\beta_L = 2LI_c/\Phi_0 \approx 1.5$.

In addition to the reduced the shunt conductance, the type *B* junctions have an increased shunt capacitance. Both of these factors increase the McCumber parameter, β_c, and allow for the fabrication of underdamped junctions. Hysteretic I-V characteristics were observed from 4.2 K up to 80 K in the type *B* junctions where we estimated the McCumber parameter, $\beta_c = 2eI_cR_n^2C/\hbar$, to be about 20. This value agrees with the calculation from the parallel plate capacitor formed by the 100 nm $SrTiO_3$ layer between the YBCO and the Au. The gate area and the thickness of the dielectric $SrTiO_3$ can be modified to control the hysteretic behavior. This is the first time hysteretic junction behavior has been reported at 77 K which may allow one to make relaxation oscillation SQUIDs operating at 77 K.

4. CONCLUSIONS

We have achieved high I_cR_n products (0.18 mV at 77 K and 7.83 mV at 4.2 K) in YBCO/Au/YBCO step-edge junctions by depositing a thin layer of $SrTiO_3$ in between the YBCO and Au. The best dc-SQUID made from these junctions had a flux noise spectral density in the range of 30 $\mu\Phi_0/\sqrt{Hz}$ and the knee of 1/f noise was at about 1 Hz. Hysteretic junctions operating at up to 80 K suggest that it will be possible to operate high T_c relaxation oscillation SQUIDs at 77 K.

5. REFERENCES

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