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 $3 \times 10^{-5} \Phi_0/\sqrt{Hz}$ 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. 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. 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 $3 \times 10^{-5} \Phi_0/\sqrt{Hz}$ 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.

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 ($I_c \sim 5 \times 10^3$ 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
roughly scales with the junction width (and hence area). The high $R_n$ values result in high $I_s R_n$ products. The type $A$ junctions have a $I_s R_n$ product of 0.01 mV at 77 K and 0.4 mV at 4.2 K while the type $B$ junctions have $I_s R_n$ 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 $2\cdot12\Omega\mu m^2$. 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.

In addition to the reduced shunt conductance, the type $B$ junctions have an increased shunt capacitance. Both of these factors increase the McCumber parameter, $\beta_c$, 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, $\beta_c = 2e I_s R_n^2 C / h$, 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 $I_s R_n$ 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 $\mu\Phi_0/J\sqrt{Hz}$ 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