Journal of Low Temperature Physics, Vol. 117, Nos. 3/4, 1999

High-T_c Ramp-Type Josephson Junctions for Rapid Single Flux Quantum Circuits

M.Q. Huang, Z.G. Ivanov, P.V. Komissinski, P.B. Mozhaev, and T. Claeson

Department of Microelectronics and Nanoscience, Chalmers University of Technology and University of Göteborg, S-412 96 Göteborg, Sweden

Ramp-type Josephson junctions with YBCO superconducting electrodes and $PrBa_2Cu_{2.6}Ga_{0.4}O_{6+\delta}$ (PBGCO) barriers were fabricated and characterized. The YBCO ramp junctions with 25 nm-thick barriers of PBGCO showed typical resistively- shunted-junction (RSJ)-like I-V behavior and 1σ spread of less than 13% in critical current density. Differential conductance-voltage characteristics registered using a lock-in technique indicate that the resonant tunneling via localized states in the barriers plays a dominant role in the conduction process of the ramp junctions.

PACS numbers: 74.50.+r, 74.76.Bz

1. INTRODUCTION

Rapid Single Flux Quantum (RSFQ) circuits implemented in high-T_c superconductors (HTS) have the potential to perform at temperatures 20-40 K, as compared with that of Nb/NbN circuits at 4 K. The main obstacle in realization of such circuits is the lack of Josephson junctions (JJ) with high reproducibility and with ability to be integrated in oxide multilayer structures. Ramp-type Josephson junctions[1] are probably the only choice at present that fulfills these demands. Here we report on fabrication and properties of YBCO ramp type JJ with $PrBa_2Cu_{2.6}Ga_{0.4}O_{6+\delta}$ (PBCGO) barriers. The mechanisms of normal and supercurrent transport in these junctions are investigated.

0022-2291/99/1100-0587$16.00/0

2. JUNCTION FABRICATION

Junction parameters are determined by the ramp roughness, barrier material and thickness, and insulator between the bottom and top electrodes. In all our studies we have used a tri-layer insulator, PBCO/$SrTiO_3$/PBCO. Since the STO tends to form oxygen deficient interfaces with YBCO, the thin PBCO layer prevents this effect. PBCGO was chosen as barrier since it allows JJs with higher R_n, keeping J_c unchanged. All films were grown by pulsed laser deposition at 800°C and 0.2 mbar oxygen pressure. Ramps in YBCO/PBCO/STO/PBCO were formed by Ar ion milling at beam energy of 270 eV and beam current density of 0.2 mA/cm^2. Smooth ramps with an angle of 25-29° to the substrate were formed only when a hard baked photoresist mask with gentle edges was used in combination with an etch angle of 45° normal to the rotating substrate. An AFM image of a photoresist mask on a multilayer structure is presented in Fig. 1a. The edge slope of the mask was about 40°.

Two chips with 44 junctions on each were fabricated for each of the barrier thickness: 8, 10, 15, 20 and 25 nm. Current-voltage (I-V) characteristics of the junctions were measured by a four-probe technique. Differential conductance - voltage (G - V)

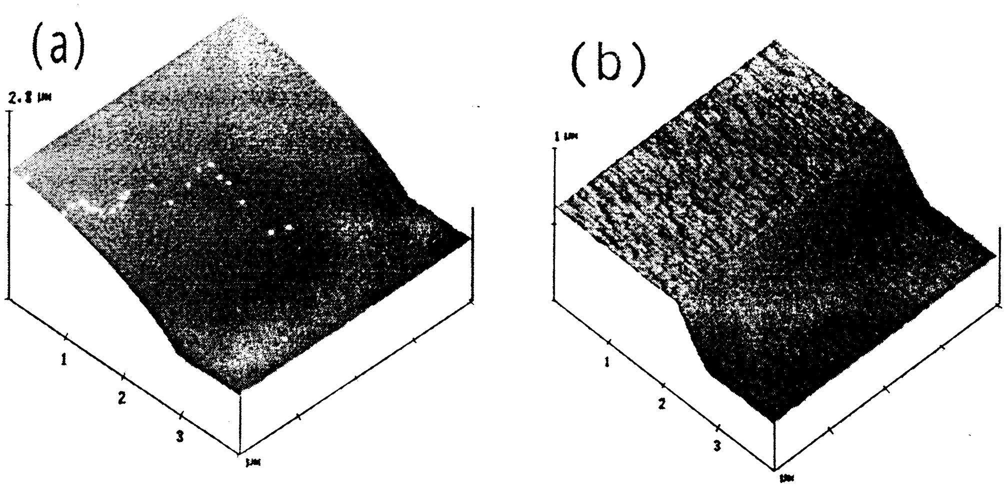

Fig. 1. AFM tapping mode images of the morphology of (a) a photoresist mask after a postbake at 120°C for 30 min, and (b) a uniform ramp after etching and annealing at 780°C and 0.2 mbar O_2 for 30 min.

characteristics were measured for some of the junctions by a lock-in technique at different temperatures.

3. RESULTS AND DISCUSSION

Ramp roughness determines the epitaxial growth of the barrier and correspondingly the barrier homogeneity. An AFM image of a ramp is presented in Fig. 1b. The ramp was prepared under the optimized processing conditions, specified above, and the typical ramp roughness after ion beam milling was 5 nm, however it increased to 8-9 nm after annealing under conditions similar to that for the deposition of the barrier and top electrode.

Junctions with barrier thickness of 7-20 nm had a J_c of 10^5–10^4 A/cm^2 and flux-flow-type I-V curves. Although for 15-20 nm thick barriers, some of the junctions showed RSJ-like behavior with large excess current, $I_{ex} \approx I_c$. Here we report only on the properties of junctions with 25 nm thick barriers. 27 junctions of 44 in total were investigated. All junctions showed I-V characteristics with RSJ behavior with negligible excess current, less than 10% of I_c as shown in Fig. 2a. The 1σ spread in critical current density was less than 13 % (cf. Fig. 2b). Such a spread in junction parameters allows for the design RSFQ circuits with 20-40 junctions.

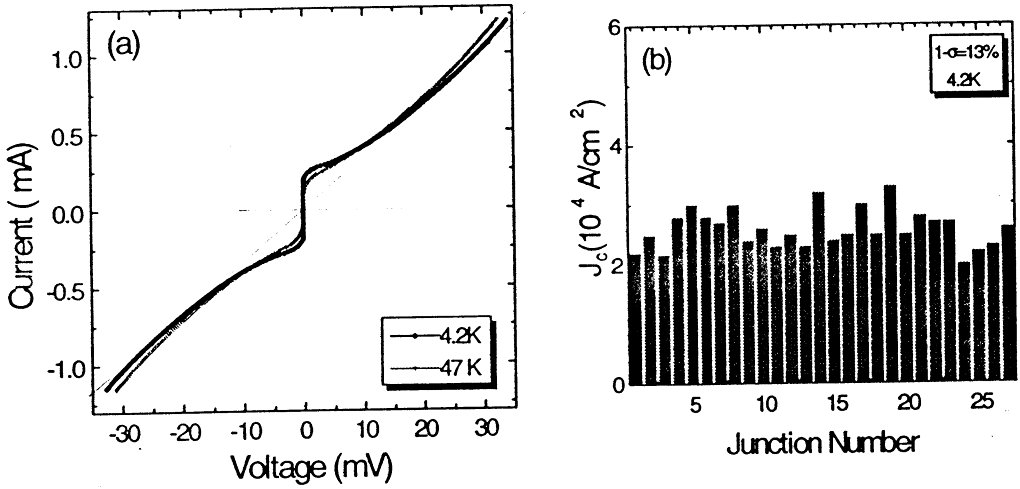

Fig. 2. (a) The I-V curves of a 4 μm wide YBCO ramp junction, (b) critical current density spread of YBCO ramp junctions with 25 nm thick PBCGO barriers.

Keeping in mind that the roughness of the ramps was measured to be about 9 nm, it is clear that the supercurrent transport is determined by microshorts in the junction with the barrier thickness of less than 15 nm.[3]

The G-V characteristics were measured for three junctions. A set of G-V curves measured in the temperature range of 4-71K is shown in Fig. 3. The shape of the conductance curves can be described by a $G = AV^{4/3}$ dependence at high bias voltages, with A as a fitting parameter. (cf. Fig. 3) The latter indicates that the normal transport is dominated by resonant tunneling through localized states in the PBCGO barrier.[2] For all three junctions, pronounced peaks were observed in the G-V dependencies and they were well correlated in voltage scale. If we assume a superconducting gap of 31±1 meV, most peaks can be identified

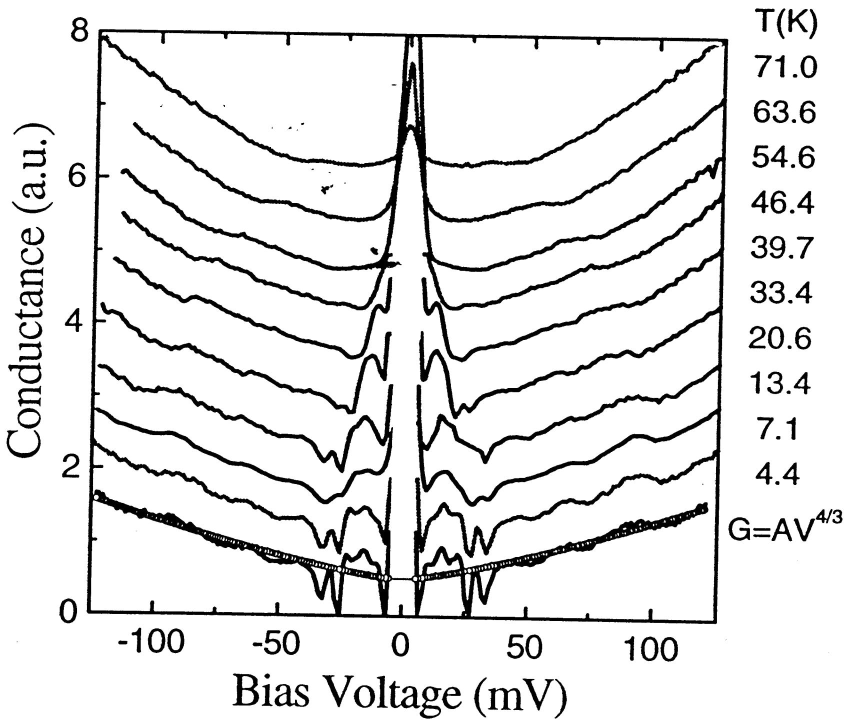

Fig. 3 The differential conductance vs. bias voltage of a 4 μm wide YBCO ramp junction with a 25 nm thick PBCGO barrier at different temperatures. The conductance curve marked by open circles represents a fitted curve with $G = AV^{4/3}$. (The central peaks in the curves at temperatures lower than 55K have been removed. All the curves have been offset and rescaled for clarity.)

at the voltages corresponding to 2Δ/n, where n=1-4. Even though the peak near Δ/4 was observed, the peaks at 2Δ/n (n=5,6,7) were absent. It is probably due to the limited sensitivity or resolution in bias voltage of the measurement. Maybe, some peaks merged because of the resolution. The results differ from the reported measurements pointing on the presence of two gaps, Δ_s=25 meV and Δ_n=16 meV.[4] The well-pronounced subgap structure indicates that supercurrent transport is dominated by multiple Andreev reflections.[5]

4. SUMMARY

A technology for preparation of YBCO ramp-type JJs with PBCGO barriers has been developed. An optimal thickness of the junction barrier was found to be about 25 nm and I_cR_n of the JJs were about 4 mV at 4.2 K and 2 mV at 40 K, at these conditions. 1σ spread in J_c was less than 13%. The current transport in these JJs was determined by the Glazmann-Matveev mechanism of resonant tunneling.

ACKNOWLEDGMENTS

The work has been supported by the ESPRIT project 23429 "HTS-RSFQ", Materials consortium on superconductivity and SSF Microelectronics program.

REFERENCES

1. J. Gao, Yu. M. Boguslavskij, B. B. G. Klopman, D. Terpstra, R. Wijbrans, G. J. Gerritsma, and H. Rogalla, *J. Appl. Phys.* **72**, 1 (1992).
2. M. Verhoeven, G. Gerritsma, H. Rogalla, and A. Golubov, *Appl.Phys.Lett.***69**,848(1996); *Physica C 235-240,3261(1994)*
3. M. Gustafsson, E. Olsson, M.Q. Huang, P.V. Komissinski, P.B. Mozhaev, Z.G. Ivanov, and T. Claeson, *this volume*
4. A. Engelhardt, R. Dittmann, and A. I. Braginski, *Phys. Rev. B* **59**, 3815 (1999).
5. B. A. Aminov, A. A. Golubov, and M. Yu. Kupriyanov, *Phys. Rev. B* **53**, 356 (1996).