

Influence of $\text{PrBa}_2\text{Cu}_{3-x}\text{Ga}_x\text{O}_7$ barrier material on electrical behaviour of ramp-type Josephson junctions

M.A.J. Verhoeven, Yu.M. Boguslavskij, E.M.C.M. Reuvekamp, G.J. Gerritsma and H. Rogalla
University of Twente, Department of Applied Physics, P.O. Box 217, NL-7500 AE Enschede, Netherlands

The use of $\text{PrBa}_2\text{Cu}_{3-x}\text{Ga}_x\text{O}_7$ barrier material with increased resistivity by Ga doping ($x=0; 0.05$ and 0.1) in ramp-type $\text{DyBa}_2\text{Cu}_3\text{O}_7/\text{PrBa}_2\text{Cu}_{3-x}\text{Ga}_x\text{O}_7/\text{DyBa}_2\text{Cu}_3\text{O}_7$ Josephson junctions has been investigated. All junctions have been fabricated with very smooth sputtered films and show good RSJ-like I-V characteristics with clear Josephson behaviour. Both critical current I_c and normal state resistance R_n are influenced by the doping level as well as the barrier thickness. The temperature dependence of the normal state resistance at different Ga doping levels and barrier thicknesses will be discussed.

1. INTRODUCTION

In ramp-type Josephson junctions, $\text{PrBa}_2\text{Cu}_3\text{O}_7$ (PBCO) can be used as barrier material [1]. Typically, the resistivity at 4K is a few $\Omega \cdot \mu\text{m}^2$ in the normal state for a PBCO barrier thickness of 10nm. This value can be increased easily by using a thicker barrier, but this will reduce the critical current of the device exponentially. Hence, the $I_c R_n$ product decreases simultaneously. Many applications require the ability to modify the junction resistivity and critical current density, while keeping a proper $I_c R_n$ product.

Charge carriers are localised in the PBCO materials, and the transport process through a PBCO barrier can be described as a hopping conductivity. It is interesting to investigate the transport properties in our junctions at different barrier thicknesses and carrier density. The resistivity of PBCO can be increased several orders of magnitude by replacing the bivalent base Cu(1) atoms by trivalent Ga [2-4]. In this paper, we study the use of $\text{PrBa}_2\text{Cu}_{3-x}\text{Ga}_x\text{O}_7$ ($x=0; 0.05$ and 0.10) as barrier materials in ramp type Josephson junctions in terms of I_c and R_n values.

2. EXPERIMENTAL

Bulk material $\text{PrBa}_2\text{Cu}_{3-x}\text{Ga}_x\text{O}_7$ (PBCGO) has been obtained by citrate synthesis, as has been described earlier [4].

Deposition of thin films of DBCO and PBCGO is performed by off-axis RF-magnetron sputtering from single stoichiometric targets. Adding 0.1 Pa of H_2O

allows us to place the substrates very close to the visible plasma. Thus obtained films show good crystallinity, high T_c^0 for DBCO and very smooth surfaces.

Ramp type junctions have been made with electrode thickness of 100nm and widths of 5 to 25 microns. The overlap was usually about 5 microns long. For PBCO barriers, thicknesses of $L=8, 10$ and 30 nm were used; for PBCGO ($x=0.05$): $L=10$ and 20 nm and for PBCGO ($x=0.10$) $L=10$ nm.

3. RESULTS AND DISCUSSION

The IV-characteristics for the junctions show good RSJ-like behaviour, with abrupt transitions from the supercurrent regime to the resistive state. There is little excess current, and under application of a magnetic field clear Fraunhofer-like $I_c(H)$ can be observed, with complete suppression of the supercurrent at minima. The scaling of I_c and R_n is excellent for junctions on the same chip, typically variations of 5-10% in $R_n A$ and j_c values are found. These observations give strong evidence that the current distribution inside the barrier is quite homogeneous. For a PBCO barrier thickness of 10nm the $I_c R_n$ product is 1-2 mV at 4K; the T_c^0 of the device is about 80K.

In figure 1a the $R_n A$ dependence on T for several thicknesses of the PBCO barrier is shown ($L=8; 10$ and 30 nm), and in figure 1b for the three doping levels. The values of J_c at 4K for the thickness series are $J_c=4 \cdot 10^4 \text{ A/cm}^2; 3 \cdot 10^4$ and 0, for the doping series: $3 \cdot 10^4 \text{ A/cm}^2$ ($x=0.05, L=10\text{nm}$); 20 ($x=0.05, L=20\text{nm}$) and $2 \cdot 10^3$ ($x=0.10, L=10\text{nm}$) respectively.

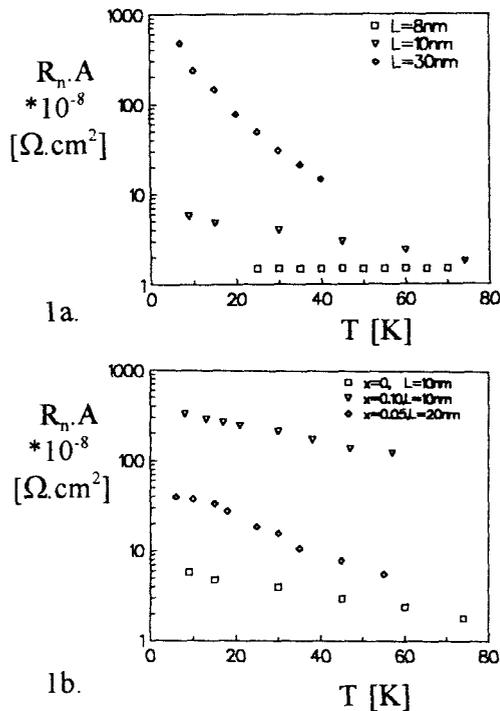


Figure 1. $R_n A$ product as a function of temperature; a: varying PBCO thickness; b: varying Ga-doping-level x .

Clearly, an increase of R_n can be obtained by doping PBCO with Ga. This will also result in a depression of I_c , but about one order of magnitude less than it would have been by increasing the barrier thickness to get the same R_n value. In the same time, $I_c R_n$ products for 10nm thick barriers remain some 1-2 mV at 4K for doped barrier material.

With increasing PBCO barrier thickness there is a transition from almost temperature independent normal state resistance at 8 nm thickness towards a temperature dependent R_n close to the behaviour of bulk PBCO at large barrier thickness. The temperature independent resistivity at small thickness reflects tunneling via one (effective) localised center in the barrier, while with increased thickness several hopping centers are involved [5,6].

The hopping conductivity in disordered systems (variable range hopping) as proposed by Mott is often used to explain transport processes in PBCO. This model cannot fit our data very well, however:

the plots of resistance versus $(1/T)^{-1/4}$ show clear deviation at lower temperature from straight lines. Additional Lifschitz correlations, involving not only hopping via localised single centres but also some resonant motion inside the barrier, may be important in this material, as was discussed by Kostadinov and Alexandrov [8]. Plots of $\ln(R)$ versus $\ln^3(T/T_0)$ can fit our data quite well for T_0 in the order of 1K.

The effect of Ga doping on the transport process could give some more insight in the localisation nature in PBCO: by 10% Ga doping, the resistivity is increased by an order of magnitude. The I_c of the junctions is also depressed by one order of magnitude however; probably by a more effective localisation at lower carrier densities. In the same time, it doesn't fully correspond to an effective barrier thickness of normal PBCO: for the same increase in barrier resistivity, a somewhat stronger depression of I_c occurs on increasing L than on doping the material with Ga.

4. CONCLUSIONS

It has been shown by these measurements that in ramp type junctions an increase in R_n can be obtained for thicker barriers, on the expense of I_c . A same increase of R_n for a constant barrier thickness can be achieved by doping of the PBCO material with gallium, with somewhat weaker decrease of I_c values. The $I_c R_n$ products tend to remain 1-2 mV at 4 K for 10 nm thick barriers.

$R_n(T)$ cannot be properly described by the VRH model, and likely some modification is required, such as involment of Lifschitz correlations.

REFERENCES

1. J. Gao et al, *Physica C* 176, 126 (1990).
2. E.Sodtke et al, *Physica C* 180, 50 (1991).
3. Y. Xu et al, *Physica C* 206, 59 (1993).
4. E.M.C.M. Reuvekamp et al, EMRS fall 1992.
5. Y. Xu et al, *Phys. Rev. B* 42, 1492 (1990).
6. Yu.M. Boguslavskij et al, *IEEE Trans. Magn.*, Mag-29 (1993).
7. B. Fisher et al, *Physica C* 176, 75 (1991).
8. I.Z. Kostadinov et al, *Physica C* 201, 126 (1992).