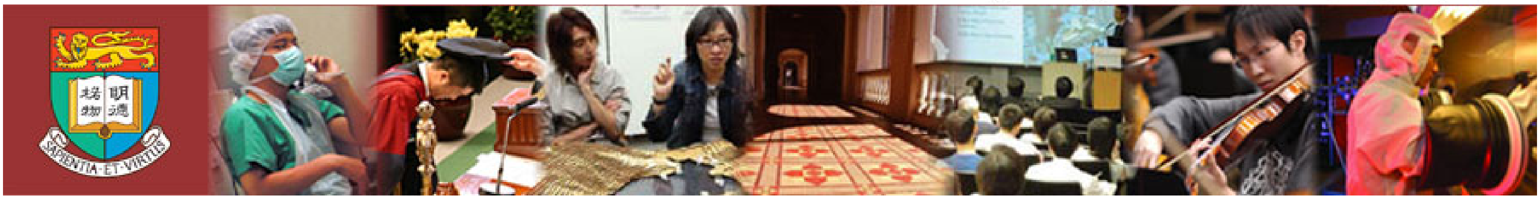

Title	**High-Tc ramp-type Josephson junctions with a continually graded Y1–xPrxBa2Cu3Oy barrier**
Author(s)	**Gao, J; Sun, JL; So, SM; Tang, WH; Li, TK**
Citation	**Applied Physics Letters, 2001, v. 79 n. 19, p. 3101-3103**
Issued Date	**2001**
URL	**http://hdl.handle.net/10722/42202**
Rights	**Creative Commons: Attribution 3.0 Hong Kong License**

High-T_c ramp-type Josephson junctions with a continually graded $Y_{1-x}Pr_xBa_2Cu_3O_y$ barrier

J. Gao,[a] J. L. Sun, S. M. So, W. H. Tang, and T. K. Li
Department of Physics, the University of Hong Kong, Pokfulam Road, Hong Kong

(Received 27 April 2001; accepted for publication 31 August 2001)

High-T_c Josephson junctions with a graded barrier have been prepared by using a composite target. Such a barrier is synthesized by utilizing $Y_{1-x}Pr_xBa_2Cu_3O_y$ with a continually graded concentration of Pr, in which no lattice mismatch and other incompatible problems take place. The structural interfaces are absent in the weak link region and Josephson coupling occurs at the naturally formed superconducting/normal interfaces within the $Y_{1-x}Pr_xBa_2Cu_3O_y$ layer. Thus, it can significantly enhance the reproducibilty and performance of these junctions. The temperature dependences of the barrier thickness and Josephson were also studied. [DOI: 10.1063/1.1414295]

The ramp-type high-T_c Josephson junctions have been extensively studied in the last decade.[1–4] Such junctions formed on the ramp surface of epitaxial multilayers favor tunneling along the ab plane and can have well-controlled properties. The main problem associated with ramp junctions is the low reproducibility due to the poor interface and the structural, thermal, and chemical incompatibility between barrier and electrodes. In general, the superconductor/normal (S/N) interface is damaged and defective caused by ex situ lithography and the ion-milling process, resulting in a large boundary resistance R_b. The mismatching between $YBa_2Cu_3O_y$ (YBCO) and the barrier also introduces antiphase defects and structural strain near the interface.[5] To improve the damaged interface and reduce the incompatibility, various approaches like chemical etching and use of intermediate layers were reported.[6,7] However, the interfacial problems still remain although the interface or the lattice match could be improved.

In this letter, we report a barrier structure utilizing $Y_{1-x}Pr_xBa_2Cu_3O_y(Y_{1-x}Pr_xBCO)$ with a continually graded concentration of Pr for high-T_c junctions. In our junctions the Josephson coupling takes place at the naturally formed S/N interfaces in the $Y_{1-x}Pr_xBCO$ layer rather than at the ramp surface. It leads to a highly transparent S/N boundary and an enhanced reproducibility.

Our junctions were fabricated by using off-axis rf-magnetron sputtering. $Y_{1-x}Pr_xBCO$ was used as the barrier with x gradually changing from 0 to 1 and then from 1 to 0 at two interfaces contacting YBCO electrodes [Fig. 1(a)]. Our initial attempt to fabricate such a barrier was using cosputtering.However, the cosputtering process is too complicated and the film composition is difficult to control. Thus, we have developed a technique using a composite target to make the graded barrier [sketched in Fig. 1(b)]. Such a target consists of two semidisks, YBCO and $PrBa_2Cu_3O_{7-\delta}$ (PBCO), respectively. During the deposition, the substrate was slowly rotated from the YBCO side to the PBCO side to form a continually varied composition and then to a PBCO target to make a pure PBCO central layer. The reason to insert a PBCO layer between two graded $Y_{1-x}Pr_xBCO$ layers is to ensure that no short circuits can occur even at low temperatures. After the deposition of the PBCO layer, the substrate was rotated back to the YBCO/PBCO composite target and gradually moved from the PBCO side to the YBCO side to form another graded layer, and finally to the YBCO target to grow the top electrode. This technique is very simple and highly reliable. The changing of composition from YBCO to PBCO is quite smooth and the thickness of the graded intermediate layer d_g can be easily controlled by the rotation speed. For most samples studied in this work, the thickness of the PBCO central layer is $d_{PBCO}=8$ nm and the values of d_g lie between 6 and 38 nm. All junctions were structured into a width of either 10 or 20 μm.

To ensure that no possible shorting could take place at the planner part of the junction, R–T measurements were performed on a set of $Y_{1-x}Pr_xBCO$ graded layers with a thickness up to 38 nm. All these graded $Y_{1-x}Pr_xBCO$ showed a semiconductor behavior, and no T_c could be found

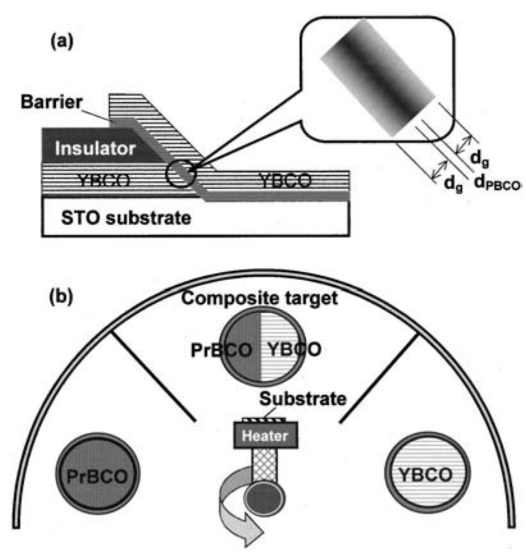

FIG. 1. (a) Schematic diagrams of the graded barrier structure; (b) top view of our deposition system with a composite target.

[a]Electronic mail: jugao@hku.hk

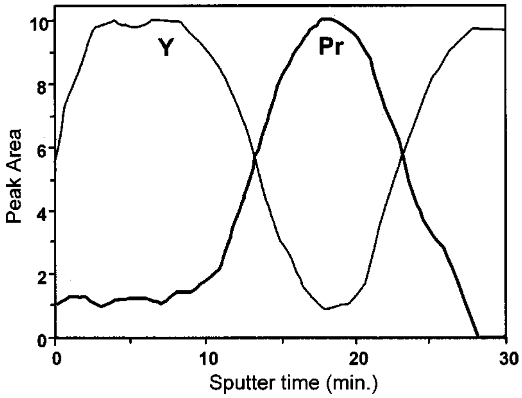

FIG. 2. XPS depth profille in the junction region.

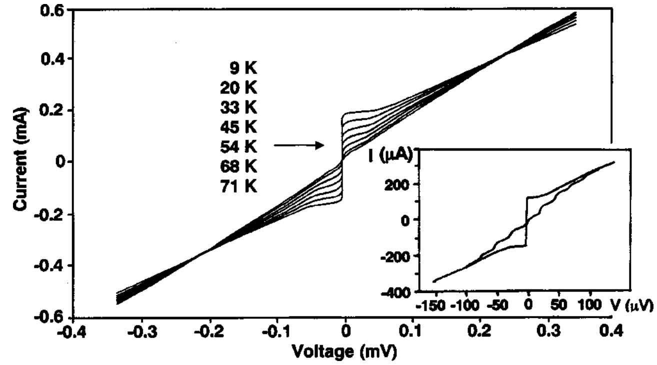

FIG. 3. I–V characteristics of a junction (d_g=25 nm and d_{PBCO}=8nm) at different temperatures. The inset show the I–V curves in a microwave field at 9 K.

down to 10 K. Hence, we can rule out shorting from the planner surface in our junctions. On the other hand, we found that ramp structures with no barrier still showed a T_c~86 K, implying the damaged ramp surface could be partially repaired. This agrees with the results of Char, Antognazza, and Geballe.[8] They reported that the ion-mill-damaged YBCO surface could restore its crystallinity during the subsequent deposition.

Our goal to develop such a graded barrier is to avoid any abrupt change of structure or composition in the weak link region, hence, to obtain a highly transparent S/N boundary. The depth distribution of Y and Pr in our junction was probed by x-ray photoelectron spectrometry (XPS). As shown in Fig. 2, the variation of the Pr concentration x was quite smooth within the whole junction region. Thus, the lattice match between every adjacent atomic layer would be very small and the occurrence of interfacial defects can be prevented, if the graded $Y_{1-x}Pr_xBCO$ layer is sufficiently thick.

The transparency of the S/N boundary can be described by two dimensionless parameters: $\gamma=\rho_s\xi_s/\rho_n\xi_n$ and $\gamma_b=R_b/\rho_n\xi$, where $\rho_{s,n}$ and $\xi_{s,n}$ are the normal-state resistivity and coherence lengths in the S or N layer, respectively.[9] The value of γ reflects the relation between order parameter Δ in the S and N layers. For $\gamma \gg 1$, Δ in the S-layer is strongly suppressed. On the other hand, the suppression on Δ is negligible if $\gamma \ll 1$. The parameter γ_b describes the quality of the S/N interface and the jump of Δ at the boundary. A very small γ_b implies the absence of the potential barrier, whereas $\gamma_b \gg 1$ suggest a low transparency for the quasiparticles at the S/N interface. In order to obtain high I_cR_n products, both highly transparent S/N boundaries and a low suppression of Δ in the S layer are necessary. The estimate of the proximity effect between YBCO and an isotropic normal metal, like Au or Ag, in the case of an atomically sharp S/N boundary, results in values γ~5 and γ_b~20.[9] It was also reported that for high-quality ramp junctions with a PBCO barrier, $\gamma\sim10^{-3}$ and γ_b~0.5.[10] In our junctions with a continually graded barrier, γ and γ_b are determined by d_g. If d_g is sufficiently large, the resistivity and other physical properties near the S/N interface should be similar as the S and N layers are the same material (e.g., $\rho_s\sim\rho_n$ and $\xi_s\sim\xi_n$). Thus, the parameter $\gamma=\rho_s\xi_s/\rho_n\xi_n \sim 1$ and $\gamma_b=R_b/\rho_n\xi_n\sim0$ due to the absence of the structural interface (hence, $R_b\sim0$). The low values of the proximity effect parameters show an advantage of this barrier structure.

These junctions exhibited typical RSJ-like I–V characteristics (Fig. 3). Almost all junctions showed clear Shapiro steps under irradiation of a microwave field, given unambiguous evidence of the Josephson coupling. The normal-state resistance R_n is typically around a few ohm. Such values was remarkably lower than that reported on superconductor/normal-conductor/superconductor (SNS) junctions with a PBCO barrier, implying that the R_b has been reduced to a low level and was no longer an overwhelmingly dominant factor in R_n. The I_c is in the range of 0.1–2 mA and the I_cR_n product is ~1 mV at 10 K. We also found that R_n varied slightly with T. It can be explained from the nature of the $Y_{1-x}Pr_xBCO$ material.

It is known that $Y_{1-x}Pr_xBCO$ may be superconductive for $x<0.5$. The $T_c(x)$ dependence can be described by $T_c(x)=T_{c0}-Ax^2-Bx$, where T_{c0} is the critical temperatures at $x=0$.[11] Taking the first-order approximation, it can be further simplified as $T_c(x)=T_{c0}(1-x/0.5)$ for $x<0.5$. In our barrier the location of the S/N boundary varies within the $Y_{1-x}Pr_xBCO$ layer, depending on T and x. Based on the XPS results and a linear $T_c(x)$ approximation, the effective barrier thickness d_e will be a function of temperature $(T\leqslant T_{c0})$:$d_e=d_{PBCO}+d_g(1+T/T_{c0})=d_{PBCO}+(1+T/T_{c0})/\alpha$. Here, α represents the Pr concentration gradient. It follows that the barrier thickness in such junctions strongly depends on T and d_g (or the gradient $\alpha=1/d_g$). Therefore, with the same junction we are able to control d_e simply by varying T. The barrier thickness is known as one of the crucial factors to influence the performance of multilayer junctions. Although it is controllable, in principle, practically the appropriate thickness is hard to find as such a value is affected by many factors like the S/N interface, R_b, etc. Our graded barrier would make it possible to optimize d_e within a certain range, even postfabrication, to gain a better performance. On the other hand, such a feature may also lead to different junction behavior.

The temperature dependences of the junction parameters were investigated. The R_nA (A is the junction area) product was slightly increased as T decreased, although d_g changed in a wide range. With different x and T, the $Y_{1-x}Pr_xBCO$ can behave as a normal metal or a semiconductor and d_e also varies. The whole barrier presents a complicated system and the $R_nA(T)$ dependence can be influenced by all these factors. The normalized I_c as a function of T for junctions with

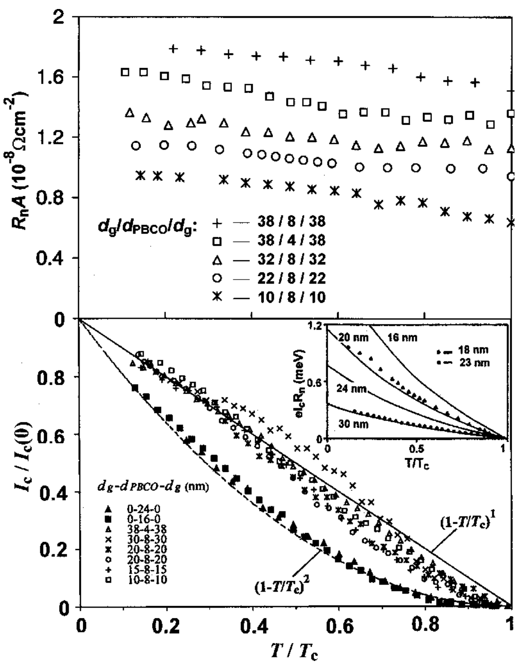

FIG. 4. The R_nA products and the normalized I_c vs T/T_c for various d_g. The inset shows a comparison between experimental data and numerical results of eI_cR_n vs T for junctions with different values of d_g.

various d_g is shown in Fig. 4. Most of the data lie on a nearly straight line, approaching a $(1-T/T_c)$ (Ref. 1) relationship. In contrast, I_c of the junctions using a single PBCO barrier usually exhibits a $(1-T/T_c)$ (Ref. 2) dependence, characteristic of a SNS junction.[1,12,13] The detailed study will be discussed elsewhere.

With this grade barrier the yield of successful junctions, which show a supercurrent and clear Shapiro steps, is nearly 100%. The uniformity of junction parameters, known as an essential issue for applications, was considered, too. Damaged interfaces often cause variation in the junction properties like I_c, R_n, etc. By using this barrier structure, the damageed ramp surface is excluded from the weak link region so it has little influence on the junction performance. In our experiments, I_c variation as low as $1-\sigma=12\%$ for ten junctions with identical parameters was found at 60–65 K. The uniformity has been improved significantly.

In conclusion, high-T_c Josephson junctions with a continually graded $Y_xPr_{1-x}BCO$ barrier have been developed using a composite-target technique. Such a barrier showed some superior features compared with the conventional single barrier and should encourage further studies.

This work has been supported by the Research Grants Council of Hong Kong (Project No. HKU 7082/01P) and the Research Committee of HKU (Seed Funding Grants 2000/2001).

[1] J. Gao, W. A. M. Aarnink, G. J. Gerritsma, and H. Rogalla, Physica C **171**, 126 (1990).
[2] D. K. Chin and T. Van Duzer, Appl. Phys. Lett. **58**, 753 (1991).
[3] B. D. Hunt, M. C. Foote, and L. J. Bajuk, Appl. Phys. Lett. **59**, 982 (1991).
[4] G. Koren, E. Aharoni, E. Pulturak, and D. Cohen, Appl. Phys. Lett. **58**, 634 (1991).
[5] Y. Yang, J. Gao, J. L. Sun, T. C. Chui, and L. Li, Physica C **300**, 151 (1998).
[6] M. I. Faley, U. Poppe, H. Soltner, C. L. Jia, M. Siegel, and K. Urban, Appl. Phys. Lett. **63**, 2138 (1993).
[7] Q. X. Jia, X. D. Wu, D. Reager, S. R. Foltyn, C. Mombourquette, P. Tiwari, I. H. Campbell, R. J. Houlton, and D. E. Peterson, Appl. Phys. Lett. **65**, 2866 (1994).
[8] K. Char, L. Antognazza, and T. H. Geballe, Appl. Phys. Lett. **63**, 2420 (1993).
[9] K. K. Likharev, Rev. Mod. Phys. **51**, 101 (1991).
[10] Yu. Boguslavskij, J. Gao, A. J. H. M. Rijnders, D. Terpstra, G. J. Gerritsma, and H. Rogalla, IEEE Trans. Appl. Supercond. **3**, 2034 (1993).
[11] W. H. Tang and J. Gao, Physica C **315**, 59 (1999).
[12] J. Gao, Yu Boguslavski, B. B. G. Klopman, D. Terpstra, R. Wijbrans, G. J. Gerritsma, H. Rogalla, J. Appl. Phys. **72**, 575 (1992).
[13] J. L. Sun and J. Gao, Phys. Rev. B **62**, 1457 (2000).