Perpendicular transport properties of YBa$_2$Cu$_3$O$_{7-\delta}$/PrBa$_2$Cu$_3$O$_{7-\delta}$ superlattices.

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Abstract

The coupling between the superconducting planes of YBa$_2$Cu$_3$O$_{7-\delta}$/PrBa$_2$Cu$_3$O$_{7-\delta}$ superlattices has been measured by c-axis transport. We show that only by changing the thickness of the superconducting YBa$_2$Cu$_3$O$_{7-\delta}$ layers, it is possible to switch between quasi-particle and Josephson tunneling. From our data we deduce a low temperature c-axis coherence length of $\xi_c = 0.27$ nm.

Keywords: Josephson effect; tunneling; YBa$_2$Cu$_3$O$_7$

Artificial YBa$_2$Cu$_3$O$_{7-\delta}$/PrBa$_2$Cu$_3$O$_{7-\delta}$ superlattices (Y123/Pr123) constitute ideal model systems for isolating given properties of High Temperature Superconductors. In those systems it is possible for instance to modify the c-axis tunneling properties simply by varying the periodicities of the Y123 and Pr123 layers.

Series of 200 nm thick Y123/Pr123 superlattices have been prepared by high-pressure dcsputtering. The high quality of the samples was checked by detecting up to third order satellite peaks in x-ray $\theta-2\theta$ scans. Later on series of mesa structures with dimensions between $15 \times 15$ and $50 \times 50$ $\mu$m$^2$ were prepared by ion milling. In this work we present low temperature data on 2:7 (2 layers of Y123 and 7 of Pr123) and 8:8 superlattices.

We measured simultaneously the $U$ vs. $I$ characteristics and the differential conductivity $\sigma(U)$ by means of a standard Lock-In technique. In Fig. 1 we show the $\sigma(U)$ on a $30 \times 30 \mu$m$^2$ mesa done on a 2:7 superlattice at 2.0 K. No superconducting current could be detected. However the peak in $\sigma(U)$ corresponds to a c-axis superconducting gap. From the peak to peak voltage $U_{pp}$, we estimate that each of the $n=8$ to 10 bi-layers constituting this mesa have a c-axis gap $\Delta_c = U_{pp}/4n = 5.0 \pm 0.5$ meV. This value is in excellent agreement with the value of $\Delta_c$ given in the literature which scatters between 4 and 6 meV for planar junctions [1].

In Fig. 1, we observe sharper features in $\sigma(U)$. In order to verify a quasi-periodicity, we marked each minimum by a vertical line which is associated to an integer. In Fig. 1 we plot this index as a function of the minima position. A clear zero crossing of the linear fit is obtained by choosing an index $n=9$ for the lowest index. From the linear fit we deduce...
a period of \((11.1 \pm 0.5)\) mV which gives a periodicity \(\delta U = (1.2 \pm 0.1)\) meV for a single junction. These features are reproducible and temperature independent up to 20 K.

Such a quasi-periodic structure in the density of states has been theoretically predicted by Hahn [2]. According to this work, above the superconducting gap, additional structures should appear with a periodicity of:

\[
\frac{\xi_c}{s} = \frac{1}{\pi^2} \frac{\Delta_c}{s}
\]

where \(s\) is the period of the superlattice and \(\xi_c\) the c-axis coherence length. From our data and by taking \(s = 10.5\) nm we deduce a c-axis coherence length of \(\xi_c = 0.27\) nm. If we assume for Y123 an anisotropy of \(\gamma \approx 5\) [3] we would obtain a in-plane coherence length \(\xi_{ab} = \gamma \xi_c \approx 1.4\) nm. This value is close to the generally quoted \(\xi_{ab} = 1.5\) nm for Y123 [4].

In Fig. 2, we show the \(I\) vs. \(U\) characteristics of a \(40 \times 40\) \(\mu m^2\) mesa done on a 8:8 superlattice for zero field and for \(B = 1\) T. From the difference between the two curves we deduce the presence of two distinct low and high current regimes. To investigate the difference between these two regimes we measured the \(B\) dependence of \(\sigma(U = 0)\) at zero bias current and at 115 \(\mu\)A (see inserts).

At zero current \(\sigma(B)\) shows a modulation of \(B_\Phi = 0.7\) T. By considering that \(B_\Phi = \Phi_0 / (s + t)b_{eff}, s=9.4\) nm (Y123 thickness) and \(t=9.4\) nm (Pr123 thickness), we deduce \(b_{eff} = 0.152\) \(\mu m\). The low current regime can therefore be associated to structural shorts [5]. At 115 \(\mu\)A we observe a \(\sigma(B)\) modulation of 2.4 mT. This value is very similar to the 2.5 mT predicted for a \(40 \times 40\) \(\mu m^2\) mesa. The high current regime can therefore be associated to a c-axis Josephson Effect. The absence of a similar effect in the 2:7 superlattices is probably due to a non-fully developed superconducting order parameter in the 2 unit cells thick Y123 layers.

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[5] Such shorts can mainly occur in superlattices having similar thicknesses for both layers. Superlattices having Y123 thicknesses much smaller than the Pr123 layer show usually no shorts.