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ANL/MSD/CP--95670
CONF-980713--

MICROSTRUCTURE OF JOSEPHSON JUNCTIONS: EFFECT ON SUPERCURRENT TRANSPORT IN YBCO GRAIN BOUNDARY AND BARRIER LAYER JUNCTIONS*

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January 1998

Paper to be submitted to Microscopy and Microanalysis, July 12-16, 1998, Atlanta, GA.

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*Work supported by the U.S. Department of Energy, Basic Energy Sciences-Materials Sciences, grant No. W-31-109-ENG-38 and by the National Science Foundation under contract #DMR 91-20000.

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MICROSTRUCTURE OF JOSEPHSON JUNCTIONS: EFFECT ON SUPERCURRENT TRANSPORT IN YBCO GRAIN BOUNDARY AND BARRIER LAYER JUNCTIONS

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The electric transport of high-temperature superconductors, such as $YBa_2Cu_3O_{7-x}$ (YBCO), can be strongly restricted by the presence of high-angle grain boundaries (GB). This weak-link behavior is governed by the macroscopic GB geometry and the microscopic grain boundary structure and composition at the atomic level. Whereas grain boundaries present a considerable impediment to high current applications of high T_c materials, there is considerable commercial interest in exploiting the weak-link-nature of grain boundaries for the design of microelectronic devices, such as superconducting quantum interference devices (SQUIDs). The Josephson junctions which form the basis of this technology can also be formed by introducing artifical barriers into the superconductor. We have examined both types of Josephson junctions by EM techniques in an effort to understand the connection between microstructure/chemistry and electrical transport properties. This knowledge is a valuable resource for the design and production of improved devices.

Since the supercurrent transport in YBCO is highly anisotropic and proceeds largely within the a,b plane, thin film devices with [001] tilt GBs are the preferred geometry for Josephson junctions. Figures 1-3 give examples of the extremes of structures and properties that are possible within this range: Fig. 1 represents an HREM image of a low-angle GB (3.5°). Via the undisturbed lattice between the dislocation cores this GB provides strong coupling between the two grains. Fig. 2 depicts a GB with a $\theta=45°$ misorientation, the effective maximum θ for this tilt axis. Note that this GB is well structured and consists entirely of (110)(001) type GB facets. Measurements on this same GB have yielded the highest critical current density for this misorientation. For the same GB geometry Fig. 3 shows a largely resistive GB, which is not able to maintain a sufficient supercurrent across the disordered GB region [1, 2].

Since the signal strength is determined by the critical current J_c times the normal state resistance R_n of the boundary, a high J_cR_n product is highly desirable for practical Josephson devices. Commercial GB junctions typically are produced by YBCO epitaxy on $SrTiO_3$ bicrystal substrates at $\theta=24°$. A severe limitation to the application of high-T_c SQUIDs is their 1/f noise. Microstructural defects can often be the origin of the noise as seen by comparing the structure of low-noise and high-noise devices (see Figs. 4 and 5)[3].

Josephson junctions that are manufactured by interspersing a non-superconductive layer between the superconducting material allow design of tailor-made properties by controling interlayer thickness and material type. A cross-section of an edge-junction is shown in Fig. 6 . For the interlayer a number of conductive oxides, such as Ca RuO3, SrRuO3, and also Co-doped YBCO have been used. To maintain epitaxy between the different layers and at the same time obtain a uniform thickness is difficult, typically defects and quite high steps are formed (Fig 6)[4].

Recently, Conductus Inc. has developed a process in which the YBCO is modified by an appropriate plasma treatment in such a mannner that it forms a barrier with much improved properties [5]. The barrier layer of this interface-engineered junction, as seen in Fig. 7, is quite uniform and does not have the typical high steps of the heterophase junctions. Detailed investigations of the atomic-scale nature of these junctions are in progress.

Clearly, detailed information on the structure and composition of high-T_c interfaces obtained by various EM techniques is essential for understanding the correlation between their structure and electric properties of Josephson devices.

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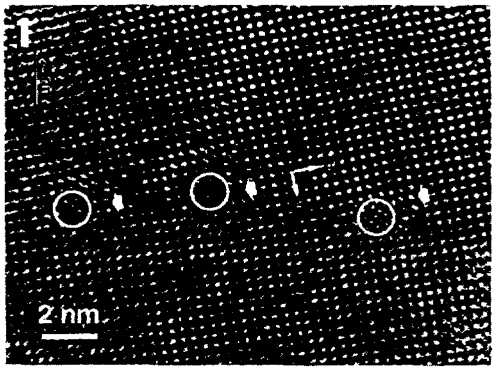
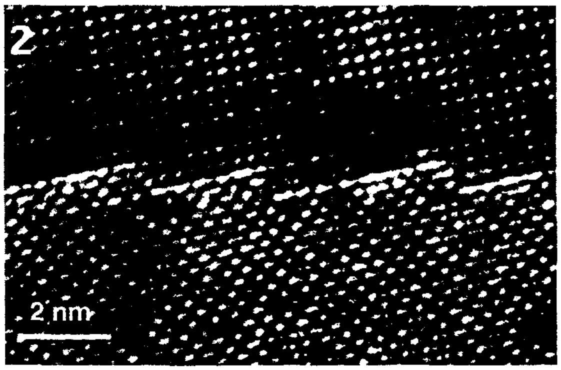
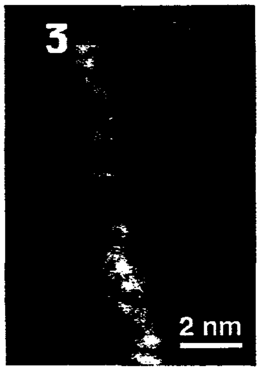
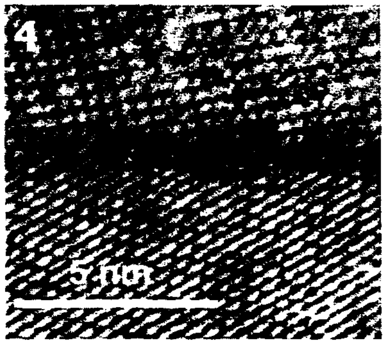
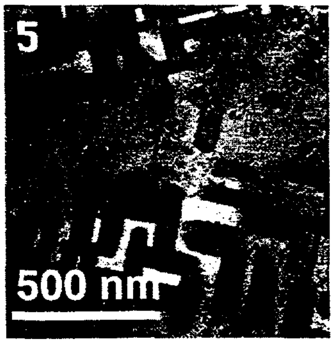
6. The authors acknowledge the use of the facilities of the ANL/MSD Electron Microscopy Center. This work was supported by the U.S. DOE, BES, under contract W-31-109-Eng-38 (KLM) and by the NSF under contract #DMR 91-210000 (YH).











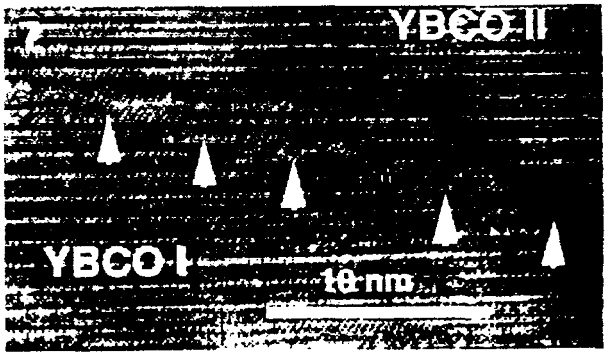


Fig.1. HREM image of low-angle, 3.5°, [001] tilt GB in YBCO, showing 3 reconstructed dislocation cores, indicated by circles.

Fig. 2. YBCO 45°, [001] tilt GB with (110)(001) type microfacets.

Fig. 3. Resistive 45° [001] YBCO tilt GB.

Fig. 4. Low-noise 24° [001] YBCO tilt GB SQUID.

Fig. 5. A-axis growth in high-noise SQUID.

Fig. 6. Cross section of YBCO edge junction with $SrRuO_3$ interlayer.

Fig. 7. Interface-engineered YBCO Josephson junction, showing narrow junction with modified structure in the plasma-treated region.