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Under this contract, thin film deposition technology suitable for in situ deposition of the high temperature superconductor $YBa_2Cu_3O_7$ was developed and the materials science of the resulting films examined. The important role of cation disorder was identified. The composition dependence of the superconducting properties of the films near stoichiometry was characterized, providing critical information on the degree of composition control needed. In addition, amorphous silicon tunnel barriers were used to study the role of localized states on transport through tunnel barriers. The importance of directed chains of localized states in this process was definitively proven and compared with theory. The correlated nature of such tunneling was also demonstrated. A deleterious effect of localized states on Josephson tunneling was documented.

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FINAL REPORT

to

THE OFFICE OF NAVAL RESEARCH

for a program on

PHYSICAL PROPERTIES OF THE HIGH-Tc OXIDE SUPERCONDUCTORS

for the period

October 1, 1989 to September 30, 1995

Principal Investigator

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July 1996

Physical Properties of the High-Tc Oxide Superconductors

This program had two foci. The first was to develop approaches to the deposition of thin films of the high temperature cuprate superconductors and to study the physical properties of these films, in particular the behavior of tunneling and proximity effect junctions made on these materials. The second was to study transport through barriers containing localized states in a model barrier material (amorphous silicon) and to apply the knowledge gained to new tunneling and proximity devices and to the interpretation of tunneling and proximity junctions made with real, complex barrier materials, such as those encountered with the high-Tc superconductors.

The main accomplishments under this contract were:

1) Study of 1/f noise in early thin films of the high-Tc superconductor 123 YBaCuO, and demonstration of the connection between the magnitude of the 1/f noise and the microstructure of the film. [1].

This work was carried out collaboratively with the group of John Clarke at the University of California at Berkeley. It was one of the first measurements of the 1/f noise in the then new high-Tc superconductors. It was on the basis of this work that the Berkeley group then focused on the reduction of 1/f noise in 123 YBaCuO thin films through improved microstructure that has led to the rather good performance now available.

2) Carried out some of the earliest studies of proximity tunneling on the high-Tc superconductors 123 YBaCuO. [2,3].

This work was one of the first to show that there was a large boundary resistance in 123 YBaCuO/noble metal/Pb proximity junctions and that the IcRn products were anomalously low. The results were compared with the existing theory of the times, and led to the conclusion that it was not possible to quantitatively explain the data. Much work has transpired since this early work—in some cases in agreement, and in some cases contradictory to our early results. It seems fair to say that a quantitative understanding of the interface between 123 YBaCuO and noble metals is still not available.

3) Carried out systematic studies of the reactive coevaporation of 123 YBaCuO thin films. [4,5]

In this work we developed the technology necessary to deposit *in situ* thin films of 123 YBaCuO using electron beam coevaporation and made a careful study of the composition dependence of the properties of the resultant films. The work raised a number of questions that are still not fully resolved regarding the role of cation disorder in the properties of 123 YBaCuO thin films. It also is one important pillar in the information base being used now to develop thermal evaporation as a commercial approach to the deposition of 123 YBaCuO thin films for application in passive rf devices.

4) Completion of our major study of the temperature and voltage dependence of the conductance due to localized states in our amorphous silicon model system barriers, and the test of the relevant theories developed in response to our experiments [6].

The agreement with the theory of Glazman and coworkers based on hopping along statistically arising, directed chains of optimally located localized states is remarkable, indicating that the independent electron (no interactions) theory of such processes is in outstanding shape. The temperature and voltage dependence of the conductance could be fit over many, many decades of conductance with a single set of material parameters.

5) Demonstration and understanding of the correlated nature of tunneling via localized states in tunneling barriers [7,8,9].

More recent extensions of the theory of Glazman, et al., for transport via localized states predicts that the presence of strong on-site coulomb interactions on the localized states (a large so-called on-site U) introduces correlations into the tunneling of degenerate spin up and spin down electrons. Basically two electrons cannot exist on the site at the same time. We have quantitatively demonstrated the existence of such correlations for resonant tunneling via single localized states through studies of the magnetoconductance of our amorphous silicon junctions.

Working with these theorists, we have extended the theory to include correlations in transport via chains of localized states containing more than one localized state. This in turn has provided a means of demonstrating that states both near the fermi level in the barrier, and states a distance U below the fermi level, actually participate in the transport. This is the first direct demonstration of this fact, to our knowledge.

The theories of correlated resonant tunneling via localized states also predict that such tunneling leads to a negative Josephson coupling energy---otherwise known as a π junction, referring to the lowest energy state corresponding to a quantum phase difference of π across the junction. These predictions remain untested. The process is of some practical interest. For example, under our ONR URI support, we have suggested that such junctions could be the basis of a complementary Josephson circuit technology analogous to CMOS.

6) Demonstration of a zero-bias resistance anomaly in the conductance of our junctions that is not understandable in terms of any of the existing theories of zero-bias anomalies [10].

At very low biases and very low temperatures we see deviations from the theories described above that are remarkably successful at higher temperatures. Zero-bias resistance anomalies are not new. They are customarily ascribed to interactions of a tunneling electron with localized spins in the barrier. (This is distinct from tunneling via localized states. Here it is a spin-spin interaction.) Our inability to account for this behavior should not be taken to say this basic physical picture is wrong, only that it is not yet complete. In any event, this is one aspect of data that can be said to be still very poorly understood and worthy of further investigation, particularly as it arises in the voltage and temperature regime of interest in superconducting devices.

7) We have re-examined the affect of localized states on both quasiparticle and Josephson tunneling in our junctions [11].

In a recent review article, we took the opportunity to re-examine the influence of the presence of localized states on the I-V characteristics of SIS tunnel junctions using our amorphous silicon barrier. In particular, we examined how the I-V characteristic and the Josephson current become non ideal as the thickness of the barrier increases (and the relative importance of transport localized states increases). Not surprisingly, there is marked deterioration of the characteristics from their ideal form. What was surprising is that the degradation was pronounced long before a significant fraction of the tunneling current was being transported via localized states.

Hence, the existence of localized states in a tunnel junction has a major effect on superconducting tunneling. Whether this is an effect of the localized states on the correlated nature of superconductive tunneling is not clear. In any event, what is clear is that much of the previous thinking on the effects of localized states on superconducting tunneling has been quite naive, and that a real understanding is still lacking, despite invocations to their presence in accounting for the non idealities in the junction characteristics with the high-Tc superconductors. At least we have a model system in which the nature and density of localized states is well characterized with which to pursue further resolution of these issues.

8) We have studied the transport mechanisms in PrBaCuO in an attempt to clarify the origins of the long-range proximity effect sometimes observed in this material [12,13].

There have been scattered but persistent reports of anomalously long proximity coupling through PrBaCuO barriers in high-Tc Josephson junctions. In an attempt to understand these observations, we carried out a careful study of the transport processes in PrBaCuO. Our results support the contention that, in fact, in this nominally insulating material the linear CuO chains are actually conducting. While we did not prove that this remarkable property of PrBaCuO is, or even could be, the origin of the so-called long-range proximity effect, our results are provocative. Clearly there is a need to better understand transport processes in the cuprate family of materials in their insulating states and, in particular, near the superconductor/insulator transition.

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