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Effects of Surface Properties on Metal-Oxide Superconductor Contact Resistance

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INTRODUCTION

The recent discovery of ternary metal oxide ceramic superconducting materials (Tc 98K) has led to a sudden burst of research activity all over the world (1-9). The demonstration of $10^5 A/cm^2$ critical current density at 77K, (7) the boost of transition temperature to 155K by adding flourine atoms to the superconductor structure (10) and some evidence of room temperature superconductivity further promoted the promise and interest of these materials. Processing of these materials into useful forms such as wires, rods, tubes, films, ribbons, ... etc. will make it possible for applications to high-field magnets, power transmission lines, magnetic coil, microelectronics ... etc.

The applications of the new class of very exciting superconductor materials to microelectronics and microsensors rely on the research to solve the problems of relatively low superconductor critical current density for non-single-crystalline materials and the poor metal to superconductor contacts. Scientists in IBM have demonstrated the superconducting critical current density above $10^5 A/cm^2$ for single crystalline $YBa_2Cu_3O_6$+x thin films by means of magnetic measurements. The contact resistance was too high to measure the superconducting critical current density directly. Therefore, a more detailed study and optimization of the metal to superconductor contacts is desirable. Almost every application of the high temperature superconductor materials requires a good metal-superconductor contact.

EXPERIMENTAL

Ternary metal oxide $YBa_2Cu_3O_{6+x}$ is fabricated by mixing Y_2O_3, $BaCO_3$, and CuO in appropriate proportion, burning in the air at 950°C for 6 hrs., and sintering in an oxygen flowing tube at 950°C for 12 hrs. Aluminum shadow masks are used to define four circular dots of metal deposition on the surface of the hgih temperature superconductor (HTSC). Copper is deposited by the DC sputtering and gold is deposited by a filament evaporator.

The deposited four dots are used to do the four point resistance measurement in order to check the superconductivity of each sample. Two metal dots are selected for measuring the two-point resistance. In the two-point measurement, a desired current is passed through two metal dots on the superconductor using two wires and the voltage across these two dots is measured by another pair of wires connecting these two metal dots to a voltmeter. When the substrate is superconducting the measured voltage to current ratio should be the contact resistance of two metal-superconductor contacts.

RESULTS AND DISCUSSION

The metal-oxide superconductor contact resistance is very dependent of the surface conditions of the samples. Although some contacts to different batches of samples show a decreasing contact resistance with a decreasing temperature, most of our samples have contact resistance increasing with decreasing temperature. This is opposite to the trend of superconductor resistance. Although the superconductivity critical current density can be high at a low temperature the poorer contact makes the lower temperature not beneficial. More work certainly is needed to improve this contact resistance.

The typical voltage-current characteristics are shown in Figure 1 at three temperatures. These curves show that the

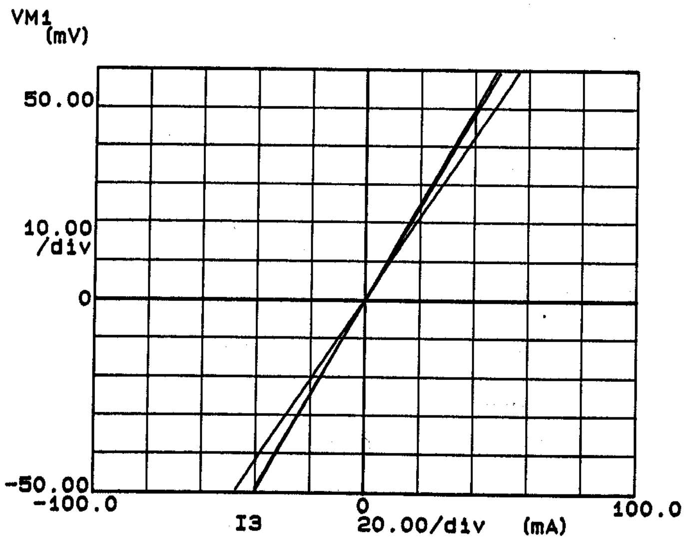

Figure 1. Typical voltage-current characteristics of a metal-oxide superconductor contact at three temperatures.

contact is ohmic. Four HTSC samples from the same batch with different surface conditions are deposited with copper to form ohmic contacts. The ohmic contact on the fresh HTSC sample shows increasing contact resistance with decreasing temperature. The measured two-point resistance decreases a little when the HTSC sample reaches the superconductivity state and then increases again when the temperature decreases further. Since the two-point resistance is the summation of the contact resistance and the bulk resistance, the slight decrease of two-point resistance is attributed to the decrease of bulk resistance. The specific contact resistance of this copper to fresh sample contact is about 4 x 10^{-3} ohm-cm^2 at 77°K.

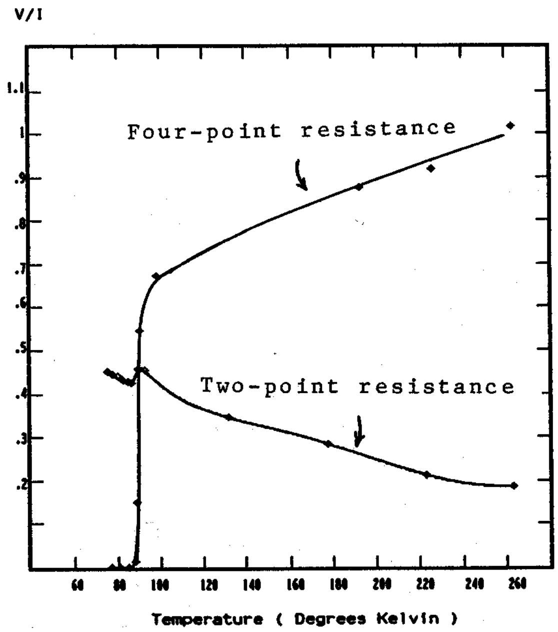

Figure 2. Two-point and four-point resistance measurements for a fresh HTSC sample with copper contacts. The specific contact resistance at 77°K is 4 x 10^{-3} ohm-cm^2.

One of these four samples is heated in a vacuum oven at 300°C for 2 hours before copper is sputtered on it to form ohmic contacts. The vacuum baking accelerates the degradation of the surface layer by reducing the oxygen concentration. This is evidenced by the XPS analysis of the O1S peaks before and after vacuum baking. Copper ohmic contacts to this sample shows rapid increase in contact resistance when temperature decreases. The overall trend of Rc v.s. T is similar to that of the fresh sample. Both the four-point and two-point resistances for this sample is shown in Figure 3. The specific contact resistance is about 2×10^{-2} ohm-cm^2 at 77°K. This is 5 times higher than that of a fresh sample.

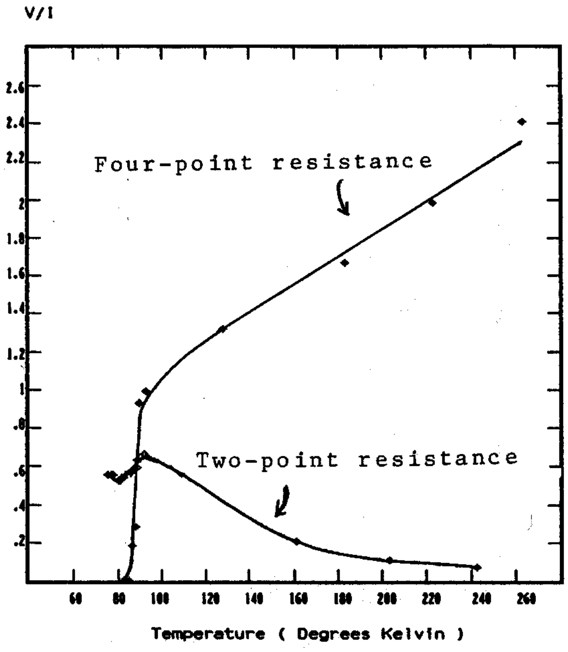

Figure 3. Two-point and four-point resistance measurements for a vacuum baked HTSC sample with copper contacts. The specific contact resistance at 77°K is 2×10^{-2} ohm-cm^2.

The third sample is baked in air at 500°C for 2 hours before copper contacts are formed. The rate of increase of contact resistance with decreasing temperature is between that of a fresh sample and a vacuum baked sample. The two-point and four-point resistances are shown in Figure 4. The specific contact resistance is 8 x 10^{-3} ohm-cm^2 at 77°K.

The fourth sample is also a fresh sample. Before the copper deposition, the sample is exposed to an oxygen plasma for 5 minutes without intentional heating. After the oxygen treatment, the sample is deposited with copper to form contacts without exposing to the atmosphere. The two-point resistance decreases

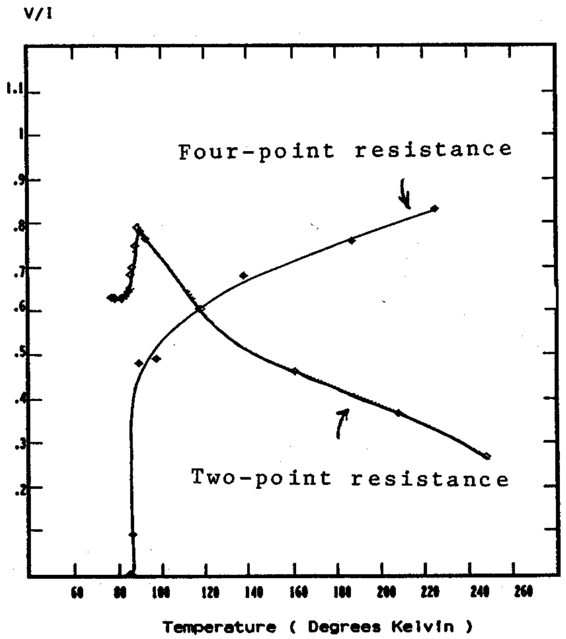

Figure 4. Two-point and four-point resistance measurements for a copper contact to a HTSC sample baked in air at 500°C for 2 hours. The specific contact resistance is 8 x 10^{-3} Ω-cm^2.

with decreasing temperature just like the bulk resistance does. This is shown in Figure 5. The oxygen treatment has apparently recovered at least partially the oxygen deficiency at the surface of the HTSC sample and made the ohmic contacts more desirable. The specific contact resistance is around 1 x 10^{-3} ohm-cm^2 at 77^oK. Further improvement of the contact resistance requires the compensation of the segregation and pile-up of elements in the ternary metal oxide at the sample surface after high temperature treatments. We are currently working on this subject.

In addition to copper contacts, gold contacts are also studied. The gold contact to a fresh sample also shows increasing contact resistance with decreasing temperature as shown in Figure

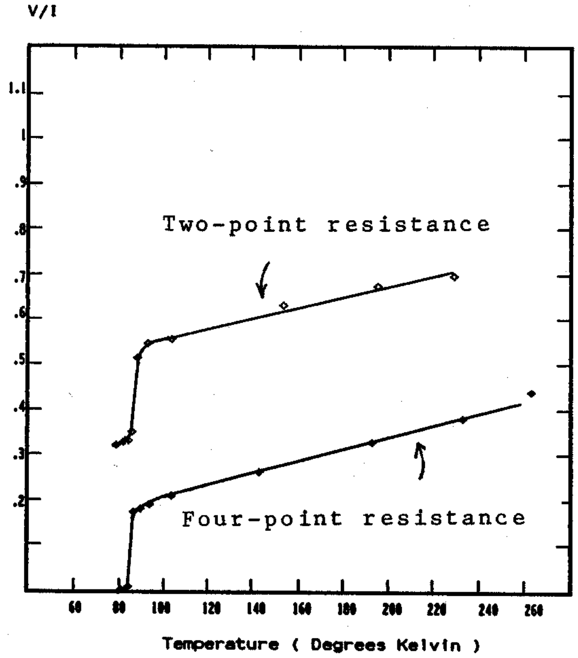

Figure 5. Two-point and four-point resistance measurements for a copper contact to a HTSC sample treated with an oxygen plasma. The specific contact resistance is 1 x 10^{-3} ohm-cm^2.

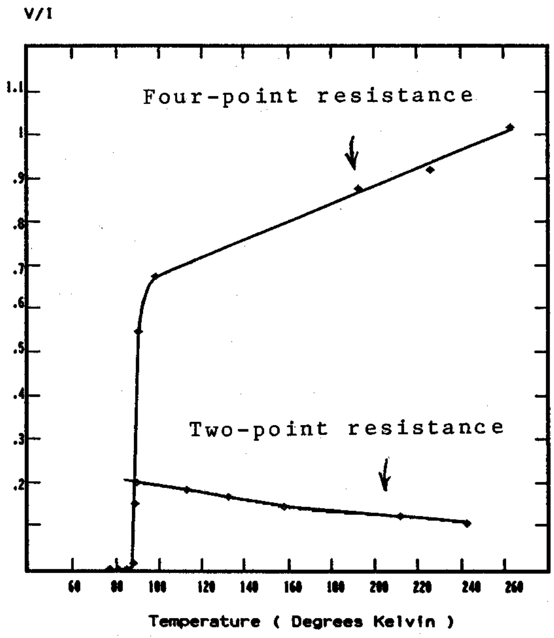

Figure 6. Two-point and four-point resistance measurements for a gold contact to a fresh sample. The specific contact resistance is 8 x 10^{-3} ohm-cm^2 at 77°K.

6. The specific contact resistance is 8 x 10^{-3} ohm-cm^2 at 77^oK. After the gold contact is heated to 450^oC in the air for 1 hour, the gold apparently diffuses into the HTSC as the color of the gold contacts turns into dark brown. This causes the contact resistance to increase significantly as shown in Figure 7. The specific contact resistance increases from 8 x 10^{-3} ohm-cm^2 to 6 x 10^{-1} ohm-cm^2 at 77^oK.

CONCLUSION

Ohmic contacts between a metal layer and an oxide superconductor prepared by a simple deposition of metal onto the oxide

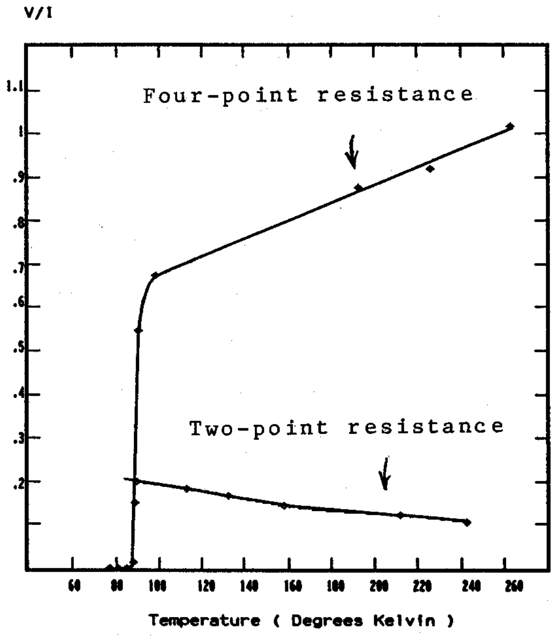

Figure 6. Two-point and four-point resistance measurements for a gold contact to a fresh sample. The specific contact resistance is 8 x 10^{-3} ohm-cm^2 at 77°K.

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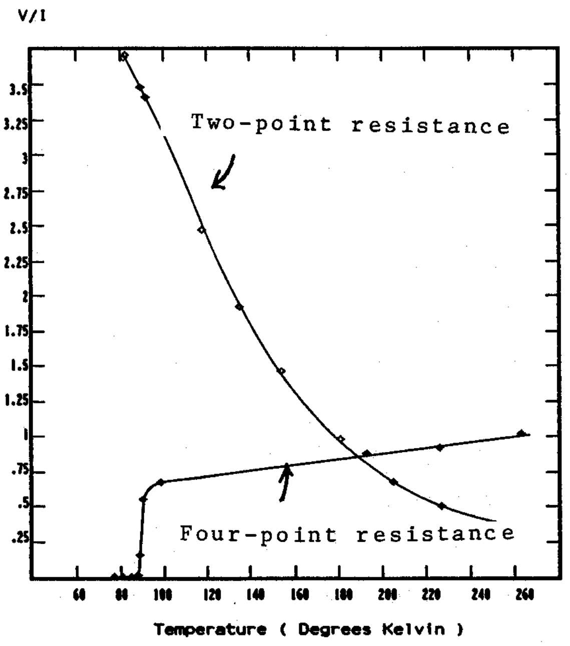

Figure 7. Two-point and four-point resistance measurements for a gold contact to a fresh sample followed by a heat treatment at 450°C for 1 hour. The specific contact resistance is 6 x 10^{-1} ohm-cm^2 at 77°K.

superconductor surface have poor contact resistance. Oxygen plasma treatment of the sample surface before metal deposition improves the contact resistance. A better and maybe more sophisticated metal-oxide superconductor interface is required to achieve acceptable ohmic contacts.

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