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Processing Techniques to Locally Alter the T_c of Aluminum Thin Films

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We report on the successful use of reactive ion etching techniques and ion implantation to locally alter the superconducting transition temperature of aluminum thin films by as much as 5%. The mechanism by which T_c is shifted is by the replacement of surface oxygen with fluorine in the case of the reactive ion etch, with a secondary effect due to damage being evident at long exposure times. The ion implantation produces a shift in T_c of similar magnitude through the damage induced uniformly in the entire film.

1. INTRODUCTION

Previously, it has been shown that the superconducting transition temperature, T_c, of aluminum thin films can be shifted by a few percent by altering the surface of the films using the technique of reactive ion etching with freon gas[1, 2]. Uniform thin aluminum films whose T_c is locally altered simulate a 2D analog of a superlattice. These films produce a long range proximity effect on a length scale much longer than that predicted by theory[3, 4]. Auger microscopy has shown that the reactive ion etching process results in replacement of surface oxygen with fluorine[5]. However, it has been difficult to produce the T_c shift in a controlled manner, and the hypothesis that surface modification plays an important role for the long range proximity effect needs a more thorough investigation. We report on a process that successfully controls the T_c shift. We also report results that test the role of surface modification.

2. EXPERIMENTAL DETAILS

The sample is a photolithographically defined thin film of aluminum, evaporated onto a silicon nitride on silicon substrate. Nominal thicknesses of the films range from 250 to 550Å, and their diffusion constants are ~70-90cm^2/sec. A given film is selectively modified using either ion implantation or reactive ion etching techniques. Low temperature resistance measurements on such samples are carried out in a ^{4}He cryostat.

3. RESULTS

First, we used oxygen and fluorine ion implantation at 5 KeV with doses equivalent to one to five monolayers. This technique gives us a reproducible positive T_c shift proportional to ion dose, as shown in figure 1 for an aluminum film of thickness 530Å. It is apparent that this positive

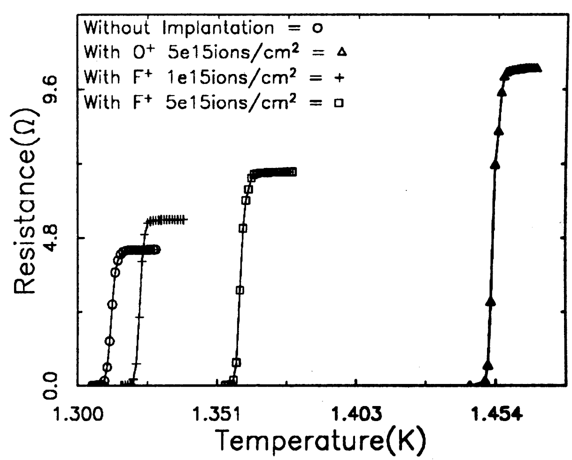

Figure 1. T_c Shifts with Different Ion Implantation Doses.

shift is due to structural damage by the energetic ions deposited throughout the entire volume of the sample because the normal state resistance is increased substantially after the implantation. The aluminum structures modulated by this technique show a proximity effect on length scales of about 2μm or less.

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We also altered the T_c of aluminum films by the use of reactive ion etching techniques with CF_4 gas at a power of 18W and a pressure of 2mtorr. This plasma condition is at significantly lower power and pressure than the previous experiments[1, 2, 5]. CF_4 gas was chosen since it is a very poor etchant for aluminum, and thus aluminum removal by reactive ion etching with CF_4 is negligible. This technique produces a negative T_c shift, proportional to the etching time at first, but saturating with longer times. This is shown in figure 2 for an aluminum film of thickness 350Å. When the sample is exposed to the plasma over

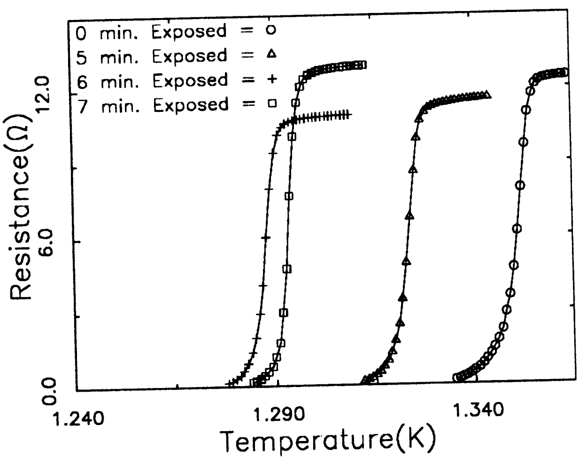

Figure 2. T_c Shifts Due to Exposure to CF_4 RIE.

a long period of time, the secondary effect due to damage is no longer negligible and the negative T_c reverses, accompanied by a sudden increase in the normal state resistance. We have obtained T_c shifts of as much as 5%. The usual values of diffusion constant and normal state resistivity before the saturation are about $60 cm^2/sec$ and $2.5 \mu\Omega$-cm respectively. The aluminum structures modulated by this CF_4 reactive ion etching technique show a proximity effect on a length scale of about $10 \mu m$. The technique results in a smaller length scale than the previous experiments[1, 2, 5], but a more reproducible T_c shift.

4. CONCLUSION

We have developed techniques of ion implantation and reactive ion etching to shift the superconducting transition temperature of aluminum thin films reproducibly and in a controlled manner. The T_c shift is controlled by varying the implanted ion dose or the reactive ion etching exposure time. The implantation technique produces uniform damage throughout the film thickness, whereas the etching technique alters only the top layer of the film. By comparing the experimental length scales of the modulated aluminum structures by these two techniques, the hypothesis that surface modification is important for a long range proximity effect appears to be correct.

5. ACKNOWLEDGEMENTS

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