Physica B 165&166 (1990) 483–484
North-Holland

ALUMINUM THIN FILMS WITH IN-PLANE MODULATED SUPERCONDUCTING STRUCTURES

K. LIN, Y. K. KWONG, M. ISAACSON, and J. M. PARPIA

School of Applied and Engineering Physics and Department of Physics
Cornell University, Ithaca, NY 14853, USA

We have investigated superconducting properties of aluminum thin films with periodically modulated regions of different transition temperatures (Tc). These samples are made by microlithography and reactive ion etching techniques. They provide a simple and flexible alternative to metallic superlattices previously used in studying the effects of periodicity and anisotropy on superconductivity. Results indicate that these films show global superconducting behavior with properties determined by modulation length scales.

1. Preliminaries

Superconductors with modulated compositions have always been of great interest for studying the effects of periodicity (or controlled aperiodicity) and anisotropy. Well-known effects include enhanced Tc (1), critical field anisotropy, and various dimensional crossovers (2). All previous studies use artificial metallic superlattices (3), which are prepared by successive deposition of two (or more) different materials by sputtering or evaporation. Since the transport properties of these superlattices depend critically on the interfaces, experimenters must always carefully consider such factors as interlayer mixing and diffusion, sample purity, deposition vacuum conditions, interfacial mismatch, and layer uniformity (3). We present here a simple method for modifying the transition temperature, in selected regions of arbitrary shape or size, of a continuous aluminum thin film. We have used this method to study the resistive transitions of films with periodically spaced regions of different Tc's. The relationship between various transport and fabrication length scales are discussed.

2. Samples

In a previous investigation (4), we observed that reactive ion etching (RIE) using freon gas can alter the superconducting transition temperature of aluminum thin films without affecting other transport properties such as the diffusion constant, residual resistance, and inelastic scattering rates. Standard photo- or electron beam lithography followed by RIE can thus define any arbitrary configuration of regions of higher and lower Tc's in a single continuous film (Fig. 1). Aluminum films have the advantage of simple preparation and long coherence lengths (ξ). To be useful as alternatives to superlattices, these samples should have structure sizes comparable to or less than ξ. The elastic mean free path in our films is estimated to be $\geq$90Å, from which we estimate the zero-temperature coherence length, $\xi(0)\approx 0.1\mu$m. Since our data is taken close to Tc, $\xi(T)$ should be $\geq 1\mu$m, much larger than minimum achievable lengths in microlithography. The interface between adjacent regions has a definition of $\leq 0.1\mu$m. Thus, sensitivity to interface quality should be negligible. Since we have shown that other transport properties remain unaltered (4), the spatial variation of the superconducting potential can be studied as an isolated variable.

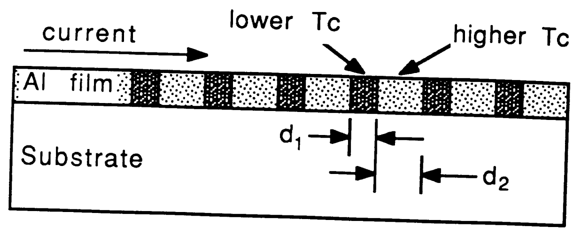

Figure 1: Schematic of aluminum film with modulated Tc regions.

3. Results

Our films consist of gratings of etched and unetched regions with width d_1 and d_2 respectively, for an overall periodicity of d_1+d_2 (Fig. 1). The resistive transitions are measured with currents perpendicular to the grating, using a four-point resistance bridge. Resistance thermometry is used to regulate sample temperatures to better than $\pm 100\mu$K in a He-3 cryostat. Figure 2 plots some observed transitions. The leftmost one is that of a

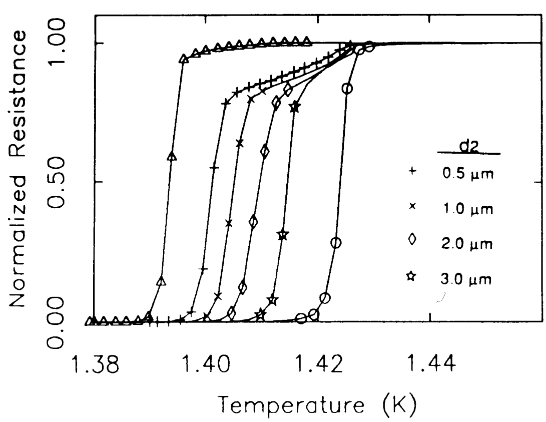

Figure 2: Resistive transitions of modulated superconducting films, (Δ) T_{c1}, (O) T_{c2}. All intermediate transitions are for d_1=1µm and d_2 as indicated.

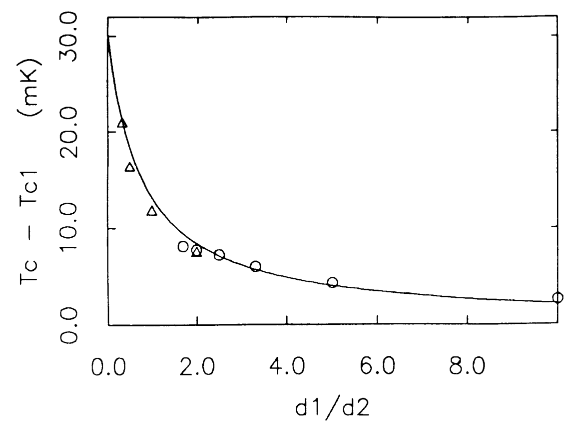

Figure 3: Change in Tc vs. the ratio (d_1/d_2). (Δ) d_1=1µm, (O) d_1=5µm. Solid curve is from Equation (1) using p=1.3.

uniformly etched section, with lowest Tc (T_{c1} =1.394K). The highest transition belongs to the totally unetched section (T_{c2} =1.424K). The two transitions have nearly identical widths. The curves in the middle are representative of those for gratings with various values of d_1/d_2. The resistance of all the gratings slowly decreases from their normal state value, Rn, to ≈0.8Rn in the temperature range between T_{c2} and their own "real" Tc, where a sharp transition to near-zero resistance occurs. We speculate that this gradual decrease is due to charge imbalance effects (5). Figure 3 plots the shift in Tc (Tc-T_{c1}) as a function of the ratio d_1/d_2. Only two values of d_1 (physical width of lower Tc region), 1.0µm and 5.0µm, are used. Tc appears to be determined by the ratio d_1/d_2 rather than the size of the region d_1, indicating that the characteristic length scale is ≥5µm. For example, the transitions for d_1/d_2= 1µm/0.5µm and 5µm/2.5µm coincide. This is contrary to our estimate of $\xi(T)$. Using linearized Ginzburg-Landau equations and the assumption that $\xi(T)$>>d_1, d_2 everywhere, it can be shown that

$$T_c - T_{c1} \approx \frac{T_{c2} - T_{c1}}{1 + p\left(\frac{d_1}{d_2}\right)} \qquad (1)$$

where p is a factor of order unity which characterizes interface conditions (3). This function is shown in Figure 3, using p=1.3. It fits remarkably well, implying that the characteristic length may be considerably larger than our estimate.

4. Remarks

For the lengths d_1 and d_2 that we have used, the modulated films act as a single superconductor. As the lengths d_1 and d_2 are increased we expect that the film should act like different superconductors in series, with distinct transition temperatures. We plan to vary the lengths over a wider range which together with critical field measurements now underway, should provide more clues as to the origin and magnitude of the characteristic length scales. We will also investigate other pattern configurations in the future.

*This work is partially supported by the National Nanofabrication Facility under NSF grant ECS-8619094, the Cornell Materials Science Center under DMR85-16616, and AFOSR grant 90-0111.

1. M. Strongin, O. F. Kammerer, and J. E. Crow, Phys. Rev. Lett. **21** (1968) 1320.
2. I. Banerjee, Q. S. Yang, C. M. Falco, and I. K. Schuller, Phys. Rev. B **28** (1983) 5037 .
3. B. Y. Jin and J. B. Ketterson, Adv. in Phys. **38** (1989) 189 (Equation 6-66).
4. Y. K. Kwong, K. Lin, P. Hakonen, J. M. Parpia, and M. Isaacson, J. Vac. Sci. Tech. **B7** (1989) 2020.
5. J. Clarke, Experiments on charge imbalance in superconductors, in: Nonequilibrium Superconductivity, eds. D. N. Langenberg and A. I. Larkin (Elsevier, New York) pp. 1-63.