followed by sputter cleaning at 5 mTorr Ar pressure for 2 min at 1 W/cm². Substrates for closed cycle fabrication, however, were transferred directly to an oxidation and evaporation system. A dc-plasma oxidation (40 mTorr O₂ pressure, 800-V potential, 45 s) produced the tunneling barrier for either type of sample. A Pb film of approximately 0.5-μm thickness was then deposited at 6 × 10⁻⁶ Torr with a 2-min evaporation time. Patterning concluded the fabrication of standard junctions. For the closed system process another Pb deposition under similar conditions followed. Immediately before this evaporation, the samples were etched in acetic acid to remove PbOX and prevent formation of an unwanted junction. Length and width of the junctions were 120 and 60 μm respectively.

Volt-ampere curves, typical of the two processes, are shown in Figs. 2 and 3. The knee in the left curve is characteristic for our standard junctions. It has not appeared in I-V curves of closed cycle devices. Note, however, the somewhat reduced gap for the latter. At present, we have no explanation for this decrease in gap voltage. Nevertheless, I_eR products for both types of junctions are in the order of 1 mV.

We conclude that completion of tunnel junction sandwiches in one pumpdown of a vacuum system is compatible with the requirements of lithographic techniques. The described method should be applicable to other devices and to a large variety of material combinations.


Optical probing technique for inhomogeneous superconducting films a)

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We report a nondestructive optical probing technique for superconducting films, by which a cross-sectional gradient of the local transition temperature T_c and a two-dimensional map of the local critical current I_c of an Al film were obtained. The two-dimensional map clearly shows a variety of defects of the Al film. Some of them can be correlated to visible pinholes.

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In many applications and fundamental studies of superconducting films, it is important or very desirable to know the uniformity of the superconducting properties, e.g., the local transition T_c and critical current density I_c, for a large-area sample. These properties are usually sensitive to the physical homogeneity of the superconducting films, i.e., film thicknesses, composition variations, defects or contamination, etc. While various techniques are available for probing the inhomogeneity of these thin film properties from which the local superconducting properties might be inferred, a nondestructive method to directly probe the uniformity of T_c and I_c of a superconducting film should be most valuable. Recently, a nondestructive two-dimensional probing technique for superconducting films, utilizing a low-temperature scanning electron microscope, has been used to probe the distribution of the supercurrent density in a wide film, and the formation of hot spots in a long, narrow film. Probing the spatial distributions of T_c and I_c of a superconducting film with this technique was not reported, and it is not clear whether it can be done easily. In this letter, we report a much simpler optical projection technique which can easily give us useful information on the inhomogeneity of T_c and I_c.

Optical illumination is well known for its capability of destroying or weakening superconductivity; it is often used to study various nonequilibrium phenomena of supercon-
Localizing optical perturbation of superconducting films can be achieved by using an intimate contact mask, or an optical waveguide, or a sharply focused laser beam. Here, for maximum flexibility we use a simple high resolution projection system which can project any two-dimensional pattern onto a superconducting film. Interesting superconductor-normal metal mixtures of various shapes and sizes can thus be created. Our optical projection setup is schematically shown in Fig. 1. With the illumination of a laser beam (or any collimated light beam), a high quality front lens was used to project a predesigned pattern from a conventional lithographic mask plate onto a 300 Å thick superconducting Al film deposited on a 250-μm-thick crystalline quartz substrate. The sample was vertically mounted in an optical immersion dewar with liquid helium pumped down to below the superfluid transition temperature to avoid helium bubbles. Since our Al film was semitransparent, an image lens was used to project both the sample and the focused image pattern onto a distant wall to check the sharpness of the focus and the relative position of the image pattern with respect to the sample. In the case of nontransparent samples, a low power microscope could be set up in front for viewing. For our present optical system, about 5-μm optical resolution is achieved on the sample plane, with a field size of about 3 mm.

It is, of course, most important to check whether the spatial perturbations of the superconducting properties are comparably localized. To answer this question a relatively thick (2000 Å) and narrow (25 μm) Pb counter electrode was evaporated onto the slightly oxidized Al film to form a tunnel junction. Both of the superconducting gaps of Al and Pb can be determined from the I-V characteristics of the junction. We used our projection system to create a sharply defined dark-to-bright edge. The light intensity was adjusted so that the gap of the Al film was suppressed but not totally destroyed when illuminated from the Al side. Figure 2 shows the measured Al gap as a function of the position of the dark-to-bright edge with respect to the junction position. The 10% to 90% change in gap occurs with 30 μm, which is just about our optical resolution length plus the junction width. Thus the laser induced spatial perturbation for our superconducting Al sample was localized on the scale of our optical resolution length. This implies that the quasiparticle inelastic diffusion length of our Al film is less than 5 μm, which is consistent with an estimated value about 1-2 μm.

Having determined the spatial resolution of the laser effect on the superconducting film, we can now describe a novel method to probe the distributions of \( T_c \) and \( I_c \) of a 300-Å Al film. First, to determine the \( T_c \) gradient perpendicular to the current flow, an image of a dark line about 25 μm wide was projected on the sample with the line direction parallel to the current flow. The laser power was adjusted to a level high enough to drive the illuminated part of the film into the normal state at any ambient temperature within our experimental range (\( > 1.4 \) K). Resistive transition measurements, i.e., resistance versus ambient temperature, were carried out as a function of the dark line position. The resulting \( T_c \) versus position curve is shown in Fig. 3. Note that except for one edge of the film there is a global \( T_c \) gradient, about 0.02 K/mm, from one side to the other which probably reflects the gradient of the film thickness.

Secondly, local critical currents \( I_c \) can also be measured at a temperature below the minimum \( T_c \) of the film. In this case, to demonstrate the two-dimensional scanning capability, we used the optical mask shown in the insert of Fig. 4, which can be projected on the sample to produce a short weak link of dimensions 16 × 16 μm between the two large triangular superconducting pads. With the illuminated portion of the film driven normal, the entire supercurrent must...
then flow through the weak link. By scanning this dynamically created weak link, a two-dimensional map of the critical current inhomogeneity can be created. Typical data is shown in Fig. 4. For ease of visualization, we plot, on the $z$ axis, $1 - \left[ I_e(x,y)/I_{e\text{MAX}} \right]$, where $I_{e\text{MAX}}$ is the maximum local critical current. The large disturbances correspond to visible pinholes. Other smaller disturbances could not be detected visually.

In conclusion, we have experimentally demonstrated that the effect of the optical illumination on a superconducting Al film immersed in superfluid helium is limited to our optical resolution $\sim 5 \mu m$. A factor of 2–3 improvement of our current optical projection system could be made with a better lens of larger $f$ number. Two-dimensional superconducting-normal metal mixtures of any desired shapes and concentrations can be easily created by projecting the shapes from a predesigned photolithographic plate onto the superconducting films with either laser or white light. The dark regions remain superconducting while the illuminated regions are driven into the normal state with a boundary width limited by either the optical resolution length or the quasiparticle diffusion length, whichever is larger. The optical probing technique for the spatial distributions of $T_c$ and $I_c$ of the superconducting films is described and illustrated with a specific Al sample, which has visible defects to be correlated with the experimental measurement. Finally, we would like to point out that such an optical projection system is also suitable for many interesting physical studies. One specific example we have carried out is a percolation study of two-dimensional random lattices of superconducting normal squares. Thanks to the nondestructive optical projection method, the whole range of the concentrations of superconducting squares can be studied with a single Al sample. In conclusion, we have experimentally demonstrated that the effect of the optical illumination on a superconducting Al film immersed in superfluid helium is limited to our optical resolution $\sim 5 \mu m$. A factor of 2–3 improvement of our current optical projection system could be made with a better lens of larger $f$ number. Two-dimensional superconducting-normal metal mixtures of any desired shapes and concentrations can be easily created by projecting the shapes from a predesigned photolithographic plate onto the superconducting films with either laser or white light. The dark regions remain superconducting while the illuminated regions are driven into the normal state with a boundary width limited by either the optical resolution length or the quasiparticle diffusion length, whichever is larger. The optical probing technique for the spatial distributions of $T_c$ and $I_c$ of the superconducting films is described and illustrated with a specific Al sample, which has visible defects to be correlated with the experimental measurement. Finally, we would like to point out that such an optical projection system is also suitable for many interesting physical studies. One specific example we have carried out is a percolation study of two-dimensional random lattices of superconducting normal squares. Thanks to the nondestructive optical projection method, the whole range of the concentrations of superconducting squares can be studied with a single Al sample.

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7The quasiparticle inelastic diffusion length can be estimated by $(r_n V_f/3)^{1/2}$, where the Fermi velocity $V_f$ is taken to be $2 \times 10^6$ m/sec for Al, the elastic mean free path $l$ is estimated by using $\rho l = 9 \times 10^{-16} \Omega m^2$ with the experimentally measured resistivity $\rho$ in the range of $1.5 - 3 \times 10^{-7} \Omega$, and the inelastic scattering time $\tau_n \approx 1.2 \times 10^{-8}$ sec for dirty Al film with $T_c \approx 1.8 K$ [C. C. Chi and J. Clarke, Phys. Rev. B 19, 4498 (1979)].