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ANISOTROPY AND MAGNETIC FIELD DEPENDENCE OF CRITICAL CURRENTS IN Pb/Ge MULTILAYERS

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We have measured critical currents in Pb/Ge multilayers as a function of direction and magnitude of a magnetic field perpendicular to the current. The higher J_c for a field parallel to the layers indicates flux pinning at the Pb/Ge interfaces. The critical current as a function of a perpendicular field displays a pronounced maximum at low fields. TEM reveals Pb grain sizes of about 1000 Å and indicates that the enhanced flux pinning may be explained by grain boundary pinning.

1. INTRODUCTION

Artificially prepared superconducting multilayers have received a renewed interest, since they offer the possibility to test phenomena related to the high-T_c superconductors. Up to now, most work in multilayers has been focussed on the dimensional effects in the critical fields (1), whereas the behaviour of the critical current has been much less studied. Critical current measurements in Nb/Ta (2) and NbN/AlN (3) multilayers both show an enhanced flux pinning for parallel magnetic fields due to the multilayering. Recently, Tachiki and Takahashi (4) presented a model to explain the critical current anisotropy in layered superconductors, which was then applied to single crystal high-T_c superconductors. In this paper we focus on the anisotropy and magnetic field dependence of artificial superconducting Pb/Ge multilayers.

2. EXPERIMENTAL

The Pb/Ge multilayer samples were prepared by electron beam evaporation in an UHV chamber. The base pressure of the system is 2×10^{-9} Torr, and the pressure increased during evaporation up to 10^{-8} Torr. The evaporation rates (5 Å/s for Pb, 2 Å/s for Ge) were kept constant using a quadrupole mass spectrometer (5). The layers were evaporated onto liquid nitrogen cooled oxidized silicon wafers. All multilayers consist of 10 bilayers. The top and bottom layers are always Ge, and the sample is covered with an extra 500 Å Ge protective layer. The four point pattern was defined photolithographically using a liftoff technique. The measurements were performed in a standard ^4He cryostat, equipped with a 7 Tesla superconducting coil. The critical current is defined as the current necessary to produce a 2 μV voltage across the sample at 4.2 K. Other voltage criteria yielded very similar results.
The structure of Pb/Ge (crystalline/amorphous) multilayers have been extensively studied and are described elsewhere (6).

3. RESULTS AND DISCUSSION

Fig. 1 shows the critical current density J_c for a Pb/Ge (220Å/50Å) multilayer as a function of the angle θ between an applied magnetic field $H = 10^3$ Gauss and

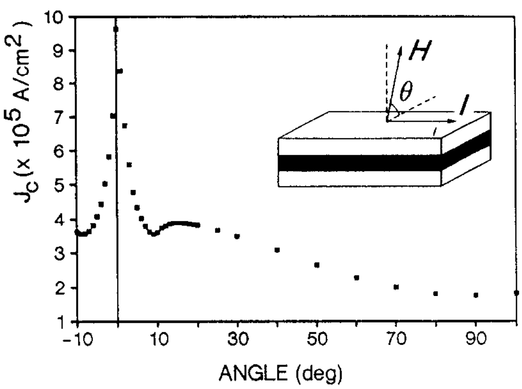

Fig. 1 : Critical current density at 4.2 K for a Pb/Ge (220Å/50Å) multilayer as a function of the angle between an applied magnetic field of 1000 Gauss and the layers. The inset shows the geometrical configuration.

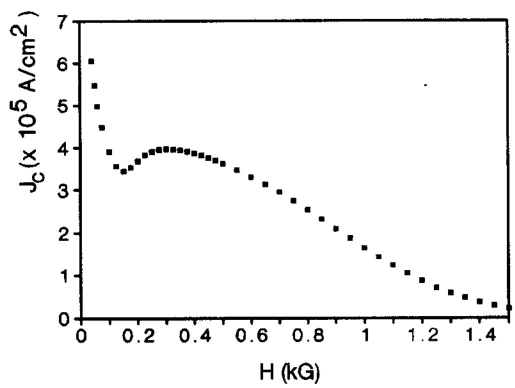

Fig. 2 : Critical current density at 4.2 K for a Pb/Ge (220Å/50Å) multilayer as a function of perpendicular magnetic field.

the film surface. The direction of the current was always perpendicular to the magnetic field. The much higher value of the depinning current for the parallel field shows the importance of flux pinning in the normal layers or at the superconductor/normal interfaces, as reported in Nb/Ta (2) and NbN/AlN (3) multilayers. However, the anisotropy of J_c in this case shows a remarkable new feature : the presence of a pronounced maximum at an angle $\theta_m \simeq 15$ degrees. Applying a larger magnetic field shifts this maximum to smaller angles, indicating that the maximum is caused by the perpendicular component $H_\perp = H sin\theta$. Indeed, the critical current density as a function of perpendicular magnetic field (θ=90 degrees) displays a maximum at $H_{\perp m} \simeq 260$ Gauss (Fig. 2). Qualitatively the same behaviour was found in a Pb/Ge (100Å/50Å) multilayer. The parallel field dependence of J_c will be the subject of future work. Assuming an equilateral triangular vortex lattice, the distance between the flux lines at which enhanced flux pinning occurs is $d = (\sqrt{3}\Phi_0)/2H_{\perp m})^{1/2} \simeq 2600$ Å, where Φ_0 is the flux quantum. The perpendicular critical field at 4.2 K is 2.2 kG, leading to a vortex normal core radius $\xi_{||} \simeq 390$ Å, much smaller than the flux line distance.

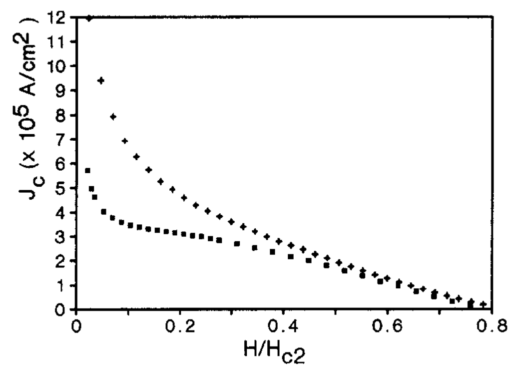

Fig. 3 : Critical current density for a 250 Å single Pb film as a function of perpendicular field (■) and parallel field (+), in reduced units ($H_{c2\perp}$=1.5 kG, $H_{c2||}$=21.7 kG).

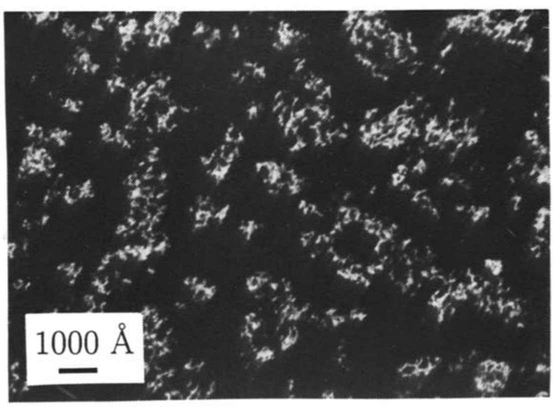

Fig. 4 : Dark Field TEM photograph of a 250 Å single Pb-film sandwiched between 50 Å Ge.

Since this enhanced flux pinning is caused by a perpendicular field, we expect the pinning mechanism to be the same in single Pb films. We prepared single Pb films of thicknesses 80 Å, 150 Å and 250 Å, sandwiched between 50 Å Ge, on locally thinned substrates, and in identical circumstances as the Pb/Ge multilayers. The critical current density as a function of perpendicular magnetic field (Fig. 3) for the 250 Å Pb film does not show a pronounced maximum, but does not decrease as monotonously as in the parallel field case (shown here for comparison). This behaviour is the same for the other film thicknesses. The microstructure of the thin films was investigated by dark field transmission electron microscopy and reveals Pb grains of dimensions varying between 500 Å and 1500 Å for all film thicknesses (Fig. 4). Since the in-plane grain dimensions are larger than the film thickness, the grain boundaries are almost perpendicular to the film surface. Therefore, grain boundaries can act as pinning centra for a perpendicular field. However, the grains have a large distribution in shape and dimensions, as seen in Fig. 4, so that an exact agreement between the vortex spacing and the grain size cannot be expected. The more pronounced maximum in the J_c versus $H_\perp$ for the Pb/Ge multilayer compared to the single film can be understood in this picture as resulting from an increase in surface density of grain boundaries.

In summary, we measured the critical current in Pb/Ge multilayers and single Pb films as a function of the perpendicular magnetic field and the angle between the layers and the field. The critical current in the parallel field case is larger than for a perpendicular field due to flux pinning in the Ge layers or at the Pb/Ge interfaces. The critical current as a function of perpendicular magnetic field displays a maximum in Pb/Ge multilayers, which may be interpreted in terms of grain boundary flux pinning.

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