

THERMALLY INDUCED TRANSITION IN THE VORTEX LATTICE OF Ge/Pb MULTILAYERS

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We report on a novel magnetic field dependence of the critical current density of M.B.E. grown Ge/Pb insulator/superconductor multilayers. When the magnetic field is applied perpendicular to the layers, the critical current density J_c drops to a minimum, followed by a broad maximum before finally decaying monotonously to zero with increasing magnetic field. The dependence of this effect on pinning strength, temperature, and layer thickness suggests either a thermally driven coupling/decoupling transition, or melting of the vortex lattice.

1. INTRODUCTION

The remarkable properties of high temperature oxide superconductors have renewed the interest in the vortex lattice structure of artificially layered superconducting materials. Within this framework, new theoretical models have been developed predicting an H - T phase diagram in which a reentrant vortex fluid phase above H_{cl} appears¹, or describing the vortex lattice in terms of a superposition of 2D "pancake" vortices². The study of superconducting multilayers may considerably enhance our understanding since they can be regarded as model systems in which it is rather easy to change important parameters like layer thicknesses, interlayer coupling strength, pinning strength, etc.

2. EXPERIMENTAL

The samples were prepared by electron beam evaporation in a M.B.E. apparatus on liquid nitrogen cooled SiO₂ substrates. Evaporation rates were monitored and controlled using a quadrupole mass spectrometer. Xray diffraction experiments³ on these multilayers reveal a well-layered structure with a negligible amount of interdiffusion and interfacial roughness. The samples have a [Ge/Pb]_nGe structure where n denotes the number of bilayers. The final Ge film is a 500 Å protective layer.

Čritical currents were obtained either from magnetization measurements in a SQUID (using the Bean model), or directly from transport measurements. In the latter case the critical current is derived from I-V curves using four probe D.C. resistivity measurements. The fourterminal patterns were obtained by a lift-off technique using electron beam lithography. The critical current is defined as the current necessary to produce a 2 μ V voltage across the sample, although other criteria give similar results.

It is important to note that at the given temperatures and thicknesses any superconducting coupling, being it Josephson or proximity effect, can be neglected.⁴



Fig. 1 : J_c at 4.2 K for a single Pb film and two Ge/Pb multilayers with a different number of bilayers.



Fig. 2 : Normalized critical current densities for a single Pb film and three Ge/Pb multilayers with a different Ge thickness d_{Ge} .

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3. RESULTS AND DISCUSSION

Fig. 1 shows the critical current density at T=4.2 K, measured resistively, of a single Pb film (i.e. a Ge(60Å)/-Pb(140Å)/Ge(500 Å) sandwich). J_c for this film decays monotonously as the applied field is increased. However, a remarkable non-monotonous behavior develops in the [Ge(60 Å)/Pb(140 Å)]₅ and [Ge(60 Å)/Pb(140 Å)]₁₀ multilayers. A minimum in J_c(H_⊥) is observed at a field H^{*}_⊥, and is followed by a broad maximum above which J_c joins the curve of the single Pb film.

The Ge thickness is a very important parameter as can be seen in Fig. 2, where $J_c(H_{\perp})/J_c(0)$ is plotted as a function of $H_{\perp}/H_{c2\perp}$ for three multilayers consisting of 50 bilayers, all with a Pb thickness $d_{Pb}=200$ Å but a different Ge thickness d_{Ge} . The single Pb film behavior is also shown as a reference. All these data were obtained from magnetization measurements. Because of uncertainties in the superconducting volume and the demagnetization factor, J_c is normalized to its zero field value. It is clear that J_c of the multilayer with $d_{Ge}=20$ Å initially drops much faster than that of the single film. For Ge thicknesses $d_{Ge}=50$ Å and $d_{Ge}=200$ Å we clearly observe the minimum in $J_c(H_{\perp})$ which was discussed in Fig. 1. Again, with increasing H_{\perp} , J_c coincides with the field dependence of the single film. The transition point (i.e. H_{\perp}^*) from "multilayer" to "single film" behavior shifts to higher fields when d_{Ge} decreases.



Fig. 3 : Critical current density of a Ge/Pb multilayer at T=1.4 K and T=5.6 K.



Fig. 4 : Critical current density of a $Ge/Pb_{0.85}Bi_{0.15}$ multilayer at various temperatures.

In Fig. 3 we show $J_c(H_{\perp})$, measured resistively, for a $[Ge(50 \text{ Å})/Pb(140 \text{ Å})]_5$ multilayer at T=1.4 K and T=5.6 K. It is clear that the minimum disappears when lowering the temperature. In Fig. 4 the J_c of a $[Ge(75 \text{ Å})/Pb_{0.85}Bi_{0.15}(100 \text{ Å})]_{10}$ sample is shown. Adding Bi to the Pb layers clearly increases the pinning strength and suppresses the existence of a minimum in J_c . From the data in Fig. 3 and Fig. 4 it becomes apparent that thermal fluctuations play an important role in the development of the minimum in $J_c(H_{\perp})$.

For a qualitative interpretation of this unusual $J_c(H_{\perp})$ behavior we may rely either on the "melting" model¹ or on the "decoupling" model². In the decoupling model, the magnetic interaction be-

In the decoupling model, the magnetic interaction between the superconducting layers is strong at low fields. As the field is increased, overlapping between adjacent vortices occurs and the coupling energy rapidly decreases with increasing field. When this energy becomes smaller than the thermal energy, a magnetic decoupling takes place at the field H_{\perp}^* . From that moment on, the pancake vortices can readjust within each layer to take full advantage of the available pinning centers, which explains the increase in critical current.

On the other hand, within the melting model the transition from coupled to single film behavior occurs because with decreasing field the in-plane vortex-vortex interaction becomes exponentially low, rendering the vortex lattice highly unstable to thermal fluctuations. When pinning can be neglected, this causes the presence of a field regime above $H_{c1\perp}$ where J_c should be zero, while J_c increases again at higher fields. For sufficiently strong pinning this transition is suppressed. We expect that for intermediate pinning strengths J_c should develop a minimum rather than dropping to zero. Further experiments are currently performed to elucidate the exact mechanism responsible for the observed $J_c(H_{\perp})$ behavior.

In conclusion, we have discovered an anomalous field and temperature dependence of J_c in Ge/Pb multilayers. The experimental findings can be qualitatively interpreted in the framework of melting or decoupling models.

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