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CRITICAL CURRENTS OF MULTILAYERED FILMS IN SUPERCONDUCTING PROXIMITY

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Abstract.- We present critical current measurements on multilayered films in superconducting proximity.

One of the causes of flux pinning in second kind superconductors has long been known to be the presence of normal inclusions of the order of magnitude of the coherence length of the superconducting matrix. The resulting increase of theoretical current density has been observed in several cases /1/. In order to fulfill the need for controlled geometries we have prepared and studied films composed of alternating layers of two materials with the following periodic sequence: $S_2 S_1 S_2 \ldots S_1 S_2 \ldots$.

$S$ is a superconducting alloy (PbIn 6 at.%) and $S_1$ is either a superconducting alloy of lower critical temperature $T < T_c$ (ZnIn 6 at.%) in the superconducting or normal state, or a normal material (Ag). These multilayers are "good" proximity effect samples (no intermetallic compound or solubility as it was checked from the absence of ageing effect).

Due to superconducting proximity, the critical temperature of the sandwich was lowered below $T_c$. An analysis in terms of the de Gennes Werthamer model and using mean free path from data on test films agrees quantitatively with the experimental $T_c /3/$. The decrease of the ratio of the critical field parallel to the film, $H_{||}$, to that perpendicular to it, $H_{\perp}$, is also consistent with the proximity effect description (the $H_{c2}$ from the outer layers $S_2$ was always lower than the upper critical field of the sandwich).

Figure 1 gives critical current versus field data in a typical experiment with the following thicknesses ($\text{SnIn} : d_1 = 500 \text{ Å}; \text{PbIn} : d_2 = 2650 \text{ Å}$). The applied magnetic field $H$ is parallel or perpendicular to the lamellas. In perpendicular geometry the monotonic decrease of $I_c (H_{||})$ is qualitatively comparable to that of a single film.

![Critical current vs field](image)

Fig. 1: Critical current of $\text{Pb-In/Ag-In}$ layered sample with $d_1 = 2650 \text{ Å}, d_2 = 500 \text{ Å}$; --- in parallel field; --- in perpendicular field at $T = 5.5 \text{ K}$ ($T_c \sim 6.7 \text{ K}$).

This variation may be used as a flux pinning background to characterize the larger value of the critical current obtained in the parallel geometry and the pinning effect of the multilayered structure: in this case the critical current is kept perpendicular to the field so that the Lorentz force driving the vortex lines is exerted perpendicularly to the layers. The peak structure observed on the $I_c (H_{\perp})$ curve is strongly reminiscent of that obtained in previous studies on superconducting PbBi alloys modulated periodically in concentration /4/ and appears to be due to a matching of the flux...
line lattice and the periodic structure of the film. The peak field is of the same order as that for a modulated film having the same period: here \( d = d_1 + d_2 \).

A characteristic feature of the proximity geometry is the non-monotonic variation of the peak amplitude: the peak disappears at high temperature (typically when the coherence length becomes comparable with \( d \)). It also decreases at low temperatures as the existence of superconductivity in \( S \) film tends to attenuate the modulation in the order parameter variation \( /5/ \). This behaviour is more pronounced for thin \( S \) films which are more coupled to the \( S \) ones. In some instances \( /6/ \) the peak disappears at low temperatures. In the same systems, a peak amplitude maximum is obtained around 4 K, i.e. slightly above \( T_c \), No such maximum is obtained in PbBi/Ag multilayered systems.

If \( d \) is kept constant, and \( d_1 \) and \( d_2 \) vary, the position of the peak does not vary much whereas the shape of the \( I_c(H) \) curve is different. Figure 2 corresponds to a slightly smaller period than figure 1. Note the decrease of the peak field value consistent with the flux line matching mechanism.

\[ \text{Fig. 2: Critical current } I_c(H) \text{ of two Pb-In/Ag-In layered samples with (1): } d_1 = 2300 \text{ Å, } d_2 = 2500 \text{ Å and (2): } d_1 = 1500 \text{ Å and } d_2 = 3500 \text{ Å.} \]

The peak structure is strongly reduced when \( d_2 \) becomes large compared with \( d_1 \); the \( I_c(H) \) variation suggests decoupled \( S \) films. The progressive increase of the excess critical current in parallel geometry obtained in some samples in low field may also be indicative of the following mechanism: as \( H \) is increased, the superconductivity induced by proximity is progressively reduced in \( S \) (this takes place for low fields) with a corresponding increase of \( j_c \).

The possible decoupling scheme is emphasized on the curves of figure 3. The same Pb-In 6 % layer thickness \( (d_1 = 2650 \text{ Å}) \) was used in sandwiches of different normal layer (Ag) thicknesses: For thicker Ag films the variation does not show a peak any longer.

\[ \text{Fig. 3: Normalized critical current } \frac{I_c(H)}{I_c(0)} \text{ at } T = 4.8 \text{ K of three Pb-In/Ag samples with the same } d_1 = 2600 \text{ Å and } d_2 = 2900 \text{ Å (1), 500 Å (2), 380 Å (3).} \]

On the other side, when \( d_1 \) is reduced below 500 Å, the peak amplitude decreases again as the Ag layer loses its individuality due to strong proximity effect.

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\*Note however that the coherence length is not infinite at \( T_c \). The peak effect can be seen very close to \( T_c \). This is slightly different from the case of 4b on PbBi modulated films.
References

/1/ Livingston, J.D., Appl. Phys. Lett. 8 (1966) 319
Several contributions along this line are found in Proc. Intern. Disc. Meeting on Flux Pinning, ed. Haasen (Göttingen Akad. Wissen).


/5/ Note the weak temperature dependence of $I_c(T)$ around $H_c2 \sim 600$ Oe, $T \sim 3$ K; such a behavior is important for stabilization purposes.