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NON-EQUILIBRIUM EFFECTS IN DYNAMIC MIXED STATE OF THIN FILMS

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I-V characteristics of wide ($w \gtrsim \lambda_\perp$) Sn, Al, Sn-6% In films are studied. Both in the external magnetic field and in its absence, near T_c the I-V curves display a step-like structure similar to that for narrow superconducting channels. In wide films this structure is attributed to the order parameter reconstruction, as moving vortices reach the critical velocity U^*. (4)

1. INTRODUCTION

The S-N current transition in thin films occurs both in narrow super - conducting channels and wide films in a wide resistive region. In the first case the resistivity arises from a specific redistribution of the order parameter and the formation of phase slip centers (PSC) due to the branch im - balance disequilibrium, which shows up as a set of regular voltage steps in I-V characteristics. In wide films the resistive state is induced by the vortex motion of the external magnetic field or the current field. The observed step-like structure,or breakdowns in I-V curves, is usually attributed to thermal instabilities developed due to the dissipative vortex motion.(1) Here we report experimental results on non-linear conductivity and step-like I-V characteristics of wide films under the condition when thermal effects were not determining. The results obtained permit a more general qualitative approach to understanding the resistive state of films irrespective of their width ($w \gtrsim \lambda_\perp$).

2. RESULTS AND DISCUSSION

The width of the films investigated (Sn,Al,Sn-6% In) varied in a wide range (6μm to 1mm, i.e. $w \sim \lambda_\perp$ to $w \gg \lambda_\perp$). The measurements were made at temperatures close to T_c (up to $t \sim 0.8$) and at $H \lesssim 0.5\, H_{c2}$. Typical I-V curves for dif - ferent temperatures and H=0 are shown in Figure 1, with the initial I-V portions taken in the external magnetic field at one of the temperatures given in the insert.

The I-V measurements versus temperature and magnetic field revealed the following features: (i) in the external magnetic field $H > H_{c1}$ and with currents exceeding the pinning current, a non - linear resistive region is observed,

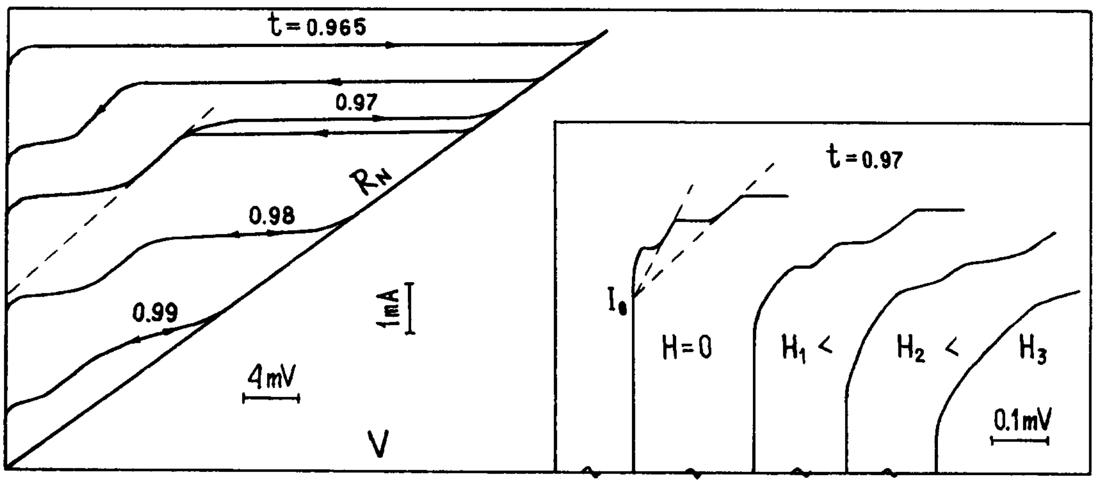

Figure 1 : I-V characteristics of wide Sn film at different temperatures.

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which is associated with a homogeneous dynamic mixed state of the film; (ii) at $T \sim T_c$ with currents I^* and voltages V^* typical of a given magnetic field, the I-V characteristics assume the shape similar to that for narrow superconducting channels (the portions of constant and multiple differential resistance separated by voltage steps); (iii) the step-like structure occurs in the absence of external magnetic field, the resistivity preceding the step formation at H=0 is essentially less prominent and may be due to the vortex motion of the self-field of current; (iv) the complete I-V curve (i.e. reaching R_N) displays in this temperature region a large (for a given voltage) step preceding the transition to the normal state; (v) as follows from extrapolation of the step slopes to V=0, they all (the step at high voltages included) cross the current axis practically at the same point I_0; (vi) with a further temperature drop the step-like structure vanishes, and as characteristic I^* and V^* are reached, the I-V curves display a "breakdown" to the normal state.

The non-linear initial I-V portion may be explained in terms of Larkin-Ovchinnikov's theory: taking into account the change in the distribution function of normal excitations in moving vortices, the viscosity coefficient is dependent on the vortex motion velocity U, the viscous forces being a non-monotonic function of U. (2) The I-V curve is of a N-shape with a maximum at U^*, I^*, V^*. The experimental dependences $V^*(H,T)$ and $U^*(H,T)$ match theory well. In Figure 2 the $U^*(t)$ dependence for Sn and Al whose energy relaxation times differ by two orders of magnitude illustrates the theoretically derived dependence $U^* \sim 1/\tau_\varepsilon$.(3) This gives

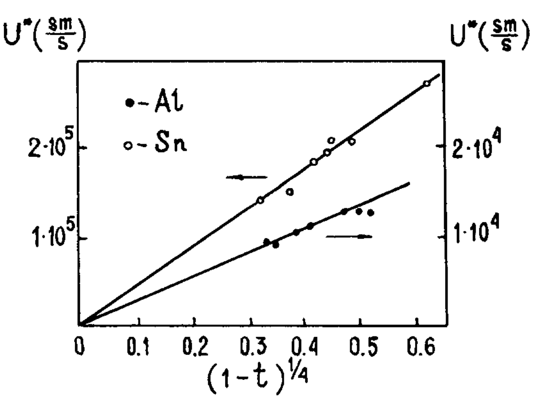

Figure 2 : Vortex velocity U versus temperature for Sn and Al.

convincing evidence of the essential importance of non-equilibrium effects in the dynamic mixed state. Theory does not treat I-V curves beyond the maximum point. It might, however, be expected that the non-equilibrium effects significantly influence the order parameter at $U > U^*$ too. With a given current bias the homogeneous quantum flux flow at the maximum point should become instable, i.e. the vortex motion velocity and hence non-equilibrium processes within the vortex cores will increase in a jump-like manner. In this case the branch imbalance in the vicinity of the radius l_E around the moving vortex will start to be important, which may lead to the formation of the order parameter minimum homogeneous over the film width (a PSC analogue). Similar processes must occur at H=0, when resistivity is induced by the current field vortex motion. To this process we attribute the step-like structure of I-V curves for wide films.(4) The wide film inhomogeneities may localize the order parameter redistribution at $U \cong U^*$, which is supported by our experiments on a film with a "weak" spot at its edge.

3. SUMMARY

Thus, on the basis of the information derived, the assumption is possible that similarly to the PSC formation in a narrow channel at the critical condensate velocity, in wide films the order parameter redistribution occurs, as the critical vortex motion velocity (U^*) is reached, which leads to the PSC analogue (phase slip lines) formation.

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