INTERACTION OF THE VORTEX LINE WITH THE SURFACE OF THE INHOMOGENEOUS SUPERCONDUCTOR

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In the experiments with the films(1) of Pb/Bi, with Bi concentration varying sinusoidally in the direction perpendicular to the film, it has been noticed that maxima of the critical current appear for some values of magnetic field. The bulk pinning owing to the modulation of the impurities has been studied in ref.(2), and the critical current has been calculated taking into account the surface pinning in ref.(3).

On the other hand, the increasing of critical current in Pb films with the parallel magnetic field has been experimentaly demonstrated in ref.(4). This suggest the influence of the surface barrier on the pinning of the vortices. The influence of defects is essential, and we study, in this paper, the effect of modulated concentration of impurities on the Bean-Livingston(5) barrier. It is important the surface to be polished.

The effect of impurities has been studied(6) by diffusion of impurities through the surface, and it has been noticed a decrease of the hysteresis of magnetization in Pb-36% Tl alloy, when the diffusion layer width $\sqrt{Dt}$ has been increased. In some cases the barrier vanishes. When the diffusion layer is removed the barrier is reestablished, and hysteresis is noticed.

In this paper we compute the field at which the Bean-Livingston barrier vanishes, as a function of the period of modulation Lo parameter b and the position X′ of maximum concentration from the surface.

The Gibbs energy in this case is given by

$$G(x_o) = \frac{\phi_o H_v(x_o)}{8\pi} - \frac{\phi_v(x_o) H_o}{4\pi} \qquad (1)$$

H_o – external magnetic field; $\phi_o H_v(x_o)/8\pi$ – the free energy of vortex line at the position x_o; $\phi_v(x_o)$ – the changed flux owing to the presence of the surface

$$H_v(x_o) = H_v^{self}(x_o) + H_v^{image}(x_o) = H_v^{o,s} + \Delta H_v^s + H_v^{o,i} + \Delta H_v^i$$
$$\phi_v(x_o) = \phi_o |1 - H(x_o)| = \phi_v^o - \Delta\phi_v \qquad (2)$$

$H(x_o)$ – satisfies the conditions $H_v(o) = 1$, $d^2H/dx^2 - H = 0$. The field H_v is given by the London equation with spatially varying λ

$$\vec{H}_v + \mathrm{rot}|\lambda^2(x)\,\mathrm{rot}\,\vec{H}_v| = \vec{\phi}_o \delta(\vec{r} - x_o\vec{e}_x)$$
$$\lambda^2 = \lambda_o^2 \left|1 + b\cos\frac{x-x'}{\lambda_o} t\right|, \quad t = \frac{2\pi\lambda_o}{L_o}, \quad b < 1 \qquad (3)$$

The disappearance of the barrier is possible when the force due to the Meisner currents (which repulses vortex line) is in equilibrium with the force due by the interaction with its image (which attracts vortex line). The condition is $(\partial G/\partial x_o)_{x_o} = 0$, but because the London model is incorect at the distances smaller than ξ_o, the condition becomes $(\partial G/\partial x_o)_{x_o=\xi_o} = 0$.

We consider only some limiting cases, for the reason of simplicity.

I. $x' = 0$; the maximum of concentration is on the surface

a) small period, $L_o \ll \lambda_o$, $\gg 1$

$$H_s = \frac{\phi_o}{2\pi\lambda_o^2} K_1 \left(\frac{2\xi_o}{\lambda_o}\right) \quad \frac{\phi_o}{4\pi\lambda_o\xi_o} = H_s^o$$

To the 1^{st} order in b, it is the same as in homobeneous superconductor.

b) large period, $L_o >> \lambda_o$

$$H_s = \frac{\phi_o}{2\pi\lambda_o^2} \left| (1-b) K_1 \left(\frac{2\xi_o}{\lambda_o}\right) - b K_o \left(\frac{2\xi_o}{\lambda_o}\right) \right|, K_1 \sim \frac{1}{x}, K_o \sim \ln \frac{1}{x}$$

The barrier is decreased, and there is a 1^{st} order correction in b to the homogeneous case. The effect of modulation is similar as the change in the thickness of the diffusion layer[6].

II. $x' = \frac{L_o}{2}$; minimum concentration at the surface

a) small period L_o

$H_s = H_s^o$ (see I.a.)

b) large period L_o

$$H_s = \frac{\phi_o}{2\pi\lambda_o^2} \left| (1+b) K_1 \left(\frac{2\xi_o}{\lambda_o}\right) + b K_o \left(\frac{2\xi_o}{\lambda_o}\right) \right|$$

K_o, K_1 are Hankel functions.

This case corresponds to removal of the layer of the thickness $L_o/2$ from the case I.b., or to the removal of the diffusion layer[6], when the barrier is reestablished.

References

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