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Relation between resistivity and temperature in the presence of two magnetic flux pinning mechanisms

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ABSTRACT

Moving of vortices in type II superconductors leads to energy dissipation, and therefore pinning of them is a significant problem. Determination of pinning potential and pinning mechanism from experimental data of resistivity is an attractive issue in the phenomenological study of superconductors. A new formalism is suggested to determination of two the δT_c and $\delta\ell$ pinning mechanisms from the resistivity as a function of temperature in type II superconductors.

1. Introduction

Study of vortices is an interesting issue in type II superconductors. In the mixed state, magnetic fluxes penetrate into the type II superconductor as vortices and it causes that superconductivity is preserved in much higher magnetic fields than the type I superconductors. However, moving of the magnetic fluxes, vortices, in the applied field is produced an electric field, which dissipate the power., When an externally applied current, J, is passed through the vortex lattice in the applied magnetic field, B, the Lorentz-like force per unit length of the vortex is given by $\boldsymbol{f}_L = \boldsymbol{J} \times \boldsymbol{B}$. Thus for large enough currents, vortices start to move and a resistance produces that results in power dissipation. So, the movement of vortices must be prevented somehow. To pin a vortex, an additional force must act on vortex, which tends to keep it in a particular place. Fortunately, pinning sites such as impurities and defects are often can be found inside the superconductor. When vortices interact with imperfections, free energy is changed and vortices prefer to be in the configuration that its free energy is minimized and they are pinned. Whatever vortex pinning be stronger, a larger force is needed to move them and so larger current can be carried by superconductor without any dissipation. The highest current that can be flowed in a superconductor without dissipation is named the critical current. In the absence of pinning, critical current is much lower than de-pairing current. In high-κ type II superconductors, where κ is the Ginzburg–Landau parameter, the most important elementary interaction between the vortices and the pinning centers is the core interaction [1]. There are two basic pinning mechanisms in type-II superconductors. The first is the pinning due to the disorder variations in the transition temperature T_c, which is called δT_c pinning. The second pinning mechanism relates to spatial variations of the charge carrier mean free path ℓ, the so - called $\delta\ell$ pinning, mostly due to crystal lattice defects [2]. Besides, based on the collective pinning theory [3], vortices, depending on circumstances, act individually as elastic objects (single vortex regime) or act collectively as elastic network (bundle regime). In the latter vortices move or be pinned to form of small or large bundles. The activation energy, or zero temperature pinning potential U_0, is the difference in the free energy of the system between a situation in which the flux-line bundle is trapped in the pinning site and one in which it can move. Three main parameters for pinning of vortices are zero temperature pinning potential, pinning mechanism, and temperature. Therefore, determination of pinning potential and pinning mechanism from experimental data is an attractive issue in phenomenological study of superconductors. There are various methods for determination of pinning mechanism from experimentally data of the critical current density [4,5], but it has not been proposed yet any method to determine pinning mechanism from resistivity data. In this paper, with the aid of previous theories, formalism is suggested that may be used to determine the pinning mechanism and potential in single vortex regime from experimentally data of resistivity.

2. Theory

Even for small currents, flux-lines are not entirely static. At finite temperatures, thermally activated flux-lines can hope between neighboring pinning sites in response to the driving force and it leads to a measurable resistivity [6,7]. According to thermally assisted flux flow (TAFF) model, for current densities and temperatures when $J \ll J_{c0}$ and $U_L \ll k_B T$, relation between resistivity and temperature can be described

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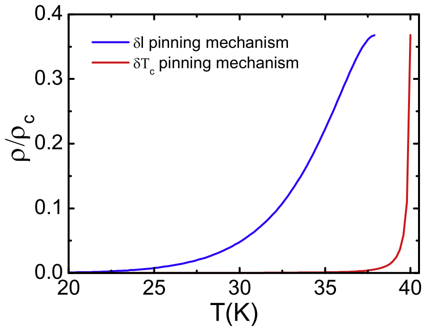

Fig. 1. Normalized resistivity *vs* temperature for $U_0 = 200\ K$ and $T_c = 40\ K$ as an example in the presence of the $\delta\ell$ and the δT_c pinning mechanisms.

with Arrhenius equation, $\rho = \rho_0 \exp(-U_c/T)$,in which pre-exponential factor is temperature independent. Where J_{c0} is the critical current in absence of thermal vortex hopping, and $U_L = JBV_c r_p$ is the Lorentz energy that obtains from the product of the Lorentz force density for bundle volume of V_c and the range of the pinning potential r_p, In modified TAFF model this relation is described by modified Arrhenius equation in which pre-exponential factor is temperature dependent [8,9]:

$$\rho = \frac{2\upsilon_0 LB}{J_{c0}}\frac{U_c}{T}\exp(-U_c/T) = \rho_c\frac{U_c}{T}\exp(-U_c/T) \tag{1}$$

Where υ_0 and L are the attempt frequency and the hopping distance, respectively. Theoretically, to achieve the temperature dependence of the pinning potential one must assume a model for pinning potential in terms of superconducting parameters that their temperature dependency is known. A conventional choice is $U_c \propto H_c^2\xi^n,\ 0 \le n \le 3$, [10] that lead to equation of $U_c(t) = U_0(1-t^2)^q/(1+t^2)^{q-2}$ with $q = 2 - n/2$ and it approximated to $U_c(t) = U_0(1-t)^q$ near T_c [8]. But this model has no information about the pinning mechanism. However based on G-L theory, Blatter et al. [2] obtained an expression for pinning potential when a magnetic field is aligned along the c axis, $U_c^c = H_c^2 \varepsilon\xi^3(\delta/\varepsilon)^{1/3}$, in which ε is mass anisotropy and δ is dimensionless disorder parameter. In this model temperature dependence of the pinning potential comes from the critical magnetic field H_c, the ξ, and the δ. Now temperature dependency of δ is related to pinning mechanism because it is proportional to ξ^{-3} and to ξ for $\delta\ell$ and δT_c mechanisms respectively [2,4]. So, by knowing the temperature dependency of the $H_c \propto 1 - t^2$ and the $\xi^2 \propto 1 + t^2/1 - t^2$, where $t = T/T_c$, [11]. The temperature dependent of the pinning potential for both the δT_c and the δl pinning mechanisms are given by [4]:

$$U_c(t) = U_0(1-t^4)\,for\ \delta\ell\ mechanism \tag{2}$$

$$U_c(t) = U_0(1-t^2)^{1/3}(1+t^4)^{5/3}\,for\ \delta T_c\ \ mechanism \tag{3}$$

Now by having the pinning potential for different sorts of pinning potentials and resistivity in TAFF regime, we can derive the relations between resistivity and temperature in transition region for both two magnetic flux pinning mechanisms.

3. Results and discussion

By combining Eq. (2) and Eq. (3) with Eq. (1), the relations between resistivity and temperature for both the $\delta\ell$ and the δT_c mechanisms are derived as:

$$\rho = \rho_c\frac{U_0(1-t^4)}{T}\exp(-U_0(1-t^4)/T)\,for\ \delta\ell\ pinning \tag{4}$$

$$\rho = \rho_c\frac{U_0(1-t^2)^{1/3}(1+t^4)^{5/3}}{T}\exp(-U_0(1-t^2)^{1/3}(1+t^4)^{5/3}/T)\,for\ \delta T_c\ pinning \tag{5}$$

The values of the U_0 and the ρ$_c$ parameters are dependent on material and applied magnetic field. So, materials in magnetic fields have different U_0 and ρ$_c$ that result to different shape of $\rho - T$ curve. But the mechanism of pinning affected the shape of $\rho - T$ curve that have not considered till now. By looking at Eqs. (4) and (5) it can be seen that different pinning mechanisms lead to different temperature depending of ρ. Therefore, the shape of $\rho - T$ curve depend, in addition to U_0 and ρ$_c$, on pinning mechanism. For better realization, Fig. 1 shows the behavior of normalized resistivity ρ/ρ$_c$ versus temperature for $U_0 = 200K$ and $T_c = 40\ K$ as an example. Different behavior of two curves is directly related to the pinning mechanism. It can be seen from Fig. 1, that in presence of the δT_c pinning mechanism, the transition region is narrower than the δl pinning mechanism. Even for other amounts of U_0 this difference is more complicated (not shown). Physical reasons for these different behaviors are under consideration. However, by fitting of these two relations to experimental data one can determine U_0 and ρ$_c$ in different magnetic fields for both the δT_c and the $\delta\ell$ pinning mechanisms

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References

[1] D. Dew-Hughes, Philosophical Magazine 30 (1974) 293–305.
[2] G. Blatter, M.V. Feigel'man, V.B. Geshkenbein, A.I. Larkin, V.M. Vinokur, Reviews of Modern Physics 66 (1994) 1125.
[3] A. Larkin, Y.N. Ovchinnikov, Journal of Low Temperature Physics 34 (1979) 409–428.
[4] R. Griessen, W. Hai-Hu, A. Van Dalen, B. Dam, J. Rector, H. Schnack, S. Libbrecht, E. Osquiguil, Y. Bruynseraede, Physical review letters 72 (1994) 1910.
[5] M. Qin, X. Wang, H.-K. Liu, S. Dou, Physical Review B 65 (2002) 132508.
[6] P. Anderson, Physical Review Letters 9 (1962) 309.
[7] Y. Kim, C. Hempstead, A. Strnad, Physical Review 131 (1963) 2486.
[8] T. Palstra, B. Batlogg, R. Van Dover, L. Schneemeyer, J. Waszczak, Physical Review B 41 (1990) 6621.
[9] Y.J. Song, B. Kang, J.-S. Rhee, Y.S. Kwon, EPL (Europhysics Letters) 97 (2012) 47003.
[10] C. Hagen, R. Griessen, Physical review letters 62 (1989) 2857.
[11] M. Tinkham, Courier Corporation 1996.