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Dynamics of disordered type-II superconductors: Peak effect and the *I–V* curves

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Abstract

We quantitatively describe the competition between the thermal fluctuations and disorder by the Ginzburg–Landau approach using both the replica method in statics and the dynamical Martin–Siggia–Rose approach which allows generalization beyond linear response. The two methods are consistent in static, while the dynamical method allows calculation of the critical current as function of magnetic field and temperature. The surface in the J–B–T space defined by this function separates between a dissipative moving vortex matter regime and vortex glass. The non-Ohmic *I–V* curve is obtained.

Keywords: Type-II superconductor; Glass transition; Quenched disorder

1. Introduction

Calculation of the thermodynamic, magnetic and transport characteristics of the vortex matter in type-II superconductors subject to both the quenched disorder and thermal fluctuations is a long standing problem. The main difficulty is to account for the "glassy" properties of the vortex matter. The vortex matter can be treated in various regions of the external parameters space (including magnetic field H, temperature T, and electric field E in dynamics) either in London approximation (far from H_{c2}), Ginzburg–Landau approximation (far from H_{c1}) or using more phenomenological models of vortex lines. In this paper we use the time dependent GL equation and the dynamical Martin–Siggia–Rose approach. The obtained results are compared with that derived in the replica method.

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2. The irreversibility line and peak effect critical current

We obtain the following line separating the vortex liquid from the vortex glass:

$$a_{\mathrm{T}}^{g} = (2r)^{2/3}(3 - 2/r), \tag{1}$$

where $a_{\mathrm{T}} = -\frac{2^{5/3}}{(2Gi)^{1/3}(bt)^{2/3}}(1 - t - b)$ and $r = \frac{a_{\mathrm{h}}^{2}}{\pi\sqrt{2Gi}t}n$ are determined by disorder parameter, n, proportional to density of the pinning centers, Ginzburg number, Gi, and by dimensionless parameters $t = T/T_{\mathrm{c}}$, $b = H/H_{\mathrm{c2}}(0)$.

Very similar line is obtained in the crystalline phase. The line is fitted to the experiment [1] on $NbSe_2$ in Fig. 1. The melting line calculated in [2] in this case is below the irreversibility line unlike in BSCCO where they intersect [3]. This leads to the peak effect in magnetisation curve $M(H)$, shown in Fig. 2.

The critical current,

$$I_{\mathrm{c}} = \frac{(bt)^{2/3}(Gi/r)^{1/3}}{2^{8/3}(2\pi)^{2}}\left[1 - t - b + (2Gi)^{1/3}(rbt)^{2/3}\left(3 - \frac{2}{r}\right)\right]$$

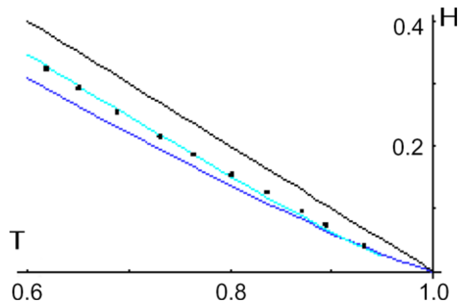

Fig. 1. H–T phase diagram with $H_{c2}(T)$ line (upper straight line), glass line, Eq. (1), (middle curve), and melting line (down curve). Experimental values (points) for glass transition are taken from [1].

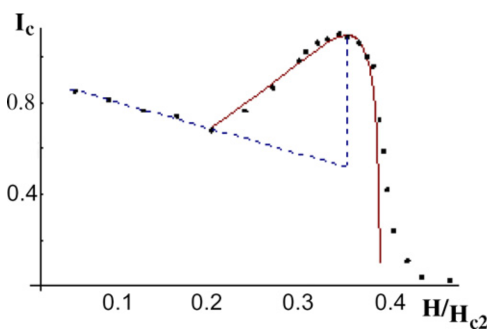

Fig. 2. Magnetic field dependence of the critical current in the vortex glass phase (solid line) and in the vortex crystalline phase (dash line) in comparison with experimental data [4] (points).

is defined as a current at which the glass is depinned and becomes a flow, neglecting exponentially small creep. It is found in a good agreement with transport data of [4] (see also [5]).

3. The *I*–*V* curves

Contributions from the LLL and via first Landau level are:

$$j_{\mathrm{LLL}} = \frac{R_0}{32\pi}\left(4t^2 Gi/b\right)^{1/3} E \tag{2}$$

and

$$j_{\mathrm{d}} = 2^{1/3}\sqrt{\left(\sqrt{2}-1\right)/3\pi t (bt)^{2/3} r^{1/6} (2Gi)^{5/6}}, \tag{3}$$

where dimensionless units for both, electrical current and field, have been used and the response function R_0 is obtained as a solution of the equation: $-4(1-r)R_0^3 - a_T R_0^2 + 1 = 0$. The first contribution is dissipative and consistent with Bardeen–Stephen, while the second contains the persistent current. They are similar to that in [5,6] (Fig. 3).

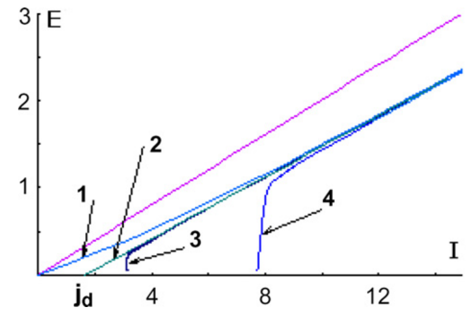

Fig. 3. E–I curve for parameters above (1), below (3,4), and on the glass transition line (2).

4. Summary

We present a quantitative theory of the vortex liquid to vortex glass transition with both thermal fluctuations and random quenched disorder effects and compare it to experiment on $NbSe_2$.

It is shown that the static flux line lattice in type-II superconductors undergoes a transition into three disordered phases: vortex liquid (not pinned), homogeneous vortex glass (pinned) and crystalline Bragg glass (pinned) due to both thermal fluctuations and random quenched disorder. The location of the glass transition line is determined and compared to experiments. The line is clearly different from both the melting line and the second peak line describing the translational and rotational symmetry breaking at high and low temperatures, respectively.

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References

[1] S.S. Banerjee et al., Physica C 355 (2001) 39.
[2] D.P. Li, B. Rosenstein, Phys. Rev. Lett. 90 (2003) 167004; D.P. Li, B. Rosenstein, Phys. Rev. B 70 (2004) 144521.
[3] H. Beidenkopf et al., Phys. Rev. Lett. 95 (2005) 257004.
[4] N. Kokubo et al., Phys. Rev. Lett. B 95 (2005) 177005.
[5] O. Dogru et al., Phys. Rev. Lett. 90 (2000) 167004; Y. Paltiel et al., Phys. Rev. Lett. 85 (2000) 3712.
[6] A.D. Thakur et al., Phys. Rev. B 72 (2005) 134524; A. Pautrat et al., Phys. Rev. B 71 (2005) 064517.