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Dynamics of the Vortex-Glass Transition

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Abstract. The dynamic of moving vortex matter is considered in the framework of the time dependent Ginzburg - Landau equation beyond linear response. Both disorder and thermal fluctuations are included using the Martin-Siggia-Rose formalism within the lowest Landau level approximation. We determine the critical current as function of magnetic field and temperature. The surface in the *J-B-T* space defined by the function separates between the dissipative moving vortex matter regime (qualitatively appearing as either the vortex creep and flux flow) and dissipation less current state in which vortices are pinned creating an amorphous vortex "glass". Both the thermal depinning and the depinning by a driving force are taken into account. The static irreversibility line is compared to experiments and is consistent with the one obtained in the replica approach. The non-Ohmic *I-V* curve (in the depinned phase) is obtained and resistivity compared with experiments in layered superconductors and thin films.

Keywords: Glass transition, Irreversibility line.
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INTRODUCTION AND MODEL

As a result of a delicate interplay between disorder, interactions and thermal fluctuations even the static *B-T* phase diagram of HTSC is very complex and is still far from being reliably determined. Once electric current J is injected into the sample, it makes the analysis far more complicated and the phase diagram should now be drawn in the three dimensional space *T-B-J*. Generally there are two phases, the pinned phase in which the vortices are pinned and thus the resistivity vanish (perfect superconductivity exists), and the unpinned phase in which vortices can move due to Lorentz force and thus a finite resistivity appears. The surface is determined by the critical current as function of magnetic field and temperature. Great efforts have been made both experimentally and theoretically to obtain the surface in *T-B-J* space which separates the two phases [1]. When the critical current vanishes, the intersection of the surface with the *B-T* plane gives the irreversibility line.

Most of the theoretical works consider the vortices as elastic lines; this assumption is valid far from the upper critical field H_{c2}. An alternative simplification is the lowest Landau level (LLL) approximation to the vortex matter near H_{c2} where many vortices are presented and due to overlaps between fields of the vortices the magnetic field is nearly homogeneous.

Dynamics in the presence of thermal fluctuations and disorder is described using the time dependent Ginzburg - Landau (TDGL) equation [1].

$$\frac{\hbar^2\gamma}{2m^*}D_\tau\psi = -\frac{\delta}{\delta\psi^*}F+\zeta, \qquad (1)$$

γ is the inverse diffusion constant and ζ is a thermal white noise. The free energy is

$$F=\int d^3x\left[\frac{\hbar^2}{2m^*}|\vec{D}\psi|^2-a'\left(1+U\right)|\psi|^2+\frac{b'}{2}|\psi|^4\right], \qquad (2)$$

U represents the disorder, with correlation

$$\left\langle U\left(x\right)U\left(y\right)\right\rangle=\delta\left(x-y\right)\xi^2 n, \qquad (3)$$

where n is the dimensionless density of pinning centers. The covariant derivatives are given by $D_\tau \equiv \frac{\partial}{\partial\tau}+\frac{ie^*}{\hbar}\Phi, \vec{D}\equiv\vec{\nabla}+\frac{ie^*}{\hbar c}\vec{A}$, where A and Φ are the vector and scalar potentials.

This model in the absence of electric field was considered by Dorsey, Fisher and Huang [2] in the homogeneous (liquid) phase using the dynamic Martin-Siggia-Rose approach [3]. They obtained the irreversibility line and claimed that it is inconsistent with experiments in YBCO.

In this paper we study the glass transition using the dynamic approach within the TDGL model at finite

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electric field. This allows us to obtain the *I-V* curve beyond the linear response. The GT line for zero electric coincide with the one obtained using the replica method [4]. Comparison of the irreversibility line and resistivity with experimental results in layered superconductors and thin films is made.

CRITICAL CURRENT

We solved this model using the LLL and Gaussian approximations [5]. The following expression for the critical current as function of temperature and magnetic field was obtained

$$J_c=\frac{\hbar c^2}{e^*\lambda^2\xi}\left(\pi\sqrt{2Gi}tb/4r\right)^{1/2}\left\{1-t-b+4\left(r\pi tb\sqrt{2Gi}\right)^{1/2}\left(2-1/r\right)\right\}^{1/2} \qquad (4)$$

where $t=T/T_c$ and $b=B/B_{c2}$. The disorder and thermal fluctuations characterized by the parameters: $r=\frac{n\left(2Gi\right)^{-1/2}}{2\pi^2}\frac{\left(1-t\right)^2}{t}, Gi\equiv\frac{1}{2}\left(\frac{2T_c e^{*2}\lambda^2}{\pi L_Z c^2\hbar^2}\right)^2$, respectively ($Gi$ is the *2D* Ginzburg parameter).

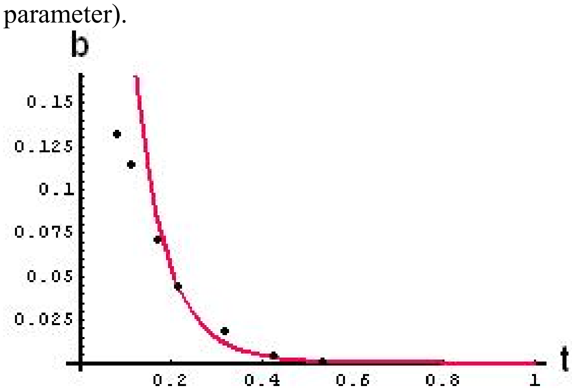

FIGURE 1. Irreversibility line for BSCCO, the dots represent data from [6], while the solid curve corresponds to the theoretical predicted line. The fitting parameters are given in the text.

In the special case of no electric field an equation for the irreversibility line is obtained in the form

$$b=2\left(\pi rtb\sqrt{2Gi}\right)^{1/2}\left(2-1/r\right)+1-t. \qquad (5)$$

This line is in agreement with the line obtained using the replica method [4].

I-V AND RESISTIVITY

The *I-V* curve is given by

$$J_y=\frac{\hbar c^2 v}{\xi e^*\lambda^2}\left(\pi tb\sqrt{2Gi}\right)^{1/2}\frac{-a_T\left(v\right)+\sqrt{a_T^2\left(v\right)+16\left(1-r\right)}}{8\left(1-r\right)}. \qquad (6)$$

The dimensionless velocity is $v=e^*\gamma E\xi^3/(4\hbar b)$, and the dimensionless scaled temperature is $a_T\left(v\right)\equiv-\left(1-t-b-v^2\right)/\left(\pi tb\sqrt{2Gi}\right)^{1/2}$.

In order to check our results we compared the irreversibility line and resistivity with experimental results in layered superconductor (BSCCO) [6]. The parameters we used are: H_{c2} =195T, T_c=93K, Gi =4.4x10^{-4} and n=0.005.

In Fig.1 we show that the theoretical and experimental results for the irreversibility line are in a good agreement.

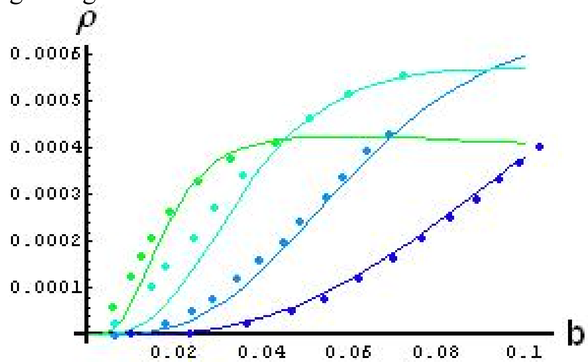

FIGURE 2. Resistivity as function of the magnetic field is plotted for different temperatures. The dots correspond to the experimental results of [6], and the solid lines to the theoretical prediction. The lines from left to right correspond to T=60, 50, 40, 30 K.

In Fig.2 we compare the resistivity as function of the magnetic field for different temperatures with experimental results of [6] for BSCCO. A non trivial temperature dependence of the inverse diffusion constant was used in order to fit the results.

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