Vortex States just below the Vortex-Glass Phase Probed by Voltage Noise

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Abstract

We measure the current-induced voltage noise in various fields H to study the vortex states of a thick amorphous Mo_xSi_{1-x} film. We focus on the field region between the Meissner phase and the vortex-glass (VG) phase, where vortex states have not yet been clarified. Noise S_V is largest in the Meissner phase ($H < H_{c1}$). With increasing $H(> H_{c1})$, S_V falls near or below the background level. With further increasing H, S_V starts to rise at certain field H_0, taking a broad peak in the VG phase, and falls again below the background level at a VG-to-liquid transition H_g. We interpret H_0 as a characteristic field around which VG order starts to form. We find that in the temperature range studied the field region ($H_{c1} < H < H_0$) grows monotonically upon cooling.

Key words: voltage noise; low field; vortex glass; plastic flow

1. Introduction

The vortex states between the Meissner phase and the vortex solid phase in type-II superconductors have not been fully clarified. For some clean systems with weak (or no) pinning, novel vortex states or phase transitions at low fields H have been suggested experimentally [1] as well as theoretically [2,3]. However, very little has been studied for disordered systems [4] which exhibit a vortex-glass transition (VGT)[5–7].

In this work we have performed measurements of current-induced voltage noise S_V for a thick amorphous (a-)Mo_xSi_{1-x} film which exhibits the VGT. Based on the field dependence of S_V, we determine the characteristic field H_0 which represents the onset of vortex-glass (VG) order. Combined with data of current-voltage ($I-V$) characteristics, dc and ac complex resistivities, we construct the phase diagram including the low-H region. Preliminary results relating to present work have been reported elsewhere [8,9].

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2. Experimental

We prepared a thick (100 nm) a-Mo_xSi_{1-x} film by coevaporation of pure Si and Mo in vacuum better than 10^{-8} Torr. Magnetic fields were applied perpendicular to the plane of the film using a superconducting magnet in a persistent-current mode. For the measurements at $H = 0$ we applied a small perpendicular field H (~ 0.1 Oe) to cancel the ambient field including the earth field [8]. The $I-V$ characteristics, frequency(f)-dependent ac complex resistivity (f =75 kHz-3 MHz), and voltage noise spectral density $S_V(f)$ (f =1 Hz-100 kHz) were measured by the four-terminal method [10].

3. Results and discussion

The mean-field transition temperature T_{c0} and zero-resistivity temperature T_c of the film are 2.93 and 2.85 K, respectively. The VGT temperature T_g (or VGT field H_g), as well as the existence of VGT, has been unambiguously determined from the ac complex resis-

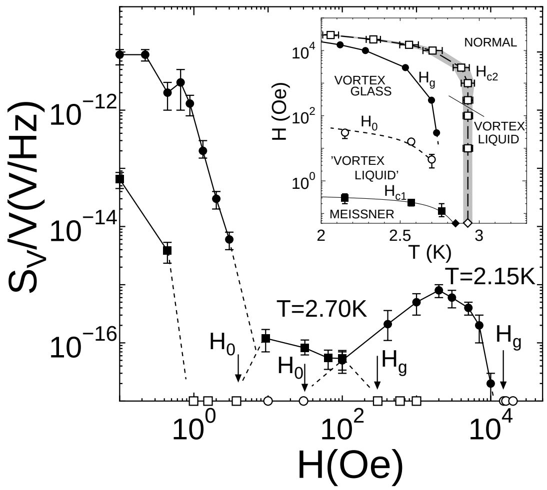

Fig. 1. S_V/V (at f =90 Hz) at low I plotted against H at T=2.15 K (●) and 2.70 K (■). Open symbols indicate data points below the background level. Inset: $H-T$ phase diagram.

tivity [5,6]. We define the "critical current I_c" for the onset of V using a criterion that $V(I_c)$ =10^{-8} V [8]. With increasing field from $H = 0$ at fixed temperature T, I_c initially stays almost unchanged up to a certain field. This field is roughly identified with a lower critical field $H_{c1}(T)$ [8]. With further increasing H, I_c decreases monotonically and vanishes at $H \sim H_g(T)$.

Over the broad-field range from $H = 0$ up to about H_g, we observe large broad-band noise with $1/f$-like form at low I where the $I - V$ characteristics show strong nonlinearity[8]. Plotted in Fig. 1 (main panel) is the field dependence of S_V/V (at f =90 Hz) at selected two temperatures T=2.15 and 2.70 K. We plotted S_V/V at low I where S_V/V is insensitive to I. Qualitatively, a field dependence of S_V/V looks independent of temperature: In the Meissner phase ($H < H_{c1}$), S_V/V is highest. When the flux lines start to penetrate the film in $H > H_{c1}$, S_V/V decreases abruptly and falls near or below the background level (open symbols). This is explained by the picture that large noise at low I is due to large vortex-density fluctuations associated with nucleation and growth of vortex loops in three dimensions [7]. With further increasing H, S_V/V starts to rise at a certain field $H_0(\ll H_g)$ and then the broad peak occurs before the VGT field H_g is approached.

Noise in the peak region $H_0 < H < H_g$ is due to different origin from that in $H < H_0$; that is attributed to plastic-flow motion [7,9,11,12] of vortex solid. The similar field dependence of noise has been obtained in computer simulations of current-driven vortices [13]. We note from Fig. 1 that S_V/V falls near or below the background level in the liquid phase just above the VG phase ($H > H_g$). We thus interpret the region just below H_0 as a region where VG order is not well established; i.e., H_0 corresponds to the characteristic field around which VG order starts to form.

In the inset of Fig. 1, we illustrate the $H - T$ phase diagram in which H_{c1}, H_0, H_g, and H_{c2} are plotted. Here, H_{c2} is determined from the dc resistivity using a 95% criterion. Within the theory for clean systems [2], the field region $H_{c1} < H < H_0$ is interpreted as a "lower liquid phase" intruding between the Meissner and vortex solid phases. However, we do not claim definitely from the present data whether H_0 corresponds to the "low-field melting transition", because in the theory pinning of flux lines is neglected, while it is essential in our system. Furthermore, the width of the field region $H_{c1} < H < H_0$ is even larger than theoretical prediction. On the other hand, an observed trend for $H_0(T)$ to increase upon cooling looks consistent with the theory. Recently, we have noticed the theory[3] for weakly disordered type-II superconductors in which the existence of novel phase ("reentrant glass") has been suggested in the low-field region just above the Meissner phase. To clarify whether the field region $H_{c1} < H < H_0$ detected in the present study corresponds to any low-field phase predicted theoretically [2,3], further measurements at lower T are in progress.

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