Anomalous Magnetoresistance below the 2D Superconductor-Insulator Transition

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Abstract

We measure the magnetoresistance $R_{LF}(B)$ of two thin films of amorphous Mo_xSi_{1-x} with nearly identical x in low fields B below the critical field B_c of the superconductor-insulator transition. We observe small but finite $R_{LF}(B)$ for both films, which is resulting from vortex motion in the liquid phase. We observe an anomalous peak for one film and a monotonic increase in $R_{LF}(B)$ for the other, indicating that $R_{LF}(B)$ is sensitive to microscopic morphology of films responsible for pinning. We do not find the $R = 0$ state at any nonzero B and T within our experimental resolutions, which is consistent with the picture of the vortex-glass transition in two dimensions.

Key words: vortex liquid; pinning; superconductor-insulator transition, amorphous films

1. Introduction

Using thin (4 nm) films of amorphous (a-)Mo_xSi_{1-x} with various x, we have accumulated evidence for the zero-field ($B = 0$) and field-driven superconductor-insulator transitions (SIT) in two dimensions (2D) [1,2]. Recently, experimental data have been reported for similar thin-film superconductors suggesting the existence of the metallic phase in the mixed state [3–5]. In these systems nonzero resistance R has been reported to remain in the zero-temperature ($T = 0$) limit over the broad B below the "field-driven SIT (B_c)". In particular, we note the results of a-MoGe films [3,4] in which a field-driven transition from a superconducting phase to a metallic phase has been observed at low (*nonzero*) B and T. This result is in contrast to the picture of the vortex-glass transition (VGT), as well as SIT, in 2D. It is interesting to study whether such behavior is widely observed for other 2D systems. In this work we present the magnetoresistance $R_{LF}(B)$ of thin a-Mo_xSi_{1-x} films at low T and B below B_c.

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2. Experimental

The thin (4 nm) a-Mo_xSi_{1-x} films [1,2] were prepared by coevaporation of pure Mo and Si in vacuum better than 10^{-8} Torr. The structure of films was confirmed to be amorphous by transmission electron microscopy. We studied two films with nearly identical $x = 0.6$; film A with $R_n = 770\Omega$ and film B with $R_n = 779\Omega$, where R_n is the resistance in the normal state (at 10 K). Both films have the nearly identical mean-field transition temperature ≈ 2 K. The resistance R was measured in a linear regime by four-terminal ac locking methods. The measuring current was 10 and 100 nA for films A and B, respectively, which determines the experimental resolutions of R (see horizontal lines in Figs. 1 and 2). For measurements in parallel fields $B_{\parallel}$ the current was also parallel to the field direction.

3. Results and discussion

Figure 1 shows the magnetoresistance $R(B)$ of film A for perpendicular fields. At $B = 0$, R is on the back-

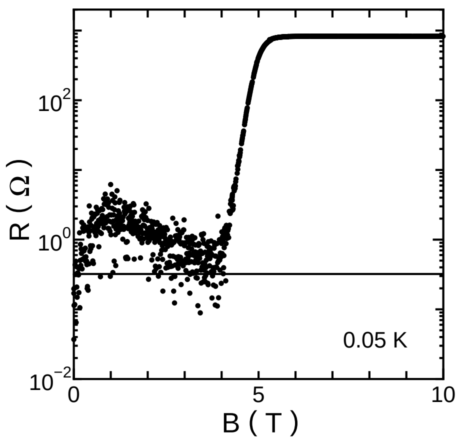

Fig. 1. Magnetoresistance $R(B)$ of film A at 0.05 K for perpendicular fields. A line indicates the experimental resolution.

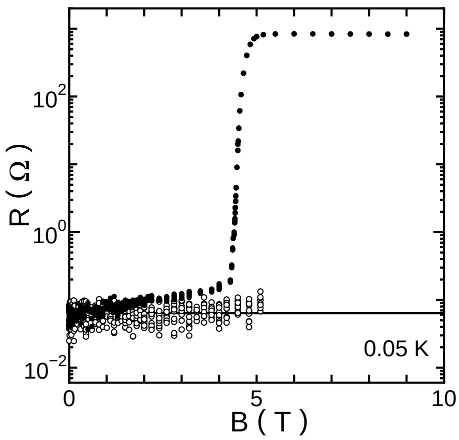

Fig. 2. Magnetoresistance $R(B)$ of film B at 0.05 K for perpendicular fields (full circles) and parallel fields $B_{\|}$ (open circles). A line indicates the experimental resolution.

ground level. With increasing field B, $R_{LF}(B)$ starts to rise from $R(0) = 0$, taking a small peak ($< 5\Omega$) at around 1 T, and then falls to the resistance near $R = 0$ at $B \approx 4$ T. With further increasing B, $R(B)$ rises again and approaches R_n at B =5-6 T, that is close to a critical field (B_c =5.5 T) of SIT where $R(T)$ at low T is nearly independent of T. Large noise is noticeable in the field region where the anomalous peak occurs.

In Fig. 2 we show $R(B)$ (full circles) of film B for perpendicular fields. At $B = 0$ the resistance again falls on the background level. With increasing B, R_{LF} shows a gradual and monotonic increase, which is approximately expressed as $\log R_{LF} \propto B$ in the field region $0 < B < 4.3$ T. Above $B = 4.3$ T, $R(B)$ exhibits a steep rise and tends to R_n at $B \approx B_c (=5.1$ T).

For either film it is natural to ascribe the origin of the magnetoresistance $R_{LF}(B)$ in low fields ($< B_c$) to vortex motion. In fact, the resistance is zero (only) at $B = 0$ and nonzero resistance R_{LF} appears when the flux lines penetrate the film at $B > 0$. Judging from much lower values of R_{LF} (except near B_c) than R_n, the number of mobile vortices contributing to R_{LF} is very small .

For thick (100 nm) a-$\mathrm{Mo}_x\mathrm{Si}_{1-x}$ films we have proved the existence of the VGT in 3D [6]. In the case of 4 nm-thick films studied here, it is difficult to obtain direct evidence for 2DVGT, since it is predicted to occur at $T = 0$ [7]. Within the picture, only the vortex-liquid phase is present in the mixed state at $T > 0$, where R_{LF} is dominated by vortex motion. The present $R_{LF}(B)$ observed for both films does not contradict the picture of 2DVGT. The fact that the anomalous peak is visible only for film A may suggest that $R_{LF}(B)$ is very sensitive to the slight difference in the microscopic morphology of films responsible for pinning. Possibly, the strength of pinning for film A is weaker than that for film B, which is inferred from the larger maximum-value of $R_{LF}(\approx 5\Omega)$ at 1 T for film A than that ($\approx 0.2\Omega$) at 4.3 T for film B. Physical origin yielding the anomalous peak in $R_{LF}(B)$ is not clear; however, it may suggest that there is a particular field region ($\sim$1 T) at low B where pinning is least effective.

Also plotted in Fig. 2 is the magnetoresistance for parallel field $B_{\|}$ (open circles). In this case, the resistance stays almost unchanged ($R = 0$) from $B_{\|} = 0$ up to the maximum field measured, that is higher than B_c for perpendicular field. This result gives us further support for the notion mentioned above that origin of $R_{LF}(B)$ is due to vortex motion.

To summarize, we have presented the magnetoresistance $R_{LF}(B)$ in low fields which shows the anomalous peak (film A) or monotonic increase (film B). Origin responsible for the peak has not yet been specified, whereas all of the $R_{LF}(B)$ data are interpreted in terms of vortex motion in the 2D liquid phase. The absence of the $R = 0$ state at any nonzero B and T is consistent with the 2D VGT (SIT) picture, but in contrast to the result reported for thin a-MoGe films [4].

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