Vortices and the mixed state of ultrathin Bi films

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Abstract

Current-voltage (I-V) characteristics of quench condensed, superconducting, ultrathin Bi films in a magnetic field are reported. These I-Vs show hysteresis for all films, grown both with and without thin Ge underlayers. Films on Ge underlayers, close to superconductor-insulator transition, show a peak in the critical current, indicating a structural transformation of the vortex solid. These underlayers, used to make the films more homogeneous, are found to be more effective in pinning the vortices. The upper critical fields (B_{c2}) of these films are determined from the resistive transitions in perpendicular magnetic field. The temperature dependence of the upper critical field is found to differ significantly from Ginzburg-Landau theory, after modifications for disorder.

Key words: Bi thin films; mixed state

1. Introduction

Transport properties of disordered ultrathin films have been studied extensively over the last decade especially in the context of disorder driven and magnetic field driven superconductor-insulator transition (SIT). [1] This transition is found to occur at a particular value of disorder corresponding to a critical resistance Rc , which clusters close to $h/4e^2$ the quantum of resistance for Cooper pairs, for both field driven and disorder driven transitions. Earlier studies on Bi, quench condensed on underlayers of Ge, showed a homogeneous type of SIT which was characterized by a strong suppression of the critical temperature Tc as disorder was increased. The presence of a thin (10 Å) underlayer of Ge is conventionally thought to improve the wetting properties of the film, and thereby assist homogeneous growth. [2,3] However, several studies have indicated that the underlayer is not inert, as conventionally assumed, and may actually play an active role in determining the transport properties of the films.

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2. Experimental Results

Figures 1 and 2 show the I-Vs on a semilog scale for Bi films on bare quartz substrates, and on a Ge underlayer respectively, until the normal state resistance is reached, where all the curves at different magnetic fields meet. For the films on bare substrates, only one critical current can be unambiguously identified. For the films on Ge underlayers, two different steplike increases in the voltage can be clearly identified for three different field values. It is only after the second step that the film resistance becomes the normal state resistance, and therefore this should be defined as the critical current. Hence the first step has to be associated with some sort of structural transition in the vortex solid. Recall that the depinning current is lower than this current at which the first step in the voltage appears.

A nonlinearity attributable to depinning seems to set in at lower currents for the films on Ge. However, the I_c for films on Ge is higher. In both these films, the dissipation is finite at any applied field, as evidenced by a linear regime of the I-V, from which a resistance can be discerned. This we attribute to thermally activated vortex motion.

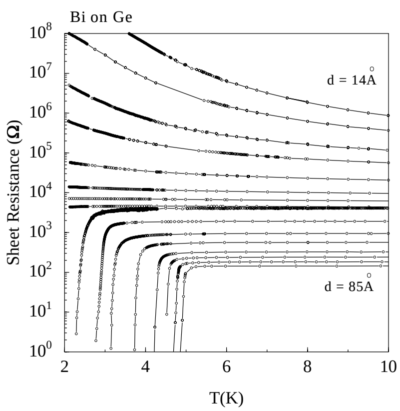

Fig. 1. I-V characteristics for Bi films on bare quartz.

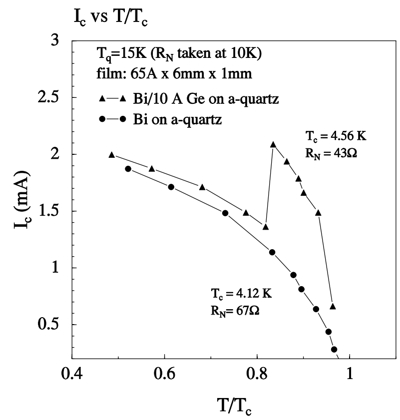

Fig. 3. Variation of I_c with T.

Fig. 3 shows the critical current as a function of normalized temperature, at zero field for films on Ge as well as on bare quartz. A peak in the critical current in the vicinity of the transition temperature is clearly visible, for the films on Ge. An identical phenomenon has been extensively investigated in layered superconductors such as $2H-NbSe_2$ citeshb and several other materials such as amorphous Nb_3Ge and Mo_3Si films. [5] This has been given the name peak effect. The pinning force density F_p exhibits a prominent peak slightly below the upper critical field B_{c2} or near the critical temperature. This effect is attributed to elastic instabilities generated by local fluctuations of the pinning forces, which induce a rapid softening of the flux line solid. This softening allows the flux lines to conform readily to a configuration that locks it to the inhomogeneities, so that the critical current Ic increases. [4,5] So the observation of a peak in I_c implies that an elastic flux line solid transforms to a plastic solid in the vicinity of the peak. For the films on Ge, we identify the first transition with the peak effect. In our films, the critical fields are higher than what we can attain using our magnet. Hence we have been unable to observe the peak effect in the I-H plane. However, the observation in the I-T plane is unambiguous proof of the peak effect. [4,5]

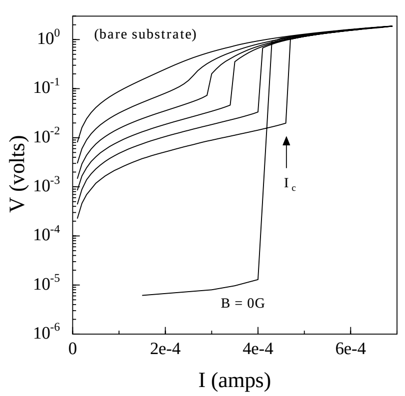

Fig. 2. I-V characteristics for Bi films on Ge underlayers.

Clearly, there are interesting phenomena involving the vortex solid and liquid phases in such ultrathin disordered films. Studies addressing the potential landscapes in which the vortices move, and the details of their motion are worth further investigations.

Acknowledgements

The work is supported by DST and UGC, Government of India. KDG thanks CSIR for the research fellowship.

References

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