Insulator superconductor transition on solid inert gas substrates

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Abstract

We present observations of the insulator-superconductor transition in ultrathin films of Bi on solid xenon condensed on quartz and on Ge on quartz. The relative permeability ϵ_r ranges from 1.5 for Xe to 15 for Ge. Though we find screening effects as expected, the I-S transition is robust, and unmodified by the substrate. The resistance separatrix is found to be close to $h/4e^2$ and the crossover thickness close to 25 for all substrates. I-V studies and Aslamazov-Larkin analyses indicate superconductivity is inhomogeneous. The transition is best described in terms of a percolation model.

Key words: Bi thin films; Quench condensation; Transport properties

1. Introduction

The insulator-superconductor (I-S) transition has been extensively investigated over the last decade, in a variety of systems such as thin films, [1,2] single Josephson junctions, [3] arrays, [4] and one-dimensional wires. [5] Values of limiting resistance close to the quantum resistance for pairs in one dimensional wires and two-dimensional nominally homogeneous ultrathin films are reported. Differing values of the limiting resistance at the transition have been observed [2] in different systems, and attributed to structure, i.e., homogeneous and granular films are expected to behave differently. A phase-only picture, first proposed by Ramakrishnan [6] and further elaborated by Fisher [7] has been considered appropriate for such systems. A scaling theory of the I-S transition has been developed. [8]

2. Experiments and Results

Fig. 1 shows the evolution of the temperature dependence of the sheet resistance R(T) with thickness for Bi films on Ge 10 Å thick, which has been deposited on amorphous quartz. A insulator-superconductor transition is immediately apparent. A similar result is obtained for Bi films on solid xenon condensed on amorphous quartz, as shown in fig. 2. A transition from insulating type behavior, to superconducting behavior as the thickness of the films is increased is clear. This type of zero field transition is considered a zero temperature quantum phase transition, controlled either by disorder, carrier concentration, or thickness. The normal state resistance at an arbitrarily high temperature R_N has traditionally been used to parametrize the transition, although it may be weakly temperature dependent above the superconducting transition temperature, and becomes ill defined as the I-S transition is approached. The value of the normal state resistance of a film on the boundary between superconducting and insulating behavior has been referred to as the resistance separatrix, and has been denoted by R_0. [1,2,5] We obtain R_0 as an algebraic average of the sheet resistances of the last insulating and the first superconducting films, measured at a relatively high temperature 10 K. R_0 is close to $h/4e^2$ for both sets of data. This observation indicates that the value of R_0 is substrate independent, and possibly experiment independent.

The form of the $R(T)$ for these films may lead us to

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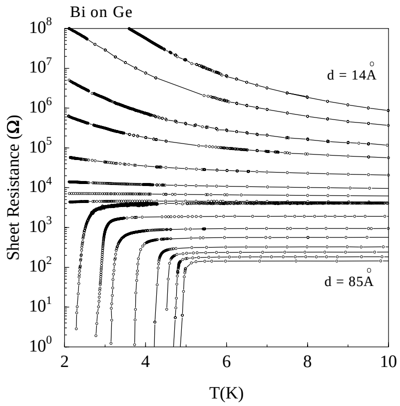

Fig. 1. IST of Bi on Ge underlayer.

the conclusion that these films are nominally homogeneous. Such a conclusion is incorrect as we show below. We find that superconductivity in our films is indeed percolative in nature [11]. Aslamazov and Larkin [9] considered the possibility of fluctuations causing superconductivity. The total conductivity is given by $\sigma = \sigma_{\rm N} + \sigma'_{2D}$, where $\sigma_{\rm N}$ is the normal state dc conductivity, and σ'_{2D} the paraconductivity. Its temperature dependance is similar to that of the magnetic susceptibility at $T - T_{\rm c}$. They derived the result

$$\frac{\sigma'_{2D}}{\sigma_{\rm N}} = \frac{e^2}{16\hbar}\frac{R_\square^{\rm N}}{\tau}. \qquad (1)$$

where $R_\square^{\rm N}$ is the normal state sheet resistance and $\tau = (T - T_{\rm c})/T_{\rm c}$ is the width factor. $T_{\rm c}$ is the mean field transition temperature. $\tau/R_\square^{\rm N} = g_{\rm AL} = \frac{e^2}{16\hbar}$ is a constant for all materials. We have evaluated $\tau/R_\square^{\rm N} = g_{exp}$ for various films. A systematic dependence of gexp on the thickness d is shown in Fig. 3. This parameter deviates

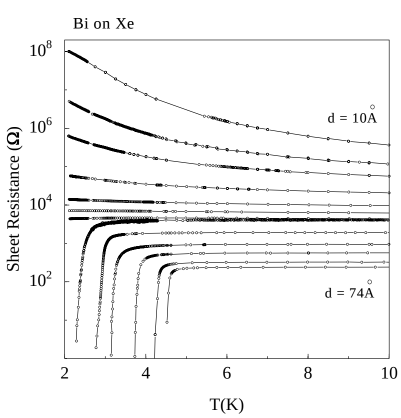

Fig. 2. IST of Bi on Xe underlayer.

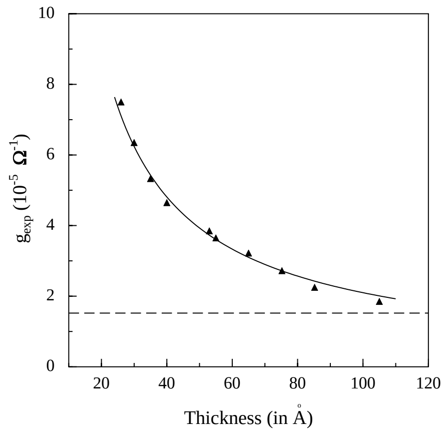

Fig. 3. Variation of the AL parameter with thickness.

from g_{AL} for thinner films. It approaches the AL value as the thickness is increased. It is assumed that theory predicts the same g_{AL} for all films, independent of microstructure. Both the normal state conductance and paraconductance depend on sample shape. Glover [10] has shown that as the microstructure deviates from a 荘 uniform rectangular slab, 鋳 gexp exceeds the AL value. The thinner the film, higher the disorder, larger are the deviations from a slab geometry, and larger the deviation of gexp from the AL value. Hence, films close to the transition are inhomogeneous.

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