Percolation and weak localization in thin discontinuous aluminum films

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Abstract

In order to investigate the crossover from the homogeneous behavior to percolative one for two-dimensional (2D) system, the temperature T and magnetic field H dependence of the sheet resistance R_{sq} have been measured for thin granular aluminum films. In a magnetic field 5T, the conductance σ decreases with decreasing T as $\sigma = \alpha_{\mathrm{T}} e^2/(2\pi^2\hbar)\ln T + \sigma_0$ due to weak localization effect. The value of α_{T} decreases when R_{sq} increases beyond 6∼ $8k\Omega$. In the network which does not contain loops smaller than the phase relaxation length, weak localization effect is considered to be suppressed. We have obtained the anomalous T-dependent diffusion constant D from the analysis of the magnetoconductance above T_C with use of the fitting parameter $D(T)$. These behaviors can be explained qualitatively by a model of scaling law for percolation.

Key words: percolation; weak localization; superconductor; magnetoconductance

1. Introduction

The percolation systems, such as metal-insulator mixture and granular structure have been widely investigated, in order to clarify the interplay among percolation, Anderson localization and superconductivity. Electron diffusion in these systems is different from that in homogeneous one. The diffusion constant D in percolative films is not constant but depends on the scale L as $D \propto L^{-\theta}$ at the range $L < \xi_P$, where ξ_P and θ is percolation correlation length and diffusion index~ 0.9[1], respectively.

The formula for magnetoconductance $\Delta\sigma$ in homogenous dirty-superconductors is given by the theory including the diffusion constant D. Therefore, the T dependence of D can be investigated by the analysis of $\Delta\sigma$ near T_C. We expect that $D(\xi_s(T))$ shows anomalous Tdependence because superconducting fluctuation relaxes in the length scale $\xi_s(T)$, where $\xi_s(T)$ is effective coherence length.

As T decreases, the interference of a single electron wave scattered by random potentials is enhanced and brings the precursor effect of $\ln T$ dependence of the sheet conductance as $\sigma' = \alpha_{\mathrm{T}} e^2/(2\pi^2\hbar)\ln T$. It has been reported that the weak localization effect in percolative films is weaker than that expected from the theory for homogenous films. In the networks which contain loops larger than the phase relaxation length L_{in}, the interference effect is suppressed[2]. Increasing ξ_p by increasing R_{sq}, we will discuss the crossover from homogeneous $L > \xi_p$ to inhomogenous $L < \xi_p$ behaviors in weak localization and superconducting fluctuations.

2. Results and Discussions

Aluminum films were made by deposition onto glass substrates patterned by photolithography. We prepared films in wide ranges of thickness and the

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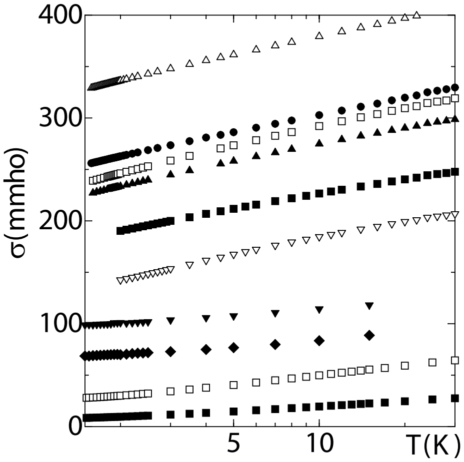

Fig. 1. Temperature dependence of the sheet conductance for various films at H=5T.

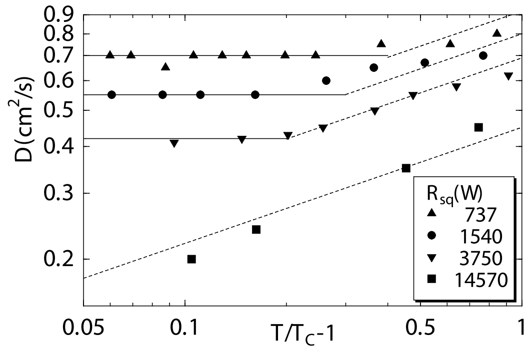

Fig. 2. The D vs T/T_C plot in films with various values of R_{sq}.

sheet resistance R_{sq}. The detail of sample preparation was mentioned at previous paper[3]. According to the TEM micrograph of thin $\mathrm{Al-Al_2O_3}$ film taken by Laibowitz et.al, clusters of films are the labyrinth-like structure[4]. The resistance has been measured with a DC four-terminal configuration.

Figure 1 shows T dependence of the sheet conductance σ for various thick films in a magnetic field 5 T. The conductance of the present films shows the $\ln T$ dependence and superconductivity seems to disappear at measured temperatures. According to theories for weak electron-localization and Coulomb interaction, T dependence of conductance due to quantum corrections in normal metallic films is given by,$\sigma' = \alpha_\mathrm{T} e^2/(2\pi^2\hbar)\ln T$. By fitting the above equation to data of σ vs $\ln T$, we determined the coefficient α_T. The value of α_T is almost the constant value ~ 2 in relatively clean films. This value is reasonable, if we take account of the sum of two contributions of weak localization with inelastic scattering rate due to electron-electron scattering and Coulomb anomaly in the case of long range interactions. The slope of lines decreases when σ decreases beyond $\sim$ 120mho($6 \sim 8k\Omega$). The length ξ_p increases with increasing R_{sq}. Therefore, it is considered that L_{in} is shorter than ξ_p and interference effect is suppressed.

We measured the resistance of films above T_C in magnetic fields $H < 5$T. For analyses of σ' with the sum of quantum correction terms due to fluctuation and weak localization effects, we fit first $\sigma' = \alpha_\mathrm{F}[\sigma'_{AL}(T,T_C)+\sigma'_{MT}(T,T_C,R_N)]+\alpha_\mathrm{T}e^2/(2\pi^2\hbar)\ln T$ to data using T_C as fitting parameter, where σ'_{AL} and σ'_{MT} is the Aslamazov-Larkin(AL) contribution[6] and the Maki -Thompson(MT) contribution[7] of superconducting fluctuation conductance. Secondly, using this value of T_C, we analyze the magnetoconductance with using D as a fitting parameter. The magnetoconductance is given by $\Delta\sigma = \Delta\sigma_{AL}(H,D,T,T_C) + \Delta\sigma_{MT}(H,D,T,T_C,\tau_{in}) + \Delta\sigma_{Lo}(H,D,T,\tau_{in},\tau_{so})$, where $\Delta\sigma_{AL}$, $\Delta\sigma_{MT}$ and $\Delta\sigma_{Lo}$ is magnetoconductance due to AL, MT and weak localization, respectively. The time τ_{in} is calculated from Ref[5]. Figure 2 shows T dependence of D. Assuming that D in the expression for superconducting fluctuations above T_C is determined on the length range ξ_s mentioned in the introduction, we can consider that the value of $D(\xi_S)$ depends on T in the region $\xi_P > \xi_S$ as follows, $D(\xi_S) \propto \tau_{GL}^{\theta/(2+\theta)} \propto (T/T_C-1)^{0.31}$ which is shown in dotted lines of Fig.2. Solid lines show that for relatively low resistance films, the value of D above T_C is almost constant at temperatures near T_C. This behavior suggests that crossover from the inhomogeneous region $\xi_S < \xi_p$ to the homogenous region $\xi_S > \xi_p$ occurs when T approaches to T_C and then the length ξ_S increases. Temperature dependence of D agrees well with the prediction from the percolation model.

It is very interested in that two crossovers from inhomogeneous to homogenous occur in the same order sheet resistance $1 \sim 8k\Omega$.

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