Mesoscopic interference effects in ultrathin Bi films

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Abstract

The resistance of continuous quantum size Bi films as function of magnetic field (5 T) was investigated. The films thickness (⟨ 25 nm) was less then the de Broglie wavelength of the electrons on the Fermi surface. The oscilllation of the resistance periodic in magnetic field were observed, that could be interpreted as the result of the electron interfrence on the ossasionally arised local films regions of the mesoscopic size with better conductivity. The area of this local regions define the period of oscillations.

Key words: quantum size films; mesoscopic interference

1. Introduction

First experimental observations of the mesoscopic interference of electron waves - Bohm-Aharonov effect in solid state, were made by Sharvin [1] on Li films, deposited on quartz fiber. Thereafter experiments were replicated on plane samples: Al rings of submicron size [2] and semiconductor heterostructures $GaAs/Al_xGa_{1-x}As$ [3]. In all cases the interference effects were studied on specially performed samples of specific geometry: a submicron ring. Observed oscillations of resistance as a function of external magnetic field were ascribed to the change of phase difference of the electron waves, propagating along different paths, one or the other arc of the ring. The area of the ring (S) defines the period (ΔB) of oscillation of resistance on magnetic field (B): $\Delta B = \Phi_0/S$ [4] ($\Phi_0 =$ h/2e - magnetic flux quantum). But the interference of electron waves happens in the case of any form of the sample: the double connecting topology is not needed necessarily due to the fact that magnetic field penetrates into the metal. The electron interference effect in small domains of continuos sample with size less then the coherence length is quite analogous to the phenomena observed in superconducting Josephson junction: the oscillating dependence of critical Josephson current on magnetic flux through the area of Josephson junction. We suppose that the oscillation of Hall resistance of thin Bi films in magnetic field, observed in our experiments are the result of these mesoscopic interference effects.

2. Experiment

Ultrathin quantum size Bi films with thickness (15-20 nm) less then de Broglie wave length of the electrons on the Fermi surface were deposited on ZrO_2 substrates with the help of the laser technology. Hall-(R_{xy}) and magnetoresistance (R_{xx}) of films were investigated at helium temperature in magnetic field up to 4 T.

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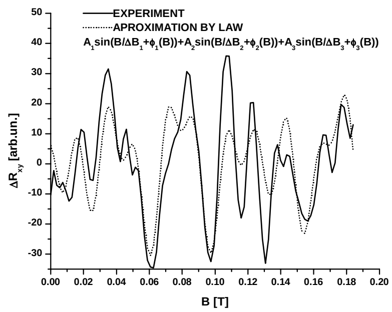

Fig. 1. Oscillating addition to Hall resistance versus magnetic field.

3. Results and discution

An oscillating addition ($\Delta R_{\rm xy}$) to $R_{\rm xy}$ periodic in straight magnetic field was found out, while no oscillating addition to $R_{\rm xx}$ was observed. On Fig.1 $\Delta R_{\rm xy}$ versus B is presented. Experimental data (solid line) may be rather well approximated by the sum of three sinusoids with different frequencies (dashed line). It should be pointed out that the magnitude of whole $R_{\rm xy}$ was for 3-4 orders lower then it is expected for Bi films of used thickness and hence of 2-dimensional concentration of carriers. We suppose that low values of $R_{\rm xy}$ obtained are due to the effects of quantum interference and electron localization. The details of this phenomena will be discussed elsewhere. The appearance of oscillating addition $\Delta R_{\rm xy}$ may be explained as follows: film is not homogeneous from the point of view of local conductivity: there are micro domains (MD) with higher and lower conductivity. Hence current density is not constant across the film, current tends to concentrate in MD with better conductivity and that's why these MD make respectively larger contribution into the Hall voltage value and subsequently into $R_{\rm xy}$. Simultaneously higher conductivity means that electron mean free path is larger, thus interference effects are to be more pronounced in these MD. If the size of the MD is less or of the order of the coherence length of the electron wave the interference will take place. (It should be mentioned that electron phase coherence length is not necessary to be equal to mean free path of electron.) Hence the classic Hall effect in this MD is to be observed (as far as it in fact has the interference origin) together with oscillating addition. In [4] it is shown that the amplitude of oscillating addition should be of the order of thaul=25 kOhm, *i.e.* of the order of $R_{\rm xyclass}$ in B=1 T in our films. $R_{\rm xyclass}$ and $\Delta R_{\rm xy}$ shunt each other since the reciprocal resistance are added $1/\mathrm{R_{xy}} = 1/\mathrm{R_{xyclass}} + 1/\Delta\mathrm{R_{xy}}$. The amplitude of oscillations $\Delta R_{\rm xy}$ would decrease with magnetic field (analogously to the decrease of Josephson critical current) and $R_{\rm xyclass}$ enhance then the contribution of $\Delta R_{\rm xy}$ into $R_{\rm xy}$ measured would not depend on magnetic field (Fig.1). The MD exhibiting large $R_{\rm xy}$ value are shunted by adjacent MD, where Hall effect is suppressed due to low value of electron phase coherence length and so the value of Hall voltage measured on the whole film becomes low. Of course, there are a lot of MD with large and small values of conductivity, and all of them of the first kind will make an oscillating contribution to $R_{\rm xy}$, but there are always one (or few) domains whose contribution will be the largest and it will be observed on the background of others. The absence of analogous oscillating addition to $R_{\rm xx}$ is related with the fact that it is shunted by high longitudinal conductivity of MD.

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