Aharonov-Bohm effect on columnar defects in thin graphite and graphene

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The first studies of Aharonov-Bohm effect on graphene ring-type samples demonstrated the oscillating contribution to magnetoresistance with periodicity of $\hbar c/e$ per ring hole, while contribution of $\hbar c/2e$ oscillations has been strongly suppressed [1]. That was one of the first indications of the absence of back scattering processes for Dirac fermions. However, the experiment was done on rather big, micron sized, ring samples which perimeter $L$ considerably exceeded the mean free path of carriers $l$. Of great interest was to study quantum interference of Dirac fermions in the opposite limit $l \gg L$. For that purpose we studied Aharonov-Bohm effect on thin graphite single crystals containing columnar defects (nanoholes) produced by irradiation with heavy ions. The thickness of irradiated single crystals has been varied from 50 nm down to less than 1 nm by thinning the thicker samples with soft plasma etching in a beam-plasma reactor [2]. For irradiated samples we found the existence of oscillating, field-periodic contribution of magnetoresistance with a periodicity corresponding to the flux quantum $\hbar c/e$ per area of nanohole independently of sample thickness [3, 4] Fig. 1.

The results point to the significant contribution of Dirac fermions to the oscillating part of magnetoresistance. The fact that effect does not depend on sample thickness indicates that effect is very likely related with the surface layers of graphite similarly as it was recently observed for topological insulators [5]. That conclusion is supported by recent STM [6] and FIR magneto-transmission [7] measurements which showed that the surface layer of graphite is often represents as a graphene layer lying on graphite substrate.

There is another interesting point following from our experiment. Normally, Aharonov-Bohm effect is observed in ring geometry samples. This geometry lets fix the quantized orbits between inner and outer boundary of the ring. In our experiment A-B type effect was observed on non-ring geometry and as shown is determined by the orbits located close to the hole. We consider that the restricted orbits near the hole can exist due to the edge states located near graphene boundary. Otherwise, the averaging contribution of all possible orbits around hole would smear out interference effect. Existence of the edge states in graphene has been recently predicted theoretically [8]. Our observations of Aharonov-Bohm effect on nanoholes (antidots) strongly support the existence of the edge states in graphene.

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References


Figure

Fig. 1. The in-plane resistance of the irradiated graphite single crystal (sample # 3) versus magnetic field $H \parallel c$ at 0.5, 2, 4, 6, 8, 10, 20, and 32 K. The sample is 50-nm thick, the columnar defect density is $c = 10^9$ defects/cm$^2$. The arrows mark the group of minima $R(H_n)$, where $H_n = nH_0$ (n is an integer, $H_0 = 7.5$ T).