Comment on "Consistent Interpretation of the Low-Temperature Magnetotransport in Graphite Using the Slonczewski-Weiss-McClure 3D Band-Structure Calculations"

In [1,2] we have shown that a substantial part of conductivity in graphite is provided by holes (h) with a massless linear spectrum $\varepsilon(p) = v|p_\perp|$—Dirac fermions (DF) that coexist with massive normal carriers (NC)—electrons (e) with $\varepsilon(p) = p^2/2m^*$. The existence of such a quantity of DF does not follow from the classical Slonczewski-Weiss-McClure (SWM) band model and can signify that at least parts of the carbon layers behave like independent graphenes.

In a recent Letter [3], Schneider *et al.* revised our conclusion point that both types of carriers are massive and described by the SWM model. Since both [1–3] use the same method of phase determination of Shubnikov–de Haas (SdH) oscillation, we comment here that the controversy originates from the improper treatment of experimental results in [3].

The sense of the method is to extract the phase ϕ_1 from the quantum oscillation of conductivity:

$$\sigma_{xx}(B) = \sum_{l=1}^{\infty} a_l \cos\left[2\pi l \frac{\mu}{\hbar\omega_c} + \varphi_1 l\right], \qquad (1)$$

where $\varphi_1 = \pi$ for NC and 0 for DF (μ is the chemical potential, $\hbar\omega_c = \frac{eB}{m^* c}$ for NC and $\frac{ev^2 B}{c\mu}$ for DF).

Note first that presented in Fig. 1 the method to find φ_1 shows the remarkable coincidence between our results [2] and those of Schneider *et al.*. [We obtained φ_1 directly from a Fourier-transformed signal, whereas in [3] the phase was extracted from the maxima of $\sigma_{xx}(B)$]. The lower line corresponds to carriers with higher frequency (HF). From its extrapolation to $B^{-1} = 0$ we clearly see that at $B \to \infty$ the lowest LL ($n = 0$) is placed exactly at $E = 0$ and that $\varphi = 0$, as it follows for DF. Similarly, the low frequency (LF) carriers with $\varphi_1 \sim \pi$ are attributed to NC.

Schneider *et al.* argue that these data cannot be used because "in the quantum limit the Fermi energy [μ in (1)] is no longer constant as carriers are transferred between the electron and holes."

To verify this point we present in Fig. 1, calculated within the SWM model diagram of B_n^{-1} at which SdH oscillation exhibits the maxima:

$$B_n^{-1} = \sqrt{n(n+1)}\left[1 - \frac{\Delta\mu_n}{\mu_0}\right] B_0^{-1}. \qquad (2)$$

The first (band) factor [4] generalizes the one used in [1,2]'s quasiclassical $n + \frac{1}{2}$ quantization. The taken from [5]'s correction to μ is due to electron-hole cross-talk.

Next, we trace the differential phase $\varphi_1(B^{-1}) = -2\pi[n(B^{-1}) - B^{-1}(dn/dB^{-1})]$ for HF carriers (smoothed by a two-point moving average) and observe that the SWM curve, as was also mentioned in [3], has the strong non-linear deviation from $-\pi$ at $B > 2T$. Our data do not demonstrate such nonlinearity whereas Schneider *et al.* stay close to $\phi_1 = 0$ and do not drop together with the SWM curve to $\varphi_1 = -\pi$ at $2T > B > 0.7T$. Contradiction with the SWM model and the closeness of φ_1 to 0 confirms the existence of DF in graphite.

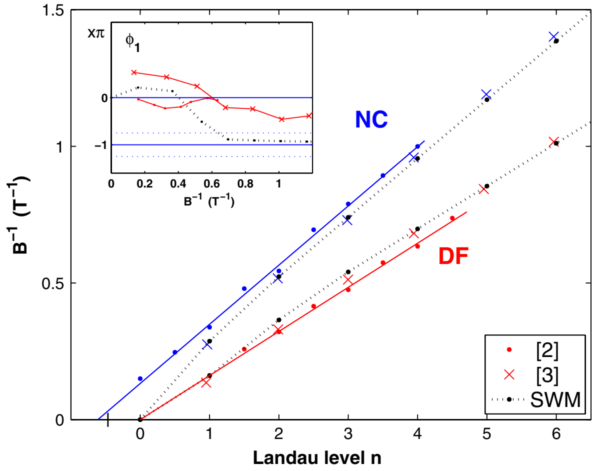

FIG. 1 (color online). Maxima (minima) of SdH oscillations for two groups of carriers as a function of their LL number n. Linear extrapolation to $B^{-1} = 0$ gives the phase—$\varphi_1 = 2\pi n_0$. The inset shows the dependence of differential φ_1 on B^{-1}.

Note that, proposed in [3], the extrapolation of φ_1 from fields $B < 0.7$ T is not reliable. Thus, for the presented in Fig. 2e of [3] phase-frequency analysis of HF carriers, one gets $\varphi_1 \simeq (0.56 \pm 0.6)\pi$. This value and error bar, determined as FWHM of a 2D Gaussian projected on the phase-axis are insufficient to discriminate between the DF and NC.

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