

Magnetisation and Transport Studies of Carbon Based Nanostructures

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Abstract

This thesis presents investigations in to the properties of bulk graphite, graphitised silicon carbide and exfoliated graphene. The background physics and theory relevant to the investigations is detailed. This is followed by descriptions of the equipment and methods used during experiments presented within this thesis.

Millikelvin de Haas–van Alphen and Shubnikov–de Haas experiments were performed for several types of graphite. These types included forms of natural, kish and highly orientated pyrolytic graphite. Oscillations for two sets of carriers (holes and electrons) were observed with varying strengths between the types. This suggests that the mobility of the charge carriers in graphite can vary significantly depending on the formation of the graphite bulk. Hall measurement results support this statement, as the electron to hole mobility ratio appears much greater in natural graphite than in highly orientated pyrolytic graphite.

Analysis of the oscillations for each sample indicates that the electrons have a higher mobility than the holes, and that the effective mass of the holes is lower than that of the electrons. Depending on the sample, the mobility of the holes was found to vary between $1.07 \rightarrow 1.42 \text{ m}^2/\text{Vs}$ and the mobility of the electrons between $1.64 \rightarrow 16.0 \text{ m}^2/\text{Vs}$. The effective masses of the charge carriers were found to be $0.031 \pm 0.007 m_0$ and $0.046 \pm 0.003 m_0$ for holes and electrons respectively.

The nature of the carriers for the different types of graphite was determined. It was found in the de Haas–van Alphen experiments that the phase of the carriers varied between samples. However, in the majority of cases, the electrons were shown to be Dirac fermions. In Shubnikov–de Haas experiments, the electrons demonstrated an indeterminate nature. In both types of measurement, the holes were found to have an indeterminate nature.

De Haas–van Alphen experiments were also performed on two graphitised silicon carbide samples. The sample fabricated at The University of Leeds exhibited a complicated background magnetisation. This is not characteristic of a carbon system and so indicates a lack of a carbon film. The sample fabricated by the Georgia Institute of Technology exhibited a magnetisation akin to ZYB grade highly orientated pyrolytic graphite.

Sheet magnetoresistance measurements were also performed on a more recent graphitised silicon carbide sample, fabricated at The University of Leeds. Weak localisation was observed as well as a large number of non-oscillatory features. These features were attributed to the absence of a defined Hall-bar geometry and the presence of multiple graphene domains between surface contacts.

Magnetotransport and activation energies of exfoliated graphene flakes were also investigated. The charge carrier mobilities at 240 K for a particular sample were found to be $20,670 \pm 30 \text{ cm}^2(\text{Vs})^{-1}$ for holes and $22,770 \pm 40 \text{ cm}^2(\text{Vs})^{-1}$ for electrons. These mobilities rose to $25,600 \pm 200 \text{ cm}^2(\text{Vs})^{-1}$ for holes and $25,900 \pm 200 \text{ cm}^2(\text{Vs})^{-1}$ for electrons by 2.5 K. This observation implies that the holes experience stronger phonon scattering than the electrons.

The activation energies for filling factors $\nu = \pm 2$ and $\nu = \pm 6$ were found at several magnetic fields for the sample. The activation energies allowed for determination of the broadening of the Landau levels. The broadening of the $\nu = \pm 6$ levels were found to be constant as a function of magnetic field, with $\Gamma_{\pm 6} = 260 \pm 40 \text{ K}$. The $\nu = -2$ level also showed a constant value for the broadening, $\Gamma_{-2} = 620 \pm 40 \text{ K}$. However, for $\nu = +2$, the activation energy approached the bare Landau level separation at high magnetic fields. This implies a zero-energy Landau level that is narrower than the higher levels. Further to the mobility asymmetry at high temperatures, the difference in broadening between the $\nu = -2$ and $\nu = +2$ sides of the zeroth Landau level suggests that there is a form of scattering which affects the holes more than the electrons near the Dirac point.

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