Small or medium-scale focused research project (STREP)

ICT Call 5

FP7-ICT-2009-5

NEW ELECTRONICS CONCEPT: WAFER-SCALE EPITAXIAL GRAPHENE

ConceptGraphene

Deliverable report.

Deliverable 3.1: ***Procedure for material characterization based on quantification of weak localization corrections is developed***

Nature of the deliverable: **R** = Report

Dissemination level: **PU** = Public.

Lead Partner: **3** = National Physical Laboratory

Delivery date: month 6 of the project

Executive summary

We present a procedure for characterization of epitaxial graphene based on quantification of weak localization corrections to conductivity. Results of low temperature magnetotransport measurements are analyzed within the theory of weak localization for single layer graphene. Large area graphene devices are free from mesoscopic phenomena, which complicate similar analyses on graphene flakes. We have determined the contribution of various scattering channels and compare with the published results on the exfoliated graphene.

Contributors and their input:

Epitaxial graphene was grown by partner **6 –** Linkoping University
Devices were patterned by partner **1 –** Chalmers University
Magnetotransport measurements were carried out by partner **3 –** NPL
Theory was developed by partner **5 –** Lancaster University
Data were analysed by partners **1** & **5**
Report written by all contributors

Introduction

Assessment of the scattering processes that limit carrier mobility in epitaxial graphene is important for optimisation of the fabrication procedures. Weak localisation (WL) is a signature of quantum coherence in disordered systems, which is sensitive to the details of the scattering processes. WL arises from coherent backscattering of charge carriers and manifests itself in magnetotransport measurements as a positive correction to resistivity centred at the zero field. Perpendicular magnetic field destroys time reversal symmetry by adding different phase factors to electrons propagating in opposite directions diminishing in this way coherent backscattering. A detailed study of localization can be carried out through magnetotrasport measurements. Since charge carriers in graphene have a chiral nature, the interference of carriers is not only sensitive to breaking of the phase coherence, but also to breaking of the chiral symmetry due to the inter- and intravalley scattering processes. The detailed theory of WL effects is presented in [1] by partner **5**.

WL had previously been studied in the exfoliated graphene [2-3] and multilayer epitaxial graphene [4].

Here we present a study of the mechanisms contributing to electron scattering in monolayer Epi-SiC, accomplished through low temperature magnetotransport measurements. We study weak localization corrections to the conductivity in a wide-temperature range and analyze the results with the theory of weak localization for single layer graphene [1]. Compared to graphene flakes, the analysis is simplified due to the large-area of the Epi-SiC structures, where mesoscopic effects, such as the universal conductance fluctuations, do not obscure the localisation phenomena.

The sample

Graphene was grown by partner **6** on the Si face of 4H-silicon carbide (Epi-SiC) [5]. Hall bars (160 μm long and 35 μm wide) (Figure 1) were patterned by partner **1** using standard electron beam lithography. The as-grown graphene was electron-doped to $n=1.1\text{x}10^{12}$ cm^{-2} as a result of charge transfer from the substrate [6]. The sample was then encapsulated with the polymer bilayer COP/ZEP520A to improve temporal stability and doping homogeneity of the sample, and exposed to Deep UV to tune the carrier concentration [7]. The resulting low temperature Hall mobility and carrier concentration for this sample were $\mu= 7300$ $cm^2V^{-1}s^{-1}$ and $n=4\text{x}10^{11}$ cm^{-2} respectively.

Half-integer Quantum Hall effect observed in this sample confirmed its monolayer nature [8].

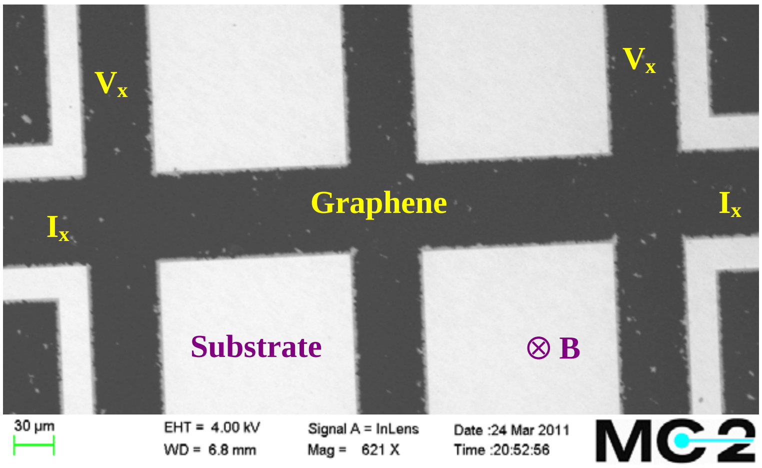

Figure 1. SEM image of the sample.

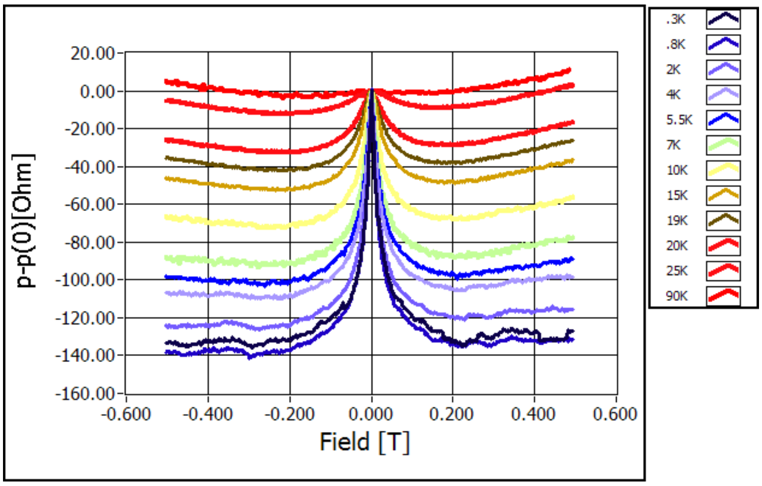

Figure 2. Magnetotransport measurement on a Epi-SiC Hall bar. $\Delta\rho_{xx}(B, T_{fixed})$ is plotted for different temperatures.

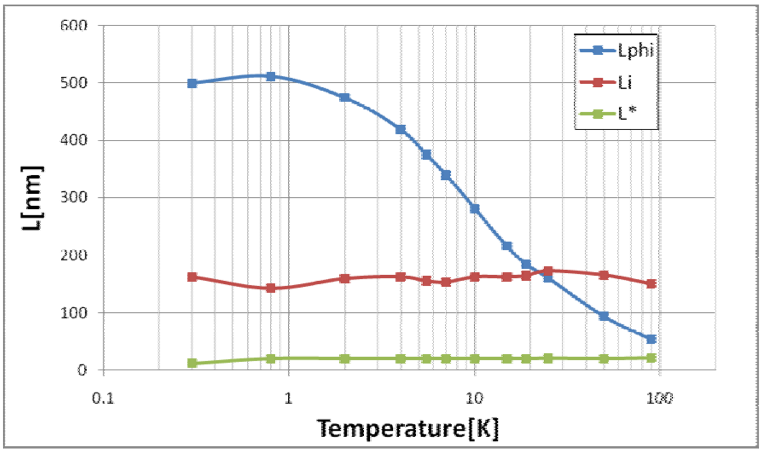

Figure 3. Temparature dependence of characteristic scattering lengths.

Procedure

Measurements were carried out by partner **3** in an Oxford Instruments Heliox system in a temperature range 0.3-100 K.

Corrections to the resistivity of Epi-SiC were determined following two approaches:

i) we determined the zero field, temperature dependent correction $\Delta\rho_{wl-fit}$ (Equation 1) using the characteristic scattering times: τ_φ – phase breaking, τ_i – intervalley, τ_* – intravalley, obtained by fitting our measurements of $\rho_{xx}(B, T_{fixed})$ to the weak localization theory of graphene (Equation 2) [1]. We have performed measurements at temperatures T_{fixed}= 0.3, 0.8, 2, 4, 5.5, 7, 10, 15, 19, 25, 50 and 90 K and the applied magnetic fields ≤ |500 mT.

ii) we suppressed experimentally the localization effects by applying a transverse magnetic field such that $\Delta\rho_{wl-\exp} = 0$, and looked for the temperature dependence of the measured ρ_{xx} (B_{fixed}, T). In this case, we have applied B_{fixed}= 0, 0.3, 0.5, 0.75 and 1 T in a temperature range from 2 to 100 K.

$$\Delta\rho_{WL} = \frac{e^2\rho^2}{\pi h}\left[ln\left(1 + 2\frac{\tau_\varphi}{\tau_i}\right) - 2ln\left(\frac{\tau_\varphi/\tau_{tr}}{1 + \tau_i/\tau_*}\right)\right]$$

Equation 1.

$$\frac{\Delta\rho(0)}{\rho^2} = -\frac{e^2}{\pi h}\left[F\left(\frac{B}{B_\varphi}\right) - F\left(\frac{B}{B_\varphi + 2B_i}\right) - 2F\left(\frac{B}{B_\varphi + 2B_*}\right)\right]$$

$$F(z) = lnz + \psi\left(\frac{1}{2} + \frac{1}{z}\right)$$

$$B_{\varphi,i,*} = \frac{h}{4De}\tau^{-1}_{\varphi,i,*}$$

Equation 2.

From the measurements of $\Delta\rho_{xx}(B, T_{fixed})= \rho_{xx}(B, T_{fixed})-\rho_{xx}(0, T_{fixed})$ we found that weak localization effects were present at all temperatures up to 90 K, being naturally stronger at lower temperatures (Figure 2). The characteristic lengths, $L_{\phi,i,*}=(D\tau_{\phi,i,*})^{1/2}$, where the diffusion coefficient $D=v_F l/2$ and the mean free path $l=h/2e^2k_F\rho$, extracted from these measurements by fitting to Equation 2 are presented in Figure 3.

Next, with the obtained characteristic scattering times/lengths we calculated the temperature dependent WL correction to resistance ($\Delta\rho_{WL\text{-}Fit}$) Equation 1, which was then subtracted from the measurement to obtain $\tilde{\rho}_{xx-fit}(B,T_{fixed}) = \rho_{xx}(B,T_{fixed}) - \Delta\rho_{wl-fit}$. The result is plotted in Figure 4 alongside the experimentally corrected data $\rho_{xx-\exp}(B_{fixed},T) = \rho_{xx}(B_{fixed},T) - \rho_{xx-\exp}(B_{fixed},T=2K)$ and the data at zero magnetic field. All corrected plots coincide fairly well, which confirms the validity of the approach. Scattering at low temperatures is determined by defects, while at the temperatures above 30 K is dominated by phonons.

The scattering lengths obtained in this study for monolayer epitaxial graphene have been compared with the data published elsewhere on the exfoliated graphene at similar carrier densities (Figure 5). We concluded that the parameters are comparable for the two types of graphene with only slightly shorter scattering lengths for Epi-SiC.

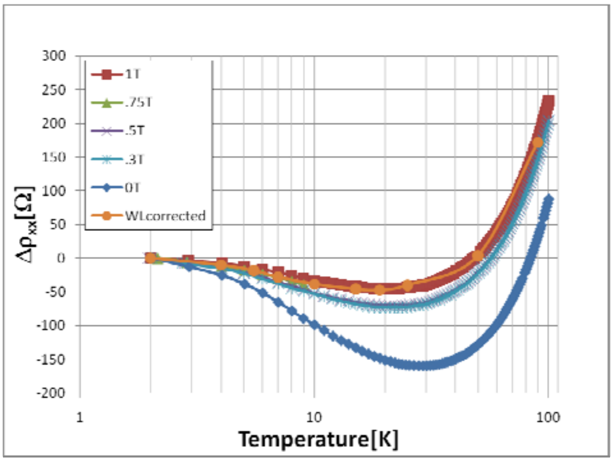

Figure 4. Temperature dependence of resistivity corrected for WL effects experimentally (by applying magnetic field) and analytically.

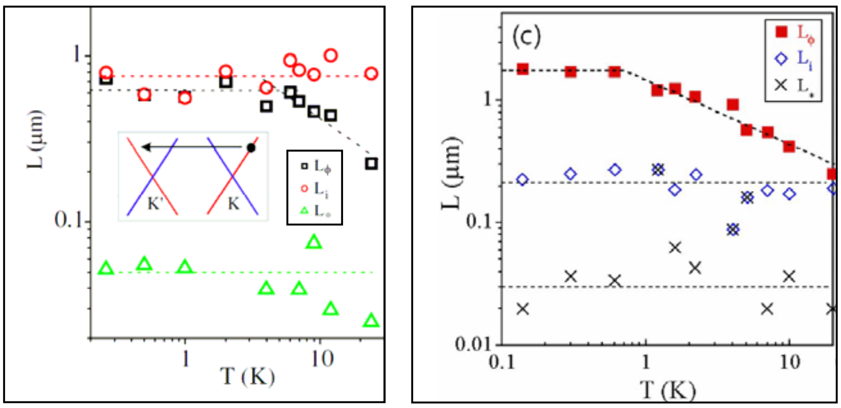

Figure 5. Temperature dependence of the characteristic scattering lengths for exfoliated graphene (a) from ref. [3] (b) from ref. [2]

Dissemination

The results of this work will be presented at ESF Conference “Graphene Week 2011: Fundamental Science of Graphene and Applications of Graphene-Based Devices”, 24-29 April 2011, Austria.

A journal article is in preparation.

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