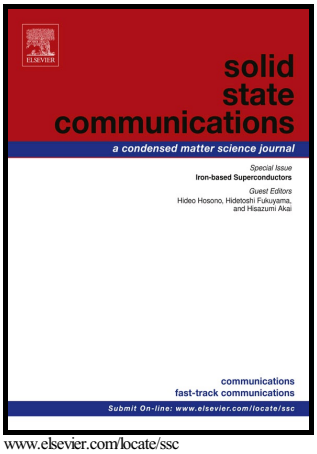

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Temperature dependence of universal conductance fluctuation due to development of weak localization in graphene

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Abstract

The temperature effect of quantum interference on resistivity is examined in monolayer graphene, with experimental results showing that the amplitude of the conductance fluctuation increases as temperature decreases. We find that this behavior can be attributed to the decrease in the inelastic scattering (dephasing) rate, which enhances the weak localization (WL) correction to resistivity. Following a previous report that explained the relationship between the universal conductance fluctuation (UCF) and WL regarding the gate voltage dependence (D. Terasawa, *et al.*, Phys. Rev. B **95** 125427 (2017)), we propose that the temperature dependence of the UCF in monolayer graphene can be interpreted by the WL theory.

Keywords: A. graphene, D. quantum interference, D. universal conductance fluctuations, D. weak localization

1. Introduction

The quantum interference (QI) effect is of fundamental importance because it is a manifestation of wave-particle duality. As a prominent aspect, QI effects of charged carriers are frequently observed to appear in conductance, such as Anderson localization [1], Aharonov-Bohm effect [2], universal conductance fluctuation (UCF) [3, 4], and weak localization (WL) [5, 6]. Regarding the latter two QI corrections to conductance, graphene shows unconventional results [7, 8, 9, 10], owing to the chirality of the carriers at two inequivalent points in the graphene momentum space (valleys), **K** and **K'** [11, 12]. There has been much discussion on their relationship [13, 14, 15], and it is known that the inelastic dephasing length obtained separately from both UCF and WL analysis are in agreement [16, 17, 18]. Recently, an essential development in understanding the relationship between UCF and WL has been made: the cause of the UCF can be attributed to WL [19] in monolayer graphene. From this reference, the ratio of inelastic scattering (dephasing) time τ_φ to intervalley scattering time τ_i, τ_φ/τ_i, which causes the WL correction to conductance, varies with the UCF. However, the effect of temperature T on the relationship between the UCF and WL remains unclear. In this communication, we demonstrate that the effect of temerature on the UCF is well described by the WL theory proposed by McCann *et al.* [12]. Through WL analysis, we find that τ_φ increases as T decreases, resulting in the QI correction in the resistivity from the WL effect to become more prominent and increase the magnitude of UCF.

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2. Sample and Method

A graphene sample is obtained using a mechanical exfoliation method [20] on a SiO_2 surface that is separated by 300 nm from an n^+-doped Si substrate. We choose a monolayer flake from kish graphite of approximately $6.2 \times 1.4\ \mu m^2$ area. The contact pattern is drawn using electron beam lithography at opposite edges of the sample (see Fig. 1 (a)), which was also used in the previous experiment [19]. Ohmic contact materials (10-nm-thick Pd and 100-nm-thick Au) are deposited through thermal evaporation, followed by a liftoff process in warm 1-methyl-2-pyrrolidone. The carrier densities are controlled by varying the back gate voltage, V_g, which is applied between the graphene sheet and the substrate, in accordance with the relation $dn/dV_g = 7.2 \times 10^{10}\,cm^{-2}V^{-1}$. The sample is first annealed at 700 K in an H_2 atmosphere for 30 min, and then placed in a sample cell containing a resistance heater. The sample is annealed again *in situ*, using the heater for 2 h at $\sim$410 K before cooling. This allows to desorb molecules on the graphene surface, and shifts the charge neutral point (CNP) to $V_g \sim 0$ V. However, this can induce further atomic defects in the sample due to the amorphous carbon produced from residual hydrocarbons during the annealing [21]. Figure 1 (b) shows the data of the Raman shift spectrum for the sample. The number of layers was confirmed by analysis of this spectrum [22], with the prominent D peak at $1320\,cm^{-1}$ indicating a large number of atomic defects. The resistances are measured using a standard AC lock-in technique with a frequency of 37 Hz. To prevent the self-heating effect caused by the carriers, we use a 10-nA r.m.s. source-drain current (current density: $7.1 \times 10^{-3}\,Am^{-1}$). A He-free Gifford-McMahon refrigerator is used to cool both the sample and a superconductor magnet with a maximum mag-