**Fractal behaviour in graphene open quantum dot**

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**Abstract.** Low temperature transport has been studied in a graphene open quantum dot and shows evidence of fractal behaviour in the presence of a perpendicular magnetic field. The graphene quantum dot was fabricated by micromechanical cleavage and standard electron-beam lithography. The magneto-conductance of the dot indicated self similarity. From the exact-self-similarity analysis, the fractal dimension was determined to be 1.4. We have also observed a strong suppression of weak localization that is attributed to mesoscopic corrugations of the graphene. The relationship between the fractal behaviour and structural topology of graphene remains so far unclear.

**1. Introduction**

The discovery that graphene can be fabricated by micromechanical cleavage is one of the most significant findings of mesoscopic physics [1-3]. This atomic flatland provides remarkable differences from conventional semiconductor heterostructures, including naturally-formed two-dimensionality, chirality of charge carriers and the presence of a linear energy spectrum. For the last decades, many theoretical studies have been stimulated by these unique properties. Recent experimental studies have also demonstrated many exotic results. High crystalline quality and submicron ballistic transport make this material a candidate for future electronics. Researchers have proposed prototype devices such as field effect transistors [2,3], nanoribbons [4], p-n junctions [5,6] and Veselago lenses [7] based on graphene. Besides their possible applications, these devices are predicted to host new phenomena that arise from the quantum relativistic nature of carriers.

In this paper, we present the first observation of the fractal behavior in the magneto-conductance (MC) of a graphene open quantum dot (GOQD), fabricated by micromechanical cleavage and electron beam lithography. While the quantum interference corrections and the Shubnikov-de Haas oscillations (SdHOs) have been widely discussed in previous studies [2,3,8,12-15], we find that the magneto-conductance of the graphene dot indicates several field-symmetric and self-similar peak-structures. We analyze these features based on exact self similarity, and determine the fractal dimension to be 1.4. Although unclear, the relationship between the fractal behavior and structural topography of graphene is very interesting. Moreover, we observe a strong suppression of weak localization (WL) consistent with previous works [8].

**2. Sample Preparation and Measurement Techniques**

Our GOQD was prepared by micromechanical cleavage of highly oriented pyrolytic graphite (HOPG SPI Grade-2) [1-3]. By rubbing the HOPG against a Si/SiO$_2$ substrate, we obtained graphene films with a thickness of approximately 9.5 Å as determined by atomic force microscopy (AFM). This is
consistent with previous experiments of monolayer graphene using AFM investigation under ambient conditions [2,3,9]. After selecting a graphene flake ~ 2 µm in length and ~ 500 nm in width, we used electron beam lithography to pattern two contacts to the graphene with a separation of 600 nm (Figs. 1(a) and 1(b)). This step was followed by using standard lift-off to deposit 30 nm of Au with a 3 nm Pt contact layer. The Pt contacts were found to give a 1.5 kΩ ohmic contact to the graphene in this study, somewhat different to previous studies using Cr contacts [2-5,7,8]. We attribute this difference to chemical doping [2] caused by organic residue between the Pt electrodes and the graphene in the resist processes.

The magneto-conductance of the GOQD was measured using a standard lock-in amplifier with a small ac excitation voltage (< 100µV @ 17 Hz) and magnetic fields up to 8 T. The sample was mounted in 3He cryostat refrigerator, and cooled down to 0.35 K.

![Figure 1(a).](image1.png)  
(a) AFM image of the graphene flake used in this experiment. The thickness of encircled area is approximately 9.5 Å thick, consistent with monolayer graphene. 
(b) Schematic image of the graphene quantum dot. Electrons injected into the graphene are weakly confined between the Pt/Au electrodes.

### 3. Result and Discussion

#### 3.1. Graphene open quantum dot (GOQD)

As mentioned already, there is a contact resistance of about 1.5 kΩ at low-temperature between the Pt/Au electrodes and the graphene flake. In this situation, electrons are easily injected into the graphene, while the contact resistance can generate weak confinement. Electron coherence appears to
be preserved over reasonable distances in the graphene, since a coherent area of \(\sim 0.1 \, \mu m^2\) is calculated from the self correlation function of the observed conductance fluctuations (discussed below). We therefore believe that the graphene essentially functions as a semi-coherent open quantum dot. Previously, both open and closed quantum dots have been realized by the same method, using graphite thicker than 5 nm [10]. The closed dots have been found to exhibit high contact resistances \(> \frac{h}{2e^2}\) and show Coulomb oscillations at low temperatures.

3.2. Fractal behaviour
Prior to this study, quantum interference corrections and the SdHOs have been reported in the magneto-conductance of graphene. In our case, however, the GOQD magneto-conductance exhibits self similar structures as shown in Figs. 2(a) and 2(b). This behavior closely resembles previous studies of fractal behavior in GaAs/AlGaAs quantum dots. The mechanism for the fractal behavior in such conventional quantum dots has been well established, and can also explain the hierarchy of structures in the GOQD. We calculated the fractal dimension as 1.4, based on a exact self similarity, see Figs. 2(a) and 2(b).

![Figure 2(a)](image)

**Figure 2(a).** The hierarchy of the structures observed in the magneto-conductance. **(b).** Determination of fractal dimension by the analysis of the self similar structures.

3.3. Strong suppression of weak localization
Near zero magnetic field, we have found a WL peak with a strongly suppressed magnitude, \(10^4\) times lower than that expected from standard theory [16]. Recent theoretical analysis has predicted that the pseudospin is conserved in graphene and positive-WL is expected rather than negative-WL. More recently, however, it has been argued that the existence of atomic-range scattering can lead to the complete suppression of these effects. In contrast, experiments have shown only negative-WL,
strongly suppressed in magnitude. This is attributed to mesoscopic corrugations of graphene which can cause a dephasing of wave function similar to a random magnetic field [8,14].

Figure 3. Strong suppression of weak localization.

4. Summary
In this work, we have fabricated a GOQD that exhibits signatures of phase-coherent transport at low temperatures. We have observed fractal behaviour in the MC and determined the fractal dimension to be 1.4. We also observed a strong suppression of WL, which may be attributed to the influence of mesoscopic corrugation. The relationship between the fractal dimension and the surface topology of graphene remains unclear.

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