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Full Length Article

Ultraviolet-light-driven carrier density modulation of graphene based field effect transistors under oxygen- and argon atmosphere

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ABSTRACT

The fine-tuning of graphene charge carrier concentrations is an essential factor to approach the integration of highly efficient electronic and optoelectronic devices. Here, we demonstrate the deep ultraviolet light driven doping tunability of graphene-based field effect transistor in presence of oxygen and argon atmosphere. The doping effect and its reversibility are confirmed from the Raman spectroscopy. These results are further corroborated by electrical transport measurements. Our findings provide an efficient, stable and defects free doping methodology to tailor the electrical properties of graphene for its potential application in desired technology.

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1. Introduction

Graphene, a two-dimensional sp^2 hybridized network of carbon atoms bounded together in honeycomb arrangement, own unique band structure and recognized as a promising material for quantum interference and optoelectronic devices [1–7]. This single layer of graphite has various intriguing properties such as ambipolar transport, quantum Hall effect, ultra-high mobility, marvelous thermal conductivity, robustness, large specific surface area, transparency and flexibility [8–15]. Graphene has zero bandgap with Fermi level (E_F) lies at the point of intersection of conduction and valence band. This property blocks the various potential applications of graphene in many electronic and optoelectronic devices.

The modulation of the graphene charge carriers concentration is one of the common methodology to tailor the electrical properties of graphene-based field effect transistor (GFET). Several approaches such as: high energy electron or ion beam irradiations, metal deposition, chemical doping, substitutional doping and oxygen plasma treatment are introduced to modify the electrical properties of graphene for its potential application in desired technology [16–22]. However, high energy electron beam irradiations, chemical doping and the oxygen plasma treatment induced unwanted disorderness in perfect crystal structure of graphene [16,23–29]. Whereas, the substitutional doping not only creates disorderness in crystal structure but also degrades the channel mobility [21,30,31]. Additionally, most of the doping processes reduce the potential applications of graphene in optical devices [32]. Therefore, an effective alternative defects free doping methodology is highly desirable for the modulation of graphene charge carriers concentration without degrading the carrier mobility. Theoretical and experimental studies reveal the possible modification in electrical properties of graphene through photo-oxidation [33–35]. The interaction of graphene carbon atoms with oxygen under atmospheric O_2 and dry O_2 gas implies p-type doping [34]. In addition, several other techniques are employed to study the reversible doping behavior in GFET [36,37]. These techniques involve the annealing of p-doped GFET under argon/inert environment at high temperature. Such high temperature may affect the adhesion of contact electrodes, which in turns degrade the performance of device.

The control of structural disorder and mobility degradation is still gigantic challenge for an application of real devices. Here, we report the defects free p-type doping and reversible behavior of GFET exposed to deep ultra violet light (UV) in presence of O_2 and argon gas environment, respectively. The shift of the Raman G and 2D peak positions towards higher wave number (blue shift) signifies p-type doping in GFET exposed to UV in a presence of O_2 gas flow (UV/O_2). Whereas, the restoration of these peaks (red shift) with UV treatment of GFET in a presence of argon gas flow (UV/Ar) indicates the reversible doping behavior. The doping effect and its reversibility are further confirmed by the electrical transport measurements. The shift of the charge neutrality point (CNP) towards positive gate voltages (V_g) with UV/O_2 treatment

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implies p-type doping in GFET. Whereas, the shift of the CNP back towards pristine state with UV/Ar treatment signifies the reversible doping behavior of GFET without degrading the carrier mobility. These results offer an effective and non-destructive methodology to tailor the electrical properties of GFET without degrading their structural and electrical characteristics.

2. Methodology

Thermal chemical vapor deposition (CVD) technique was employed to grown graphene on a copper foil (25 μm) from Alfa Aesar (99.8%). The copper foil was placed in the tube furnace and the furnace was evacuated at a pressure of $\sim 10^{-4}$ torr. After that, furnace temperate was raised up to 1010 °C and methane (CH_4) and hydrogen gases (H_2) were introduced in furnace (20 and 5 standard cubic centimeters per minute) for 8 min to synthesize the graphene. In the next step, sample was cooled down to room temperature at a rate of 50 °C per minute [1]. Then the thin layer of polymethylmethacrylate (PMMA) was spin coated (800 rpm for 10 s and 2400 rpm for 30 s) on the graphene supported with copper foil. Afterwards, the copper foil was etched with 1M solution of ammonium persulfate (APS, $(NH4)_2S_2O_8$) and de-ionized water was used to wash PMMA membrane/graphene. Later, the graphene film along with the PMMA membrane was transferred on 300 nm thick SiO_2 supported with Si substrate and dried by heating at 80 °C for 10 min. Finally the PMMA layer was removed by placing the sample in acetone for 24 h.

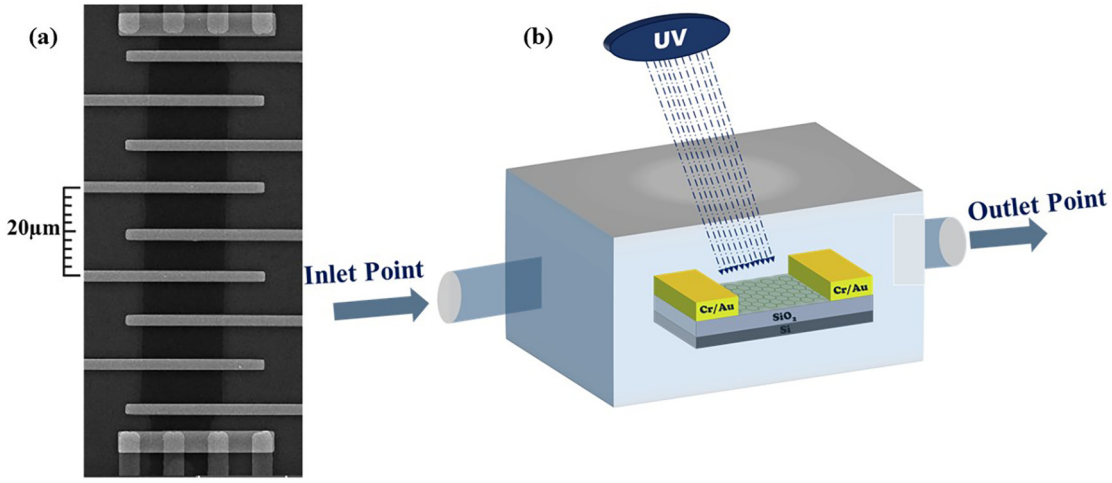

Fig. 1. (a) SEM image of the fabricated device. (b) Schematic representation of the experimental setup. The device is placed in gas controlled chamber with quartz plate surface having an inlet and outlet points for the gas flow. The p-type doping and its reversibility are studied by irradiation of UV light with O_2 and Ar gas flow, respectively. The UV lamp is placed at a distance of 25 cm from the device.

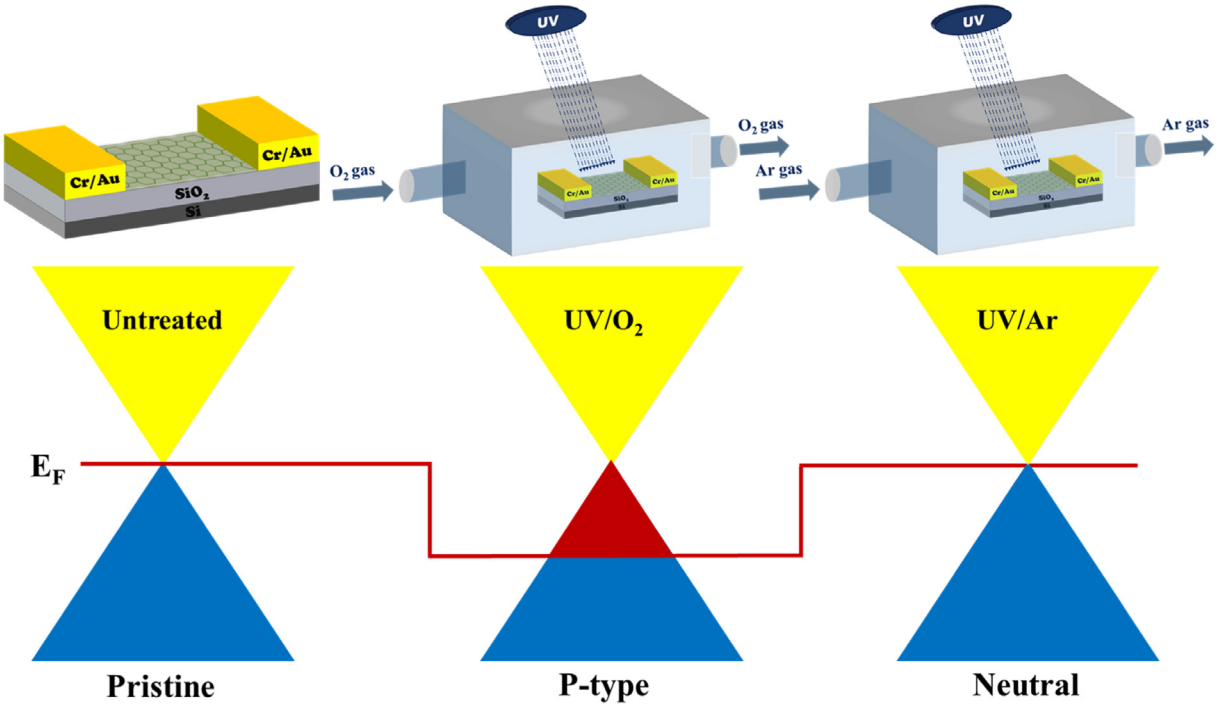

Fig. 2. Schematic view to demonstrate the doping tunability of GFET under O_2 and Ar gas environment. The shift of the E_F position in valence band with UV/O_2 treatment implies p-type doping in GFET. Whereas, the restoration of the E_F position with UV/Ar treatment signifies reversible doping behavior in GFET.

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