Student Paper

Reproducible and Reliable Metal/graphene Contact by UV-Ozone Treatment of the Contact Interface

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Graphene is a promising material for the next-generation electronic devices. Extraordinarily high mobilities (up to 200,000 cm^2/Vs) make graphene an excellent candidate for RF applications. However, due to the difficulties of obtaining low metal/graphene (M/Gra) contact resistance (R_c), the reported working frequencies of graphene transistors remain much lower than the III-V HEMT. M/Gra interface contamination introduced during the device fabrication process is an important contributor to the high M/Gra R_c. Resist residue from the device fabrication process, e.g. the transfer and subsequent lithography processes used for fabricating chemical vapor deposition (CVD) grown graphene devices, is a significant source of M/Gra interface contamination. Such contamination also affects device stability and reproducibility. The ultraviolet ozone (UVO) treatment of the contact area is found to be an effective way to remove the resist residue [1]. Here, we report low Rc with reliable electrical properties can be highly reproducibly obtained by UVO treatments.

Large area monolayer graphene was synthesized on 25 μm thick copper foil by CVD method. Graphene films were then transferred onto heavily doped silicon wafers with a thermally grown 300 nm SiO_2 insulator by "modified RCA cleaning" method [2]. Fig.1 shows the device fabrication process. Graphene transistors were fabricated by using conventional photolithography and metal deposition method. After opening the windows for the metal contacts in the photoresist layer, the substrate was put into a commercial UVO system to remove resist residue at room temperature prior to metallization. Only the graphene regions in the openings were exposed to UVO, while the channel areas were protected by the photo resist. After deposition of Ti (20nm)/Au (80nm) and lift-off, a second photolithographic process and oxygen plasma ware used to pattern the graphene channel followed by photo resist removal in acetone. A transfer length method (TLM) with pad spacing (L) of (4.5, 10.5, 16.5, 22.5, 28.5, 34.5, 40.5 and 46.5) μm was used to extract R_c. The results from electrical characterization of devices fabricated in Peking University are compared with analytical studies conducted at NIST on unpatterned graphene samples that were processed in a similar fashion, but in a different UVO reactor.

XPS and Raman spectroscopy were used to characterize the chemical and disorder changes during the UVO treatment process. There is no obvious defect peak introduced at the first 10 min. UVO exposure, however, a remarkable D-peak is observed after 16min. exposure (Fig. 2(a), Fig. 2(b) right axis) indicating defects and the partial destruction of the graphene. The C and Si atomic percent obtained from XPS measurements are shown in Fig. 2(b) left axis. The C signals originate from both the graphene and the resist residue, while the Si signal comes from the underneath substrate. The sharp increase of C atomic percent after photo lithography is due to the photo resist residue introduced onto the graphene during the device fabrication process. Fig. 3 shows output characteristics of a typical 10.5 μm channel length device for different UVO treatment times. There is a marked increase in drain current for the UVO treated devices. Since the channel region was protected by the photo resist during the UVO treatment and the resistivity of the graphene channel proved to remain unchanged [1], the increased current for the UVO treated device can only be ascribed to the large decrease of the R_c. Fig. 4a shows evolution of the total resistance with the UVO exposure time for 130 devices with different channel length (nearly 16 devices for each channel length). The devices fabricated without UVO treatment have higher total resistance and exhibit a broad distribution of resistance values. In contrast, the resistance values are significantly lower for the devices fabricated with the UVO treatment. Importantly, the standard deviation of resistance values is significantly decreased. This confirms the UVO treatment cleans the contact interface effectively for reducing R_c, and improves the repeatability which is of particular importance for large scale device fabrication. Fig. 4b. shows the corresponding average resistance of the devices in Fig. 4a. As all devices have the same channel width and contact width, it is reasonable to extract R_c in the TLM framework. The extracted R_c of the devices that underwent a 25 min. UVO treatment is 507 ± 242 Ω μm, and compares favorably with most reported results[3]. Fig. 5a shows that as the drain-source voltage (V_{ds}) sweep range

increases, the drain-source current gradually increases for the device fabricated without UVO treatment, which is due to the improved M/Gra contact during the voltage sweep. This improvement is due to the locally removal of surface contamination in the contact region by Joule heating. However, the interface has been covered by metal contact, and the resist residue in this area cannot be cleaned thoroughly. Such instability is not desirable for circuit design and operation. In contrast, this instability is not observed in the device which underwent 25 min. UVO treatment, as shown in Fig. 5b. The I-V curves for all sweeps overlap as the voltage range increases. The observed stability is due to the improved M/Gra interface which results in contact formation with greater electrical integrity. The linear current increase at low bias indicates an ohmic contact was obtained. Besides, the output currents of the UVO treated device (Fig. 5b) are significantly improved due to the improved contact.

UVO treatment has been shown by XPS and Raman spectroscopy to be a robust, simple, and controllable way of the residue contamination cleaning at the M/Gra interface. Electrical measurements prove that highly reproducible and stable contacts are obtained by UVO cleaning.

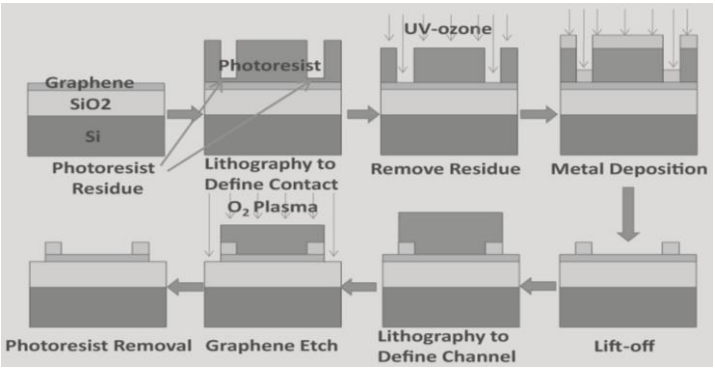

Fig. 1 Device fabrication process.

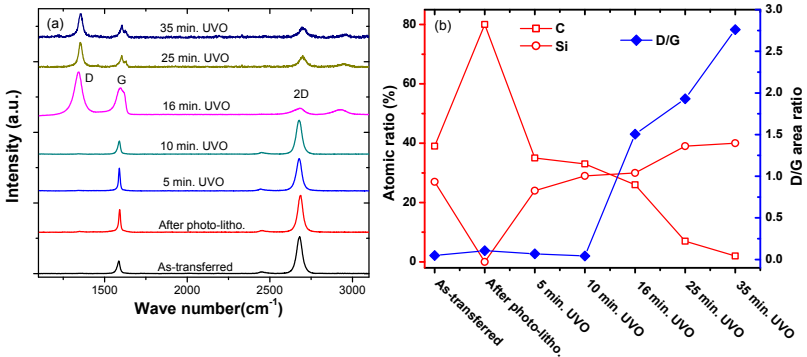

Fig. 2 Raman (a) and XPS characterization of the UVO treatment process. (b) left axis: atomic change, right axis: raman D peak to G peak area ratio.

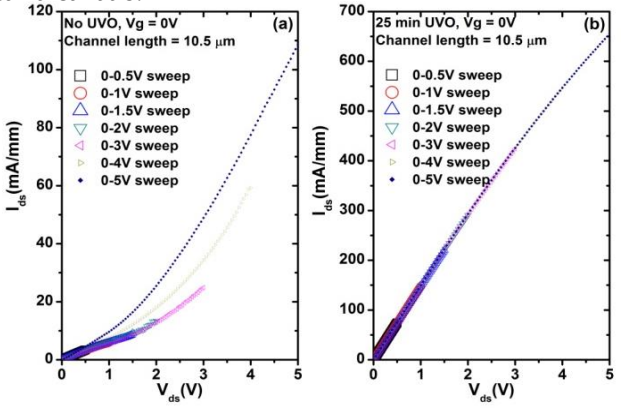

Fig. 5 Electrical stability measurement.

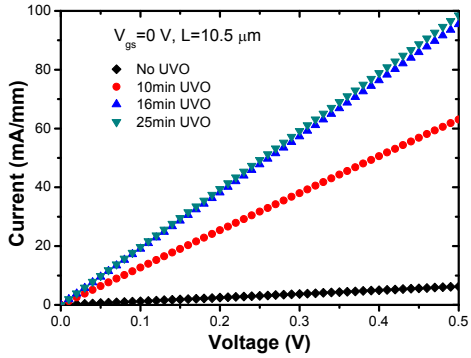

Fig. 3 I-V curve of devices with different UVO treatment time of the contact interface.

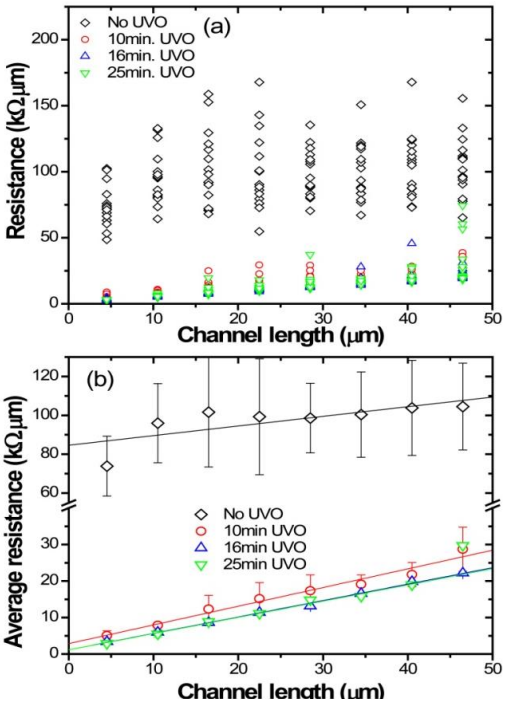

Fig. 4 (a) The statistical total resistance of devices underwent different UVO cleaning process. (b) Average total resistance corresponding to those in (a) and the TLM fitting.

References

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