Graphene Gold Nanoparticle Hybrid Based Near-Infrared Photodetector

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***Abstract*—This paper presents novel and simplistic approach towards the development of graphene based near infrared (NIR) photodetectors. The developed device comprises of Au nanoparticles integrated within the channel of the back-gated graphene field effect transistors. The introduction of Au nanoparticles enhanced response of the device under IR illumination due improved NIR absorption. Further, dynamic response of the device under IR illumination is presented. This study will trigger the development of novel hybrid graphene device for graphene based photodetectors in IR regime.**

Keywords—Graphene, Gold Nanoparticles, IR Detector

I. INTRODUCTION

The fascinating electronic and optical properties of graphene have triggered an interest for using graphene in various sensing applications [1-3]. Among these, the graphene based photodetectors is interesting as it is possible to detect photons over a broad range of spectrum, which is a prerequisite for numerous applications such as imaging, security, and optical communications etc [4]. A range of materials including GaN, InGaAs, PbS , HgCdTe and Si etc., have been employed for detection of various ranges of wavelengths of electromagnetic radiation [5]. But, graphene is different as it allows development of photodetectors owing to its broadband absorption spectrum ranging from ultraviolet to infrared spectral range. Further, the high carrier mobility of graphene allows rapid photoresponse on absorption of an incident photon. The compatibility of graphene with the existing complementary metal-oxide-semiconductor (CMOS) technology is another feature which makes it an ideal candidate for the next generation photodetectors. Despite the above-mentioned advantages, graphene based photodetectors, suffer from poor photoresponse because of its short carrier life time and poor light absorption [4, 6]. The sensitivity of graphene photodetectors could be improved by enhancing the absorption of light. Several strategies developed for this purpose, include microcavities [7], quantum dots [8] and plasmonic nanostructures etc. [9, 10].

In this work, we present back-gated graphene field effect transistor (GFET) based photodetector for near-infrared regime (NIR) detection. The photoresponse of the device is enhanced by integrating gold nanoparticles within the developed GFET. Traditionally, the introduction of nanostructures have been achieved using cumbersome electron beam lithography and transfer printing of the nanoparticles [9, 11]. Herein, we report a simple approach with GFET developed on top of the dewetted gold nanoparticles (Au NPs). The schematic of the developed device is shown in Fig.1. This paper is organised as follows: Section II of the paper presents the fabrication methodology of the device, Section III covers the results and discussion. Finally, conclusion of the paper is presented in Section IV.

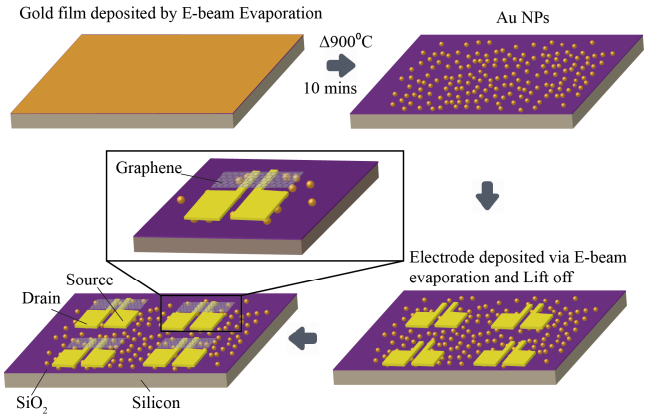

Fig. 1. Schematic representation of device fabrication.

II. FABRICATION OF DEVICE

The schematic of the key fabrication steps of the proposed device is shown in Fig 1. A 1nm thick gold film was deposited on top of SiO_2/Si substrate via electron beam (e-beam) evaporation using Plassys MEB 500S e-beam evaporator system. The deposited gold film was annealed at 900°C for 10 min in a forming gas ambient under atmospheric pressure resulting in a high density Au NPs. Next source and drain (S/D) electrodes (Ti/Au 10/30nm) were defined via e-beam evaporation followed by lift off. Finally, chemical vapour deposition (CVD) grown graphene was transferred on the destination substrate (SiO_2/Si) comprising of S/D electrodes and Au NPs.The intricate details of transfer printing process is described below.

A. Transfer Printing of Graphene

A commercially available CVD grown graphene on copper foil (Graphenea) was used in this study. Graphene on Cu foil was transferred to target substrate via a wet transfer technique using a cellulose actetate butyrate (CAB) as the polymer scaffold. CAB dissolved in Ethyl-L-lactate was spin coated on top of the graphene/Cu foil and cured at room temperature for

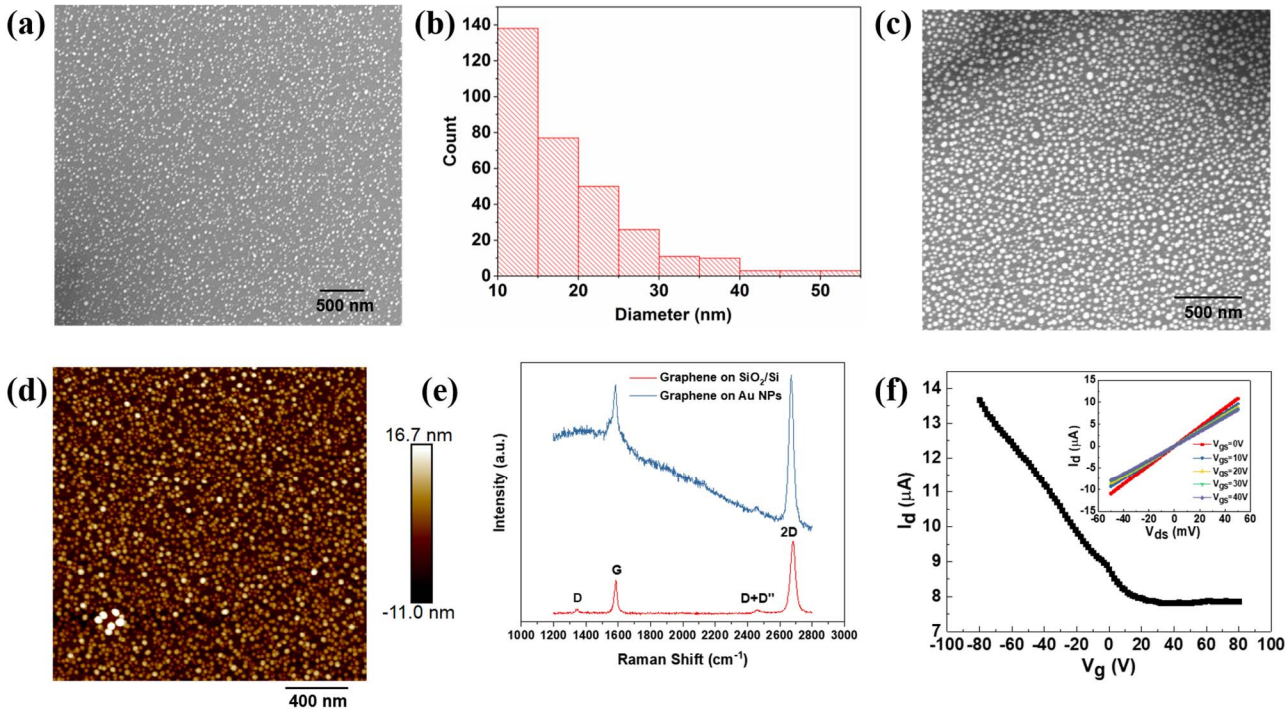

Fig. 2. (a) SEM image of AuNPs formed by dewetting 1nm Au film at 900ºC. (b) Histogram depicting the size distribution of Au NPs fromed by dewetting of Au film. (c) SEM image of graphene on top of AuNPs (d) AFM scan of region graphene transferprinted on top of Au NPs. (e) Raman spectra of grpahene on SiO_2/Si substrate and graphene on Au NPs. (f) Transfer and output characterisitcs of the GFET with Au NPs

4h. The underlying Cu foil was etched by floating the CAB/graphene/Cu in iron (III) chloride solution (0.5 M). CAB/graphene stack floating in the etchant solution was transferred to deionised (DI) water to remove the residual remains of the etchant. Subsequently, polymer/graphene was then rinsed in modified RCA 1 solution (H_2O:HCl:H_2O_2-20:1:1) and DI water for 15 min respectively before being transferred to destination substrate. Graphene transferred on top of the target substrate was baked at 65ºC to remove the water trapped between the graphene and the substrate. The sample was further baked at 90ºC in an oven. Next, the polymer scaffold was removed by overnight immersion of the sample in acetone. Finally, the sample was then rinsed in isopropanol and blow dried with N_2 air gun.

B. Patterning of graphene

The development of back-gated GFET was completed by patterning of graphene. The graphene channel was patterned via a combination of photolithography and reactive ion etching in O_2. The photolithography on graphene was carried out using a stack comprising of poly (methyl methacrylate) (PMMA) and photoresist (PR). Following the development of PR, PMMA/graphene was etched by RIE in O_2 at 300W for 13s using Oxford Instruments RIE 80+. Finally, the polymer stack on top of graphene was removed using acetone.

III. CHARACTERIZATION OF THE DEVICE

The characterization of the developed GFET was carried out using scanning electron microscope (SEM), Raman spectroscopy, atomic force microscopy (AFM) and electrical characterisation.

The size and distribution of Au NPs on SiO_2/Si substrate was studied using FEI Nova NanoSEM 630. Fig. 2a. depicts SEM image of high density Au NPs formed by dewetting of the gold film on SiO_2/Si substrate. The size distribution of Au NPs is represented by histogram in Fig.2b. with a mean diameter of 16 nm. The graphene transferred on top of Au NPs is shown in Fig. 2c. Further, the topography of the device was studied using the Bruker Dimension Icon Atomic Force Microscope (AFM). The surface morphology in the channel area of the device is shown in Fig. 2d. The average roughness of the surface was found to be around 2.32 nm, in comparison with the graphene transfer printed on top of SiO_2/Si substrate was about 0.8 nm.

The impact of transfer printing graphene on top of Au NPs was studied using Raman spectroscopy. Raman spectroscopy study was carried out using LabRAM HR system equipped with Ventus 532 nm Laser system. The Raman spectra of graphene on top of SiO_2/Si substrate and on top of Au NPs is depicted by Fig. 2e. The absence/ negligible prominence of disorder induced D-peak in Raman spectra indicates that high quality graphene transfer. Further the presence of G-Peak and 2D peak at 1581 cm^{-1} and 2670 cm^{-1} indicates the quality of graphene is preserved after transfer printing on top of Au NPs.

The electrical characterization of back-gated GFET was carried out using Keysight B1500A Semiconductor Device Parameter Analyser. The channel length and width of the developed device is 10µm and 20µm respectively. The electrical characterization of the device was carried out at drain to source voltage, V_{ds} of 50mV. The typical transfer and output characteristics of GFET device comprising of Au NPs is shown

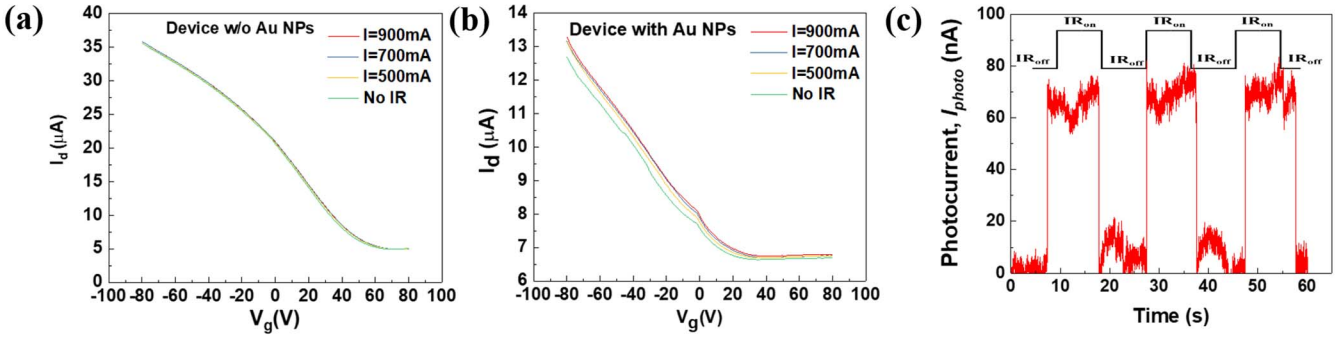

Fig.3. Device Response of GFET (a) without Au NPs (b) with Au NPs at different IR illumination intensity achieved by varying the current . (c) Transient response of the device with Au NPs under IR illumination.

in Fig.2f. The developed device comprising of dewetted Au NPs exhibited a typical carrier mobility in the range of 537-645 $cm^2.V^{-1}.s^{-1}$.

IV. Photoresponse of the Device

The photoresponse of the device was characterized using the 850 nm infrared (IR) LED at different intensities. The intensity of the IR LED was varied by changing the current. The impact of Au NPs on the photoresponse of the device evaluated by comparing the transfer characteristics of GFET with and without Au NPs. Transfer characteristics of the GFET without and with Au NPs at different intensities is shown in Fig. 3a and 3b respectively. The GFET without Au NPs exhibit a slight photoresponse under IR illumination. The minimum drain current increased with increasing intensity owing to broadband absorption of graphene. Unlike GFET without Au NPs, GFETs integrated with Au NPs showed an improved photoresponse under IR illumination. The observed increase in the drain current of the device integrated with Au NPs is attributed to scattering of the light within the device thereby increasing the IR absorption of graphene. This resulted in the observed increase in the drain current. Further the transient measurement of the device was carried out to confirm photoresponse of the device to IR illumination. The device exhibited a good response to IR illumination as shown in Fig 3c.

V. Conclusion

In summary, we have presented a novel and simplistic approach towards the development of graphene based near infrared photodetector. The presented device comprises of Au NPs formed via dewetting of thin gold film, integrated with back gated GFET. The introduction of the Au NPs results in higher light scattering within the device thereby increasing the overall IR absorption of graphene. This results in enhancement in the photoresponse of device. We believe this integration of Au NPs with graphene could pave way to new hybrid graphene based photodetectors.

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