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Graphene photo detector with integrated waveguide biochemical sensors

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ABSTRACT

In this study, we demonstrate the fabrication of a graphene integrated waveguide device with graphene as the photo detector for bio-chemical sensor applications. The working principle of the sensor is based on the variation of the local evanescent wave intensity according to the variation of the analyte's refractive index. Graphene film is transferred onto the field-effect transistor device, and an overlay of polydimethylsiloxane (PDMS) is used as the waveguide. A few microliter drop of glucose is placed on the PDMS waveguide, and the change in the photocurrent through the graphene is monitored. Depending of the refractive index of the glucose (or analyte) changed, the local evanescent field changed and hence the photo current of the graphene. We believe that this sensing platform can be used for detection of various bio-analytes and for bio reactions.

1. Introduction

With continual improvement in the quality of life, requirement of healthy life detection of diseases, drug discovery, proteomics and environment is extremely increasing [1]. Traditional methods used for detecting bioactivity like DNA hybridization are too slow and labor intensive [2]. Traditional biosensors find restricted use due to their limited detection ranges [3]. They also require pre-processing, which makes them inefficient and costly. Bulk size and complicated electronic methods employed to transduce the biological functions in these biosensors have led to new methods of bioactivity detection [4]. Some methods used for monitoring bioactivities include difference at the electronic supports for electrical transduction, such as current and potential changes, piezoelectric transduction, field-effect transistor (FET) transduction, photo electrochemical transduction [5] and others. To overcome these difficulties in these methods, new biosensors have been developed to improve the detection of bioactivity. The new biosensors are fabricated from metallic and semiconducting nanomaterial [6]. Graphene is currently the subject of intense research because of its exceptional electrical properties. Graphene also holds great promise for novel photonic devices such as photo detectors [7]. Such graphene photo detectors have been used in optical data link applications.

In this paper we report the fabrication of a graphene integrated waveguide device with graphene as the photo detector for bio-chemical sensor applications. The operating principle of this sensor is based on the change in photo current of graphene according to the refractive index (RI) of the bio-chemical (analyte) under evaluation. In this sensor, graphene serves as a photo detector, which can detect different RIs for the analysis of different bio-chemical activities on a single chip. This work aims to fabricate a fast response bio-chemical sensor that will be sensitive to changes in bio-chemical activity.

2. Materials and methods

2.1. Graphene synthesis and materials

The large-area graphene layers were synthesized by the CVD of methane gas on Cu foils at 1000 °C [8]. After the graphene film was spin-coated at 3000 rpm with 5 wt% polymethylmethacrylate (PMMA) in chlorobenzene, the underlying Cu foil was etched by 0.1 M aqueous $(NH_4)_2S_2O_8$ solution. Subsequently, the PMMA supported graphene layer was transferred onto the FET device and dried in as oven at 60 °C. Finally, the dilute acetone was used to remove the PMMA layer. The Raman spectrum of the monolayer graphene film is depicted in Fig. 1. For the fabrication of PDMS waveguide, a silicone elastomer kit (SYLGARD 184 SILICONE ELASTOMER KIT, Dow Corning) was used. Glucose, as purchased from Sigma–Aldrich, USA is used and the different concentrations were prepared in DI Water viz. 60, 70, 80, 90, 100 and 110 mg/dl were used.

2.2. Device fabrication

The micro gap FET device consists of electrodes that are fabricated on oxide-coated silicon substrate using standard

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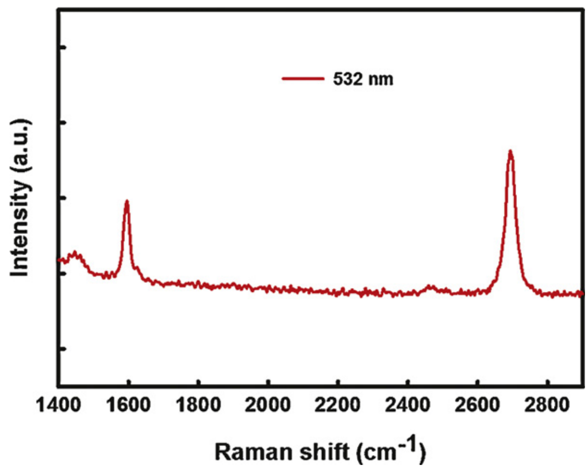

Fig. 1. Raman spectra of monolayer graphene film synthesized by CVD method.

electron-beam lithography and lift-off technique. The separation between the Au electrodes is 10 μm, and as such, seven Au electrodes were comprised in one single chip as shown in Fig. 2a. The PDMS mixing ratio of the base to curing agent was 10:1, and the mixture was kept for 1 h curing at 60 °C. The fabricated waveguide has dimensions of 5 mm × 1 mm × 20 mm ($W \times H \times L$). The fabricated PDMS waveguide is then placed on the graphene-deposited micro gap electrode chip to form a graphene-based PDMS waveguide device as depicted in Fig. 2b.

2.3. Experimental setup

Fig. 3 shows the schematic of the experimental setup employed in this study. All the studies were carried out by using the light source (λ = 530 nm). *I–V* characteristics were measured by a semiconductor parameter analyzer (Keithley, 4200 SCS, USA), and the transmitted light was collected by using a spectrometer (Avaspec, USA) to measure the change in the light's intensity.

3. Results and discussion

3.1. I–V characteristics and intensity

The operating principle of this sensor is based on a theory that relates the change in photo current of graphene according to the refractive index of an analyte is as depicted in Fig. 4. The photo current of graphene changes according to the refractive index of an analyte due to change in evanescent field and penetration depth. An evanescent field is induced when total reflection occurs at the boundary of the two media and this alternatively developed the standing waves. Hence, the incident light passes through the detection region and loses its own energy. As a result, the light falling on the graphene gets altered causing the change in photo current

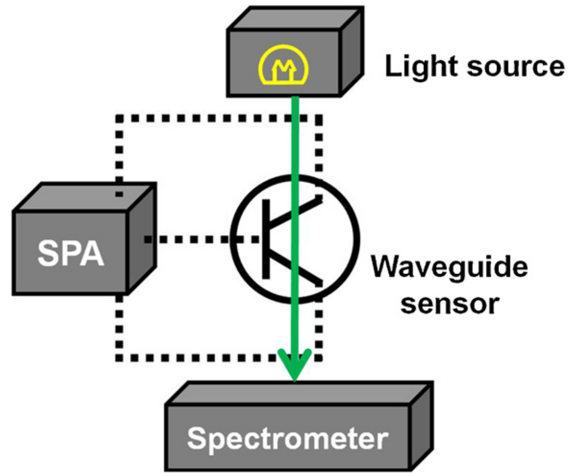

Fig. 3. Schematic of experimental setup for the evaluation of the fabricated graphene waveguide device. The spectrometer is used to detect the change in transmitted light through the waveguide, whereas the SPA measures the current through the graphene.

through it (Fig. 4a). However the penetration depth can also cause change in the photocurrent through the graphene and which is again depend on the refractive index of the analyte (Fig. 4b).

Fig. 5 shows the pre-experiment result using only graphene, which traces the change in photo current according to the amplitude of the standing wave. It is observed that the photo electric property of graphene is inversely proportional to the resistivity of graphene and the light intensity. This clearly indicates that the electric property of graphene is changed due to the variation in the light intensity. Therefore, the fabricated graphene PDMS waveguide senor can detect analytes by sensing the change of the standing wave of the light supported in the waveguide [9].

Fig. 6 shows the *I–V* characteristics of graphene for the different concentrations of glucose solutions that were used. We observed that there is a significant change in the graphene resistance and hence the current through it for a different concentrations of the glucose. Hence we can say that the evanescent field and the penetration depth are proportional to the concentration of the glucose solutions. However, the resistance of graphene is inversely proportional standing wave as seen in photoelectric property of graphene only. It can be justified by energy conservation law, as the standing wave is inversely proportional to the evanescent field and penetration depth. Hence the change in graphene resistance is proportional to the glucose concentration or the analyte under investigation (Fig. 6b).

Fig. 7 shows the transmitted light intensity according to the concentration of the glucose solution used. It is observed that the intensity is changed according to the concentration of the glucose solution as shown in Fig. 7a. The relation between transmitted light intensity and glucose solution concentration, the intensity of the

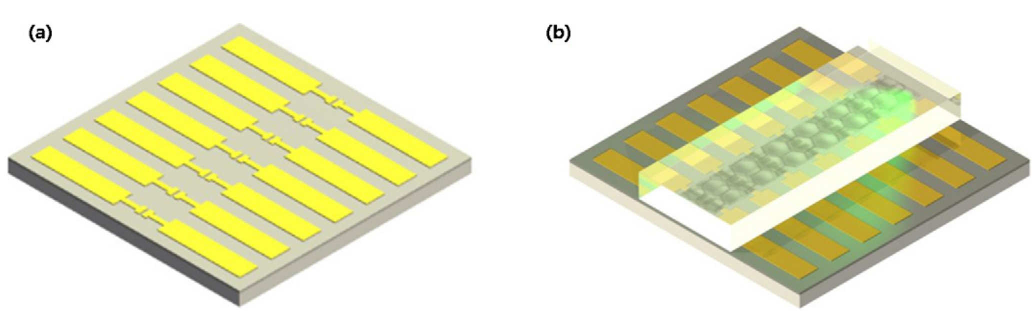

Fig. 2. Schematic representation of the (a) micro gap FET device and (b) fabricated PDMS waveguide sensor.

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