Highly Transparent Graphene Electrodes for CW THz Applications

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***Abstract*—Transparent graphene-based electrodes for CW THz devices are intensively investigated here. The multilayer graphene (MLG) electrodes were transferred on top of Low temperature GaAs (LT-GaAs) as photoconductive material. The high transparency of the graphene allows ~97% of the light to propagate through the transparent electrodes and increase the effective illuminated area. This will increase the carrier density, which leads to higher generated photocurrent. The simulation predicts more than one order of magnitude higher photocurrent can be reached by using multilayer graphene instead of a metal, such as gold. The benefits of using MLG instead of metal conductor results in a 40 times higher photocurrent than the photocurrent using gold electrodes at 20 V bias voltage.**

I. INTRODUCTION

GRAPHENE is a single two-dimensional (2D) layer of carbon atoms arranged in a hexagonal lattice. Its unique optical and electrical properties, such as high transparency, electrical conductivity, intrinsic mobility, and thermal conductivity, make graphene extremely attractive for many nano and optoelectronic devices such as transparent conductive nanoelectrodes [1]. Multilayer graphene exhibits higher absorption than the single-layer graphene, however, the transparency of the MLG is still in the range between 95 - 97%, which allows almost full light beam to propagate through the nanoelectrodes. The use of transparent material as electrodes for optoelectronic devices increase the illuminated effective area, which leads to an increase in the carrier generation rate (G_r) as shown in equation (1)

$$n_c = \tau_n G_r = \tau_n \left(n_{ph}/(Vol_m/t)\right) \quad (1)$$

where τ_n is the electron lifetime, n_{ph} is the number of the absorbed photons in the photoconductive material per material volume (Vol_m) per unit time (t). Subsequently, this will increase the number of the generated carriers (n_c). Increasing the number of generated carriers increase the generated photocurrent (I_{ph}) induced by a bias field,

$$I_{ph} = V_{Bias} G \quad (2)$$

and

$$G = \frac{A}{L}\sigma \quad (2)$$

where V_{Bias} is the bias field, G is the device photoconductance, A is the electrodes area, L is the electron travailing path from one electrode to another, and σ is the conductivity. The conductivity of a photoconductive device is represented by the mobility of the generated carriers.

$$\sigma = e\mu_c n_c \quad (2)$$

where e is the electron charge, and μ_c is the carrier mobility. The relationship between the carriers density and the generated photocurrent is given by substitute equation 3 and 4 in 2,

$$I_{ph} = V_{Bias}\frac{A}{L}e\mu_c n_c \quad (2)$$

Therefore, the higher the transparency of the electrodes, the higher the number of carriers generated, the higher the generated photocurrent becomes.

II. RESULTS AND DISCUSSION

The impact of the transparency of the electrodes on device performance was simulated and compared using the Silvaco TCAD software. The photogeneration rate in optoelectronics devices was obtained using gold electrodes (the thickness is 150 nm) and MLG nanoelectrodes (the thickness is 2.5 nm), respectively. The electrodes were located on top of LTG-GaAs as a photoconductive material. Figure 1 shows the simulated photogeneration rate for the devices using gold and graphene nanoelectrodes, respectively. For both devices, the dimensions of the electrodes were 5.5 × 20 μm^2 and the gap separation was 1 μm.

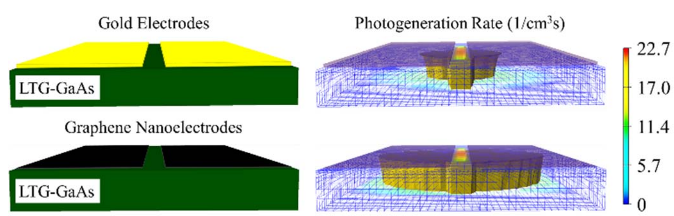

Fig. 1. Simulation results of Silvaco TCAD software of the photogeneration rate for optoelectronic devices with gold and with graphene nanoelectrodes.

It is very clear from figure 1 that due to the opaqueness of the gold material the light beam cannot propagate through the electrodes. The beam of the photogenerated rate is confined in the gap between the contacts and very close to it because of the light diffraction in the material. On the other hand, the photogenerated rate for the device with multilayer graphene nanoelectrodes is much wider and it covers almost the entire illuminated area of the light beam. The wider beam of photogenerated rate the higher the number of carriers generated, the higher the generated photocurrent becomes.

The transparency of the electrodes was compared practically using the 6-8 layers CVD-grown graphene material as a transparent nanoelectrodes and gold electrodes. The contacts of the MLG and gold were fabricated on top of LTG-GaAs using a standard optical lithography process as shown figure 2.

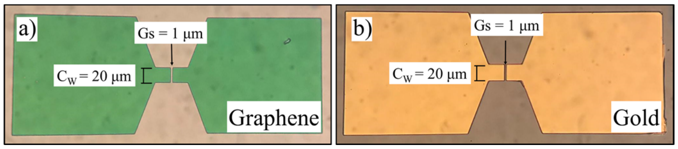

Fig. 2. Optical microscopic image of the electrodes pads a) graphene electrodes and b) gold electrodes.

The same contact dimensions and the gap separation between the contacts in the software were used based on the fabricated MLG and gold electrodes. Both Devices were characterized by illuminating the active area between the electrodes with an optical power of 25 mW and wavelength 850 nm. The bias voltage was varied from 0 V to 40 V. The DC performance of the electrodes was characterized and compared to simulations using Silvaco TCAD software. Figure 3 shows the simulated DC characterization of and the experimental measurements of the photocurrent (the simulation results are in reasonable agreement with the measurement results). The graphene nanoelectrodes show 40 times higher photocurrent at 20 V (reliable photocurrent of ~ 4 mA, and an on/off ratio of more than four orders of magnitude) than metal electrodes due to the high transparency of graphene. The reduction of the enhancement at high field is attributed to the higher darkcurrent of the gold electrodes. On the other hand, the measurement results of gold electrodes showed only on/off ratio of around two orders of magnitude due to the high darkcurrent at high bias voltage.

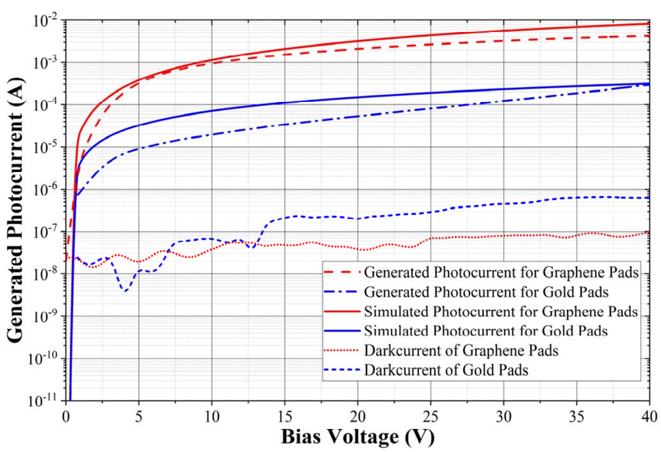

Fig. 3. Comparison of the generated photocurrent of the graphene nanoelectrodes and the gold electrodes in measurements and simulations models.

The simulation and the practical results show that graphene material can be applied as highly transparent electrodes for wide potential applications, such as THz photomixers [3-8], solar cells, supercapacitors, field-effect transistors, and diodes [9-11].

III. Summary

Multilayer graphene nanoelectrodes for optoelectronic devices was investigated. The high transparency of graphene layers plays the main role in the optoelectrical conversion. Due to the high transparent electrodes, almost all incident light propagates through the graphene layers resulting in an increase in the number of the generated carriers and photocurrent. The graphene electrodes exhibit more than one order of magnitude higher generated photocurrent compared to the photocurrent of metal electrodes and an on/off ratio of four orders of magnitude.

IV. Acknowledgment

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