DOI: 10.1478/C1V89S1P030

AAPP | Atti della Accademia Peloritana dei Pericolanti
Classe di Scienze Fisiche, Matematiche e Naturali
ISSN 1825-1242

Vol. 89, Suppl. No. 1, C1V89S1P030 (2011)

PLASMONIC NANOSTRUCTURE ENHANCED GRAPHENE-BASED PHOTODETECTORS

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ABSTRACT. Graphene exhibits electrical and optical properties promising for future applications in ultra-fast photonics[1]. High carrier mobility and Fermi velocity[2, 3] combined with its constant absorption over the visible wavelength range to the near-infrared[4] potentially allow its application for photodetection over a broad wavelength spectrum, operating at high frequencies. However, absorption being 2.3% per monolayer[4], responsivity of these devices is rather low[5, 6]. Here we show that by combining graphene-based photodetectors with metal-nanostructures, plasmonic effects lead to an increased responsivity.

Graphene is receiving large attention for its peculiar electronic properties and potential use in future electronic devices[7]. However, the field of photonics and optoelectronics is largely unexplored and it is speculated that graphene's real strength lies in this area[1] with applications such as ultra-fast lasing[9] and photodetection[5, 6]. Graphene's electronic properties such as high carrier mobility and Fermi velocity allow ultra-fast operating speeds[2, 3, 10]. Combined with its optical properties such as constant absorption of 2.3% per monolayer over the visible wavelength range to the near-infrared[4, 11], a broad wavelength operating range in graphene-based photodetectors is feasible, due to absence of a cut-off wavelength. Several groups have demonstrated graphene-based photodetectors[5, 6, 12]. However, the reported responsivities have been rather low compared to traditional photodetectors[13].

The working principle of graphene-based photodetectors relies on the formation of a p-n junction to separate incident light generated electron-hole pairs[5, 6, 12, 14], like any other photodiode[15]. One possible way to form such a lateral p-n junction in graphene is to deposit a metal contact, as schematically shown in Fig. 1. This induces a Fermi-level shift within the graphene underneath[14, 16]. In the vicinity of the contact, the Fermi-level relaxes back to the initial doping level, and an internal electric field is created right next to the contact[5, 6, 12, 14]. In this region the photodetector is responsive to incident light and a photovoltage/-current is produced.

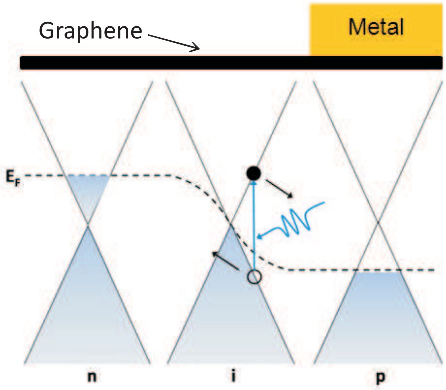

Figure 1. Pn-junction formation in graphene by metal induced doping.

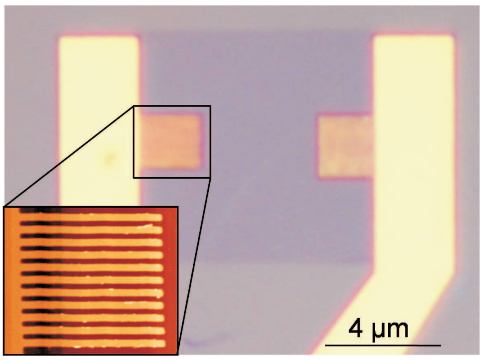

Figure 2. Graphene-based photodetector with nanostructured metal-gratings.

We fabricate graphene by mechanical exfoliation[2] on Si+SiO_2 (300 nm), and characterize it by a combination of Raman spectroscopy[17] and optical microscopy[11]. E-beam lithography is used to define the contacts; subsequent e-beam evaporation and lift-off are used to deposit the contact metals (3nm Ti+80nm Au). After bonding into a chip carrier, samples are electrically characterized using a Keithley 2400 Sourcemeters. Photovoltage mapping using lasers covering the visible to the near-infrared range of 457, 488, 514, 633 and 785 nm is carried out to determine the photoresponse. During mapping, a laser beam with a spot size of $\approx$1.5μm is scanned over the sample in the x/y direction, and the position dependent response of the device is recorded with a nano-voltmeter, which allows determination of the response of individual regions of the device.

To enhance responsivity of the graphene-based photodetector, we fabricate nanostructured metal gratings next to the macroscopic contacts (Fig. 2), with a variety dimensions.

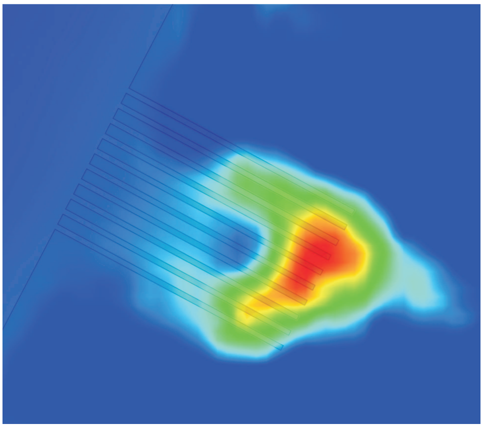

Figure 3. Photovoltage map of a metal nanostructure enhanced graphene-based photodetector.

Upon excitation of the metal nanostructured grating with incident laser light of wavelength matching the plasmon resonance of these gratings, a strong enhancement in photovoltage can be observed. Fig. 3 shows a photovoltage map of a device measured at 514nm. A photovoltage enhancement of $\approx$20 times of photovoltage is detected at the tips of the nanostructured metal grating, compared to the flat metal contact. At different wavelengths, the enhancement reduces to 1-2 times, demonstrating the wavelength selectivity and plasmonic nature of the enhancement. Plasmonic oscillations within the metal nanostructures concentrate and enhance the electric field of the incident light directly at the location of the pn-junctions. Wavelength and polarization dependence can be achieved depending on the geometry of nanostructures. This could have significant implication for broadband photovoltage generation in photovoltaic devices.

Acknowledgments

We acknowledge the Royal Society, Engineering and Physical Research Council, European Research Council, EU grants Rodin and Marie Curie ITN-GENIUS (PITN-GA-2010-264694), a SAIT GRO program, and Nokia Research Centre Cambridge, for financial support.

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Paper presented at the ELS XIII Conference (Taormina, Italy, 2011), held under the APP patronage; published online 15 September 2011.