Highlights

Activity D - Light-matter interaction and non-equilibrium dynamics in advanced materials and devices - 2021

Graphene-Silicon Device for Visible and Infrared Photodetection

Aniello Pelella[1,2], Alessandro Grillo[1,2], Enver Faella[1,2], Giuseppe Luongo[3], Mohammad Bagher Askari[4], Antonio Di Bartolomeo[1,2]

[1]Department of Physics and Interdepartmental Centre NanoMates, University of Salerno, via Giovanni Paolo II, Fisciano, Salerno, 84084, Italy
[2]CNR-SPIN, UOS Salerno c/o Università di Salerno - Via Giovanni Paolo II 132, 84084 Fisciano (SA), Italy
[3]IHP-Microelectronics, Im Technologie Park 25, Frankfurt Oder, 15236, Germany
[4]Department of Physics, Faculty of Science, University of Guilan, P.O. Box: 41335-1914, Rasht, Iran

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The fabrication of a graphene–silicon (Gr-Si) junction involves the formation of a parallel metal–insulator–semiconductor (MIS) structure, which is often disregarded but plays an important role in the optoelectronic properties of the device. In this work, the transfer of graphene onto a patterned n-type Si substrate, covered by Si_3N_4, produces a Gr-Si device, in which the parallel MIS consists of a Gr-Si_3N_4-Si structure surrounding the Gr-Si junction (see Figure1a). The Gr-Si device exhibits rectifying behavior with a rectification ratio up to 10^4, as displayed in Figure 1b. Figure 1b also shows that the device responds to light, with an unexpected current set up (kink) at V=-1.2 V. Moreover, the device can be operated as a photodetector in both photocurrent and photovoltage mode in the visible and infrared (IR) spectral regions. Figure 2a shows that the device's responsivity is up to 350 mA/W and the external quantum efficiency (EQE) reaches 75% in the 500–1200 nm wavelength range. Decreases in responsivity to 0.4 mA/W and EQE to 0.03% are observed above 1200 nm, which is in the IR region beyond the silicon optical band gap, in which photoexcitation is driven by graphene. A model based on two parallel and opposite diodes, one for the Gr-Si junction and the other for the Gr-Si_3N_4-Si MIS structure, is proposed to explain the electrical behavior of the Gr-Si device. In reverse bias, the negative voltage attracts holes at the Si-Si_3N_4 interface. As the holes accumulate, the Si undergoes an inversion and becomes p-type. When the voltage is high enough to enable tunneling through the insulator a p-type Schottky diode is formed in the MIS region. This means that, in reverse bias, the device behaves as two parallel and opposite diodes. This parallel configuration explains the aforementioned kink. Indeed, for -1.2 V<V<0 V, holes accumulated at the interface Si-Si_3N_4 can only diffuse towards the Gr-Si junction and contribute to its reverse current originating the leakage of ~10^{-7}A. For V<-1.2 V, instead, the electric field enables also FN tunneling through the Si_3N_4 layer (Figure2b), resulting in an increase of current, which generates the kink.

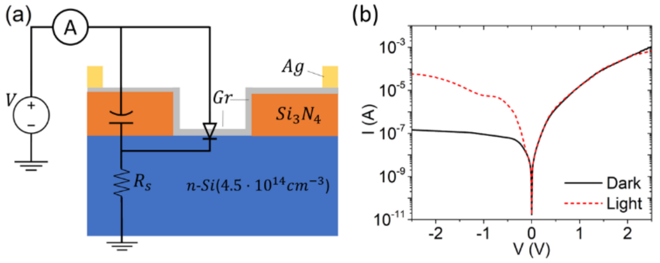

Fig. 1 - (a) Device schematic showing a Gr-Si junction modelled by a diode in parallel with a MIS structure, here represented as a capacitor. (b) IV characteristics in dark and with incident white laser.

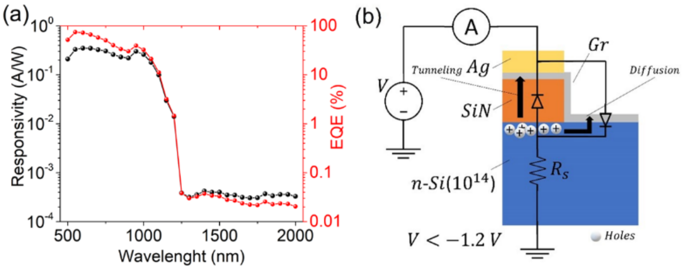

Fig. 2 – (a) Responsivity and EQE of the device in the visible and IR spectral region. (b) Schematic model of the Gr-Si device and charge carrier transport in reverse bias.