High Responsivity Silicon-Graphene Schottky Avalanche Photodetectors for Visible and Telecom Wavelengths

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Abstract: We design, optimize and demonstrate a silicon-graphene avalanche Schottky photodetector with photoresponsivities of 1A/W and 0.5A/W for visible and telecom wavelengths respectively.
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Photodetectors (PDs) are one of the building blocks of opto-electronic links, for optical to electrical conversion [1]. An essential step towards Si opto-electronic integration is the realization of Si-based PDs working at telecom wavelengths (1.3-1.6μm) using the same material platform and relying on mature CMOS technology. While Si PDs are widely employed in the visible spectral range [1], they are not suitable for detecting of near-infrared (NIR) radiation above 1.1μm because photons at telecom wavelengths do not have energy higher than that of the Si indirect bandgap (1.12eV) and thus induce photogeneration of electron-hole (e-h) pairs. Thus, no photocurrent is generated.

Graphene is an appealing material for photonics and optoelectronics because it offers a wide range of advantages compared to other materials [2-4]. Graphene-based PDs have been reported with broadband operation [4-8] and ultra-fast response exceeding state-of-the-art semiconductor devices [9]. However, even though graphene absorbs ~2.3% per layer [10], in absolute terms this is still too small to realize high responsivity PDs. Many approaches have been developed to increase responsivity, including coupling with localized plasmons [6] or semiconducting nanoparticles [11]. However, other limitations stem from these, such as loss of broad-band operation or limited speed. Waveguide integrated graphene-PD schemes have been demonstrated [12], where graphene is evanescently coupled to the waveguide [12]. In this configuration, a longer interaction length between graphene and optical mode enhances absorption and photodetection efficiency, without limiting operation speed and broadband response.

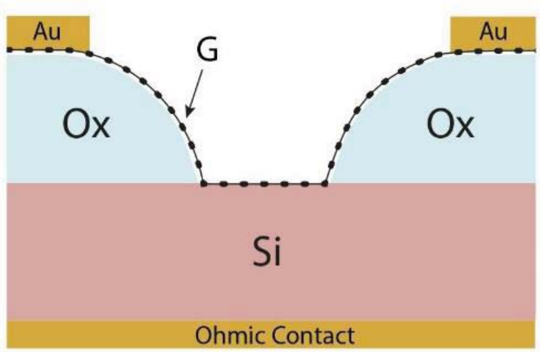

Fig 1. Schematic of Graphene-Si Schottky PD

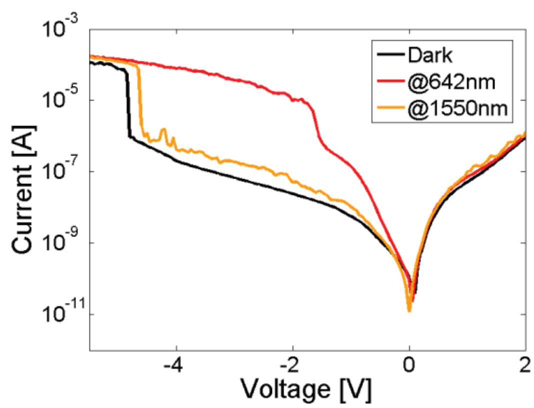

Fig 2. I-V characteristics under illumination

Here, we present a high responsivity Si-graphene Schottky avalanche PD for visible (642nm) and telecom (1550nm) wavelengths. The device is fabricated by contacting chemical vapor deposited (CVD) graphene with a p-type Si substrate forming a Schottky junction [13,14], as presented in Fig.1. Upon device illumination with photon energy above the Si bandgap, photodetection happens due to direct (band-to-band)

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photo-generation of electron-hole pairs in Si [1]. At 1550nm the photon energy (0.8eV) is below the Si bandgap, and the PD operation relies on internal photoemission, where photoexcited free carriers are injected from the graphene electrode to Si above a Schottky barrier [1]. To achieve an internal photogain the PD is designed to perform under avalanche multiplication of the photoexcited carriers in the Si depletion region for elevated (higher than 4V) reverse biases. As a result, the device has an external responsivity up to~1A/W for 642nm and ~0.5A/W for 1550nm (Fig. 2). The latter is the highest achieved so far for Si-PDs for telecom wavelengths [15], and comparable with state-of-the-art Si-Ge devices currently employed in Si photonics [16,17]. Our device paves the way towards graphene-Si optoelectronic integration.

[1] S. Sze et al, Wiley, New York, (2006).
[2] F. H. L. Koppens et al., Nat. Nanotechnology 9(1), 780-793 (2014).
[3] A. C. Ferrari et al., Nanoscale (2014).
[4] F. Bonaccorso et. al., Nat. Photonoics 4, 611 (2010).
[5] T. Mueller, F. Xia, Ph. Avouris, Nat. Photonics 4, 297 (2010).
[6] T.J. Echtermeyer et. al. Nat. Comm. 2, 458 (2011).
[7] M. Engel et. al. , Nat. Comm. 3, 906 (2012).
[8] L. Vicarelli et. al., Nat. Materials 11, 865 (2012).
[9] A. Urich, K. Unterrainer, T. Mueller, Nano Lett. 11, 2804 (2011).
[10] R. R. Nair et. al., Science 320, (2008).
[11]G. Konstantanos et al. Nat. Nanotech. 7 (2012).
[12] X. Wang et. al. , Nat. Photonics 7, (2013), A. Pospischil et. al. ,Nat. Photonics 7, (2013), X. Gan et. al. , Nat. Photonics 7, (2013).
[13] H. Yang et al., Science **336**, (2012).
[14] S. Tongay et al., Phys. Rev. X **2**, 2012).
[15] M.Casalino, Int. J. Opt. Applications **2**, 1 (2012)
[16] Y. Kang et al., Nat. Photonics **3(1)**, (2009).
[17] J. Michel et al., Nat. Photonics **4(8)**, (2010).