Chalcogen hyperdoped Silicon: a route for monolithically integrated infrared optoelectronics

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Tellurium is one of the deep-level impurities in Si, leading to states of 200-400 meV below the conduction band. Non-equilibrium methods allow for doping deep-level impurities in Si well above the solubility limit, referred as hyperdoping, that can result in exotic properties, such as extrinsic photo-absorption well below the Si bandgap [1]. The hyperdoping is realized by ion implantation and pulsed laser melting. We will present the resulting optical and electrical properties as well as perspective applications for infrared photodetectors.

With increasing the Te concentration, the samples undergo an insulator-to-metal transition [2]. The electron concentration obtained in Te-hyperdoped Si is approaching 10^{21} cm^{-3} and does not show saturation [3]. It is even higher than that of P- or As-doped Si, and mid-infrared localized surface plasmon resonances (LSPR) are also observed [4]. Using Te-doped Si, we demonstrate the room-temperature operation of photodetectors at telecommunication wavelengths with both vertical and planar device geometries (see Figure 1) [5,6]. The key parameters, such as the detectivity, the bandwidth and the rise/fall time, show competitiveness with commercial products. To understand the microscopic picture, we have performed Rutherford backscattering/channeling angular scans and hard x-ray spectroscopies [4, 7]. The Te-dimer complex sitting on adjacent Si lattice sites is the most preferred configuration at high doping concentrations. Those substitutional Te-dimers are effective donors, leading to the insulator-to-metal transition, the non-saturating carrier concentration as well as the sub-band photoresponse. Our results are promising for the integration of active and passive photonic elements on a single Si chip, leveraging the advantages of planar CMOS technology.

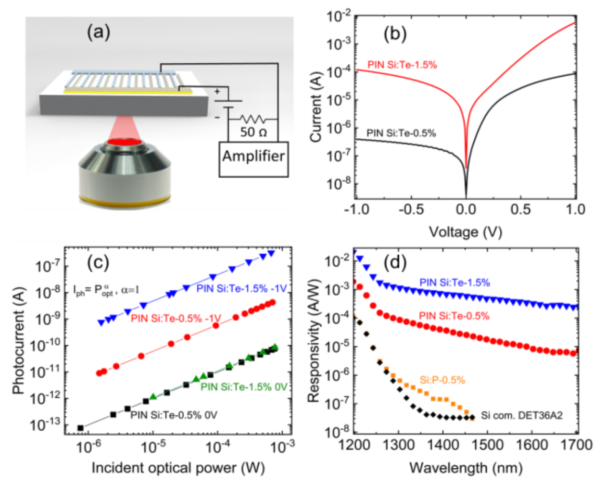

Fig. 1: PIN Si:Te detector: device schematics (a) and I-V characteristics (b). Panel c) shows the photocurrent vs. power at a wavelength of 1550 nm and d) the spectral responsivity under -1 V reverse bias.

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References

[1] J. M. Warrender, Appl. Phys. Rev. 3, 031104 (2016).
[2] M. Wang, Y. Berencén, E. García-Hemme, S. Prucnal, et al., Phys. Rev. Appl. 10, 024054 (2018).
[3] M. Wang, A. Debernardi, Y. Berencén, R. Heller, et al., Phys. Rev. Appl. 11, 054039 (2019).
[4] M. Wang, Y. Yu, S. Prucnal, Y. Berencén, et al., Nanoscale 14, 2826-2836 (2022).
[5] M. Wang, E. García-Hemme, Y. Berencén, R. Hübner, et al., Adv. Opt. Mater. 9, 2001546 (2020).
[6] M. S. Shaikh, S. Wen, M. Catuneanu, M. Wang, et al., Optics Express 31, 26451-26462 (2023).
[7] M. Hoesch, O. Fedchenko, M. Wang, C. Schlueter, et al., Appl. Phys. Lett. 122, 252108 (2023).