Hybrid PbS QDs/silicon multispectral photodetector integrable with silicon ICs

Dana Cristea, Paula Obreja, Adrian Dinescu

National Institute for R&D in Microtechnologies, IMT-Bucharest
Erou Iancu Nicolae 126 A, 077190 , Voluntari- Bucharest, Romania
Email: dana.cristea@imt.ro

Abstract

Colloidal quantum dots QDs have been considered in the last years as a candidate material for photodetectors due to their tunability of optical absorption spectra through quantum size effect. Another important advantage is solution processibility that facilitates integration with a large variety of substrates. Different types of QD-based photodetectors have been reported [1-3]. Most of these photodetectors have been fabricated on transparent indium tin oxide (ITO)-coated glass substrates. Also IR photodetectors based on PbS QDs, integrable with silicon IC circuits have been recently obtained [4].

In this paper we propose a new structure: a hybrid PbS/Si diode that can achieve higher responsivities over a broader spectral range-from UV to SWIR. The device (fig. 1) consists of a Au/n-Si Schottky diode with digitated electrode in parallel with a p-PbS/n-Si heterojunction.

PbS QDs film was deposited (in selected areas defined in PMMA) on top of Cr/Au/Si Schottky diode by multilayer spin coating. Large PbS QDs, 5.2 nm diameter, ED-P20-TOL-1500 from Evident Technologies, with first excitonic absorption feature at 1450 nm have been choose to address both the visible and SWIR spectra. The long ligand, oleic acid (C_{18}), was replaced with a shorter one (C_3), 3-mercaptopropionic acid (MPA) in order to minimize inter-particle spacing and to improve the mobility-lifetime products of PbS CQD films, leading to increases in both the diffusion lengths of charge carriers and the efficiencies of PbS CQD based photodiode [6].

Layer-by layer deposition method was used to obtain continuous films. The process steps are:

- spin-casting of PbS QDs solution (10 mg/ml) at 1000rpm/30s;
- spin-casting of 10% MPA solution in methanol for 15 s at 2500 rpm;
- rinsing two times with methanol.

The process was repeated 7 times and than the PMMA was removed to open the pads. Further improvement of film quality and of device performance was achieved by functionalization of the Si substrate with cysteamine.

I-V characteristics in dark and under illumination were recorded with the semiconductor characterization system Keithley 4200 SCS/C, connected to a dark Faraday cage, and monochromatic sources (laser diodes) with emission wavelength 370 nm, 1070 nm, 1200 nm, 1450 nm and 1550 nm respectively. We focused on UV and NIR ranges, to study the effect of PbS layer. Based on photocurrent measurements we calculated the responsivities at 5V reverse voltage.

Fig. 2 shows the responsivities at 370 nm, 1070 nm, 1200 nm, 1450 nm and 1550 nm for a reference device (Au/Si Schottky diode) and for two hybrid devices PbS QDs/Si, with and without substrate functionalization with cysteamine. One can see that the PbS/Si devices have higher responsivities in UV and NIR ranges than the reference Si-based photodiode and an extended wavelength range in IR. The improvement is due to photocarrier generation in PbS and their separation due to the built-in electric field at the PbS/Si heterojunction. Further improvement of responsivity in IR range can be achieved using a metal-semiconductor-metal (MSM) - like configuration, as one can see in fig. 3. In this case the voltage applied between two interdigitated electrodes and the PbS film acts as a photoconductor.

References

[1] G. Konstantatos and E. H. Sargent, Infr. Phys. Technol., **54** (2011) , pp. 278–282.
[2] E. J. Klem, J. S. Lewis, and D. Temple, *Proc. SPIE*, vol. 7660, Apr. 2010, p. 76602E-1,
[3] E.Heves , Y. Gurbuz, IEEE Sensors Journal **14** (2014) pp. 816-820.
[4] G. Sarasqueta, K. R. Choudhury, J. Subbiah, and F. So, Adv. Funct. Mater., **21** (2011) pp. 167–171,
[5] E. Heves, C. Ozturk, V. Ozguz, .Y. Gurbuz, IEEE Electron Dev. Lett. **34** (2013), pp.662-664
[6] K.S. Jeong,.J.Tang, H. Liu, J.Kim, A. W. Schaefer,K. Kemp, L. Levina, X.Wang, S.Hoogland, R.Debnath, L.Brzozowski, E. H. Sargent, J.B. Asbury , ACS Nano, **6** (2012), pp. 89–99.

Acknowledgements: The work was supported by the Romanian Program Space Technology and Advanced Research –STAR contract No. 14/2012

Figures

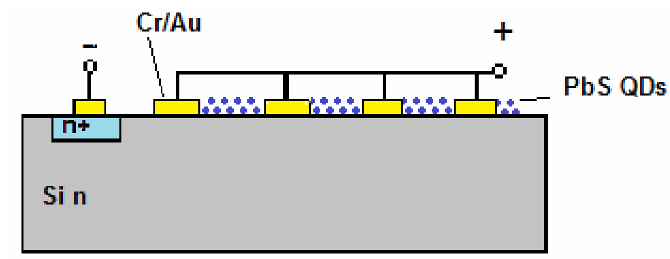

Fig. 1. Schematic diagram of the hybrid PbS QDs/n-Si photodetector.

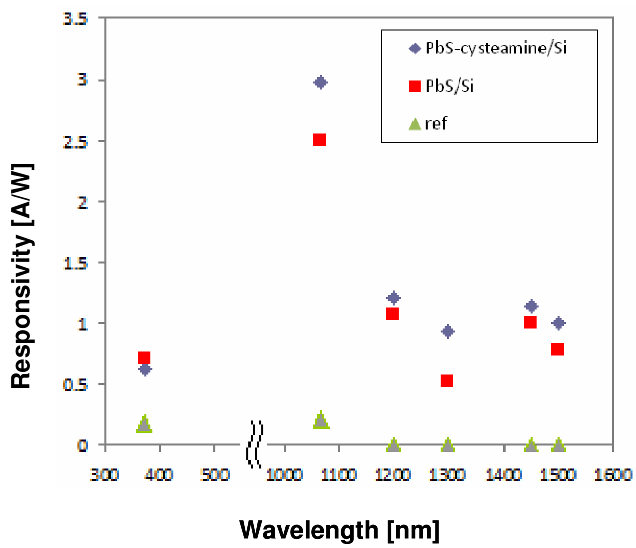

Fig. 2. Responsivities in UV and SWIR for the reference Si Schottky diode and two hybrid devices PbS QDs/Si

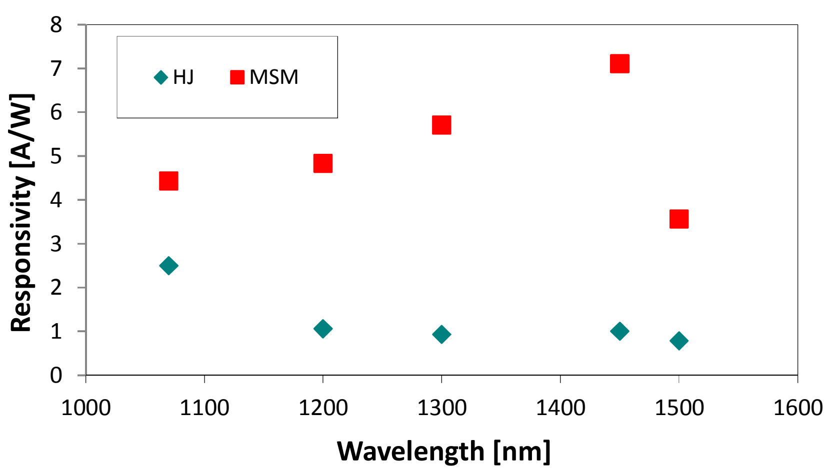

Fig. 3 Responsivity of the hybrid PbS/Si device in MSM configuration compared with the configuration with PbS/Si heterojunction.