Spectral-Dependent Performance of Colloidal PbS Quantum Dot Epitaxially-Connected Superlattice Photodetectors

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Colloidal quantum dots (CQDs) present a breakthrough to overcome the limitations of conventional photodetector materials. This class of materials can absorb broad spectra of photon energies and minimize energy losses associated with phonon generation during charge relaxation. CQDs feature tunable band gaps, enabling precise control over light absorption across various wavelengths. Additionally, they exhibit a phenomenon known as multiple exciton generation (MEG), allowing high-energy photons to produce multiple charge carriers[1], thereby significantly enhancing quantum efficiency compared to traditional materials. However, the relatively modest charge carrier mobility and poor air stability of CQDs pose substantial challenges to developing high-performing photodetector devices. Recently, our group found that epitaxially connected QD superlattices demonstrated high electron mobility values, suggesting the potential for delocalized band transport in electronic minibands[2]. Nevertheless, the existence of charge multiplication and the capability to detect a broad spectrum of photon energies from this high carrier mobility and the potential of delocalized transport remains uncertain, as the quantum confinement effect may be compromised.

Here, we present the tunable responsivity of epitaxially-connected quantum dots superlattice (QDSL) photodetector under irradiation of various wavelengths and demonstrate air-stable operation. To fabricate photodetectors consisting of a single monolayer of QD superlattice, we employed the Langmuir–Schaefer assembly technique in combination with precise QD facet control, similar to our previous reports[2,3]. In order to enable performance measurement under atmosphere exposure, the photodetector devices were passivated using a PVDF-based block copolymer[4] (Figure 1a). The use of this hydrophobic block copolymer prevented device degradation upon oxygen and moisture. The spectral response of the photodetector performance was measured using a pulsed supercontinuum laser with wavelengths selected through monochromator arrangements. Exposure to shorter wavelengths, which possess higher photon energy, yields larger responsivity values. These values are even higher than the device's responsivity when subjected to irradiation closer to the QD excitonic peak. This increased responsivity at shorter wavelengths can be attributed to the more significant number of photocarrier generation. Detailed measurement in this direction may unravel the possibility of observing MEG phenomena from the epitaxially-connected QD superlattices. These results provide a novel pathway for developing high-performance and stable QD-based photodetector devices for hyperspectral detection.

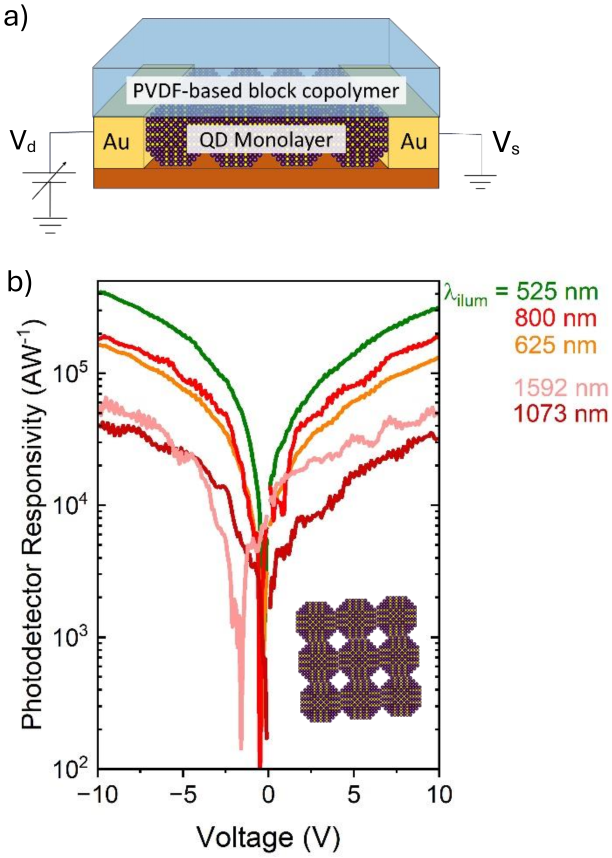

Figure 1. a) Schematic of photodetector device utilizing monolayer of epitaxially-connected quantum dot superlattice, and b) the photodetector responsivity in the different illumination wavelengths. The absorption peak of the PbS QD is λ_{abs} = 1600 nm.

Reference:

1. C. Smith and D. Binks, Nanomaterials, 4, 19-45 (2014)
2. R. D. Septianto, S. Z. Bisri, et al. *Nat Commun.* 14, 2670 (2023)
3. The 85th JSAP Autumn Meeting, 2024 [16p-C301-7]
4. A. G. Shulga, S. Z. Bisri, et al. Adv. Electron. Mater. 2, 1500467 (2016)