DOCTORAL THESIS

Perovskite/Organic Hybrid Photodetectors for Multispectral Detection

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Abstract

Selective detection of light intensity over several spectral regions is critical to applications from colour imaging to wellness monitoring. Multispectral photodetection is conventionally achieved using a planar array of broadband photodetectors with external filters, which have complex circuit designs and extra fabrication challenges. Targeted at filter-free integrated multispectral photodetection, this PhD study develops novel bias-controllable photodetectors based on a hybrid of perovskite material and organic bulk heterojunction (BHJ).

Laying a foundation, this study first addresses the quality and reproducibility of perovskite materials. The perovskite precursor solution has been stabilised using dehydrate solvent, preventing secondary phase formation in the resultant film, maintaining the built-in potential and suppressing noises of the photodiode. Morphological imperfections in the perovskite films are further eliminated by incorporating potassium cations in the precursor to regulate the phase transition during film deposition. Based on these strategies, perovskite films with different optical bandgaps have been prepared for self-powered photodetectors, yielding responsivities up to 0.5 A W^{-1}, noises around 1.0×10^{-13} A $Hz^{-1/2}$, and fast response speeds.

Based on the single-junction broadband perovskite photodetectors, a bifacial broadband/narrowband dual-mode photodetector has been designed with transparent electrodes on the two sides and a light-depleting organic hole-transporting layer (HTL). When the perovskite photoactive layer faces the incoming light, the photodetector has a broadband response. A narrowband response is delivered when the HTL faces the light. The narrowband detection window is defined by the wavelength difference between the absorption threshold of the HTL and that of the perovskite photoactive layer. For example, an NIR perovskite/organic hybrid photodetector delivers a peak responsivity over 0.2 A/W at 780 nm with a full width at half maximum of around 56 nm.

For perovskite/organic multispectral photodetectors, selective light absorption and voltage-controllable charge carrier extraction are necessary. Charge extraction modulation through inserting a CuSCN HTL has been studied using an $FA_{0.85}Cs_{0.1}K_{0.05}PbI_3$/PTB7-Th:COTIC-4F-based photodetector. The $FA_{0.85}Cs_{0.1}K_{0.05}PbI_3$ perovskite layer absorbs light with wavelengths below 820 nm, while the PTB7-

Th:COTIC-4F bulk heterojunction layer has a wider absorption band from 500 to 1100 nm. Bias-controlled carrier extraction from the two layers, enabled by the CuSCN HTL in the middle and the electron-transporting layers at two contacts, leads to two distinct detection bands. The photodetector delivers responsivities around 0.35 A/W and a low crosstalk in two distinct bands with noises around 10^{-12} A $Hz^{-1/2}$. This design applies well to other combinations of perovskite and BHJ layers.

Another interlayer-free carrier transport regulation mechanism has been proposed based on a series of hybrid photodetectors employing the $FAPbBr_{1.5}Cl_{1.5}$ perovskite material. Taking the $FAPbBr_{1.5}Cl_{1.5}$/PTB7-Th:COTIC-4F-based photodetector as an example, the key to the bias-controlled carrier extraction is the electron transport barrier between the active layers and the band bending in the perovskite layer, induced by the Fermi level difference between this layer and the neighbouring electrode. This interlayer-free photodetector delivers a low-crosstalk dual-band response with peak responsivities of over 0.25 A/W in the short-wavelength band contributed by the perovskite layer and of over 0.35 A/W in the long-wavelength band from the PTB7-Th:COTIC-4F BHJ.