Tunable Response Time in Highly Sensitive 0D/2D Materials Based Hybrid Infrared Photodetector

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In the field of telecommunication, thermal imaging, remote sensing, night vision, biometric sensing, food analysing, etc infrared (IR) photodetectors have a growing demand in the market. In that respect, 2D graphene and 0D PbS quantum dots (QD) based hybrid photodetectors were introduced as a promising infrared detector by G. Konstantatos [2] and Z. Sun [2] in 2012. Later in 2017, a high-resolution broadband image sensor based on such hybrid materials was demonstrated [3], which is highly sensitive from the ultraviolet, visible to infrared regime (300–2000 nm) of the optical wavelengths. Graphene/PBS QD based hybrid photodetectors combine a very high responsivity as well as a wide range of detectable wavelengths. However, their outstanding responsivity is the result of a gain mechanism associated with the slow recombination rate in the 2D channel due to the trapping of photogenerated carriers in the QD layer. As a result, despite exhibiting high sensitivity, such photodetectors are severely limited by their slow response time of ~1 s. Only very few studies could improve the response time, for instance by applying a back gate voltage pulse [1] or by integrating a graphene phototransistor with a QD photodiode on top, resulting in a decrease of the response time down to 0.1 ms [4]. Hence, to develop an imaging system based on such hybrid photodetectors, it is necessary to improve their response speed.

In our study [5], we investigated similar graphene/PbS QD hybrid phototransistors and explored the enhancement of their photo-sensing qualities compared to bare graphene phototransistor in the visible-NIR-SWIR region of the optical spectra. We synthesized the colloidal PbS QDs absorbing in the NIR as well as SWIR regions and developed a layer-by-layer deposition technique including simultaneous ligand exchange and surface passivation at each layer to deposit homogeneous PbS QD layers on graphene sheet leading to a well fabricated hybrid phototransistor. Such method prevents graphene from the degradation of its mobility during PBS QD deposition. Using this fabrication process, we achieved the hybrid photodetectors with significantly high responsivity of 10^8 A/W and sensitivity down to 0.1 pW incident light power in the near-infrared (NIR) wavelength range. Interestingly, bare graphene photodetector could not detect light of power below 0.06 nW for visible region and 0.1 nW for NIR region of the optical spectra, whereas the graphene/PbS QD hybrid photodetectors exhibited high responsivity at ultra-low intensity light of the order of pW covering a wider range of wavelengths from visible to SWIR.

Moreover, we presented a detailed correlation between responsivity and response time of the graphene/PbS QD hybrid photodetectors and established a unique way to achieve fast response by utilizing a pulsed incident light with an optical modulation frequency as high as 50 kHz which probes only the electron trap states with short trapping time associated with a lower response time in the photodetector. This technique leads to a measured response time as low as 5 µs which is almost two orders of magnitude lower than the previously reported values [1, 4] for the graphene/PbS QD hybrid photodetector, while preserving a high enough responsivity (144 A/W) compared to the existing commercial room temperature infrared photodetectors. Importantly, the reported approach of using pulsed incident light is not only limited to graphene/PbS QD photodetector but can be extended to various other 2D materials and colloidal quantum dots based hybrid photodetectors to initiate faster response leading to an unprecedented combination of fast response, high responsivity and low light sensitivity in the visible-NIR-SWIR range for the application of imaging system.

References

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