Vertical Integration of Graphene and Nanomaterials for Multispectral Analysis and Detection

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In this contribution we describe the simulation, fabrication and implementation of photodetectors with multiple spectral detection channels covering from the visible (λ~500 nm) to the infrared (λ~1800 nm) range by intercalating single-graphene monolayers as charge collectors with different nanomaterials such as zinc oxide or lead sulfide quantum dots used as light absorbers and photocarrier generators. Our device operation is based on the longer penetration depth of longer wavelengths, with deeper graphene layers sensing longer wavelengths and shallower graphene layers sensing shorter wavelengths as shown in Figure 1. Furthermore, by incorporating quantum dots of different sizes, and therefore bandgaps, each graphene collects photocarriers generated from different light wavelengths determined by the spectral absorption of the films.

Our devices are first modelled and designed combining the transfer matrix method with the carrier diffusion length to estimate optical absorption and the rate of carrier collection by each graphene layer, enabling the modelling of the spectral response of individual graphene layers at different depths. Figure 2 shows both our modeled and our experimental response for a device with a layer of quantum dots and a layer of ZnO with their respect graphene layers.

An intercalated device integrating graphene layers with different lead sulfide quantum dots is shown in Figure 3.a. [1] Each graphene layer, located a different depth, has a different spectral response due to the different absorption of the quantum dots and to their depth location. The response of the different graphene layers is shown in Figure 3.b, showing the top graphene (Gr-1 Top) responding in a window of λ~400 nm to 1000 nm, whereas the deepest graphene layer (Gr-5 Bottom) responds to a longer wavelength window between λ~600 nm and 1400 nm. This technology is pretty compact and encapsulated in a thin film, avoiding dispersive or filtering components that lead to bulky multispectral components or devices. While there is significant overlap between spectral response of Graphene layers, further improvements in technology and design are under investigation to achieve a individual spectral channel for each graphene layer.

[1] G. Konstantatos, et al, *Hybrid Graphene–Quantum Dot Phototransistors with Ultrahigh Gain*, Nature Nanotechnology. Chen, W.et al, *Improved Charge Extraction Beyond Diffusion Length by Layer-by-Layer Multistacking Intercalation of Graphene Layers inside Quantum Dots Films*. Advanced Materials

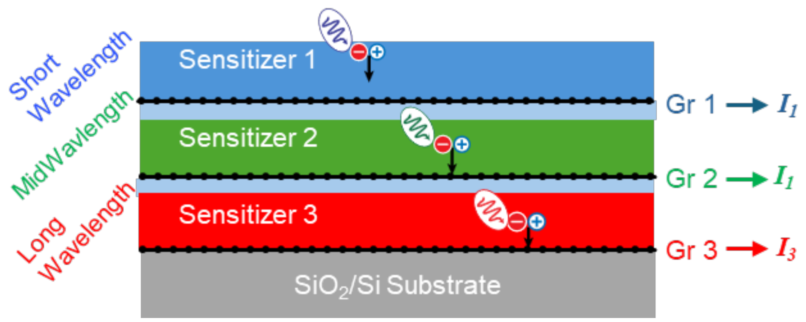

Figure 1: Intercalated graphene devices with different sensitizers. Sensitizer 3 has a smaller bandgap to enhance longer wavelength detection, where as sensitizer 1 has larger bandgap to enhance short-wavelength detection. Furthermore, longer wavelengths have deeper penetration depths, enhancing longer wavelength detection for deeper graphene layers.

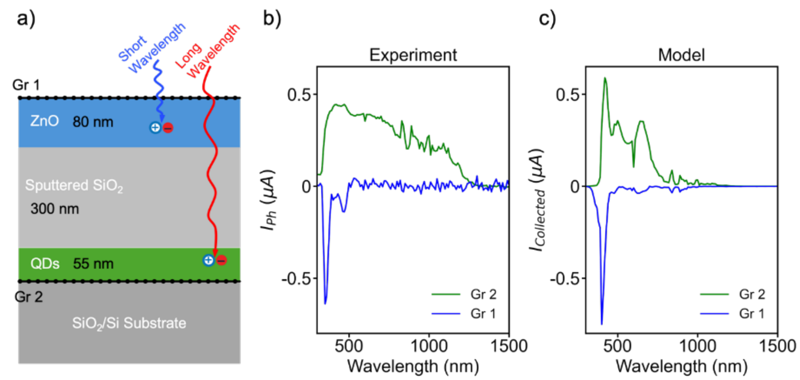

Figure 2: Our diffusion coefficient and transfer matrix method allows for predicting and modelling a ZnO and QDs device with graphene layers on top and bottom as shown in a). The experimental (b) and model (c) show a good agreement for the spectral response for Gr1 (top) and Gr2 (bottom), responds to ZnO and PbS QD spectral bands. The longer spectral response for the experiments vs. simulations is probably due to a mismatch between the n,k values between testing film and actual device.

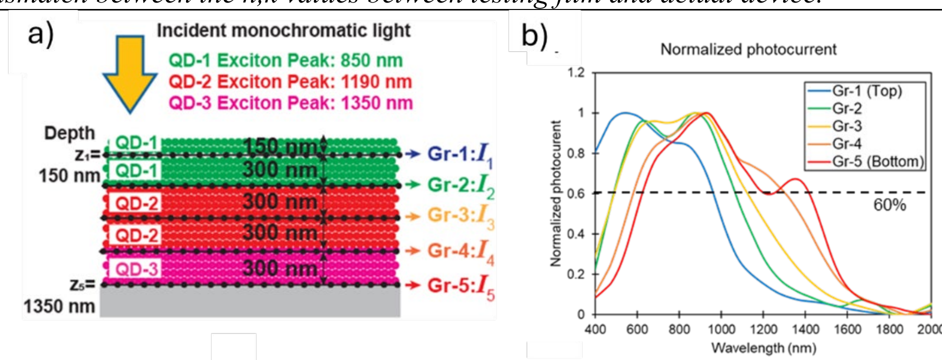

Figure 3. Vertical Integration of lead sulfide quantum dots with graphene charge collectors as charge collectors. Deeper graphene layers (e.g. Gr-5 Bottom)) respond to longer wavelengths while shallow layers respond to shorter wavelengths (e.g. Gr-1 Top)