

MEASURING LIGHT PENETRATION FOR SPECTRAL ANALYSIS WITH INTERCALATED GRAPHENE/QUANTUM DOT PHOTODETECTORS

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ABSTRACT

Herein we describe a novel architecture based on alternating stacks of quantum dot layers as light absorbers and graphene monolayers as current collectors. By implementing independent electrical contacts to each graphene layer at different depths, it is possible to probe the photocurrent depth profile which is strongly wavelength dependent. This in turns allows to extract information on the spectrum of the incident light which can potentially serve as an ultrathin multi-spectrometer. We present devices with four graphene layers intercalated with PbS quantum dots as light absorbing components.

KEYWORDS

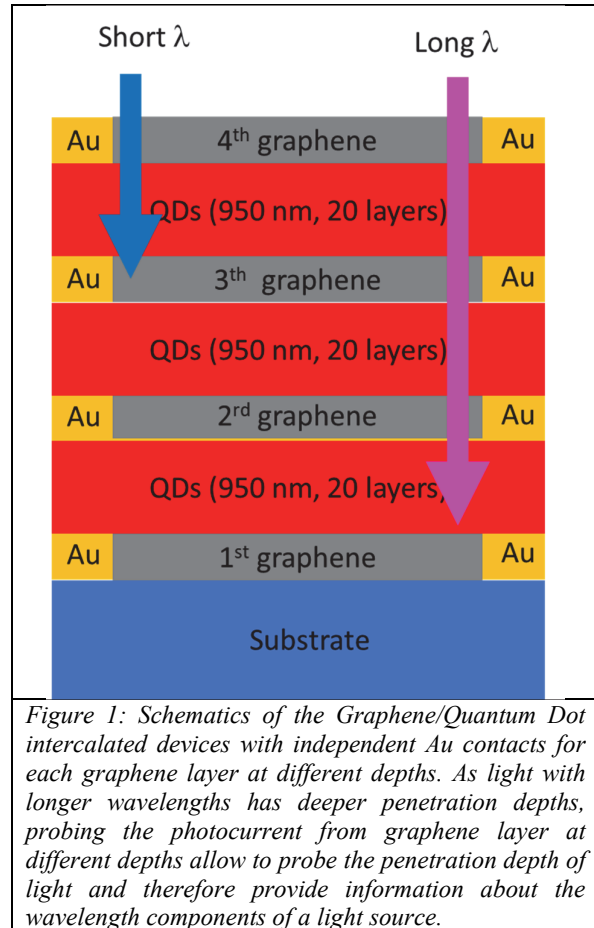
Graphene, quantum-dots, intercalated devices, spectral analysis

INTRODUCTION

Multispectral photodetectors able to operate throughout the UV-Vis-IR spectrum has important applications for sensing and material analysis. Furthermore, developing compact and low-cost multispectral photodetectors is important as a large number of detectors are expected to be deployed in transportation application for autonomous driving and drone technologies. Artificial intelligence and machine learning can also be fully exploited by gathering more data from our surroundings. However, current photodetector technologies, especially in the infrared, are still expensive and require complex optical architectures, preventing their large-scale deployment.[1] The architectures for multispectral analysis are based on dispersive beam splitters, filter arrays and interferometers. For visible and NIR wavelengths, Bayer filters and lenslet arrays have been integrated into CMOS detectors but are limited to Si absorption ranges. Dispersive gratings and prisms allow broader coverage and higher spectral resolution but require longer optical paths and multiple detectors that limit their integration into portable devices. In this contribution, we report a novel architecture that allows for probing the penetration depth of light in a thin film, which is strongly wavelength dependent, opening a path for thin film based multispectrometers that can be compatible with portable devices and flexible/wearable components.

Herein, we report a novel architecture based on graphene monolayers intercalated with quantum dot films, integrating electrical contacts of each graphene layer, allowing to probe the photocurrent through the graphene layers at different depths. Since the penetration depth is

strongly wavelength dependent, this allows to probe spectral information. As reported in previous works on hybrid graphene/quantum dot photodetector, the role of the QDs is to absorb light and generate electrical photocarriers that are transferred to graphene, which can efficiently transport the photocarriers producing a photocurrent under a bias voltage.[2-4] Using our intercalated technology with independent electrodes, it is possible to probe the light absorbed by the quantum dots at different depths and therefore estimate the penetration depth and get spectral information.



RESULTS

Figure 1 shows the schematics of our device consisting of four graphene layers with three intercalated films of 400 nm thick PbS QD layers. The graphene monolayers are

obtained by CVD growth on copper. The PbS QDs are prepared by chemical synthesis as described elsewhere.[5] The QDs have an exciton near 850 nm based on their light absorption spectrum shown in Figure 2. The devices are fabricated by sequential deposition/patterning of components. First, a chemical vapor deposited (CVD) graphene monolayer is transferred by wet transfer. Then, Au/Cr contacts are fabricated by lithography, evaporation and lift off. Then, 20 layers of QDs are spin coated using oleic acid as surface ligand, which is then replaced by TBAI by ligand exchange. This sequence is repeated, adding a graphene layer, Au/Cr contacts and QDs. An important step is to transfer the graphene layer on top of the PbS quantum dots before doing lithography. The lithography process involves organic solvents that can damage the organic ligands on the quantum dots, which can damage and deteriorate the performance of the QDs significantly. The graphene layer serves then also as a protective layer during the lithography process.

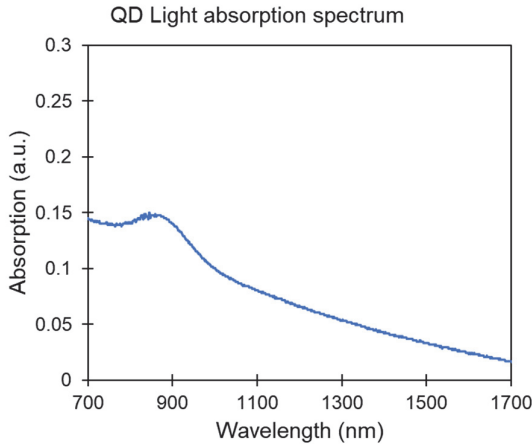


Figure 2: Absorption spectra of the PbS QDs used as for light absorption. The spectral range of the device is defined by the QD absorption spectrum.

Figure 3 shows the photocurrent response of each graphene layer, with 1st tier Graphene being the bottom layer and 4th tier Graphene being the top layer. The results show different photoresponse for each Gr layer in the visible range of 400-800 nm. However, for wavelengths longer than 800 nm the behavior of the different graphene layers is similar. There is a clear trend in the 400-800 nm range, with the top layers showing a stronger response at shorter wavelengths. This is expected as longer wavelength have smaller absorption coefficients. In the range beyond 800 nm, all the graphene layers have a similar behavior, with a strong decay around 1200 nm, which is dictated by the absorption edge of the QDs band gap.

Figure 4 shows the photocurrent for different graphene layers at different wavelengths, showing how light is absorbed through the film thickness. This plot clearly shows how short wavelengths (400-600 nm) are rapidly absorbed at the top layers with little response at the bottom layers. On the other hand, longer wavelengths of 700-900 nm have a much slower decays as their penetrations depths are longer. From this structure, using the graphene layers as light absorption probes, it is possible to extract

absorption coefficients for different wavelengths through the Gr/QD stack. The graphene absorption is not taken into account as only 2% of incident light is absorbed by graphene.

Figure 5 shows the extracted absorption coefficients taken from Figure 4 by fitting the curves to an exponential decay. This shows the expected behavior of shorter wavelength with strong absorption coefficients and longer wavelengths smaller coefficients. These results indicate that our current device can be used for identification of wavelengths based on the collective response of the different graphene layers.

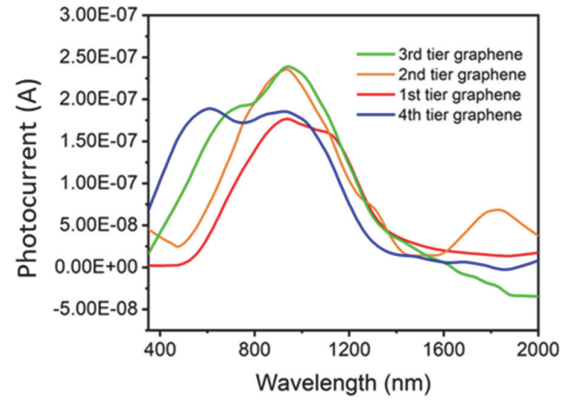


Figure 3: Photocurrent of each graphene layer showing different responses, notably, in the visible range of 400-800 nm. The top graphene layers showing stronger response for shorter wavelengths. 1st tier graphene is the bottom layer and 4th graphene is the top layer.

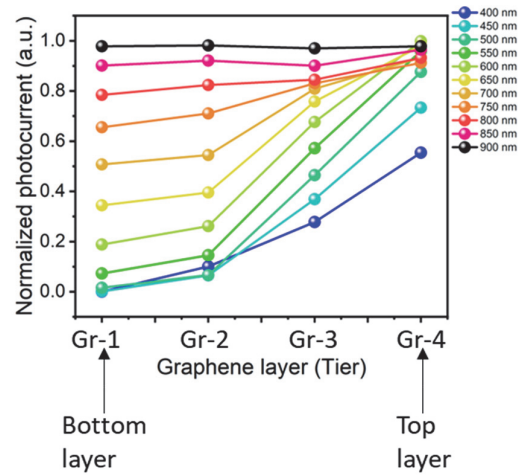
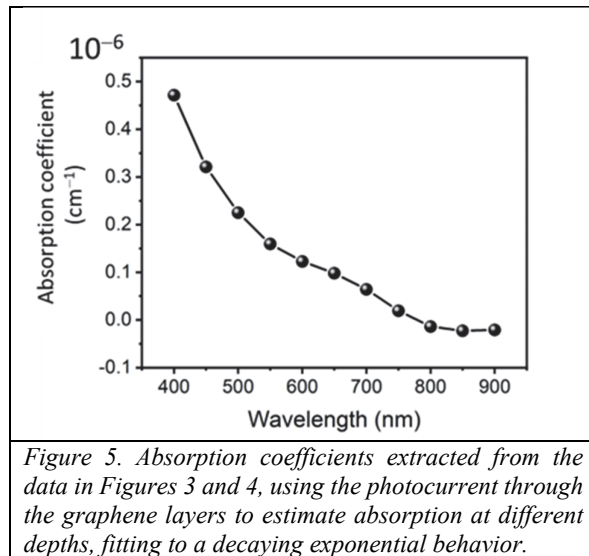


Figure 4: Plot showing photocurrent at different depths for different wavelengths. This shows the strong decays for short wavelengths and slower decays for longer wavelengths. From this plot, it is possible to extract the absorption coefficient and the penetration depth, which can then be applied for wavelength identification.

CONCLUSIONS

In conclusion, we have presented a novel device architecture based on intercalated graphene and QD layers with the integration of independent electrical contacts for each graphene layer. This independent electrodes are critical as they allow to probe the light penetration through the film and therefore extract spectral information. Further work and analysis are required to extract full spectral information. Our current work involves using inverse matrices and machine learning algorithms to use the photocurrent information from the graphene layers to infer the spectral composition of the incident light. This would let us using these intercalated nanomaterial films as thin film-based multispectral photodetectors that can be compatible with portable devices and transport devices that require light and compact geometries.



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