Light Detection with Nanocrystal Sensitized Graphene

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Abstract

Hybrid devices with graphene and sensitizer materials have proved to be promising platform for 2D optoelectronics, and to overcome the limitation of the low absorption of light in graphene [1]. In particular, colloidal semiconductor nanocrystals (NCs) has given good results in near infrared, visible and near UV range, because of their strong light absorption and simple fabrication; moreover, the chemical synthesis of these materials allows to tune their optical properties, so that different spectral range can be covered [2]. Also, it is possible to study and use non-toxic and environmentally-friendly materials.

Photodetectors based on NCs and graphene have given very good results in terms of photoconductive gain, but have a long response time which limits their use for high speed applications [3,4]. In this kind of devices, the light is absorbed in the nanocrystals and excites charges, which are transferred to the graphene layer inducing a change in its conductivity. Large photoconductive gain is the result of the short transit time in graphene (thanks to high carrier mobility) and the long relaxation time of the photogenerated charges [3].

In this contribution, we will report on photodetectors fabricated with graphene and CdS nanocrystals showing high gain and capable to measure laser pulses up to a repetition rate of 2 kHz.

We use graphene grown by chemical vapor deposition [5] on a Cu substrate, and transferred onto a n-Si/SiO2 wafer. Field effect transistors (FETs) are fabricated with these samples; the doped silicon layer is used as a back gate. CdS nanocrystals are synthetized according to the protocol in Ref. [6], dispersed in a chloroform-dichlorobenzene mixture, and deposited by spin coating on the graphene FETs. The samples are then measured in vacuum, and their photoresponse is measured using lasers at different wavelength or a Xenon lamp coupled to a monochromator.

The spectral response of the CdS follows the nanocrystals absorption, giving high sensitivity in the near UV range. The peak responsivity (photocurrent/light power) is at around 350 nm. By studying the source-drain current - gate voltage characteristics as a function of the laser power, we see that electrons are transferring from NCs to graphene.

Changing the charge density in graphene using the backgate allows to tune the responsivity, as shown in left panel of fig. 1; also the sign of the photocurrent can be switched from positive to negative, because of the ambipolar character of graphene. As the light power is varied, we find that the maximum responsivity is achieved at the lowest power (right panel of fig.1). The maximum value is $3.4 \cdot 10^4$ A/W, corresponding to a gain of the order of 10^5. The measured noise equivalent power (NEP) is of the order of pW $Hz^{-1/2}$.

We also have investigated the time response of the device. A strongly non exponential decay of the photocurrent is found with a long a time scale of the order of tens of seconds (fig.2, panel d). Indeed, high responsivity in this kind of devices is achieved at expenses of the response speed. Nevertheless, measuring the response to 349nm-laser pulses with kHz repetition rate, we observed that our system is able to measure the laser pulses up to 2 kHz (fig.2, panels a-c).

We explain the experimental response of the devices taking into account the role of surface states and adsorbed molecules on the nanocrystals [7-9]. We will discuss the effective mechanisms of charge transfer from NCs to graphene, and the role of surface states and adsorbed molecules. This study allow

us to gain insight in the charge transfer processes in the hybrid system [10]. Finally, we will compare the CdS devices with other NCs.

References

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Figures

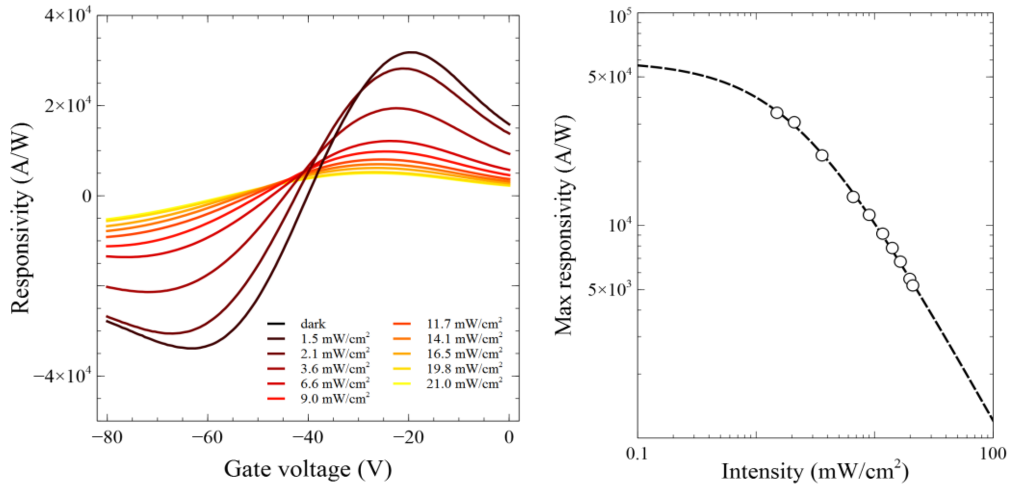

Figure 1: Left: Responsivity of the hybrid CdS/graphene photodetectors, measured with a laser at 349 nm, as a function of gate voltage. Right: dependence of the responsivity on the light power.

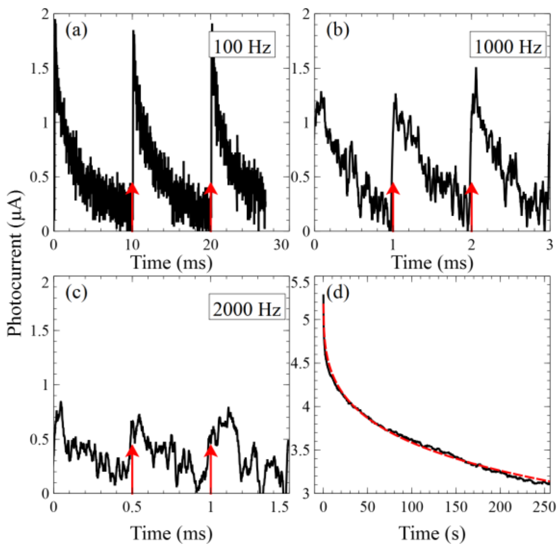

Figure 2: (a)-(c) Response of the photodetectors to ns-pulses at 349 nm, at different repetition rates. Red arrows mark the pulses. (d) Time response over a long period after turning off the laser.