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A curious observation of Pauli-Blocking in MoS_2-quantum dots/graphene hybrid system

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In this study, Pauli-Blocking has been observed in a 0D/2D MoS_2 quantum dots/graphene (MoS_2-QDs/graphene) hybrid system. For the observation of room temperature Pauli-Blocking in the 0D/2D system, a photodetector device based on n-type MoS_2-QDs and CVD grown graphene has been fabricated using a facile and lithography free technique. The current-voltage characteristics of the device have been performed at room temperature. The fabricated device shows a negative response under visible light ($\lambda \sim 400$ to 700 nm) illumination. The dark to photo current ratio of the device shows variation up to two orders of magnitude. This negative response, which results decrease in current under visible light illumination, may be attributed to the Pauli-Blocking due to high absorbance of photon energy in visible light range. Furthermore, it is believed that the present study may provide an insight into understanding the Pauli-Blocking in 0D/2D hybrid system at room temperature. *Published by AIP Publishing.* https://doi.org/10.1063/1.5042278

INTRODUCTION

A photodetector (PD) is an optoelectronic device which senses the presence of optical signals and converts them into electrical signals. The irradiation of a semiconductor leads to an enhancement of current in most of the bulk semiconductor based PD circuits. However, in the case of some semiconductor nanocrystals or quantum dots (QDs), reduction of optical transitions is possible, essentially due to Pauli-Blocking and electrostatic attenuation.[1,2] When the lowest energy interband states are filled by electrons or holes, further transitions across this band will be forbidden resulting in reduction of photon absorption. This phenomenon is known as "Pauli-Blocking." Pauli-Blocking is a state where edges of both the bands (Conduction Band and Valence Band) get filled up completely with charge carriers leading to saturation when illuminated with intense incident light. Degenerate semiconductors manifest the similar phenomena known as Moss-Burstein shift, wherein electrons cannot transit to bottom of conduction band from valence band because it is already filled and Pauli's exclusion principle does not allow two carriers at the same state. Electrostatic attenuation occurs when some carriers are trapped near the surface of the QDs, which spatially separates the photogenerated electron-hole pairs, thus reducing interband transitions and corresponding absorption.[3]

Saturation of graphene due to Pauli-Blocking under illumination of visible light has been reported by several groups.[4–6] Due to Pauli-Blocking, ultrashort soliton pulses (756 fs) at the telecommunication band were generated in the atomic layer graphene as saturable absorber in a mode-locked fibre laser, which was demonstrated by Bao *et al.*,[4] and also effect of it was seen on optical conductivity of a single layer graphene by Santoso *et al.*[5] Even, Winzer *et al.*[6] observed a linear regime for the intensity-dependence of the transmission at low pump fluences and a nonlinear saturation caused due to Pauli-Blocking in the high excitation regime. Due to unique band structure, saturation absorbance of graphene is in broad range of wavelength and can be controlled by externally applied voltage.[7] The saturation current in graphene based devices find applications in high transconductance FETs,[8] saturable absorber for ultrafast pulsed lasers,[4] single-mode cavity-free lasers,[7] and other photonic applications such as mode-locking in graphene-clad fibre lasers[9] and graphene-based random lasers.[7] Graphene is an attractive choice for 2D material based nano-optoelectronics owing to near-ballistic transport, high mobility, and relativistic motion of electrons.[10] Its electronic and mechanical properties are ideal for micro- and nano-mechanical systems, thin-film transistors, and transparent and conductive composites and electrodes. In spite of having many applications such as field effect transistors,[11,12] optical modulators,[13] photodetectors,[14,15] etc., its semi-metallic nature, frequency independence, and zero bandgap have limited its applicability in the field of photodetector integrated with Si substrate.[16,17]

In addition to Graphene, atomic-layered transition metal dichalcogenides (TMDs) exhibit unique physical properties that promote its applications in future optoelectronic components. Molybdenum disulfide (MoS_2) is an emerging 2D n-type semiconductor TMD material having good photon absorption capacity,[17] with direct bandgap (~1.8 eV) in its monolayer form and an indirect bandgap (~1.2 eV) in bulk/multilayer form.[18,19] Layer dependent bandgap tunability of MoS_2 induce its use as active material in wide applications such as photodetectors,[20,21] light emitting diodes (LEDs),[22]

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