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Ultrafast and nonlinear optical properties of two-dimensional CdSe nanostructures prepared using MoS_2 nanosheets as template

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ABSTRACT

Two-dimensional (2D) materials have attracted tremendous research interest because of their unique optical, electronic, and mechanical properties which make them suitable building blocks for various electronic and optoelectronic applications. The heterostructures formed by 2D semiconductors can play an important role in modern semiconductor industry. Here, we have grown 2D-CdSe structures over MoS_2 nanosheets via successive ion layer adsorption and reaction method. The dynamics of photoinduced charge carriers in 2D-CdSe nanostructures have been investigated using femtosecond transient absorption spectroscopy. Our photophysical studies infer that charge carrier recombination is monomolecular at low and bimolecular at high excitation densities. Nonetheless, femtosecond Z-scan technique was employed to demonstrate optical limiting behavior of 2D-CdSe films. This study will open up a new avenue of designing 2D nanomaterials for optoelectronic applications.

1. Introduction

Transition metal dichalcogenide (TMDC) semiconductors (e.g., molybdenum disulfide, MoS_2; molybdenum diselenide, $MoSe_2$) have been shown to possess diverse electronic structures and properties which make them useful in optoelectronics [1,2], nanophotonics [3], sensing [4–6], catalysis [7], hydrogen evolution reaction [8], lithium-ion batteries [9], and capacitors [10]. Assorted applications of semiconductor quantum dots (QDs) (e. g., CdSe, CdS, CdTe, PbS, PbSe, PbTe, ZnS) and their heterostructures like core-shell, platelets, nanorods, nanobarbells have already been established [11–14]. Recent developments in synthesis methods encourage the search for new hybrid 2D materials comprising of quasi-zero-dimensional (0D) QDs and 2-dimensional (2D) nanostructures i.e., 0D-2D materials [15,16,19,20], and consisting of two or more than two 2D materials (i.e., 2D-2D) like MoS_2/graphene [17] and MoS_2/WS_2 [18]. Many groups even studied the charge transfer processes in 0D-2D systems consisting of QDs and MoS_2 [21]. Recently, charge transfer between perovskite QDs and MoS_2 has also been reported [22].

MoS_2-CdSe composite material has been prepared by mixing individual nanostructures. There, MoS_2 nanosheets were prepared by exfoliation and chemical synthesis method was employed to synthesize CdSe nanostructures. The photocatalytic activity of such composite material has been shown to enhance by a factor of four in comparison to bare CdSe QDs [15]. Highly efficient non-radiative energy transfer from CdSe QDs to single- and few-layer MoS_2 resulting in quenching (>95%) of QD PL has been reported [16]. Li et al. explored temperature dependent electron transfer from CdSe QDs to MoS_2 monolayer [23]. They synthesized QDs/MoS_2 heterostructure by spin coating QDs over monolayer MoS_2. Their main finding was while the PL intensity of CdSe QDs was decreased, the MoS_2 PL was increased with increasing temperature. This behavior was attributed to the transition of localized excitons of QDs in the QDs/MoS_2 structure to free exciton with increasing temperature. Molybdenum sulfide-chitosan/CdSe QDs (MoS_2-CS/CdSe QDs) composite has been shown to have strong and stable electrochemiluminescence (ECL) and used as ECL sensor for uric acid detection [6]. Highly photosensitive phototransistor based on hybrid structure of bilayer MoS_2 and CdSe nanocrystals with improved rise/decay time has been reported by Ra et al. [24]. Taghipour et al. have reported non-radiative Förster resonance energy transfer (FRET) with almost 100% efficiency from the thin film of CdSe/CdS nanoplatelets to a MoS_2-monolayer by varying thickness of spacer layer of Al_2O_3 [25]. Mushtaq et al. studied ultrafast multiple exciton harvesting at CdSe-MoS_2 (0D-2D) heterojunction utilizing steady-state and time-resolved spectroscopic

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