
DOMINIK KUFER
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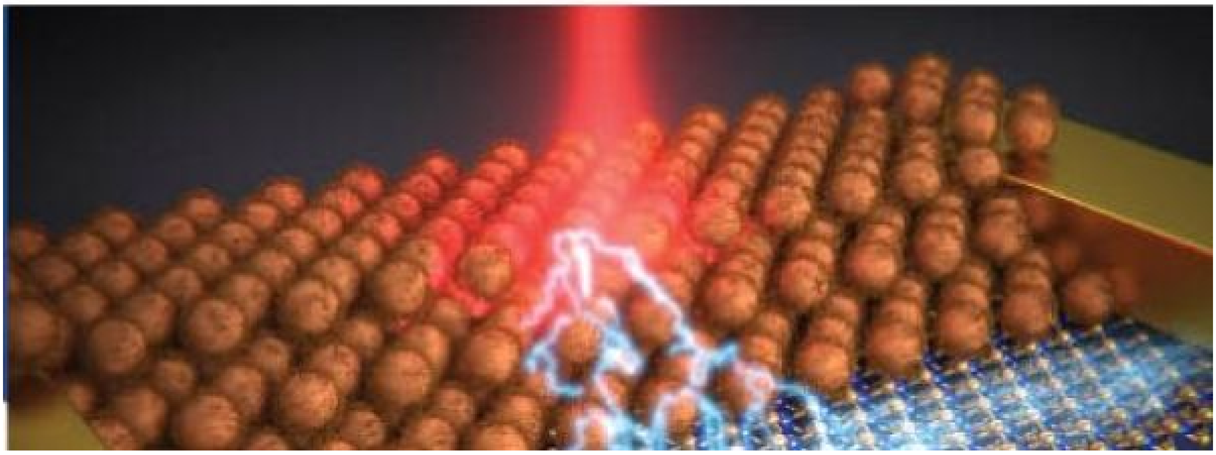

PhD Thesis Defense DOMINIK KUFER 'Photodetectors Based on Low-dimensional Materials and Hybrid Systems'

DOMINIK KUFER

June 13, 2016

Monday, June 13, 11:00. ICFO Auditorium

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Functional Optoelectronics Nanomaterials

ICFO-The Institute of Photonic Sciences

In the last decade, two-dimensional (2D) materials have attracted attention both in the nascent field of flexible nanotechnology as well as in more conventional semiconductor technol-ogies. Within the rapidly expanding portfolio of 2D materials, the group of semiconducting transition metal dichalcogenides (TMDCs) has emerged as an intriguing candidate for various optoelectronic applications. The atomically thin profile, favorable bandgap and outstanding electronic properties of TMDCs are unique features that can be explored and applied in novel photodetecting platforms.

This thesis presents highly sensitive two-dimensional phototransistors made of sub-nanometre thick TMDC channels. Firstly, an encapsulation route is developed to address the detrimental and, to date, uncontrollable impact of atmospheric adsorbates, which severely deteriorate detector performance. The passivation scheme improves the transport properties of TMDCs, leading to high photoconductive gain with gate dependent responsivity of 10 - 10^4 A/W throughout the visible, and temporal response down to 10 ms, which is suitable for imaging applications. The atomic device thickness yields ultra-low dark current operation and record detectivity of 10^11 - 10^12 Jones for TMDC-based detectors is achieved.

The use of monolayer TMDCs, however, has disadvantages like limited spectral absorption due to the bandgap and limited absorption efficiency. In order to increase the absorption and to extend the spectral coverage, TMDC channels are covered with colloidal quantum dots to make hybrid phototransistors. This compelling synergy combines strong and size-tunable light absorption within the QD film, efficient charge separation at the TMDC-QD interface and fast carrier transport through the 2D channel. This results in large gain of 10^6 electrons per absorbed photon and creates the basis for extremely sensitive light sensing. Colloidal quan-tum dots are an ideal sensitizer, because their solution-processing and facile implementation on arbitrary substrates allows for low-cost fabrication of hybrid TMDC-QD devices. Moreover, the custom tailored bandgap of quantum dots provides the photodetector with wide spectral tunability. For photodetection in the spectral window of NIR/SWIR, which is still dominated by expensive and complex epitaxy-based technologies, these hybrid detectors have the potential to favorably compete with commercially available systems.

The interface of the TMDC-QD hybrid is of paramount importance for sensitive detector operation. A high density of trap states at the interface is shown to be responsible for inefficient gate-control over channel conductivity, which leads to high dark currents. To maintain the unique electrical field-effect modulation in TMDCs upon deposition of colloidal quantum dots, a passivation route of the interface with semiconducting metal-oxide films is developed. The buffer-layer material is selected such that charge transfer from QDs into the channel is favored. The retained field-effect modulation with a large on/off ratio allows operation of the phototransistor at significantly lower dark currents than non-passivated hybrids. A TMDC-QD phototransistor with an engineered interface that exhibits detectivity of 10^12 - 10^13 Jones and response times of 12 ms and less is reported.

In summary, this work showcases prototype photodetectors made of encapsulated 2D TMDCs and TMDC-QD hybrids. Plain TMDC-detectors have potential for application as flexible and semi-transparent detector platforms with high sensitivity in the visible. The hybrid TMDC-QD device increases its spectral selectivity to the NIR/SWIR due to the variable absorption of the sensitizing quantum dots and reaches compelling performance thanks to im-proved light-matter interaction and optimized photocarrier generation.

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Thesis Director: Prof Dr Gerasimos Konstantatos