

heterostructures

MATHIEU MASSICOTTE

Advisor: Prof. Dr. Frank H. L. Koppens



PhD Thesis Defense MATHIEU MASSICOTTE 'Ultrafast optoelectronics in 2D materials and their heterostructures'

MATHIEU MASSICOTTE

September 05, 2017

Tuesday, September 5, 16:00. ICFO Auditorium

MATHIEU MASSICOTTE

Quantum Nano-optoelectronics

ICFO-The Institute of Photonic Sciences

Understanding and improving how light is converted into electricity in materials is one of the central goals in the field of optoelectronics. This basic physical process lies at the heart of several major technologies, including solar cells and ultrafast optical communication

systems, which have pervaded and shaped the world we live in. As technological performance approaches the limit of conventional materials, the need for optoelectronic platforms presenting novel properties and superior characteristics, in terms of speed, efficiency and wavelength range, is rapidly growing.

Two-dimensional (2D) layered materials, such as graphene and transition metal dichalcogenides (TMDs), have recently emerged as prime candidates for optoelectronic applications. This new class of one-atom-thick materials has sparked huge interest due to their exceptional electrical and optical properties, which can be very different from those of their bulk counterpart. Since the first isolation of graphene in 2004, the library of 2D materials has grown considerably and now comprises many other crystals covering a wide range of complementary properties. Assembling these 2D building blocks into vertical heterostructures opens up exciting possibilities for designing artificial materials with atomic-layer precision. The resulting van der Waals heterostructures (vdWH), in addition to combining the properties of their constituent layers, provide a rich playground for studying photophysical phenomena and implementing novel photodetection schemes.

The goal of this thesis is to explore the optoelectronic response of devices based on 2D materials and vdWHs in order to understand the dynamic processes governing their photocurrent generation mechanisms, and thereby facilitate the design of high-performance photodetectors. From the broad library of 2D materials, we focus our attention on the three that have attracted the most interest: graphene, TMDs and hexagonal boron nitride (hBN). These materials possess entirely distinct optoelectronic properties. For instance, graphene, a semimetal, displays a broadband photoresponse dominated by hot carriers, whereas the optical response of semiconducting TMDs is governed by strong excitonic effects. Studying how these light-matter interactions induce an electric signal in actual devices poses many experimental challenges. Besides the fabrication of high-quality devices, one of the main difficulties is to assess the ultrafast electronic processes involved in the photocurrent generation. To this end, we developed a versatile time-resolved photocurrent measurement technique (TRPC) which combines electronic detection with subpicosecond optical excitation.

This thesis comprises three introductory and technical chapters and four experimental chapters, each covering a different 2D material system. Chapter 1 gives an overview of the electronic and optical properties of graphene, TMDs, hBN and their vdWHs, with an emphasis on the dynamics of their photocarriers. Chapter 2 presents the basic photodetection concepts and measurement techniques relevant for this thesis, along with a review of the main photocurrent generation mechanisms observed in 2D materials. Chapter 3 describes techniques to fabricate state-of-the-art devices based on 2D materials and vdWHs. Chapter 4 presents an in-depth study on the photocurrents generated laterally in various graphene devices and an investigation of the ultrafast heating dynamics of the hot carriers driving this process. Chapter 5 explores the interlayer transport of photocarriers in graphene-based vdWHs and demonstrates the possibility of extracting hot carriers vertically. Chapter 6 shows that vdWHs made of thin TMD crystals can possess both a high efficiency and a fast photoresponse, and examines the processes that limit their performance. Finally, Chapter 7 reports on the dissociation of excitons under in-plane electric fields in monolayer WSe₂, and on the related Stark and Franz-Keldysh effects.

Tuesday September 5, 16:00 h. ICFO Auditorium

Thesis Director: Prof Dr. Frank Koppens

