ICFO


# PhD Thesis Defense  ACHIM WOESSNER 'Exploring Flatland Nano-Optics with Graphene Plasmons'

ACHIM WOESSNER

May 11, 2017

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Thursday, May 11, 10:00. ICFO Auditorium

**ACHIM WOESSNER**

Quantum Nano-Optoelectronics

ICFO-The Institute of Photonic Sciences

Plasmons are charge oscillations coupled to electromagnetic radiation. One of their most intriguing properties is their deep subwavelength confinement resulting in strongly enhanced light-matter interaction. Metal plasmons have received tremendous interest over the last decades and have sparked the development of a range of new fields such as plasmonic nanophotonic components, metamaterials, metasurfaces and more exotic

research areas such as quantum plasmonics. One of the main drawbacks of conventional metal plasmonics is that the plasmon lifetime is extremely short when the light is confined to deep subwavelength scales and that their wavelength is not tunable in situ.
This is where graphene, a one atom thick semimetal consisting of carbon atoms arranged in a two dimensional honeycomb lattice, comes into play. In graphene plasmons can be confined to extreme subwavelength scales while still having a long lifetime and their wavelength is tunable in situ. Graphene plasmonics is a relatively new research area but has already attracted a lot of attention. This is undoubtedly due to the fact that graphene plasmons are extremely versatile. They are a unique platform for exploring the limits of light matter interaction, two dimensional transformation optics, biosensing, and mid-infrared integrated optics.

The goal of this thesis is to explore the frontiers of graphene plasmonics both to understand the fundamental properties and limitations as well as to use the gained understanding to develop new concepts towards applications. We will mainly be using graphene encapsulated in hexagonal boron nitride (h-BN). This material has already shown that it is an excellent substrate for graphene as graphene fully encapsulated by h-BN at room temperature shows a mobility limited by the lattice vibrations of the graphene itself. Furthermore it has very intriguing optical properties as it is a natural hyperbolic material which we will explore in the second part of the thesis. As measurement apparatus for the studies presented here we mainly used scattering-type scanning near-field optical microscopy (s-SNOM) as well as a technique based on s-SNOM we developed called near-field photocurrent nanoscopy. These techniques provide great insight into the working mechanisms of graphene optoelectronics with a nanometer resolution over a broad frequency range from the mid-infrared to the terahertz.

This thesis is split into a general introduction chapter and two main parts with experimental results. In the beginning I will give an introduction to graphene and its opto-electronic properties, graphene devices and their fabrication. I will also introduce h-BN, a dielectric layered material commonly used as substrate for graphene (Chapter 1). Then in the first main part of the thesis I will introduce the background and fundamentals of graphene plasmons (Chapter 2). In the following I will then introduce an experiment where we explore the limitations of the graphene plasmon lifetime at room temperature (Chapter 3). I will then show am optical phase modulator which is capable of tuning the phase in situ from 0 to 2? with a footprint of only 350nm exploiting the unique capability of tuning the graphene plasmon wavelength (Chapter 4). In the second part of the thesis I will give a background on photodetection with graphene (Chapter 5). I will then introduce a new measurement technique called infrared photocurrent nanoscopy (Chapter 6) and show how it can be used to study the optoelectronic properties of a variety of graphene devices in the infrared at the nanoscale (Chapter 7). Then I will show how graphene plasmons can be detected electrically using this technique (Chapter 8). Finally I will introduce a way of detecting phonon polaritons in h-BN electrically using graphene and show how this can be used to greatly enhance the photoresponse of graphene photodetectors in the mid-infrared (Chapter 9).

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**Thesis Director: Prof . Dr. Frank H. L. Koppens**