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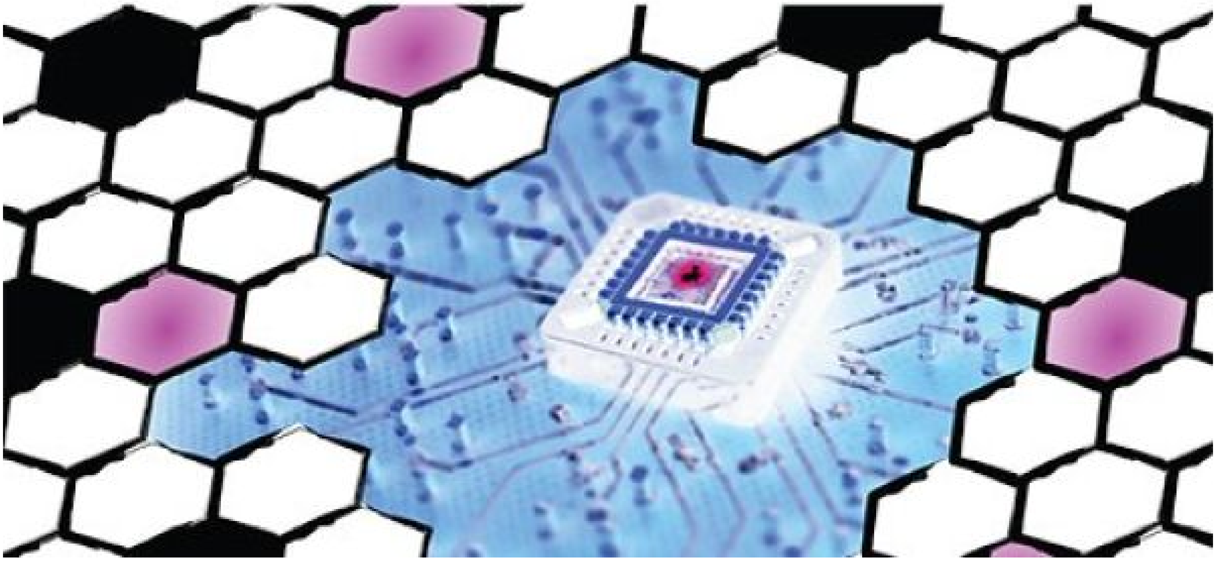

PhD Thesis Defense MICHELA BADIOLI 'Graphene Optoelectronics from the Visible to the Mid-Infrared'

MICHELA BADIOLI

December 04, 2015

Friday, December 4, 10:00. ICFO Auditorium

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Nano-Optoelectronics

ICFO-The Institute of Photonic Sciences, SPAIN

Since its discovery in 2004, graphene, a one-atom-thick layer of carbon atoms arranged in a hexagonal lattice, has attracted huge interest from the scientific community due to its extraordinary electronic, mechanical, and optical properties. While most of the earliest studies focused on electronic transport, in recent years the fields of graphene photonics and

optoelectronics have thriven.
The goal of this thesis is to explore the use of graphene for novel optoelectronic devices, adopting different approaches to enhance the electrically tunable graphene-light interaction in a broad spectral range, from the visible to the mid-infrared. This includes investigating the sub-wavelength interaction and energy transfer between a dipole and a graphene sheet, as well as working on efficient photodetection schemes.

Indeed graphene high electronic mobility, broadband absorption, flexibility and tunable optoelectronic properties (described in Chapter 1) make it extremely appealing for the development of optoelectronic applications with new functionalities.

Concerning the devices, the starting point of the experiments presented in the thesis are graphene field effect transistors of different geometries, whose fabrication and characterization techniques are described in Chapter 2. The tunability of the optoelectronic properties via control over the Fermi energy is an essential feature of the fabricated devices. The change in the Fermi level is achieved applying a voltage to a back-gate or a polymer electrolyte top-gate.

We address both aspects at the core of optoelectronics, i.e. the control of optical properties with electric fields and the modification of electrical quantities, such as current, with light. Therefore the first part of the thesis (comprising Chapter 3, 4 and 5) is devoted to graphene nanophotonics and plasmonics, while the second part deals with graphene-based photodetection (Chapter 6, 7, 8 and 9).

In Chapter 3, the main concepts at the basis of graphene nanophotonics are presented, such as the electrical tunability and the strong field confinement of the 2D plasmons, as well as the coupling of an optical emitter to graphene plasmons or electron-hole pair excitations. Then we present two experiments showing the control of light by means of static electric fields. In Chapter 4 we show the electrical control of the relaxation pathways of erbium ions in close proximity to a graphene sheet: the energy flow from the emitters is tuned to electron-hole pairs in graphene, to free space photons and to plasmons by changing the graphene Fermi level. In Chapter 5 we present the real-space imaging and tuning of highly confined graphene plasmons in the mid-infrared, launched by the dipole of a metallized s-SNOM tip (Chapter 5). In this case modifying the graphene Fermi level leads to a change in the plasmon wavelength.

In Chapter 6 we review existing schemes for graphene photodetectors and the main mechanisms enabling photodetection with graphene, with particular emphasis toward the photothermoelectric effect. Then we present three cases where graphene photoresponse is enhanced exploiting the interaction with surrounding materials. A hybrid graphene-quantum dot photodetector in the visible and near-infrared is reported in Chapter 7: a photogating effect after light absorption in the quantum dots leads to extremely high responsivities (over one million A/W). In Chapter 8 we demonstrate how the excitation of bulk phonons of a polar substrate enhances the mid-infrared photocurrent via a photothermoelectric effect. Also substrate surface phonons, launched by illuminating a metal edge with light polarized perpendicularly to it, lead to an increase in the photoresponse, as described in Chapter 9.

The results presented in this thesis open new avenues in the field of graphene-based optoelectronics for active nano-photonics and sensing.

Friday December 4, 10:00 h. ICFO AUDITORIUM

Thesis Advisor: Prof. Dr. Frank Koppens