PhD Thesis Defense RENWEN YU 'Toward Next-Generation Nanophotonic Devices'

RENWEN YU

July 11, 2019

Thursday, July 11, 12:00. ICFO Auditorium

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Nanophotonics Theory

ICFO-The Institute of Photonic Sciences

In this thesis, we aim to explore several novel designs of nanostructures based on graphene to realize various functionalities. We briefly introduce the fundamental concepts and theoretical models used in this thesis in Chapter 1. Following the macroscopic analytical method outlined in the first chapter, in Chapter 2 we show that simple simulation methods allow us to accurately describe the optical response of plasmonic nanoparticles, including retardation effects, without the requirement of large computational resources.

We then move to our proposed first type of device: optical modulators. We explore graphene sheets coupled to different kinds of optical resonators to enhance the light intensity at the graphene plane, and so also its absorption, which can be switched on/off and modulated through varying the level of doping, as explored in Chapter 3. Unity-order changes in the transmission and absorption of incident light are predicted upon electrical doping of graphene.

Heat deposition via light absorption can severely degrade the performance and limit the lifetime of nano-devices (e.g., aforementioned optical modulators), which makes the manipulation of nanoscale heat sources/flows become crucial. In Chapter 4, we exploit the extraordinary optical and thermal properties of graphene to show that ultrafast radiative heat transfer can take place between neighboring nanostructures facilitated by graphene plasmons, where photothermally induced effects on graphene plasmons are taken into account. Our findings reveal a new regime for the nanoscale thermal management, in which non-contact heat transfer becomes a leading mechanism of heat dissipation.

Apart from the damage caused by heat deposition, generated thermal energy can be in fact used as a tool for photodetection (e.g., silicon bolometers for infrared photodetection). In Chapter 5, we show that the excitation of a single plasmon in a graphene nanojunction produces profound modifications in its electrical properties through optical heating, which we then use to demonstrate an efficient mid-infrared photodetector working at room temperature based on theoretical predictions that are corroborated in an experimental collaboration with the group of Prof. Fengnian Xia in Yale University.

Finally, in Chapter 6, we show through microscopic quantum-mechanical simulations, introduced in the first chapter, that both the linear and nonlinear optical responses of graphene nanostructures can be dramatically altered by the presence of a single neighboring molecule that carries either an elementary charge or a small permanent dipole. Based on these results, we claim that nanographenes can serve as an efficient platform for detecting charge- or dipole-carrying molecules.

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