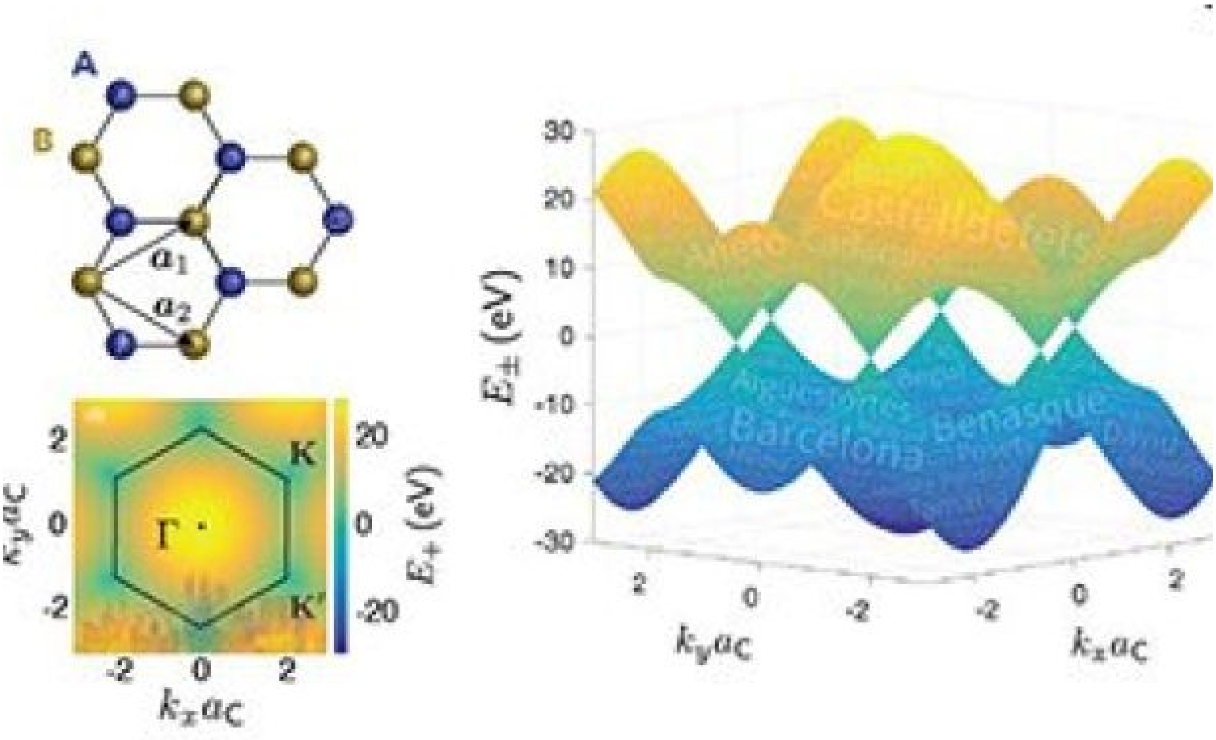

PhD Thesis Defense SANDRA DE VEGA 'Plasmon-Electron Interactions in Low Dimensional Materials'

SANDRA DE VEGA

February 17, 2020

11:00

ICFO Auditorium

Monday, February 17, 2020, 11:00. ICFO Auditorium

SANDRA DE VEGA

Nanophotonics Theory

ICFO-The Institute of Photonic Sciences

Ever since the advent of modern technology, major developments have come hand in hand with miniaturization and speed of operation. A proof of this is provided by the impressive success of Moore's law, which predicted that the number of transistors per affordable microprocessor would double every two years. That would not have been possible if transistors kept their initial physical dimensions. By the end of 2018, MIT and University of Colorado researchers broke a new record for the smallest 3D transistor yet with a lateral size of only 2.5 nm. As of 2019, there are commercially available 5 nm transistors. Considering these sizes it is then remarkably important to understand and to be able to manipulate materials at the nanoscale, where they behave differently compared with macroscopic structures.

Hence, researchers have put substantial efforts towards finding the explanation of diverse phenomena at the nanoscale, engineering new nanodevices, and proposing or predicting new mechanisms to achieve the next generation of chips and integrated circuits. Indeed, the rise of the so-called low dimensional materials (graphene, transition metal dichalcogenides, cuprates, hBN, black P, carbon nanotubes, and others), i.e., those whose atomic planes are bonded by weak van der Waals forces (2D) or whose atoms are arranged in chains or tubes (1D), has been influenced by the quest for new more efficient and compact designs. In this thesis we study the optical properties of some of these materials and how they are modified by the interaction with electrons that, depending on the specific case, we consider to be either dopants, or impinging in highly-focused beams, or via tunneling.

Specifically, we start with a comprehensive analysis of plasmons, the collective oscillations of free electrons coupled to light, in finite highly-doped carbon nanotubes. Next, we explore how to select the proper plasmon mode excited by electron beams depending on the orientation and position of the latter and also how to improve the interaction between two quantum emitters when mediated by the main plasmonic mode in our structures. We predict record-high Purcell factors of the order of 10^8, which supports the use of carbon nanotubes as active plasmonic elements with high potential in optoelectronics and quantum optics.

We then continue with one dimensional systems, but now focusing on atomic chains to emulate simple solid-like structures where to inspect strong-field driven electron dynamics in solids. Specially, we tackle several still pending questions about the role of electron-electron interactions and the proper choice of material to achieve better high-harmonic generation yields. After that, we test these findings in more realistic 1D systems: carbon nanotubes. Eventually, we find that the addition of a small number of doping charges to semiconductors can enable intraband plasmon excitations that concentrate the impinging light and boosts the high-harmonic generation efficiency.

Next, we investigate how to use two dimensional heterostructures (stacked layers) for new compact ways of generating plasmons that do not need external light sources. More precisely, we propose tunneling electrons as plasmon triggers. We thus design a device consisting of a 1 nm-thick sandwich of graphene-hBN-graphene whose activation mechanism would be by an electron that tunnels from one graphene layer to another losing energy in the process that is invested into exciting plasmons. We predict a generation efficiency that can reach one plasmon per tunneled electron and that is robust upon distortions and variations in doping. We then complete this study by analyzing graphene-insulator-metal structures, which unfortunately present less efficient generation rate.

In summary, the outcomes of this thesis open new paths towards a more efficient generation of nonlinear processes in solid nanoarchitectures and optics-free manipulation at the nanoscale for future optoelectronic devices.

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Thesis Advisor: Prof Dr Javier Garcia de Abajo

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