ICFO



PhD THESIS DEFENSE: Nanoscale manipulation of optical fields

EDUARDO DIAS

November 18, 2022
10:00
Auditorium

Besides its relevant fundamental interest, the in-depth understanding of light-matter interactions at the nanoscale has a profound impact on modern technological applications in diverse areas including telecommunications, information processing, sensing, and energy harvesting. In this context, surface polaritons provide us with the appealing ability to confine light down to subwavelength regions and produce strong near-field enhancements, thus assuming a growing importance in Nanophotonics research.
In this Thesis, we explore the precise control of nanoscale optical fields enabled by strong light-matter interactions in different materials. We concentrate on noble metals, due to their technological relevance and alluring near-infrared response, and graphene, due to its wide tunability and exceptional optical and thermal properties.
After an introductory revision of the necessary theoretical concepts in Chapter 1, we address

in Chapters 2 and 3 the long-standing problem of efficiently coupling light into polaritons via scattering by small particles. Specifically, in Chapter 2, we quantify the coupling strength between light and 2D polaritons using accurate rigorous analytical methods, and find closed-form constraints that limit the maximum possible values of the corresponding coupling cross-section. We further argue that resonant particles placed at an optimum distance from the film can boost light-to-polariton coupling to order unity.

In Chapter 3, we address the poor light-to-polariton coupling problem by demonstrating that, indeed, a small scatterer placed at a suitable distance from a planar surface can produce complete coupling of a focused light beam to surface polaritons. We formulate detailed general prescriptions on the beam profile and particle response that are required to achieve maximum coupling.

We then turn our attention to the manipulation of the plasmonic response of nanostructures via the modulation of the thermal response of graphene. In Chapter 4, we demonstrate the ability of hybrid systems composed by graphene and thin metal films to undergo large photothermal optical modulation upon ultrafast pumping by laser pulses to raise the electron temperature of graphene. Furthermore, we predict that ultrafast electron microscopy can be used to trace the rich out-of-equilibrium temporal dynamics of plasmons in graphene samples.

Finally, in Chapter 5, we propose that a high-energy electron beam can be used to experimentally probe the ultrafast nanoscale dynamics of dense charge-carrier plasmas. The interaction between the electron beam and the plasma results in a sizeable electron-beam energy variation as a signature that reveals information about the femtosecond and nanometer time- and length-scale dynamics of the electron cloud. We develop a comprehensive microscopic theory describing this interaction and allowing us to explain recent experimental results. We further propose that the low-frequency and strongly localized electromagnetic fields generated by the electron cloud can be manipulated and optimized via the geometrical characteristics of the system and the optical characteristics of the laser pump.

In summary, in this Thesis we explore the modulation of the nanoscale optical fields that arise from resonant light-matter interactions in different nanostructures, via the optimized shaping of light pulses or the induction of thermal effects. We hope that the results presented in this Thesis contribute to deepen the fundamental understanding of optical excitations at the nanoscale.

Thesis Director: Prof Dr. Javier Garcia de Abajo
Hosted by: Prof. Dr. Javier Garcia de Abajo