Congratulations to New ICFO PhD Graduate

Dr Valerio di Giulio graduated with a thesis entitled ?Nanophotonics with charged particles'

April 12, 2023

We congratulate Dr Valerio di Giulio who defended his thesis today in ICFO's auditorium. Dr di Giulio obtained his MSc in Theoretical Physics from the Sapienza Universita di Roma in Italy. He joined the Nanophotonics Theory research group at ICFO led by ICREA Prof Dr Javier Garcia de Abajo as a PhD student. Dr di Giulio's thesis entitled ?Nanophotonics with charged particles' was supervised by ICREA Prof Dr Javier Garcia de Abajo.

ABSTRACT:

Among the fundamental constituents of matter, charged particles such electrons and positrons are leading protagonists in physical phenomena associated with small (~ meV) and high (~ MeV) energy scales. For example, conductive electrons in condensed-matter systems can collectively respond to the action of an external electromagnetic field and sustain

plasmon excitations that dominate their visible optical behavior. The presence of material boundaries produces a dramatic modulation of such modes, allowing us to mold their interaction with light for the exploration of fundamental phenomena and the design of practical applications, which are central themes in the field of nanophotonics.

Electrons traveling in free space, such as those in electron microscopes, constitute ideal probes for imaging materials with nanometric resolution. In an effort to push energy resolution down to the meV regime and simultaneously perform time-resolved measurements with fs precision, laser and electron pulses in transmission electron microscopes can now be synchronized to meet at the specimen in the so-called photon-induced near-field electron microscopy (PINEM). Here, efficient electron coupling to intense laser-driven evanescent fields results in a strong energy reshaping of the electron wave function. Over the last decade, PINEM has been used to tailor the wave function of free electrons, thus emphasizing the role of these microscopy probes as information carriers.

This Thesis lies in this general and broad context as an effort to explore new scenarios in the interaction between free electrons and optical excitations. In particular, Chapter 2 addresses the theoretical investigation of quantum-mechanical aspects associated with PINEM interaction by means of a quantum-optics description of the optical field. Building up on those results, in Chapter 3 we show that improved control over electron pulse shaping, compression, and statistics can be gained by replacing coherent laser excitation by interaction with quantum light, such as phase- and amplitude-squeezed optical fields.

Chapter 4 explores the role played by fluctuations of the electromagnetic vacuum in the coupled dynamics of a free-electron beam and a macroscopic object, producing elastic diffraction and decoherence. In particular, we show that diffraction can dominate over decoherence, therefore suggesting a nondestructive approach to microscopy based on the specific choice of parameters that minimize the inelastic interaction with the specimen.

As a radically different aspect of electron-light interaction, Chapter 5 is devoted to the study of the interference produced in the cathodoluminescence emission by the synchronized interaction of free electrons and dimmed laser pulses scattered by the specimen. Here, we argue that such effect may enable measurements combining the spectral and temporal selectivity of the light with the atomic resolution of electron beams to resolve the phase associated with optical modes in the sample.

In Chapter 6, we consider that elastic diffraction, similar to that studied in Chapter 4, is also experienced by conduction electrons in a two-dimensional material, therefore altering the properties of the latter by simply adding a neighboring neutral structure.

Going to higher energy scales, Chapter 7 explores the potential of confined optical modes to assist electron-positron pair production arising from the scattering of gamma rays by surface polaritons propagating along a material interface.

In summary, throughout this Thesis we exploit the coupling between evanescent light, harnessed in the vicinity of material boundaries, and charged free particles in order to access new effects only found at the point where nanophotonics, quantum optics and high-energy physics meet through strong light-matter interaction.

Thesis Committee:

Prof. Dr. Mathieu Kociak, Universite Paris-Saclay

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Thesis Committee