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Enhorabona a la nova graduada de doctorat de l'ICFO

La Dra. Yina Wu s'ha doctorat amb una tesi titulada ï¿½Theoretic l aspects of the interaction of free and tunneling electrons wi h low-dimensional photonic systemsï¿½

October 24, 2025

Felicitem la Dra. Yina Wu que aquest mati ha defensat la seva tesi a l'Auditori de l'ICFO.
La Dra. Wu va obtenir el Master en Enginyeria per la Universitat de Xiamen a Xina i es va unir a l'equip d'investigacio Nanophotonics Theory dirigit pel professor ICREA Dr. Javier Garcia de Abajo. La seva tesi titulada ï¿½Theoretical aspects of the interaction of free and tunneling electrons with low-dimensional photonic systemsï¿½ va ser dirigida pel professor ICREA Dr. Javier Garcia de Abajo.

RESUM:

Light has long served as a fundamental probe in scientific observation, yet conventiona optical microscopy faces an inherent limitation in spatial resolution. In 1873, Ernst Abb formulated the diffraction limit, establishing a fundamental barrier: traditional microscope cannot resolve features smaller than approximately half the wavelength of light (on the orde of a few hundred nanometers in the visible)1. This restriction rendered viruses, proteins, an other nanoscale structures beyond the reach of optical observation.

Pushing observation to the nanoscale demanded transcending the limits of classical optics. This can be done by moving from photons to electrons, with a substantial reduction in the corresponding wavelength. Current state-of-the-art aberration-corrected STEM-EELS instruments can resolve spectral features with meV-scale energy resolution while maintaining sub-?angstrom spatial precision2,3, enabling direct visualization of electromagnetic near-fields and dark excitations inaccessible to conventional optical microscopy techniques4. In STEM-EELS systems, the electron beam is used to excite localized electromagnetic modes within a sample, generating characteristic energy losses associated with plasmons, phonons, and hybrid polariton modes.

This thesis mainly explores electron-driven photon emission and polaritons at the nanoscale. First, we discuss the basics of plasmons and phonons as polaritons that can be sampled through electron microscopy. The corresponding theoretical frameworks are presented in Chapter 2 and Chapter 3. Specifically, in Chapter 2, we study infrared plasmons in

fluorine-doped indium oxide nanocube dimers. By bringing two cubes close together and observing the energy loss experienced by the electrons, we observe how their infrared plasmons change when the cubes are approached and nearly touching at a point, along an edge, or over a face. We observe that a sharp low-energy mode appears only for point or line contacts and vanishes once the cubes are pulled apart, thus establishing a nonsingular transition between the regimes of cube touching and non-touching.
Complementing these plasmonic polaritons with an electron beam, Chapter examines the excitation of vibrational phonon polaritons in a finite hexagonal boron nitride nanostructure. We build an atomistic framework based on first-principles calculations to investigate the vibrational phonon modes, showing that nonlocal effects are important to be considered and that the simple local model fails to capture some key features of these modes. This study bridges the gap between bulk material properties and nanoscale behavior, demonstrating that nonlocal effects and surface interactions are indispensable for understanding phonon polaritons in confined systems. Unlike passive probe techniques such as EELS, integrated nanophotonic devices require active, electrically driven light sources. One promising approach utilizes light emission from inelastic electron tunneling (LIET) in metal-insulator-metal (MIM) junctions, where tunneling electrons exhibit ?angstrom-scale wavelengths 5,6. Specifically, in Chapter 4, we move from passive probing to active emission. We design an MIM tunnel junction covered by a gold antenna metasurface. When electrons tunnel across a thin oxide layer, they lose energy and emit photons. The system is complemented by plasmonic antennas that boost this weak process, producing bright and uniform light emission from a large area. Theory matches the measured spectrum and shows that the resulting devices can detect changes in the refractive index of thin films placed on top of the metasurface, thus serving as sensors in which no external light is required.
In summary, this work helps us gain new insights into how electrons can both reveal and generate optical fields on the nanometer scale by combining advanced microscopy techniques with detailed theoretical work. These findings could lead to practical applications in sensors, light sources, and photonic circuits based on plasmons and phonon polaritons in low-dimensional materials.

Tribunal de Tesi:

Prof. Dr. Niels Asger Mortensen, University of Southern Denmark
Prof. Dr. Adrian Bachtold, ICFO
Prof. Dr. Alejandro Manjavacas Arevalo, Consejo Superior de Investigaciones Cientificas

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