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# Felicidades al nuevo graduado de doctorado del ICFO

## El Dr. Sergi Batlle Porro se ha doctorado con una tesis titulada "Near-field photocurrent in correlated 2D moire materials"

May 30, 2025

Felicitamos al Dr. Sergi Batlle Porro que ha defendido su tesis esta manana en el Auditorio del ICFO.

El Dr. Batlle Porro obtuvo su Master en Fisica por la Universidad de Luxemburgo, antes de unirse al grupo de investigacion de Quantum Nano-Optoelectronics dirigido por el profesor ICREA en ICFO el Dr. Frank Koppens. Su tesis titulada "Near-field photocurrent in correlated 2D moire materials" ha sido supervisada por el Prof. Dr. Frank Koppens y el Dr. Petr Stepanov.

**RESUMEN:**

Since the discovery of graphene, two-dimensional (2D) materials have garnered significant attention from the condensed matter physics community owing to their potential to engineer new physical, optical, and mechanical properties. The 2D material class now includes insulators (hexagonal boron nitride, hBN), semiconductors (transition metal dichalcogenides, TMDs), superconductors (NbSe2), topological insulators (Bi2Te3), and ferromagnets (CrI3). Beyond their inherent properties, layered materials allow for new characteristics through vertical stacking. Recent developments have led to the discovery of moire materials, in which electronic properties are significantly altered by twisting adjacent 2D layers.

The discovery of superconductivity in magic-angle twisted bilayer graphene (MATBG) marked a milestone in moire physics, initiating a rapidly growing field. The resulting phase diagrams of other high-Tc superconductors, MATBG, serve as a platform for exploring highly tunable strongly correlated states. At a twist angle of approximately 1.1°, the "magic angle,ï¿½ MA BG shows significant band flattening near the Dirac points, reducing the Fermi velocity nd making the kinetic energy smaller than the repulsive Coulomb interactions. This results in superconductivity and various emergent phases dominated by many-body physics, includ ng correlated insulators, orbital magnetism, nematic orders, and topological states.

Moire materials with large superlattice unit cells facilitate the exploration of strongly correlated phenomena at low charge carrier densities. Local back-gate electrodes enable capacitive tuning between strongly correlated states in-situ, a unique feature not available in other high-Tc superconductors. Advances in scanning probe techniques have allowed researchers to determine local properties at the sub-nanometer scale. Scattering-type scanning near-field optical microscopy (s-SNOM) is particularly suited for exploring MATBG because it can measure scattering and photovoltage signals at the nanometer scale while simultaneously probing mesoscopic electron transport.

Utilizing a groundbreaking cryo-near-field nanoscopy method, we will conduct s-SNOM measurements at cryogenic temperatures (as low as 8 K) to assess the optical and photovoltage near-field responses. This approach employs energies in the mid-infrared (MIR) and terahertz (THz) ranges, which align with the anticipated optical transition energies in the band structures of these materials.

The primary objectives of this thesis are to ascertain the pertinent optical and thermoelectric coefficients in twisted moire materials, evaluate the impact of inhomogeneities through gate-tuned near-field photovoltage and optical measurements, visualize correlated phenomena and broken symmetry states, and comprehend the nature of dephased signals in various measurements. This dissertation seeks to highlight crucial advancements in quantum phases, quantum nano-optoelectronics, and thermoelectricity, while supporting interest in unresolved questions, such as the characteristics of low-temperature correlated states. Additionally, it outlines future objectives for near- and far-field photovoltage experiments.

**Tribunal de Tesis:**

Prof. Dr. Justin Chien Wen Song, Nanyang Technological University

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