Enhorabona al nou graduat de doctorat de l'ICFO

El Dr. Alvaro Moreno Abajo s'ha doctorat amb una tesi titulada ï¿½ Optical investigation of 2D materials with in-plane engineering: exciton confinement and chirality sensing"

July 20, 2026

Felicitem el Dr. Alvaro Moreno Abajo que ha defensat la seva tesi aquest mati a l'Auditori de l'ICFO.

El Dr. Moreno Abajo va obtenir el seu Master en Fotonica per la Universitat Politecnica de Catalunya, abans d'incorporar-se al grup de recerca de Quantum Nano-Optoelectronics dirigit pel professor ICREA d'ICFO el Dr. Frank Koppens. La seva tesi titulada "Optical investigation of 2D materials with in-plane engineering: exciton confinement and chirality sensing" ha estat dirigida pel professor ICREA Dr. Frank Koppens i el professor Dr. Antoine Reserbat-Plantey.

RESUM:

Two-dimensional (2D) materials provide a powerful platform for nanoscale engineering and control of geometry and energy landscapes without directly modifying the material, owing to their interfacial nature. This thesis explores how we can harness this potential by introducing in-plane engineering in van der Waals heterostructures. We present two case studies: in one, the exciton dimensionality is reduced using a designed 1D electrostatic trap; in the other, twisting two monolayers yields a chiral configuration that modifies the interaction with other chiral systems. Together, these two parts demonstrate how inplane symmetry breaking (translational and mirror symmetry, respectively) in 2D material platforms enables new modalities of control and sensing.

In the first part, we investigate electrostatically defined confinement of intralayer excitons in MoSe2. A p-i-n junction is induced in the monolayer by asymmetric gating, creating a tight 1D potential with an effective exciton confinement length down to 10nm. Combining photoluminescence and reflectance-contrast spectroscopy, we resolve a discrete spectrum of localized states arising from center-of-mass quantization, with linear polarization aligned with the trap geometry, consistent with confinement-enhanced valley-exchange interactions. Importantly for the development of this technique, we show that the confinement potential cannot be understood as a purely electrostatic effect. Illumination reshapes device operation by inducing dissociation-driven photo-doping and Auger-assisted charge extraction, thereby stabilizing a working p-i-n configuration. We resolve photoinduced carrier-redistribution dynamics on the scale of seconds and demonstrate that their dependence on excitation position produces sharp switching between confined and unconfined excitonic responses. A rate-equation description captures the competition between dissociation and Auger processes, highlighting a route to nonlocal optical control of carrier density and, consequently, of the confinement potential. Programmable excitonic potentials that reach the 0D limit could enable quantum technologies such as single-photon sources or optically addressable qubits, and open a route toward strong exciton-exciton interactions and Bose-Hubbard physics.

In the second part, we leverage the structural chirality of twisted bilayer graphene (TBG) to realize a novel enantiomeric sensing strategy based on chirality-dependent non-radiative energy transfer. In the presence of TBG, the decay rate of chiral fluorophores is modified depending on handedness matching between molecule and substrate, which we read out by measuring the fluorescence lifetime in time-resolved photoluminescence experiments. The observed asymmetry is statistically tested by spatially resolving the enantioselective contrast, observing a sign reversal upon inversion of the TBG handedness, and exploring the role of the twist angle as a control parameter. We quantify the effect of chirality through a lifetime-based dissymmetry factor that reaches the 1 - 10% level, implying an enhancement of several orders of magnitude compared with the natural optical circular dichroism of both the molecule and TBG. The presented approach is conceptually distinct from schemes that rely on electromagnetic field engineering, and achieves sensitivities down to the single-molecule layer without requiring surface functionalization. This opens the door to developing a

platform with tunable, strong chiral light-matter interactions with implications in optics, sensing, and chemistry, including chiral catalysis and homochiral synthesis.

Tribunal de Tesi:

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