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Felicidades al nuevo graduado de doctorado del ICFO

El Dr. Krystian Nowakowski se ha doctorado con una tesis titulada ï¿½Graphene-based Moire superlattices under opto-electron c spotlight: Bloch oscillations, single photon detection, a d polarization-resolved photocurrentsï¿½

December 11, 2024

Felicitamos al Dr. Krystian Nowakowski que ha defendido su tesis esta manana en la sala Elements del ICFO.
El Dr. Nowakowski obtuvo su Master en Nanotecnologia por la University of Twente, en los Paises Bajos, 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 ï¿½Graphene-based Moire superlattices under opto-electronic spotlight: Bloch oscillation , single photon detection, and polarization-resolved photocurrentsï¿½ha sido supervisada por el Prof. Frank Koppens.

RESUMEN:

In the last two decades, two-dimensional (2D) materials have captivated the scientific community thanks to their surprising characteristics and technological potential. Significant advancements in the understanding of their properties have opened up promises of applications in the electronics, photonics, sensing, and energy sectors.
One of the most unprecedented prospects is the ability to freely combine various 2D materials into heterostructures. The 2D layers can be twisted with respect to each other, enabling a novel tuning mechanism in the solid-state physics toolbox. Introducing a few-degree angle between the layers can create a superlattice structure because of th moire effect, allowing one to tune the material band structure. Graphene-based moir superlattices have become a focal point of research in recent years, facilitating the design o many exotic phenomena and effectively bridging the fields of strongly correlated electrons 2D materials, and topological physics. Optical measurements of these materials wer non-existent at the inception of this thesis, prompting the investigation presented herein.
In the first part of this thesis, the initial goal was to understand the photoresponse mechanisms of these materials using optoelectronic techniques in the mid-IR wavelength range. Our study reveals a nontrivial polarization-dependent photocurrent response in

graphene-based materials. This response can significantly affect the measured signals and exhibit complex spatial patterns. A novel approach was developed to extract spatial maps of polarization-dependent components.

One potential responsible mechanism is the bulk photovoltage effect (BPVE) response. BPVEs are second-order photocurrent generation mechanisms that are intricately connected to the quantum geometric tensor, reflecting the phase of the electron wavefunctions and distances between quantum states. Measuring BPVEs can provide insights into the underlying quantum nature of electronic states in moire materials. We discuss role BPVEs in our results and the potential artifacts that can mimic it as well as the methodology and insights that are fundamental for discerning these different contributions.

In the second part of this thesis, we report the discovery of negative differential conductance (NDC) in the high-bias regime in bilayer graphene aligned with hexagonal boron nitride. The NDC probably arises from Bloch oscillation-like mechanisms enabled by a folded band structure of the \moire superlattice. From the NDC we engineer a bi-stable state and demonstrate its sensitivity to single photons. This moire single photon detector (MSPD) can operate at wavelengths from 675 nm to 11.3 um (and beyond) and up to temperatures of 20 K, a combination that remains elusive in the single-photon detector field. The design is compact, CMOS-compatible, and array-integrable, presenting exciting opportunities for upscaling.

This is the first observation of Bloch oscillations in a 2D system, enabling the entire arsenal of highly versatile experimental methods suited to these material platforms. We introduce spatially resolved photocurrent measurements as a pioneering technique for visualizing the Bloch oscillation regions. This advancement could lead to new high-frequency electronics and optoelectronic applications in addition to single-photon detection.

This thesis lays the groundwork for further exploration of BPVE effects and high-bias phenomena in moire superlattices and promising breakthroughs in Bloch oscillations, 2D optoelectronics, and photodetector technologies. These findings significantly advance our understanding of both the applied and fundamental physics in these systems, while also introducing crucial methodological innovations for future research in optoelectronics and photodetection.

Tribunal de Tesis:

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