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PhD THESIS DEFENSE | Graphene-based Moire superlattices under opto-electronic spotlight: Bloch oscillations, single photon detection, and polarization-resolved photocurrents

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10:30

Elements Room and Online (Teams)

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 photorespons mechanisms of these materials using optoelectronic techniques in the mid-IR wavelengt range. Our study reveals a nontrivial polarization-dependent photocurrent response i graphene-based materials. This response can significantly affect the measured signals an exhibit complex spatial patterns. A novel approach was developed to extract spatial maps o polarization-dependent components

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

In the second part of this thesis, we report the discovery of negative differential conductanc (NDC) in the high-bias regime in bilayer graphene aligned with hexagonal boron nitride. Th NDC probably arises from Bloch oscillation-like mechanisms enabled by a folded ban structure of the \moire superlattice. From the NDC we engineer a bi-stable state an demonstrate its sensitivity to single photons. This moire single photon detector (MSPD) ca 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 i compact, CMOS-compatible, and array-integrable, presenting exciting opportunities fo upscaling

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

This thesis lays the groundwork for further exploration of BPVE effects and high-bia phenomena in moire superlattices and promising breakthroughs in Bloch oscillations, 2 optoelectronics, and photodetector technologies. These findings significantly advance ou understanding of both the applied and fundamental physics in these systems, while als

introducing crucial methodological innovations for future research in optoelectronics an photodetection

Wednesday December 11, 10:30 h. ICFO Elements room and Online (Teams)
Thesis Director: Prof Dr. Frank Koppens
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