PhD THESIS DEFENSE: Probing Magic-Angle Twisted Bilayer Graphene with Monolithic Gate-Defined Josephson Junctions

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10:00
ICFO Auditorium and Online (Teams)

In 2018, following a theoretical prediction from 2011, it was found that stacking two layers of graphene with a relative twist angle of 1.1° between them leads to multiple new properties. A this so-called magic angle, the electronic band structure of the material reconstructs creating a narrow flat band at the Fermi level. The formation of a flat band enhance electron-electron interactions, resulting in the emergence of states of matter not present i the original graphene layers, including correlated insulators, superconductivity ferromagnetism and non-trivial topological states. The understanding of the origin of thes correlated states could help unravel the physics of highly correlated flat band systems whic

could potentially provide key technological developments
The main objective of this thesis is to study magic-angle twisted bilayer graphene (MATBG by creating monolithic gate-defined Josephson junctions. By exploiting the rich phase spac of the material, we can create a Josephson junction by independently tuning th superconductor and the weak link state. Studying the Josephson effect is a first step toward understanding fundamental properties of a superconductor, such as its order parameter
First, we have optimized the fabrication of these gate-defined junctions made of all van de Waals materials. We have made double-graphite-gated hBN encapsulated MATBG device where the top gate is split into two parts via nanolithography techniques. This configuratio allows to independently control the three regions of the Josephson junctio (superconductor, weak-link and superconductor). Then, we have studied the gate-define Josephson junctions via low-temperature transport measurements. After demonstrating th Josephson effect in the fabricated devices, we focus on the behavior of one of thes junctions in great detail
In particular, we have observed an unconventional behavior when the weak link of th junction is set close to the correlated insulator at half-filling of the hole-side flatband. W have observed a phase shifted Fraunhofer pattern with a pronounced magnetic hysteresis characteristic of magnetic Josephson junctions. To understand the origin of the signals, w have performed a critical current distribution Fourier analysis as well as a tight bindin calculation of a MATBG Josephson junction. Our theoretical calculations with a valle polarized state as the weak link can explain the key signatures observed in the experiment Lastly, the combination of magnetization and its current-induced magnetization switchin has allowed us to realize a programmable zero-field superconducting diode
Finally, we have shown the flexibility of these devices by studying a MATBG p-n junctio under light illumination. We have studied the relaxation dynamics of hot electrons using tim and frequency-resolved photovoltage measurements. The measurements have revealed a ultrafast cooling in MATBG compared to Bernal-bilayer from room temperature down to 5 K The enhanced cooling in MATBG can be explained by the presence of the moire pattern an corresponding mini-Brillouin zone
In summary, we have demonstrated that by integrating various MATBG states within a singl device, we can gain a deeper insight into the system's properties and can enginee innovative, complex hybrid structures, such as magnetic Josephson junctions an superconducting diodes

Thursday May 23, 10:00 h. ICFO Auditorium and online via Teams
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