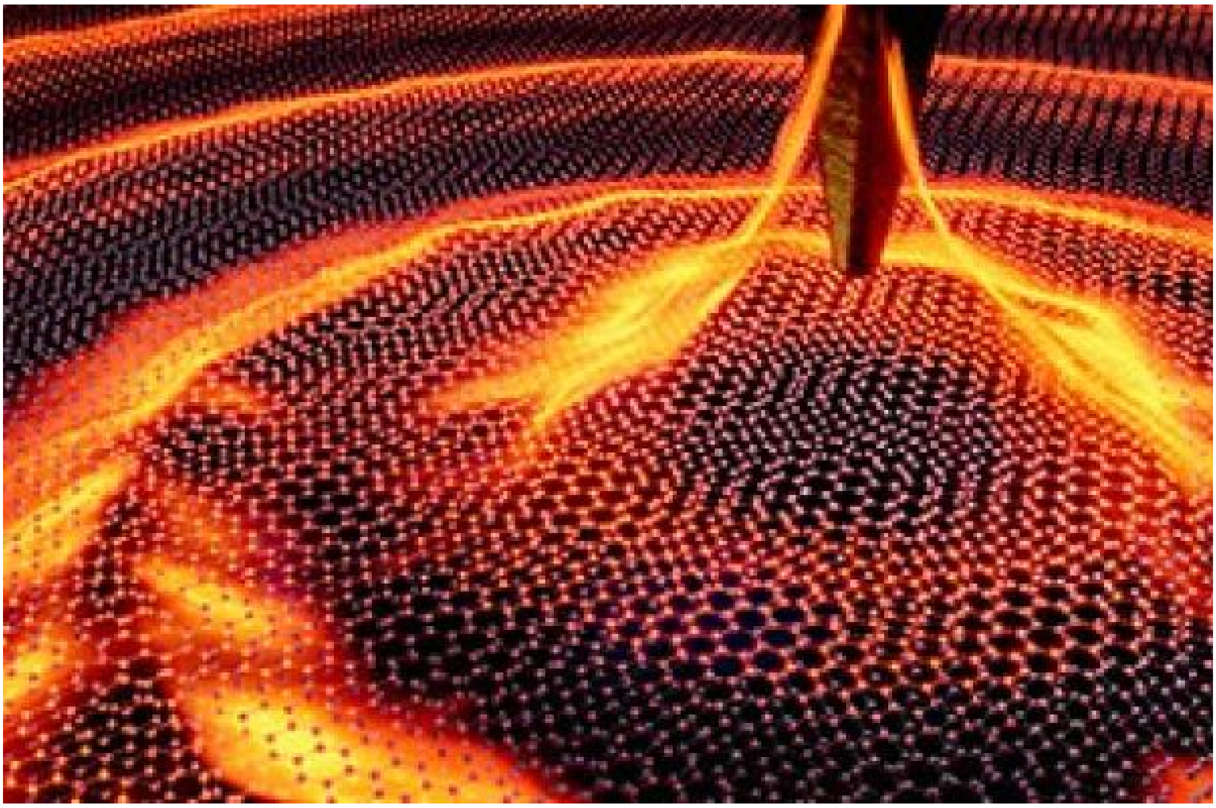


PhD THESIS DEFENSE: Exploring Twisted Bilayer Graphene with Nano-Optics

NIELS CASPAR HERMAN HESP

October 20, 2021

15:30 to 17:30

ICFO Auditorium and Online (Teams)

Nano-optics studies the behaviour of light on the nanoscale. In particular, it probes the interaction of light with objects, often of nanometre-size, and reveals fine details of the material's optical properties. Optoelectronics is an integral part of optics and describes the interaction between light and electronics, such as the detection of light and subsequent conversion to an electrical signal. Understanding such mechanisms at the nanoscale is of importance for improving imaging and light-harvesting applications. In this Thesis, we apply near-field microscopy to study optics on the nanoscale. It probes optical properties using light interacting with the near-field electromagnetic field near the material's surface.

Twisted bilayer graphene (TBG) is formed by stacking two layers of graphene - a one-atom-thick sheet of carbon atoms - with a small twist angle. This causes an interference pattern in the atomic lattice called a moire pattern, which affects the electronic properties dramatically. The discovery of unconventional superconductivity in TBG in 2018 made it a thriving field of research. Adding to this, TBG revealed strongly correlating states and topological features, making it a host of tunable exotic phases that may shed light on the origins of unconventional superconductivity. These phenomena motivate us to study the optical properties of TBG on a nanoscale, which have received little attention thus far.

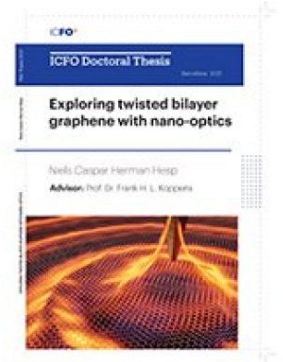
In the first part of this Thesis, I describe spatially oscillating patterns within selected regions of TBG that we detected using near-field microscopy. We interpret them as a manifestation of plasmons --- electrons moving collectively in a wave-like pattern --- driven by interband transitions. We model these areas with a reduced interlayer coupling, which enhances the strength of interband transitions and explains the observed plasmon dispersion.

After this, I discuss large-scale periodic features observed in minimally twisted bilayer graphene (?
I focus in the second part of the Thesis on the development of new experimental techniques, which enable nano-optical studies on exotic states of TBG and its relatives. I show that the semiconducting material WSe_2 can be used as an ambipolar transparent top gate for infrared near-field experiments. This enables full control of the carrier density and transverse displacement field without blocking near-field access.

Hereafter, I describe a commercial cryogenic near-field microscope with a base temperature of 10 K, which required modifications for reliable operation. I present an active damping system to oppose the vibrations in the system and enhance the mechanical stability. We further improve the AFM stability by changing the AFM excitation position.

In the final two Chapters I examine the photoresponse of TBG at low temperature. We observe semi-periodic modulations across our sample, which we believe manifests a second-order superlattice arising from TBG aligned to the hBN substrate in combination with strain. In a different sample, we reveal a spatially inhomogeneous response from which we deduce a map of the local twist angle.

Hosted by: Frank Koppens



Niels Caspar Herman Hesp's Thesi Cover