Moiré materials for infrared and THz technologies

FLAG-ERA 2022 Project Workshop
21st March 2022

This work is supported by the FLAG-ERA grant [PhotoTBG], by ICFO, RWTH Aachen and ETHZ/Department of Physics

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Introduction

[Call: FLAG-ERA JTC2021]

- **Duration:** 36 months (1 December 2021 – 30 November 2024)
- **Partners:** ICFO (coordinator), RWTH Aachen and ETHZ/ Department of Physics

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PhotoTBG team

ICFO (Coordinator)

- Photocurrent studies in 2D materials
- non-linear quantum transport in moiré superlattices

F. Koppens

R. Krishna Kumar

RWTH Aachen

- quantum transport in pristine gapped graphene

C. Stampfer

B. Beschoten

ETHZ

- THz and mid-infrared QCL experts

G. Scalari

J. Feist

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Motivation: Superlattices for Optoelectronics

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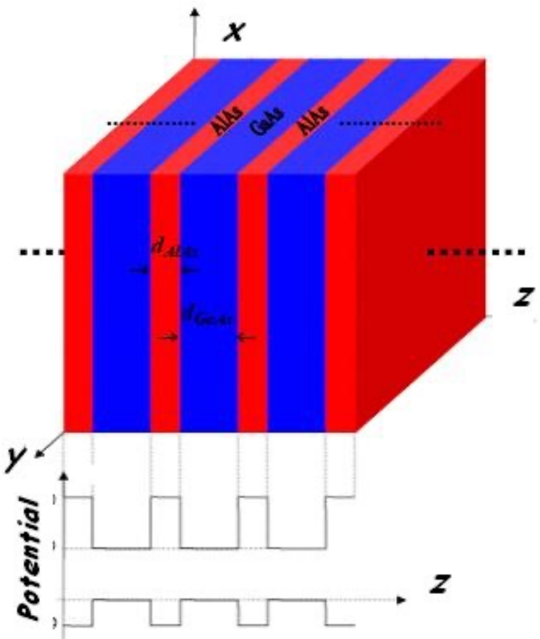
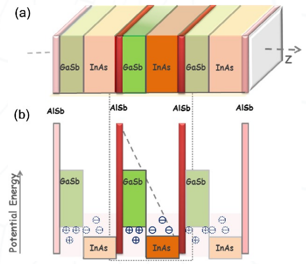
Esaki and Tsui superlattices

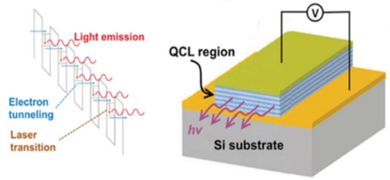


Detection technologies

State of the art infrared detectors
And THz detectors



Emission technologies



Quantum cascade lasers!

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a new generation of superlattice engineering

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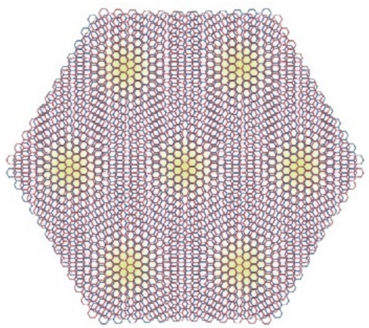
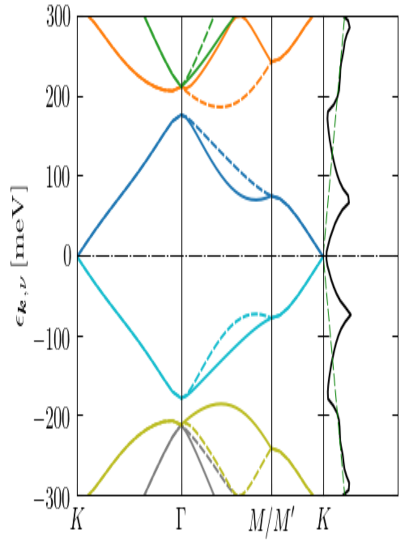
Moire

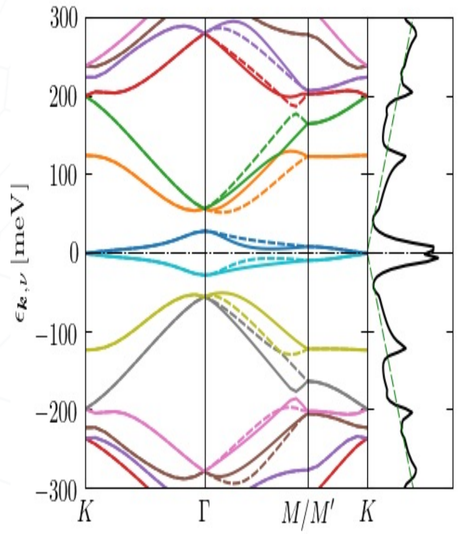


$\lambda \sim 10\ nm$

$\theta = 1.8^o$



$\theta = 1.1^o$



- Tunable spectral gaps ranging from 10-100 meV
- narrow electronic bands with high oscillator strength and non-trivial topology
- Small Brillouin zone

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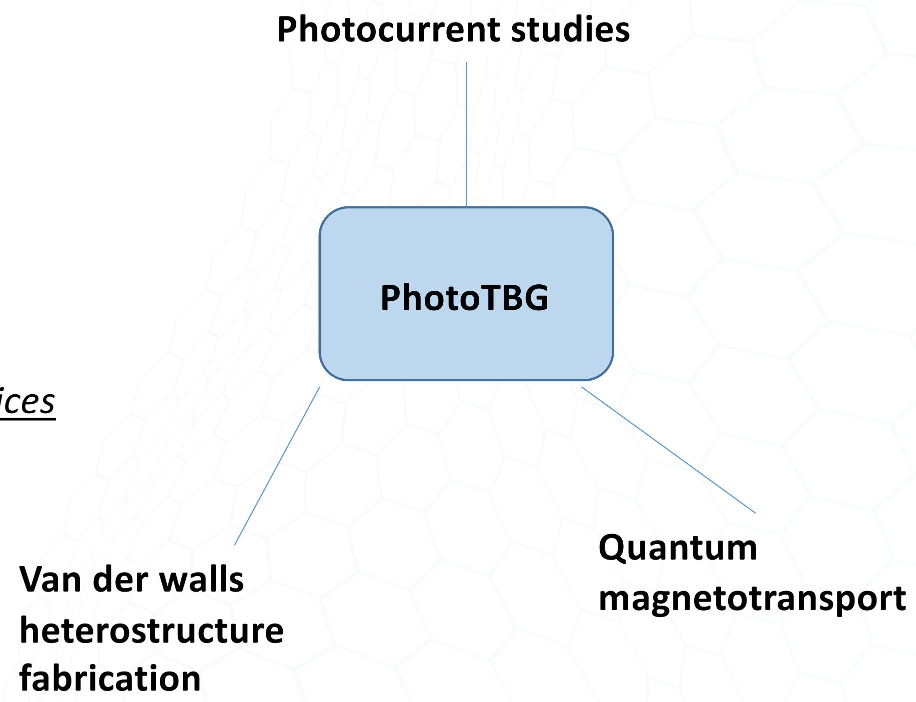
Objectives

Detection technologies

- ***Objective 1:** Electrically tuneable Infrared and THz photoconductivity in gapped twisted GRMs*
- ***Objective 2:** Moiré induced topological enhancement of photoconductvity*

Emission Technologies

- ***Objective 3**: Wannier-stark localization in twisted graphene superlattices*
- **Objective 4***: THz emission from Bloch oscillations:*



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Detection – moire photoconductors

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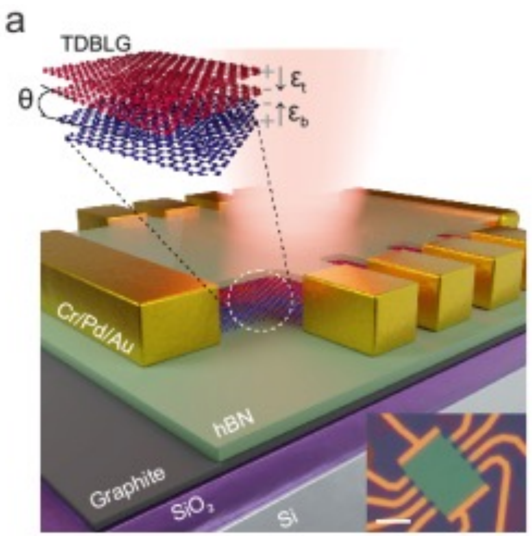
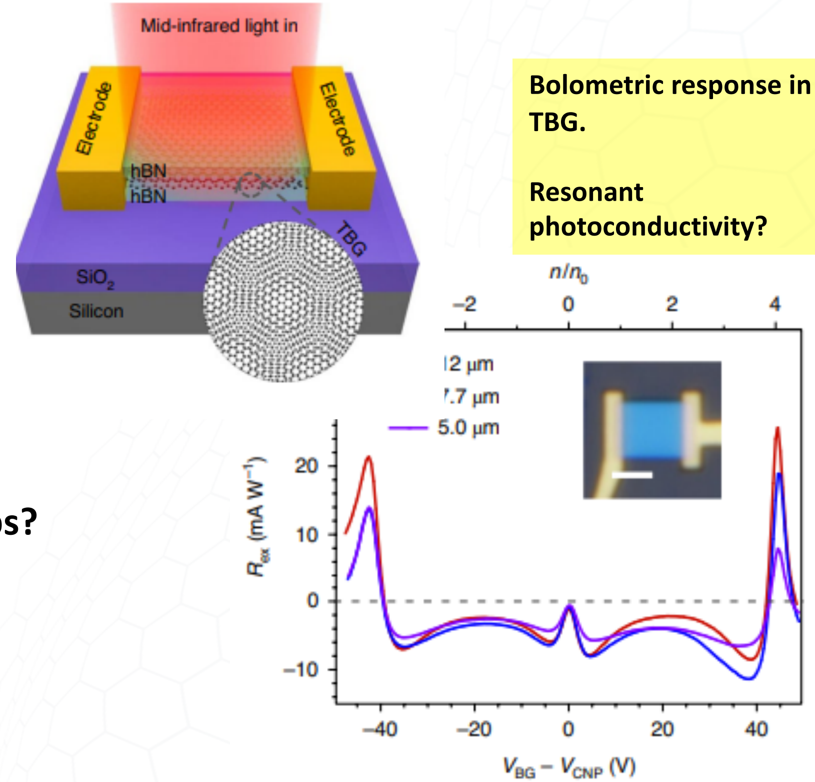
***Objective 1:** Electrically tuneable Infrared and THz photoconductivity in gapped twisted GRMs*



Superlattice gaps?



Bolometric response in TBG.

Resonant photoconductivity?

Gapped graphene-based materials have a very competitive broadband photoresponse

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Detection – bulk photocurrents in moire superlattices

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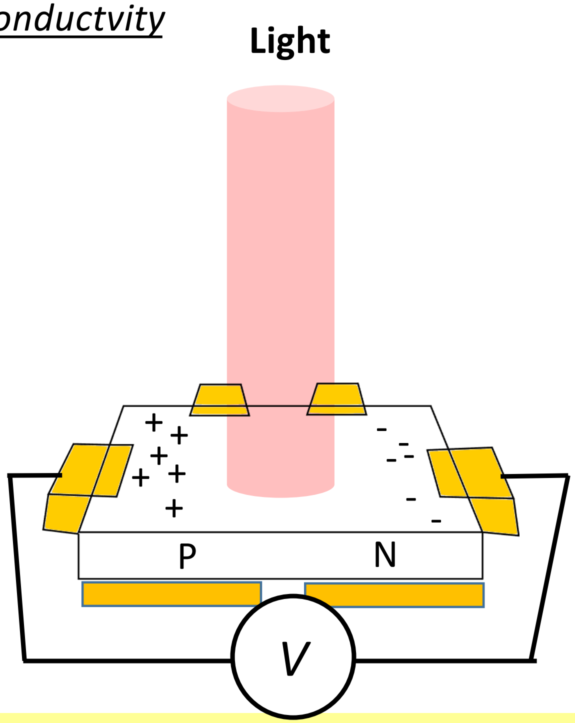
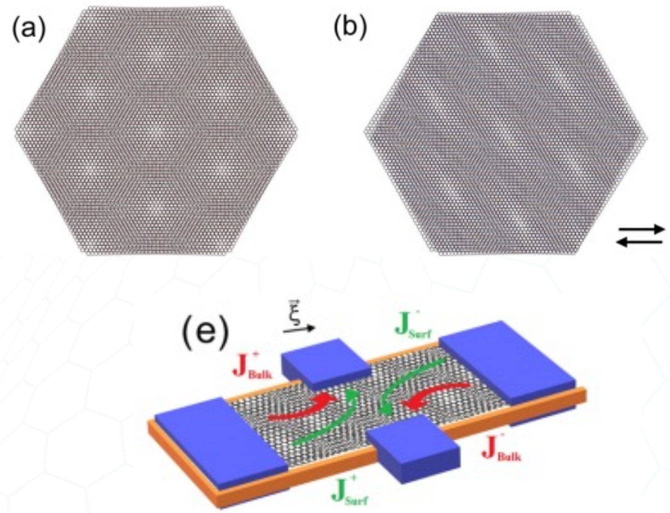
Objective 2: *Moiré induced topological enhancement of photoconductvity*



In graphene-based moiré superlattices, broken inversion symmetry can lead to bulk photocurrents (in the absence of PN junctions)

Moiré induced symmetry breaking



Pierre. A. Pantaleon *et al* Phys. Rev. B 103, 205403 (2021)

Conventional graphene photodetectors require artificially created PN junctions

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Emission – Bloch Oscillations in twisted bilayer graphene

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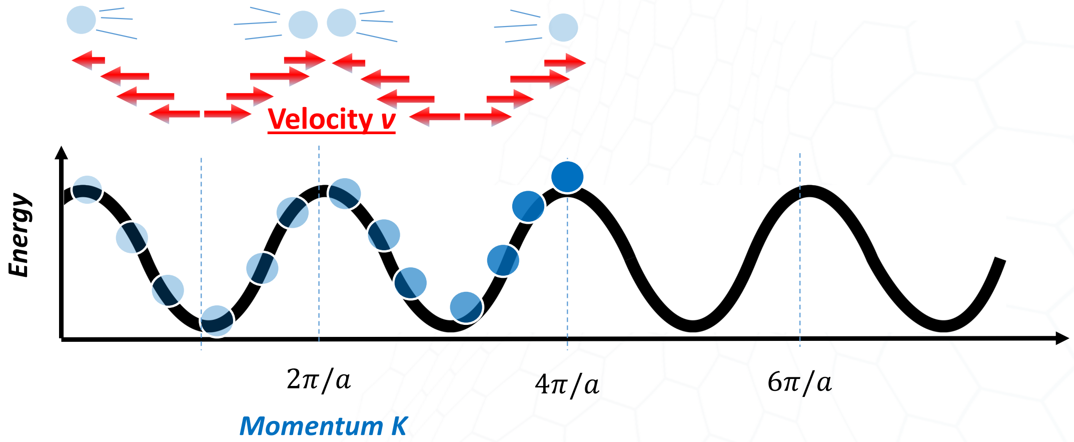
***Objective 3**: Wannier-stark localization in twisted GRM's*:

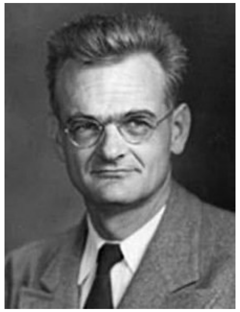
$$k(t) = k(0) - \frac{eE}{\hbar} t.$$

Objective 4: *THz emission from Bloch oscillations:*



Felix Bloch,

Clarence Zener



Bloch frequency

$$\omega_B = \frac{eEa}{\hbar}$$

Time for one period

$$t_B = \frac{\hbar}{eEa}$$

Bloch oscillations is one of the oldest quantum transport phenomena

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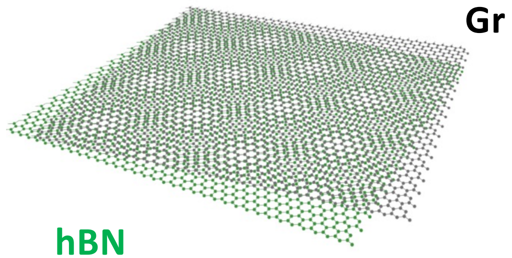
Emission – Bloch Oscillations in twisted bilayer graphene

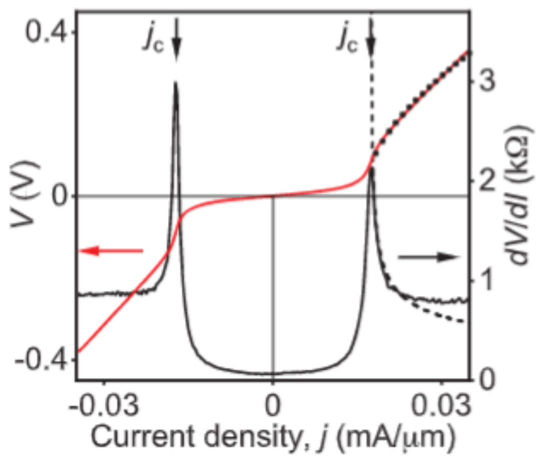
PhotoTBG

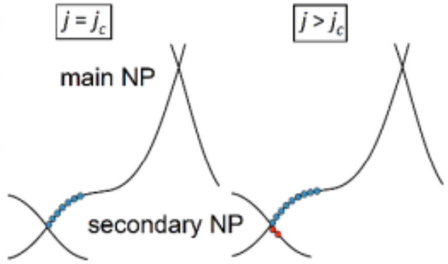
A. Berdyugin….R.Krishna Kumar *et al*
Science 375, 430-433 (2022)

***Objective 3**: Wannier-stark localization in twisted GRM's*:

Objective 4: *THz emission from Bloch oscillations:*







Zener transitions dominate…..There is a need for larger and cleaner gapped systems

The Fermi surface can be biased to the edge of the Brillouin zone!

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Techniques and workflow

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- Infrared and THz photocurrent spectroscopy (far-field and near-field)
- Fabrication of graphene-based moiré superlattices

ICFO

- Photocurrent studies in 2D materials
- non-linear quantum transport in moiré superlattices

- Fabrication of pristine gapped twisted graphene materials.
- Quantum magneto transport

RWTH Aachen

– quantum transport in pristine gapped graphene

- THz magneto photocurrent
- FTIR photocurrent spectroscopy
- Photodetector benchmarking

ETHZ

– THz and mid-infrared QCL experts

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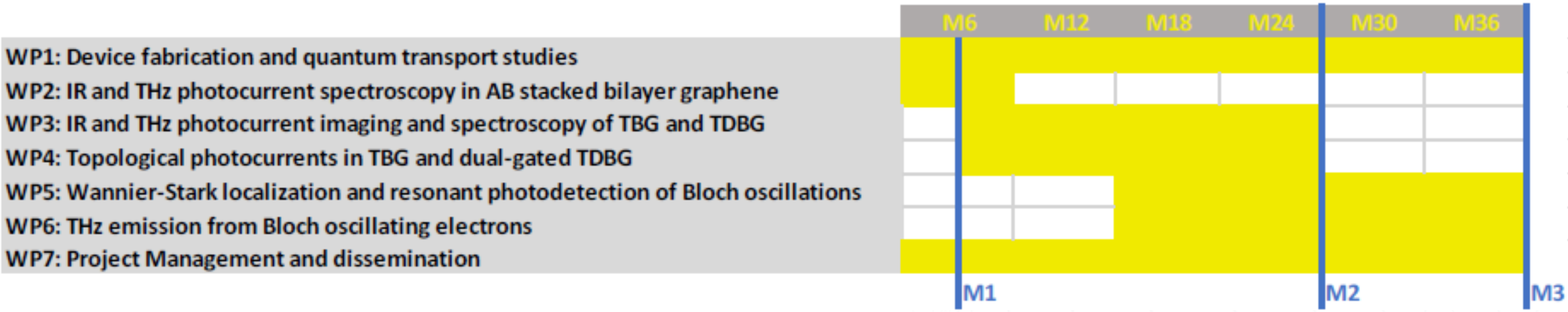
PhotoTBG work plan

WP1 + 2 – Fabrication, characterization and benchmarking of clean gapped twisted graphene systems

WP3 + 4 – Photocurrent spectroscopy in twisted graphene systems

WP5 + 6 – Bloch oscillations – detecting emission



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