M2 Internship

Optical Characterizations of Moiré Photonic Structures in bilayer Photonic crystals

Research group: i-Lum
Main location: INSA de Lyon
Secondary location: Ecole Centrale de Lyon

Keywords: photonic crystals, moiré photonic structures, Fourier spectroscopy, micro-reflectivity

Profile: Physics, Materials Science, Optics/Photonics
Duration: 5/6 months with a perspective to follow a PhD path

Research Project

Context et Objective

In recent years, the exploration of moiré patterns has unlocked a treasure trove of fascinating phenomena in the realm of materials science and nanophotonics. These patterns emerge from the intricate stacking of two periodic structures, resulting in a macroscopic pattern that unveils a complex interplay between the component layers (see Figure 1).

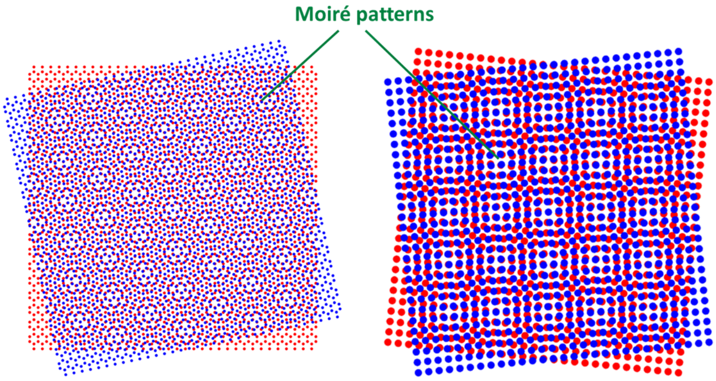
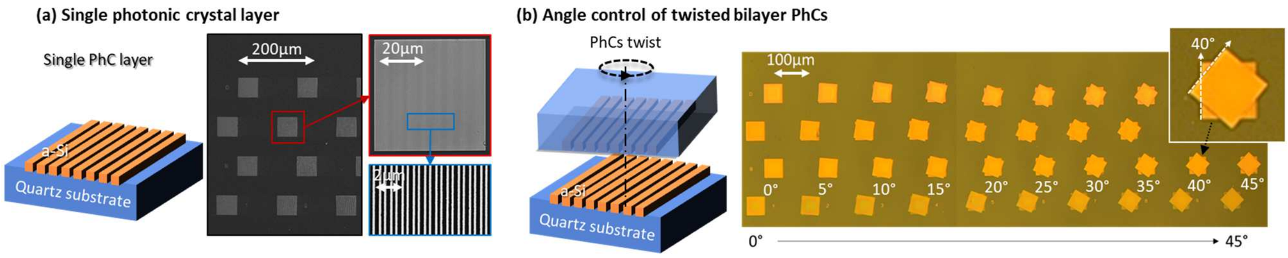


Figure 1: Moiré patterns that emerge when overlay two honeycomb lattices (left) and two square lattices (right) layers at 12° twisted angle.

The moiré patterns, characterized by their variation with the twist angle or lateral shift between the constituent figures, have fueled groundbreaking studies, particularly in the domain of condensed matter physics. When monolayers of two-dimensional (2D) materials such as graphene and transition metals are superimposed, exotic states materialize, marked by localized electron-hole pairs within these bilayer structures. Remarkably, these localizations have heralded the observation of unconventional superconductivity and anomalous fractional quantum Hall effects.

In nanophotonics, moiré structures are also attractive: they consist of two superimposed layers of photonic crystals separated by a distance much smaller than the wavelength, with the second level shifted laterally or angularly (see figure 2(b)). Interest in these 3D photonic structures is very recent: theoretical and simulation studies of the i-Lum team at INL reveal that modes with high quality factors, intensely localized within a moiré pattern's supercell, emerge [1,2]. These unique modes, unattainable in a singular layer of photonic crystals, hold promise in probing robust interactions between light and matter. However, the technological difficulties involved in realizing these structures and the tight constraints on the alignment of the two levels (distance, lateral and angular detuning) have prevented the experimental demonstration of these effects so far.

Most recently, at INL's i-Lum team at INL, we have pioneered a fabrication technique to create photonic moiré structures with varied twisted angles between the layers (see figure 1 (b)). The aim of the internship is to optically characterize these structures and experimentally demonstrate the tunability of the optical properties of the moiré structures (photonic band dispersion, polarization patterns) with the twist angle.



<u>Figure 2:</u> (a) First level of photonic crystals, diagram and electron microscope image. (b) Moiré photonic structures with angular mismatch between 1st level and 2nd level.

In this context, the intern will become an integral part of INL's i-Lum team, specifically contributing to the "Photonic Moiré Structures" project group. Entrusted with the responsibility of conducting angle-resolved micro-reflectivity optical characterizations of moiré structures, the intern will embark on a collaborative journey alongside a dedicated team of researchers, including permanent researchers and PhD students. The intern will collaborate closely with team members who specialize in the fabrication of these intricate structures, as well as with those who are experts in simulating the optical properties of moiré lattices. This synergy aims to meticulously fine-tune the experimental parameters of the structures, fostering conditions conducive to unveiling the exotic effects of light within these captivating moiré patterns.

Profile

The candidate for this role should harbor a passion for experimental work, as the nature of the proposed work is primarily experimental. A particular interest in the optical characterization of photonic structures is essential. Tasks involve utilizing specialized optical setup, which enable the experimental reconstruction of band structures through both angle-resolved and wavelength-resolved micro-reflectivity. Rest assured, comprehensive training on these optical benches will be thoroughly provided to the selected candidate.

We hold in high esteem candidates who possess a robust affinity for fundamental physics. A background in nanophotonics and/or solid-state physics is highly desirable, as it will facilitate a more nuanced engagement with the project's objectives and enhance the overall research process.

Prospectives for Students:

The internship offers a unique opportunity for aspiring scientists to delve deeply into a dynamic scientific environment. Here's what the intern can anticipate:

- <u>Multidimensional Scientific Exposure:</u> Interns will immerse themselves in INL's multifaceted scientific ambiance, which seamlessly amalgamates technological, theoretical, and experimental paradigms, furnishing a well-rounded apprenticeship across diverse spectra of nanophotonics.
- <u>Collaborative Team Dynamics:</u> Becoming a part of the i-Lum team signifies joining a tapestry of devoted minds, ranging from Ph.D. candidates and fellow interns to veteran scientists. The convivial ethos of the group nurtures collaborative learning, reciprocal knowledge sharing, and professional evolution.

- Presentation and Feedback Opportunities: Interns will get chances to showcase their discoveries and advancements during i-Lum team gatherings. Such presentations are instrumental in sharpening communication prowess and garner invaluable, constructive critiques from seasoned members, facilitating the fine-tuning of the research.
- Pathway to a Ph.D: For those enraptured by their research, there exists a potential pathway to further delve into the topic through a Ph.D., allowing for an even more profound exploration and contribution to the field.

Contacts:
Lydie Ferrier – lydie.ferrier@insa-lyon.fr
Hai-Son Nguyen– hai-son.nguyen@ec-lyon.fr

[1] Nguyen, D. X., Letartre, X., Drouard, E., Viktorovitch, P., Nguyen, H. C., & Nguyen, H. S. (2022). Magic configurations in moiré superlattice of bilayer photonic crystals: Almost-perfect flatbands and unconventional localization. Physical Review Research, 4(3), L032031
[2] Saadi, C., Nguyen, H. S., Cueff, S., Ferrier, L., Letartre, X., & Callard, S. (2023). How many supercells are required to achieve unconventional light confinement effects in moiré photonic lattices?. arXiv preprint arXiv:2307.05525