



## **Master in Photonics – “PHOTONICS BCN” Master ERASMUS Mundus “EuroPhotonics”**

### **MASTER THESIS PROPOSAL**

**Full time from April 2026** (it can start part time from February 2026)  
**Presentation date to be chosen: end of July or beginning of September 2026**

**Note:** The main Master Thesis supervisor has to be a professor of the Master in Photonics program. One co-supervisor (internal or external) can be defined. Main Supervisor is responsible for the subject of the proposal and has to give continuous support to the student (research development, Report writing and presentation preparation). For external proposals a co-supervisor from the Master program and a collaboration agreement with UPC are needed. You can find all information about the Master Thesis process in [our webpage](#).

**Laboratory:** Quantum Nanooptoelectronics group

**Institution:** ICFO

**City, Country:** Castelldefels, Spain

**Title of the master thesis:** Light-assisted momentum-resolved tunnelling spectroscopy and microscopy of 2D materials

**Name and affiliation of the master thesis supervisor:** Frank Koppens

**Name and affiliation of the co-supervisor** (if any): Sergi Batlle

(for external proposals a co-supervisor chose among the Master Program professors and a collaboration agreement with UPC is needed)

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**Keywords:**

#### **1. Summary of the subject (maximum 1 page):**

The quantum twisting microscope (QTM) is an emerging scanning probe platform that extends the capabilities of conventional scanning tunnelling microscopy (STM) by incorporating rotational control and van der Waals heterostructure engineering directly into the tunnelling junction. In a QTM, a two-dimensional (2D) material—such as graphene, hexagonal boron nitride, or a transition metal dichalcogenide (TMD)—is placed on the tip side of the STM junction, and the relative twist angle between this probe layer and the sample can be continuously tuned with sub-degree precision. This tunability allows the creation of moiré superlattices directly within the tunnelling interface, offering unprecedented access to twist-dependent electronic phenomena at the atomic and momentum scales.



Unlike conventional STM, where tunnelling occurs locally and primarily probes the real-space density of states, the QTM can access momentum-resolved information through the moiré-induced momentum mixing between tip and sample states. In this way, the QTM bridges real-space imaging and band-structure spectroscopy, enabling a direct mapping of the quasiparticle dispersion and interlayer coupling in complex 2D materials and heterostructures.

Coupling the QTM to light opens a powerful new frontier: light-assisted momentum-resolved tunnelling spectroscopy and microscopy. By illuminating the junction with coherent optical fields—ranging from continuous-wave lasers to ultrafast pulses—one can modulate the tunnelling process via photon-assisted tunnelling and Floquet engineering. This allows selective excitation of electronic transitions in momentum space, control of valley and spin degrees of freedom, and even time-resolved probing of photo-induced band structure dynamics. When integrated with the twist-tuneable moiré interface of the QTM, optical coupling could enable the direct visualization of light-driven band renormalizations, interlayer excitons, and coherent tunnelling phenomena with both spatial and momentum resolution.

Such a hybrid approach—combining quantum twisting microscopy with light-assisted tunnelling—would thus provide a unique experimental window into the interplay between electronic correlations, moiré potential landscapes, and non-equilibrium optical fields in van der Waals materials. This synergy holds promise for exploring light-tuneable quantum phases, nonequilibrium quasiparticles, and the fundamental mechanisms governing quantum coherence in 2D systems.

## 2. Objectives (maximum 1 page):

The first objective is **fabrication of high-quality 2D heterostructures**. The student will prepare graphene-graphene, graphene/hBN-graphene and graphene/TMD-graphene tunnel junction stacks using established dry-transfer and polymer stamp techniques for the tip and the sample. Tasks include exfoliation of monolayers, optical identification, thickness verification via AFM or Raman spectroscopy. The student will produce electrically contacted tunnel junctions optimized for QTM measurements, and document fabrication yield and interface cleanliness.

The second objective is **establishing photon-assisted tunnelling spectroscopy**. The student will integrate continuous-wave or pulsed laser sources into the existing room-temperature QTM, align the optical path to the sample, and implement optical modulation synchronized with lock-in tunnelling measurements. They will work to achieve stable, reproducible  $dI/dV$  spectra under illumination and identify photoinduced features such as tunnelling sidebands, band shifts, or changes in density-of-states contrast.

The final objective is **qualitative spectral and momentum-space analysis**. The student will develop analysis routines to extract band structure information from rotationally and spectroscopically resolved data. Fitting of tunnelling models, they will determine moiré features and light-induced modifications such as excitonic or plasmonic features. Comparison between illuminated and non-illuminated datasets will enable identification of true photoinduced effects.

A secondary objective is **instrument development**, supporting the creation of a new cryogenic QTM with twist-angle control and integrated optical access. The student will assist in assembling nanopositioners and rotational stages, instrument-control scripts, and verifying low-vibration, low-temperature stability. They will participate in UHV preparation, pump-down and bake-out



procedures, and perform initial tunnelling tests to confirm instrument functionality. With the cryogenic and room-temperature instruments operational, the student will be able to target how optical perturbations interact with exotic quantum phases.

Through this project, the student will gain expertise in 2D material fabrication, low-temperature and UHV instrumentation, optical alignment, tunnelling spectroscopy, and Fourier-space  $(r, t) \rightarrow (k, \omega)$  data analysis—contributing to the development of next-generation QTM platforms and to the understanding of light–matter interactions in quantum materials.

**Additional information (if needed):**

\* Required skills: quantum mechanics, solid state, transport, electromagnetism, optics

\* Miscellaneous: python

**References:**

1. Inbar, A., Birkbeck, J., Xiao, J. et al. The quantum twisting microscope. *Nature* 614, 682–687 (2023).
2. Birkbeck, J., Xiao, J., Inbar, A. et al. Quantum twisting microscopy of phonons in twisted bilayer graphene. *Nature* 641, 345–351 (2025).
3. Wang, L., Papadopoulos, S., Iyikanat, F. et al. Exciton-assisted electron tunnelling in van der Waals heterostructures. *Nat. Mater.* 22, 1094–1099 (2023).
4. Wei, N., Guinea, F., von Oppen, F. and Glazman, L.I.. Theory of plasmon spectroscopy with the quantum twisting microscope. *Phys. Rev. B* 112, 155157 (2025).