Master in Photonics – "PHOTONICS BCN"
Master ERASMUS Mundus "EuroPhotonics"

MASTER THESIS PROPOSAL

Starting full time from April 2025
Presentation at the end of July or beginning of September 2025

Laboratory: ICFO, Molecular nanophotoncs, Niek van Hulst
Institution: ICFO
City, Country: Castelldefels

Title of the master thesis:
"Light to charge: photo-current detection of excited state energy flow"

Name of the master thesis supervisor and co-supervisor:
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Keywords :

- fs laser spectroscopy, nanoscale microscopy, transient spectroscopy, superresolution tracking, light-harvesting membranes, photocurrent detection, exciton transport, energy hopping, (de)coherence

Summary of the subject (maximum 1 page) :

We will track the photon-to-electron conversion in light-harvesting complexes, through antenna reaction center complex, by electric read-out. To detect the photo-induced current you can choose one of two complementary techniques: (i) 2D-material devices and (ii) electrochemical detection. The graphene ultrafast photo-thermoelectric response will allow tracing the ps dynamics, potentially at few protein levels. The photo-electrochemical current will allow quantifying the charge separation rate and photon-to-electron efficiency.

For the 2D-materials device, we will explore ultrafast photocurrent detection both in bare and hexagonal boron nitride (hBN)-encapsulated graphene. The devices will be fabricated in collaboration with the groups of Tielrooij (ICN2-Barcelona) and Koppens (ICFO-Barcelona), both specialized in 2D-materials. We will exploit dual action spectroscopy, a photocurrent and luminescence detected Fourier-transform excitation spectroscopy scheme to microscopically map the energy landscape of the 2D material (ref 1). Using our broadband laser and pulse shaper we have already found the photovoltage generation time to be faster than 50 fs due to efficient electron heating. The several-nm-size LH-complex, and even more a membrane will dramatically affect the photocurrent response. Interestingly the light-harvesting and reaction centre complex will experience fast ps quenching of the exciton, but also rapid transfer of the created charge, both in competition with each other. Therefore, tuning of the device layout, spacer layer and thickness will

be important to control the competitive decay channels. The idea is to determine the photovoltage spectrum by tuning through the light-harvesting complex excitation band, and by controlling the back-gate voltage of the graphene device. To this end we will use broadband Fourier excitation spectroscopy and at the same time verify the ultrafast and non-linear response (ref. 1, 2)

Literature:

1. Joseph Wragg, Luca Bolzonello, Ludovica Donati, Karuppasamy Pandian Soundarapandian, Riccardo Bertini, Sefaattin Tongay, Kenji Watanabe, Takashi Taniguchi, Frank H. L. Koppens and Niek F. van Hulst, Dual Action Spectroscopy Exposes the Bright and Dark Excitons of Room Temperature WSe2, *NanoLett* (2024)
2. Manuel López-Ortiz, Luca Bolzonello, Matteo Bruschi, Elisa Fresch, Elisabetta Collini, Chen Hu, Roberta Croce, Niek F. van Hulst, Pau Gorostiza, Photoelectrochemical two-dimensional electronic spectroscopy (PEC2DES) of photosystem I to study charge separation dynamics in photosynthesis, *ACS Appl. Mater. Interfaces,* 16 (33), 43451 – 43461 (2024).
3. Guillermo D. Brinatti Vazquez, Giulia Lo Gerfo Morganti, Cvetelin Vasilev, C. Neil Hunter, Niek F. van Hulst, Structured Excitation Energy Transfer: Tracking Exciton Diffusion below Sunlight Intensity, *ACS Photonics* **11** (3), 1318-1326 (2024).
4. Luca Bolzonello, Matteo Bruschi, Barbara Fresch and Niek F. van Hulst, Non-Linear Optical Spectroscopy of Molecular Assemblies: What Is Gained and Lost in Action Detection? *J. Phys. Chem. Lett.* **14**, 11438−11446 (2023); https://doi.org/10.1021/acs.jpclett.3c02824
5. Brinatti Vazquez GD, Lo Gerfo Morganti G, Block A, van Hulst NF, Liebel M & Tielrooij KJ, 'Spatiotemporal Microscopy: Shining Light on Transport Phenomena. Review paper', *Adv. Electron. Mater.*, 10 (2), 2470009 (2024). Journal Back Cover.
6. Luca Bolzonello, Francisco Bernal-Texca, Luis G. Gerling, Jana Ockova, Elisabetta Collini, Jordi Martorell & Niek F. van Hulst, "Photocurrent-Detected 2D Electronic Spectroscopy Reveals Ultrafast Hole Transfer in Operating PM6/Y6 Organic Solar Cells", *J. Phys. Chem. Lett*. **12**, 3983-3988 (2021)

Additional information (if needed):

Required skills:

Exact Sciences or Physics or Engineering or Nanotechnology or Physical Chemistry.
Interest in experimental research, nanotechnology, sensitive imaging and detection.
Assertiveness and group spirit.

Training outcome:

- Skills: nanofabrication, nanocontrol, single particle detection, super-resolution, ultrafast detection, pulse lasers,
- Insight: advanced imaging, inferometric sensing, Fourier imaging, shot-noise limit of detection, single particle detection.....
- Getting prepared for a PhD project and position;
- Report of master project culminating in a publication.