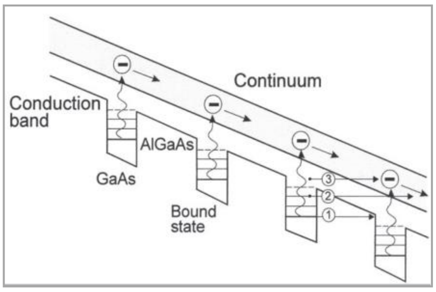
Master 2: **INTERNSHIP PROPOSAL**

Laboratory name: **C2N – Centre de Nanosciences et de Nanotechnologies / Palaiseau**
CNRS identification code: **UMR9001**
Internship director'surname: **Raffaele Colombelli** – raffaele.colombelli@c2n.upsaclay.fr Tel: 01 70 27 06 29
Internship supervision: **M. Jeannin -** mathieu.jeannin@c2n.upsaclay.fr
Web: https://odin.c2n.universite-paris-saclay.fr/en/activities/mir-thz-devices/

Thesis possibility after internship: YES, funded with a research grant

Optoelectronic devices enabled by vacuum field photons

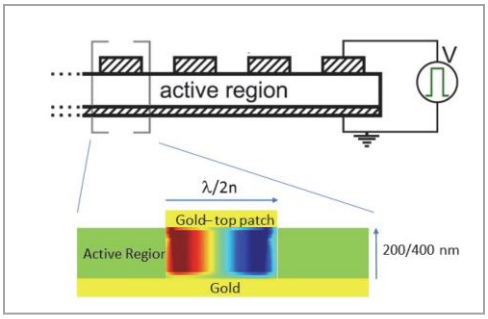
Scientific project: Optoelectronic devices, from light-emitting diodes and solar cells to lasers and detectors, are an integral part of our daily life and are expected to play an increasingly important role in the future. As the basic operating principles of optoelectronic devices are known, their improvement – while important – is often incremental. Finding radically new avenues to implement novel functionalities is very important: cavity quantum electrodynamics (QED) promises new approaches to innovate such devices by exploiting the quantum mechanical principles of strong (SC) and ultra-strong (USC) light-matter coupling regimes [1] in microcavities.



In this regime, even the coupling of a single photon to electronic/molecular excitations exceeds the decay processes, causing the formation of new hybridized states known as polaritons. Taking this coupling to the extreme, the polariton splitting becomes comparable to the unperturbed electronic transition energy. **The sole presence of the cavity can induce modifications of ground and excited states, and therefore of the device electronic behavior.** Such effects have been observed in several systems like organic conductors [2] or two dimensional electron gas [3], and are laying the grounds for the field of polaritonic chemistry [4].

In this context, the project's main goal is to study on a model system how virtual photons – i.e. the sole presence of a cavity – affect its energy levels of and therefore its electronic properties. The model system we will use is a semiconductor quantum heterostructure consisting in a periodic stack of doped quantum wells, operating in the dark and at cryogenic temperatures to ensure that no external photonic or thermal excitation perturbs the system.

The internship we propose is experimental, and aims at measuring the effect of a cavity on the electronic transport in semiconductor heterostructure devices. The active region will be embedded in metal-metal ribbon cavities that strongly confine the electromagnetic field inside the semiconductor active region (see figure below), and current-voltage measurements will be performed as a function of the temperature in a closed-cycle cryostat (from 4K to 200K) AND as a function of the cavity energy. This latter parameter is crucial as it affects the details of the light-matter interaction. An important part of the internship will be devoted to setting up the measurement system (the equipment is already in place), **mostly in terms of automation with a PC *via* programming in python.** The temperature scan needs to be very fine, therefore it is important that the measurements can run automatically controlled by a PC. This will permit to focus on the science, and optimize the quantum active region and/or the resonators in order to maximize the light-matter interaction and the expected effect on the dark transport. This study will be complemented by measurements of the response of mid-infrared detectors operating in the strong coupling regime, to help building a comprehensive vision of electronic transport in the strong light-matter coupling regime in semiconductor heterostructures.



This research project will also benefit from collaborations with ETHZ/Zurich (Switzerland) and TU Vienna (Austria).

[1] A. Frisk Kockum,*et al.*, Nat. Rev. Phys. 1, 19 (2019). [2] Orgiu *et al.*, Nature Materials 14, 1123 (2015)
[3] Appugliese *et al.* arXiv:2107.14145 [4] A. Thomas,*et al.* Angew. Chemie Int. Ed. 55, 11462 (2016).

Methods and techniques: Modeling of optical properties of the devices; quantum design of semiconductor heterostructures; use of lasers for optical pumping experiments; labview/python instrument control; optoelectronic characterization techniques (mid-IR FTIR microscopy/spectroscopy).