Coherence in Semiconductor Nanostructures

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Optical spectra of semiconductors display resonances below the band edge, which are attributed to **excitons**, i.e., bound electrons holes pairs, correlated by Coulomb interaction. For decades, epitaxial growth provides modulated nano-structures, where a smaller bandgap material is surrounded by a higher bandgap one. Such growth-designed, static potentials restrict the motion of the charge carriers and excitons in one, two or three dimensions in so-called **quantum wells, wires and dots**, respectively, and their energies consequently become quantized. Engineering the quantum confinement of excitons is a key to control the light-matter interaction dynamics in semiconductors, where the electron-hole overlap integral along with the Fermi golden rule govern the radiative lifetime T_1. Another relevant optical observable is **coherence**, describing the phase relation within the exciton polarization, vanishing beyond the dephasing time T_2. In particular quantum dots, whose relevance was recognized with the Nobel Prize in Chemistry in 2023, host individual excitons with extended T_2. They can serve as optically adressable qubits, which are key ingredients in prospective quantum technologies.

During my research carrier I have been developing a technique of **nonlinear spectroscopy** conceived to measure dynamics of quantum coherence of individual excitons, which also turned out to be a perfect optical tool to investigate coherences in their ensembles. In this talk, I would like to highlight the relevance of the scientific results obtained with this approach over the last decade.

I will start by presenting my track record and highlighting multiple facets of my professional activity. I will then introduce the concept of a single exciton coherence and demonstrate that - by combining coherent nonlinear spectroscopy with **nano-photonic devices**; microcavities, photonic waveguide antennas, micro-lenses, etc. – the single exciton coherence retrieval efficiency can be enhanced by several orders of magnitude, redefining the state of the art in this field. To illustrate new phenomena that can be measured in this settings I will discuss two experiments: i) a recent achievement of a **controlled coherent coupling** in a vertically stacked quantum dot molecule, ii) observation of phonon-induced dephasing and **polaron formation** within a single quantum dot. I will elaborate on the intrinsic limits of measuring coherence of single quantum dots, which will bring me to the project that I wish to develop in the following years in the framework of the CNRS International Research Laboratory J-FAST, hosted by the University of Tsukuba. The project consists in **fabricating photonic structures in diamond**, by developing Atomic Layer Etching and performing back in my lab in Grenoble coherent spectroscopy of single colour centres in diamond at elevated temperatures, possibly up to the room temperature.

In the remaining part of the talk, I would like to highlight my recent prospects in coherent spectroscopy of two-dimensional materials, with the aim to find further collaboration axes with the partners from Tsukuba. As a first example, I will show how nonlinear, multi-pulse spectroscopy can be employed to reveal coherent **spatial propagation of excitons** in a classical **CdTe quantum well**. As a second example, I will discuss results regarding exciton coherence in emerging two-dimensional magnetic material namely, **tri-layers of CrSBr**. Finally, I will show how with coherent ultrafast spectroscopy one can monitor a **variable exciton confinement** in an advanced transition metal dichalcogenide heterostructure, namely in a **doubly-gated $MoSe_2$** device.