International Doctoral Program in Science Position

Coherent control of electronic dynamics in layered quantum materials

Background and motivation

Cooperative effects induced by light-matter interactions have been studied for decades. These studies have focused on atomic and molecular systems and have led to spectacular experimental findings in the realm of cavity quantum-electrodynamics (QED). In standard cavity-QED, direct interactions between matter constituents are often weak and can be neglected. In this case, collective effects are solely due to effective interactions, which emerge from the microscopic interactions between matter constituents and a common cavity mode. Recent experimental advances have made it possible to monolithically integrate graphene and other two-dimensional (2D) materials, such as transition metal dichalcogenides (TMDs) or 2D oxides, with optical microcavities, paving the way for fundamental studies of cavity QED at the nanometer scale with 2D materials as the active medium. Here, in stark contrast to ordinary cavity QED of atomic and molecular systems, direct interactions between medium excitations (electrons, holes, and excitons) in 2D materials are strong and can be further enhanced by stacking 2D materials in a var der Waals (vdW) heterostructure.

The aim of this project is to investigate the main channels driving the electronic decoherence in layered quantum materials embedded in properly designed cavities and develop strategies and excitation protocols to preserve coherence and exploit coherent dynamics to enhance the physical properties of the material.

The PhD student will develop a coherent 2-dimensional electron spectroscopy (2DES) experiment to investigate the decoherence dynamics of optical and electronic excitations in nanostructured correlated materials. 2DES measures the third-order material coherent polarization by exploiting two coherent phase-locked pulses acting as a pump, and a third pulse acting as a probe, allowing for simultaneous resolution of excitation and detection frequency axes with fs temporal resolution. 2DES thus allows to investigate not only the population relaxation time, but directly the decoherence time of relevant modes. 2DES will be used to probe the decoherence dynamics of light-induced exciton gases in 2D materials (TMDs and oxides). In particular, we will look for signatures of modification of the intrinsic **decoherence dynamics** driven by: i) coherent interactions within the exciton gas; ii) coupling of inter-layer excitonic modes in vdW heterostructures; iii) coupling to cavity modes.

A crucial challenge is related to the sample dimensions, which command spatial resolution, mandatory to perform 2DES on micrometer-sized samples, possibly embedded in cavities. Much of the initial experimental efforts will focus on the implementation of a microscopy measurement scheme, to be coupled to state-of-the-art 2DES setups available at Univrsità Cattolica del Sacro Cuore, providing few-micron spatial resolution while retaining the intrinsic temporal resolution (10-20 fs).

Supervisors

Prof. Claudio Giannetti, Università Cattolica del Sacro Cuore, Italy, claudio.giannetti@unicatt.it

Prof. J-P Locquet, KU Leuven, BE, jeanpierre.locquet@kuleuven.be

Profile

- Master's degree or comparable qualification in physics, materials science or adjacent fields. The title must be obtained before OCTOBER 31st 2022.
- A strong interest for multidisciplinary research is required.
- Previous experience in ultrafast science, solid state spectroscopies, 2D materials, cavity-embedded devices will be considered as an advantage.

https://scuoledidottorato.unicatt.it/phdschools/science-home?rdeLocateAttr=en

- Good knowledge of the English language, both spoken and written, is essential.
- Strong commitment, ability to work in a team, and eagerness for international mobility is desired.

Opportunities

- The PhD will join the ultrafast dynamics group, led by Prof. Claudio Giannetti, and will have full access to the research facilities of the ILAMP research center, located in the new Mompiano Campus in Brescia.
- The researcher will take part to a joint experimental/theoretical effort to tackle the control of coherent dynamics in condensed matter by using different multidisciplinary platforms. The network includes Prof. J-P Locquet and M. Houssa (KU Leuven), Prof. Marco Polini (theory of collective phenomena in 2D materials, Università di Pisa), Prof. Massimo Capone (theory of correlated materials, SISSA Trieste)
- The PhD will spend approximately 1 year (out of 4) at KU Leuven. At the end of the program the PhD student will be awarded a degree from both UCSC and KULeuven (double-degree).