Nonlinear interactions of excitons and polaritons in atomically thin semiconductors

A. Genco

Polytechnic University of Milan, Italy

The reduced Coulomb screening in monolayers of Transition Metal Dichalcogenides (TMDs) grants high binding energies (up to 0.5 eV) and large oscillator strengths to excitons, enhancing the stability of their many-body complexes, such as trions and biexcitons. Cryogenic temperatures and encapsulation in hBN narrow the excitonic linewidths, unveiling a hydrogen-like Rydberg series of excitonic states below the free particle bandgap. Moreover, the broken spatial inversion symmetry of the 2D lattice, together with a large spin-orbit coupling, provides a pseudo-spin degree of freedom to excitons in the K and K' valleys of the Brillouin zone, which become selectively addressable by opposite circularly polarized light. Very recently, exciton hybridization in TMD bilayers emerged as a perfect tool for generating excitons with an out-of-plane dipole moment and high oscillator strength.

All of those excitonic degrees of freedom can be exploited to achieve high nonlinearities, key for accessing collective quantum phenomena when TMDs are strongly coupled to light. In this condition, resonant photons coherently exchange energy with excitons at a rate (Rabi frequency, Ω_R) higher than that of the dephasing processes (i.e. the rate at which photons escape from the cavity or excitons dephase), entering the so-called strong coupling (SC) regime. From this process, new hybrid quantum states are formed, called polaritons. Reaching the SC regime opened new avenues for observing highly nonlinear phenomena in the solid state, such as Bose-Einstein condensation, polariton lasing and optical parametric amplification. These discoveries have been recently exploited for the creation of all-optical logic gates and polariton-based neural networks.

Excitons in TMDs uniquely combine high temperature stability and large oscillator strengths with strong nonlinearities, which makes them an ideal solution for room-temperature polaritonics. The strongly interacting behavior of excitons and polaritons explored in our studies offers novel insights on the many-body physics in atomically thin semiconductors and opens up wide opportunities for accessing extreme ultrafast nonlinear quantum phenomena in such systems.