Optical coherence of confined excitons inferred with nonlinear spectroscopy

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Optical spectra of semiconductors display narrow resonances below the absorption edge, which are attributed to the **excitons**, i.e. Coulomb correlated excitations of electrons and holes. Semiconductor growth and processing techniques permit us to fabricate structures where the excitons are quantum confined in so-called quantum dots, wires and wells. When shining laser light onto a quantum well, the induced excitonic polarization collectively oscillates in phase - this phenomenon is known as the exciton **coherence**. The coherence decays in time owing to various ultrafast processes occurring in a solid: radiative and nonradiative decays, scattering with carriers and lattice vibrations (phonons).

In the first part of this tutorial, I will introduce the concept of exciton coherence and discuss its limits, defining the observable known as **dephasing**. Measuring the exciton's dephasing and ascertaining the underlying mechanisms is at the heart of solid state optics. In particular, the dephasing time T_2 defines the homogeneous spectral line width $\gamma = 2\hbar/T_2$ of an optical transition. Owing to the presence of disorder in real life devices, γ is often dominated by the inhomogeneous broadening σ, such that it cannot be directly read from the spectrum.

This issue can be overcome by performing **nonlinear spectroscopy**, employing two or more short laser pulses. In the second part of the the tutorial I will thus introduce this spectroscopic tool, permitting us to accurately measure a pair (γ, σ).

In the third part, I will show that, using this methodology, we have addressed several important questions regarding optoelectronic properties of semiconducting transition metal dichalcogenides.

After a short break, I will focus on the coherence properties of a single exciton strongly-confined in a semiconductor quantum dot. I will explain a non-intuitive concept of coherence within individual nanoscopic quantum few-level systems. I will argue that embedding single quantum dots in **photonic devices** enables to routinely access their quantum coherence, otherwise obscured by the strictly **resonant** laser background. I will then elaborate on several experimental results, demonstrating single exciton coherent dynamics, phonon-induced dephasing and Rabi floppings.

The last part of the tutorial will tackle a more involved concept of **coherent coupling** between individual quantum systems. I will show that by performing two-dimensional spectroscopy, we achieved controlled coupling in advanced quantum dot molecule devices.

The talk will be concluded by pointing out future plans, new research directions and challenges in that research field.