Quantum optics beyond quantum-degenerate excitons

Mackillo Kira*

Department of Physics, Philipps-University, Renthof 5, D-35032 Marburg, Germany.

Conceptually, a single-mode laser light may be perceived as a quantum-degenerate state because all of its photons occupy one and the same light-mode state. One can utilize this property in direct-gap semiconductor in order to excite, e.g., quantum-degenerate excitons that are Coulomb-bound electron-hole pairs. For example, if a classical laser resonant with an exciton resonance, the resulting excitation injects a quantum-degenerate state of *coherent* excitons. This process is fully explained by the semiconductor Bloch equations [1] where the quantum-degenerate coherent excitons are simply described by a polarization.

One can rigorously generalize [2] this state-injection concept to realize *quantum-optical spectroscopy* beyond simple excitons because also laser's quantum fluctuations are injected as such to the quantum-degenerate electron-hole pairs, before the onset of Coulomb and phonon-induced scattering. More explicitly, the quantum aspects of a single-mode pump laser are defined by a boson operator B while the Coulomb-bound electron-hole pairs are described by an exciton operator X that is bosonic only approximately. When the pump laser has quantum-optical correlations $\Delta\left\langle (B^\dagger)^J B^K \right\rangle$, the light-matter interaction generates identical electron-hole correlations

$$\Delta\left\langle (X^\dagger)^J X^K \right\rangle = \lambda^{\frac{J+K}{2}} \Delta\left\langle (B^\dagger)^J B^K \right\rangle \qquad (1)$$

to the light-generated many-body state. Here, λ determines the transfer efficiency between the correlations having J creation and K annihilation operators. As a result of the transfer relation (1), the light-matter interaction inherently converts light correlations into quantum-degenerate many-body correlations. Consequently, the quantum fluctuations of light can be utilized to achieve targeted excitation of many-body states [2] and the related state-dependent [3] optical response. This leads to a precise excitation and characterization of desired many-body states, as the first step toward the many-body quantum-state tomography.

In this talk, I will present a theory-experiment comparison realizing targeted access of many-body states within condensed-matter systems via quantum-optical spectroscopy. As an essential tool, we use the cluster-expansion transformation [4] to represent the quantum-optical fluctuations of the pump laser and then to project classical spectroscopy into quantum-optical spectroscopy. The results expose a completely new level of many-body physics of interacting excitons, biexcitons (exciton-exciton molecule), and electron-hole droplets, that remains otherwise hidden.[5] This allows us to control and characterize, especially, optical nonlinearities of the system with unprecedented accuracy. The resulting tomographic insights to the many-body dynamics will be viewed through several illustrative examples.

References

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**corresponding author: mackillo.kira@physik.uni-marburg.de*