Quantum-optical semiconductor spectroscopy

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Direct characterization or control of semiconductor many-body state seems inconceivable due to the enormous amount of degrees of freedom involved. However, semiconductor's optical nonlinearities depend sensitively on the actual many-body state it resides in. At the same time, the light-matter interaction maps quantum fluctuations of light into distinct many-body correlations [1-2] within semiconductor and visa versa. Our microscopic calculations [1-3] show that optical nonlinearities can indeed be controlled thought the quantum statistics of light. For example, the Coulombic scattering experiences an anomalous reduction when excitation is switched from a coherent into a thermal state. This makes is possible to develop quantum-optical spectroscopy where the "usual" spectral and temporal characterizations are complemented by quantum-statistical measurements. In fully fledged quantum-optical spectroscopy, one needs quantum-statistically tunable laser sources and/or quantum-statistical characterization of the semiconductor light emission in order to gather unprecedented level of information and control over semiconductor many-body states.

To gain insight of the possibilities of quantum-optical spectroscopy, we first investigate quantum optics in simple systems. These examples indicate how quantum-optical interaction effects are still detectable and controllable through quantum-optical spectroscopy even when dephasing completely removes direct quantum-optical signatures, such as the Jaynes-Cummings ladder or the revivals [4-5]. We systematically extend this investigation for semiconductors on the basis of a microscopic theory [1] that includes the quantized light field, Coulomb interacting fermionic electrons and holes, as well as phonons at the same consistent level. The presented theoretical results also indicate how quantum-optical spectroscopy can be realized by combining existing experimental techniques. In particular, the results show how one can simulate intense quantum sources as a first step toward quantum-optical spectroscopy in solids. By introducing a cluster-expansion approach for quantum-optical fields [6], one also can address how quantum-statistical characterization of light emission can be conducted even when detection is considerably deteriorated by quantum efficiency.

References:

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