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OPTICAL NONLINEARITIES AND BOSONIZATION METHODS

ボゾン化法による非線形性の解明

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We introduce two theoretical works on optical nonlinearity in semiconductors and metals; (i) the third-order excitonic nonlinearity in undoped semiconductors with an exciton bosonization technique, and (ii) the pump-probe dynamics (ac Stark effects) of the Fermi-edge singularity in doped semiconductors or metals with the coupled-cluster method.

(i) Starting from a general model including semiconductor systems with a photon field, we derive the bosonized Hamiltonian for the two-exciton processes with the use of a new bosonization method. The obtained Hamiltonian clarifies dependence of quantum statistics of the component particles of excitons, momenta of the exciton center-of-mass motion, and spin degrees of freedom of the constituents. We introduce a composite-particle effect (CPE) of the excitons to represent deviation of the excitons from ideal bosons, and discuss how the CPE affects the interboson interactions in the resulting Hamiltonian. As an example of this general theory, we demonstrate an application to a semiconductor quantum-well system with a radiation field to describe the third-order nonlinear optical processes under 1s exciton resonance in the weakly excitation regime, and show that concrete and exact forms of the various physical values obtained in the general theory. This theory can explain also the bound and unbound biexctions.

(ii) The Fermi-edge singularity (FES) in the vicinity of the Fermi level in metals results from the infrared divergence, orthogonality catastrophe, and many-body (Mahan) exciton effects. This singularity leads to a pronounced peak in linear absorption and photoluminescence spectra near the Fermi energy. The nonlinear response of the FES has recently been studied experimentally in terms of the ac Stark effect of the FES with the use of the pump-probe technique. Thus far there have been only simple theories with the ladder approximation assuming the contact-type Coulomb interaction and the infinite hole-mass. Here we propose new theoretical treatment of the pump-probe response of the FES. Effects of the pump light is renormalized into the relevant Hamiltonian with a time-dependent unitary transformation, and the electron-hole correlation is taken in a nonperturbative manner by the coupled-cluster expansion. Our theory can treat the crossover between a simple exciton system (in the undoped case) and the FES system (in the heavily-doped case). Comparison with the ac Stark effects on a single exciton will be carried out.