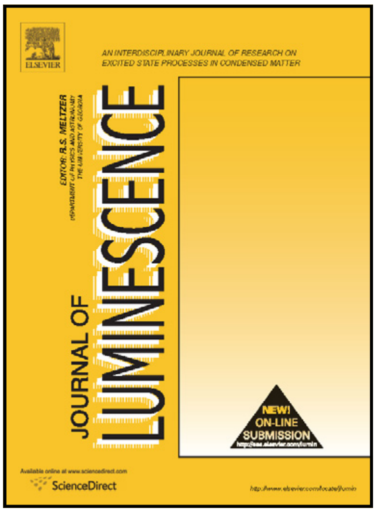

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Influence of free carriers on exciton ground states in quantum wells

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Abstract

The influence of free carriers on the ground state of the exciton at zero magnetic field in a quasi-two-dimensional quantum well that contains a gas of free electrons is considered in the framework of the random phase approximation. The effects of the exciton-charge-density interaction and the inelastic scattering processes due to the electron-electron exchange interaction are taken into account. The effect of phase-space filling is considered using an approximate approach. The results of the calculation are compared with the experimental data.

Keywords: excitons, trions, two dimensional electron gas, exchange interaction, exciton electron scattering
PACS: 71.10.Ca, 71.45.Gm, 73.21.Fg, 78.55.Et

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1. Introduction

The presence of free electrons in quasi-two-dimensional semiconductor structures strongly alters their physical characteristics. At low and intermediate electron concentrations, the Coulomb interaction between the electrons and the holes leads to formation of the bound exciton state. In addition, starting from very low concentrations of free electrons in the quantum well, a bound trion (negatively charged exciton) state [11, 12, 13, 14] is observed in experiments [6, 7, 8, 9, 10]. At high concentrations the free electrons causes a static screening of the electron-hole Coulomb potential. The screening as well as the filling of phase-space up to the Fermi energy leads to a strong decrease of the exciton binding energy. At some concentration of free electrons the bound states disappear and the so-called Mahan exciton can be expected. Considerable attention has been paid in the literature to experimental and theoretical investigations of the 2D-systems at high concentration of free carriers. The theory of this phenomenon was developed in Ref.[1] for the 3D crystal and in Refs. [2, 3, 4, 5] for 2D systems. Experimental data [6, 7, 8, 9, 10] give evidence that, within a relatively narrow interval of free electron concentrations below the metallic phase, the optical absorption band associated with the bound exciton shifts and broadens, and its oscillator strength decreases as carrier concentration is increased. The dependence of these characteristics on the electron concentration allows one to relate these processes with exciton-electron interactions. The observed broadening of the exciton line [6, 7, 8, 9] clearly shows that not only static screening but also inelastic dynamical processes should be considered for the explanation of the exciton spectrum.

The exciton created by a photon has almost zero wave-vector. Further interaction of the exciton with free electrons followed by scattering of a conduction electron near the Fermi level with $p \approx p_F$ creates a conduction electron – conduction hole pair. This pair has an arbitrary wave-vector of the center of mass motion $\mathbf{q}$ and an energy $\hbar^2 q^2/2m + \hbar^2 \mathbf{pq}/m$ which is the difference between the conduction electron's energy in the final and initial states, ($\hbar^2(\mathbf{p}+\mathbf{q})^2/2m$ and $\hbar^2\mathbf{p}^2/m$, respectively).

The threshold energy of this excitation at $q = 0$ and temperature $T = 0$ K is zero. Therefore, the lower boundary of the continuum spectrum of the combined excitation consisting of the free exciton plus an electron – conduction hole pair coincides with the energy of the free exciton. As a consequence, this inelastic scattering process results in a homogeneously broadened absorption spectrum with its maximum shifted toward high energies with increasing free electron concentration.

The mechanism responsible for the creation of an electron (above Fermi surface) - hole (below Fermi surface) pair can be either the Coulomb interaction or the exchange interaction between the electron bound in the exciton and the free electrons.