

Screening of short-range quantum well disorder by indirect excitons

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Recent advances in spectroscopic techniques have allowed the observation of sharp lines in the emission spectra of indirect excitons in coupled quantum wells (QWs) [1]. These emission lines are attributed to well-localized states i , which can accommodate only one indirect exciton and are separated from the exciton continuum (delocalized states) by a binding energy $\varepsilon_i^{(0)}$ of about 1 – 3 meV. The latter values refer to rather low average densities, $n_{2d}^{(0)} \leq 10^9 \text{ cm}^{-2}$. With increasing optical excitation, i.e. $n_{2d}^{(0)}$, the binding energy ε_i decreases, and the localized states eventually disappear at $n_{2d}^{(0)} \sim 10^{10} \text{ cm}^{-2}$.

We report on screening of the short-range QW disorder by incoherent delocalized excitons. A localized state is described by the nonlinear Schrödinger equation:

$$-\frac{\hbar^2}{2m}\nabla^2\Psi_i + u_0n_{2d}^{(0)}\Psi_i + \frac{U_{\text{imp}}(r_{\parallel})}{1 + \alpha(T, T_0)}\Psi_i + \frac{u_0}{1 + \alpha(T, T_0)}|\Psi_i|^2\Psi_i = \varepsilon_i\Psi_i, \quad (1)$$

where $\alpha(T, T_0) = [(u_0n_{2d}^{(0)})/(k_B T_0)](e^{T_0/T} - 1)$, $T_0 \propto n_{2d}^{(0)}$ is the degeneracy temperature, $u_0n_{2d}^{(0)}$ is the mean-field energy due to dipole-dipole repulsive interaction between indirect excitons, $U_{\text{imp}}(r_{\parallel})$ is a bare (unscreened) short-range potential that gives rise to the state i with binding energy $\varepsilon_i^{(0)}$, and T is the temperature. In order to analyze how the wave function Ψ_i and binding energy ε_i change with increasing $n_{2d}^{(0)}$, we have performed numerical statistical simulations of Eq. (1) for various model potentials $U_{\text{imp}}(r_{\parallel})$ (e.g., for $U_{\text{imp}}(r_{\parallel}) = -V_0/\cosh^2(r_{\parallel}/a_{\text{loc}})$ in parametric space $\{V_0, a_{\text{loc}}\}$, see Fig. 1). The main results of our study are (i) an effective screening of $U_{\text{imp}}(r_{\parallel})$ and removal of the localized state i ($\varepsilon_i \rightarrow 0$) when $u_0n_{2d}^{(0)}$ becomes comparable with $\varepsilon_i^{(0)}$, (ii) a drastic increase of the screening effect with decreasing temperature T below T_0 , and (iii) the prediction of a mesoscopic ring of radius $\sim 10 - 100 \text{ nm}$ in the density profile $n_{2d}(r_{\parallel}) = n_{2d}^{(0)} + \delta n_{2d}(r_{\parallel})$ of delocalized indirect excitons around the localized (impurity) state i (see Fig. 1 (a), where δn_{2d} is plotted against the radial distance from the impurity).

The present work complements the study of the screening effect by dipole-dipole interacting excitons, previously developed in [2] for long-range-correlated disorder.

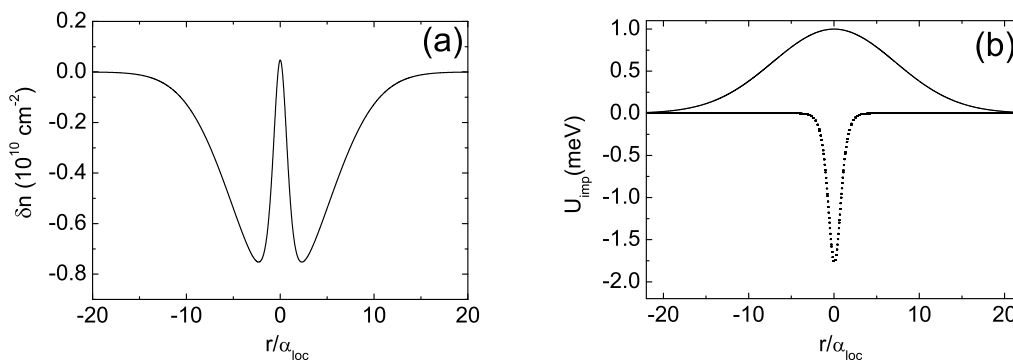


Figure 1: Screening of short-range disorder. (a) The spatial change of density n_{2d} of delocalized excitons near the localized state. (b) The input potential U_{imp} and wave function Ψ_i calculated with Eq. (1).

References

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