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Theory of condensation of indirect excitons in a trap

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We present theoretical studies of condensation of indirect excitons in a trap. Our model quantifies the effect of screening of the trap potential by indirect excitons on the condensation scenario. The theoretical studies are applied to a system of indirect excitons (IX) in a GaAs/AlGaAs coupled quantum well structure in a diamond-shaped electrostatic trap where exciton condensation was studied in earlier experiments [1]. The estimated condensation temperature of the indirect excitons in the trap reaches a few hundred milliKelvins.

To find the exciton energy levels and wave-functions we solve 2D single-particle Schrodinger equation with effective mean field potential controlled by exciton density. The IX density is calculated self consistently using the equilibrium occupation numbers of the single-particle states, which are defined by the Bose-Einstein distribution. With lowering temperature, the trap profile becomes more and more flat and at $T = 50$ mK the splitting between IX states reduces to $3{\cdot}10^{-8}$ eV ($\sim 10^{-3}\, k_B T$). At these temperatures the exciton density essentially follows the inverted trap profile that is characteristic for a system with an energy shift due to contact exciton interaction.

Dependencies of the condensation temperature on the number of indirect excitons in the trap are shown in Fig.1. Red diamond displays calculations for 2D problem with interaction constant $g = 20$ μeV·μm^2, which corresponds to IX interaction strength given by the “plate capacitor” formula, and is compared to simplified 1D problem with $g = 71$, 20, 7.1, and 2 μeV·μm^2 where a lower g corresponds to a weaker IX interaction due to IX correlations [2] (green dash-three-dotted, red solid, blue dashed, and magenta dotted lines, respectively), and analytically solvable problems for non-interacting IXs in the effective parabolic potential (cyan dash-two-dotted line) and in 3.5x30 μm^2 rectangular trap with infinite wells (black dash-dotted line)

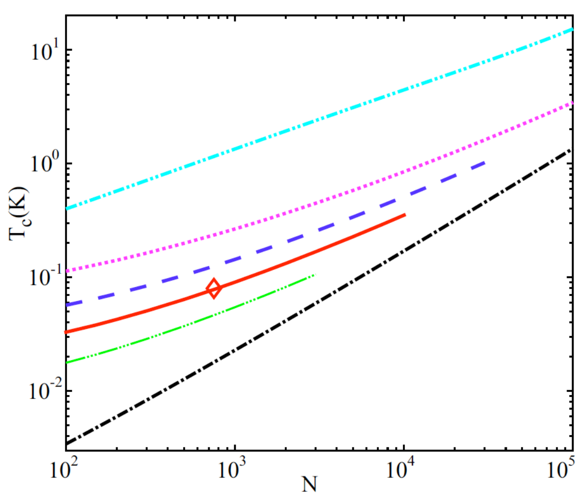

Figure 1. Dependencies of the condensation temperature on the number of indirect excitons in the trap (N)

This indicates that a helium refrigerator is needed for experimental studies of the exciton condensate. The application of the model to various traps and materials, which were studied or can be studied experimentally, as well as improving the accuracy of the simulations by including to the model the effects of disorder, different spin states, and density- and spin-dependent exciton interaction form the subject for future work.

[1] A.A. High, J.R. Leonard, M. Remeika, L.V. Butov, M. Hanson, A.C. Gossard, Nano Lett. 12, 2605-2609 (2012).
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