Mott Transition of Excitons in Quasi-Two-Dimensional Systems

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The excitonic Mott transition [1] is the avalanche ionization of an insulating excitonic system arising from the joint effects of screening and k-space filling. A quasi-two-dimensional (2D) electron-hole plasma with excitons is considered to be a promising medium for observation of the Mott transition, due to the unique capability for tailoring of the exciton parameters in this system.

Particular attention is directed towards double quantum wells (DQWs) - heterostructures containing two quantum wells (QWs) situated close enough so that the Coulomb correlations between particles in different QWs are significant. Electrons and holes from adjacent QWs form spatially indirect excitons possessing very long lifetimes, which is due to the small electron-hole wavefunction overlap [2]. This fact allows one to hope that long-living electrons and holes will have enough time to cool down from a hot photo-generated state into a low-temperature state, and participate in such effects as the formation of a degenerate Bose gas of excitons or the Mott transition.

Up to now the exact nature of the excitonic Mott transition has not been established. The main theoretical difficulty in investigation of the Mott transition is based on the fact that this is inherently a medium-density effect, where both low-density and high-density approximations do not work. The correct approach requires careful handling of the Coulomb interaction depending on the thermodynamic state of the system, which implies a self-consistent procedure.

We are going to present the results of a rigorous investigation of the quasi-2D electron-hole plasma at quasi-equilibrium, which reveals the presence of the Mott transition in a certain temperature-density region. We pay special attention to the correlation effects in continuum and take into account screening by spatially separated excitons in DQWs. The powerful Green's function technique is used to treat bound states, scattering states and k-space filling effects on the same footing. The method is similar to that of Zimmermann and Stoltz for the 3D case [3]. Some of our results are shown in Figs. 1 and 2.

In Fig. 1 we plot the ionization degree of the quasi-2D electron-hole plasma, α, as a function of electron (or hole) density for three different temperatures. One can see that for low enough temperatures there is a density region (confined between n^{min} and n^{max}) where α is a three-valued function. Physically, this situation means the following. Changing the density of the carriers in the QW, one reaches a critical value n^{max}, at which a slight increase of the carrier concentration results in a large jump in the ionization degree. Effectively, this means a transition from a system consisting mainly of excitons to an almost completely ionized state. Clearly, this is what the Mott transition is meant to be.

In Fig. 2, the Mott transition critical points for the single and the double QW structures are shown. There are two characteristic temperatures for each curve. One is the maximum temperature at which the Mott transition disappears, and the other is the temperature at which the critical density increases drastically. Both temperatures are smaller for the DQW structure, which indicates their relation to the exciton binding energy. The most striking feature here is the much lower transition density for the DQW structure. This can be explained qualitatively by the larger Bohr radius of indirect excitons. This fact may facilitate the observation of the Mott transition in DQW structures, since the transition density can be lowered (by increasing the QW separation) to experimentally accessible values.

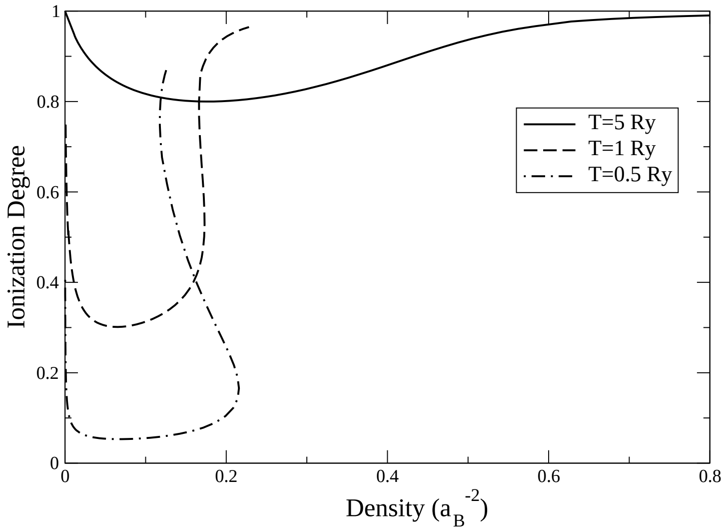

Figure 1: Ionization degree for an electron-hole plasma in a single QW as a function of electron (hole) density at different temperatures. Density is in units of a_B^{-2}, temperature is in units of Ry, where a_B and Ry are the Bohr radius and Rydberg of the bulk (3D) exciton.

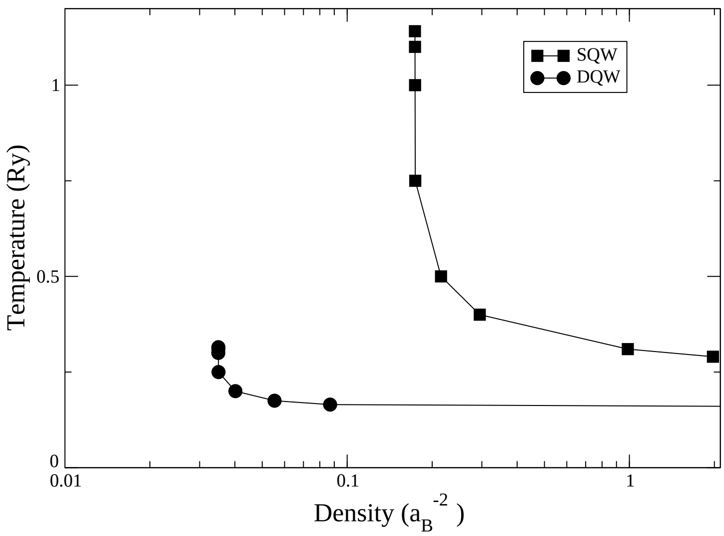

Figure 2: Mott transition temperature as a function of density for single and double QWs. In the DQW structure the inter-well distance is 0.2 a_B.

[1] N.F. Mott, Philos. Mag. **6**, 287 (1961).
[2] V.V. Krivolapchuk *et al*, Phys. Rev. B **64**, 045313 (2002).
[3] R. Zimmermann and H. Stolz, Phys. Status Solidi B **131**, 151 (1985).