

Ultracold Dipolar Excitons

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PhD Thesis Defense MATHIEU ALLOING 'Experimental Evidence for the Quantum Condensation of Ultracold Dipolar Excitons'

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In this thesis, we report experimental evidence of a "gray" condensate of excitons, as predicted theoretically by M. Combescot et al. Most importantly, the condensate is characterized by the macroscopic population of dark excitons coherently coupled to a weak population of bright excitons through fermion exchanges. Such quantum condensation

results from the excitons internal structure, with a dark i.e. optically inactive ground state. It is actually very similar to what occurs in the phases of superfluid ^3He or in the more recent spinor condensates of ultracold atomic Bose gases. While it is our belief that such a "gray" condensate will eventually be observed in other excitonic systems, our study focus on its appearance together with the macroscopic auto-organization of dipolar excitons. Precisely we emphasize fragmented exciton rings in an electrically biased GaAs single quantum well. This very striking pattern was first observed independently by the groups of L. Butov and D. Snoke. It was interpreted as the result of an ambipolar diffusion of carriers in the quantum wells. The fragmentation of the macroscopic ring observed at low temperature by Butov and coworkers, and the subsequent evidence for long-range spatial coherence together with complex pattern of polarization, led Butov et al. to interpret the fragmentation as an evidence for the transition to a quantum regime where coherent exciton transport dominates.

Our experiments led us to a very different interpretation. Indeed, we show that for our sample the formation of the fragmented ring is dominated by the diffusion of dipolar excitons in an optically induced electrostatic landscape. This potential landscape arises from the modulation of the internal electric field by excess charges injected in the QW by the same excitation beam which induces the ring. Dipolar excitons then explore a potential landscape characterized by a wide anti-trap inside the ring and more strikingly by microscopic traps distributed along the circumference of the ring. There, i.e. in the outside vicinity of the ring, a confining potential is responsible for the formation of "islands" where the population of dark excitons is dominant. Due to the low energy splitting between the bright and dark excitonic states in our sample, the observation of a dominant population of dark excitons signals that excitons condense in the low-lying dark states.

To confirm this interpretation we show that the weak photoluminescence emitted in the outer vicinity exhibits macroscopic spatial coherence, up to 10 times larger than the de Broglie wavelength. Islands of extended coherence are in fact identified and quickly disappear upon increase of the bath temperature. This leads to an evolution of the coherence length strongly dependent on the temperature. Finally, we show that the photoluminescence emitted in the vicinity of the fragmented ring is dominantly linearly polarized and also organized in islands outside the ring. All these observations confirm the predicted signatures of a "gray" condensate, as formulated by M. and R. Combescot.

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