TuM1d: Excitons: Towards Bose-Einstein-Condensation I

Time: Tuesday 9:00–10:30 Location: Rittersaal

Invited talk TuM1d.1 Tue 9:00 Rittersaal

Collective state in bose-gas of interacting interwell excitons — ALEXANDER V GORBUNOV and •VLADISLAV B TIMOFEEV — Institute of Solid State Physics, Russian Academy of Sciences, Chernogolovka, Moscow Distr., Russian Federation, PB 142432

We present experimental studies of spatially resolved luminescence for interwell excitons in GaAs/AlGaAs double quantum well heterostructures coated with metal mask containing circular windows of μm sizes [1]. Under applied bias and photoexcitation radial distribution of electrical field inside window proves to be strongly nonuniform: a ring-like lateral potential trap is formed along the window edge.

Spatially resolved luminescence structures were investigated both for inter- and intrawell excitons. It was discovered that luminescence patterns for interwell excitons exhibit along perimeter of window axially symmetrical spatial structure of equidistant bright spots which strongly depends on excitation power and temperature. The structure appears above some excitation threshold and the number of equidistant spots increases with pumping. At the same experimental conditions luminescence pattern for intrawell excitons remains homogeneous and shows no spatial fragmentation. It was established that the discrete luminescence structure starts to wash off with temperature: pairs of spots are merging at $T \geq 4$K. The above-mentioned experiments were performed on dozen of circular windows with sizes of 2, 5 and 10 μm. The spatial configurations of equidistantly placed luminescence spots in windows of given size and measured at similar experimental conditions were always reproduced.

We assume that observed phenomenon is a manifestation of collective coherent properties of interacting two-dimensional interwell excitons. It is effect of exciton bose-condensation in a ring-shaped lateral trap. Collective exciton state is characterized by large coherence length (around 1 μm) and is destroyed by temperature due to the thermal order parameter fluctuations across the system of interacting interwell excitons (along the ring structure of luminescence spots). Recently, it was shown [2] that vortex character of the bose-condensate of interwell excitons in a lateral trap is manifested in a peculiar angular distribution of luminescence intensity due to destructive interference. We emphasize that expected vortex configurations in real and K-space [2] coincide qualitatively with presented experimental observations [1]. Effects of polarization and interference of spot patterns are presented and discussed.

1. A.V.Gorbunov, V.B.Timofeev Pis'ma Zh.Exp.Teor.Fiz. (JETP Letters) **83**, N4 (2006)

2. J. Keeling, L.S.Levitov, P.B.Littlewood Phys.Rev.Lett. **92**, 176402 (2004)

TuM1d.2 Tue 9:30 Rittersaal

Artificial trapping of a stable high-density dipolar exciton fluid — RONEN RAPAPORT[1], •GANG CHEN[1], LOREN PFFEIFER[1], KEN WEST[1], PHIL PLATZMAN[1], STEVEN SIMON[1], ZOLTAN VOROS[2], and DAVID SNOKE[2] — [1]Bell Laboratories, Lucent Technologies, 600 Mountain Avenue, Murray Hill, New Jersey 07974 — [2]Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania 15260, USA

Two-dimensional dipolar excitons are new promising candidates for the realization of superfluidity in semiconductors, as their extremely long lifetime should make their cooling and thermalization feasible. However, a rapid expansion of such an exciton fluid as a result of the repulsive dipolar interaction within the exciton fluid [1,2] can be a major obstacle in realizing such quantum phases since it prevents the formation of a stable and high-density exciton fluid. Here, we experimentally realize a scheme for trapping excitons electrostatically under a local gate following our design in Ref.[1]. We report on compelling evidence that the trapped exciton fluid is long-lived, highly stable, spatially uniform, and can reach densities much higher than those achieved without a trap [3]. This ability to trap excitons in a well-controlled and flexible electronic device should allow for more general studies of various possible phases of strongly interacting bosons in two dimensions as our new temperature-dependent measurements suggest.

We follow our exciton trap concept and design [4], where dipolar excitons are trapped under local electrostatic gates. GaAs/AlGaAs double quantum well (DQW) structures are grown on top of an n^+ doped GaAs substrate. Circular semi-transparent Ti gates with different diameters ($D = 4 - 80\mu m$) are deposited on top of the DQW samples. An electric bias is applied to each of the gates.

We performed time, spectrally, and spatially-resolved measurements to probe the dynamics of the exciton fluid in different trap designs at liquid-He temperatures. We experimentally show the importance of designing traps that minimize the exciton ionization at the trap boundary in order to achieve stable, high density, and uniform exciton fluid. We show that, with the right design, the optically excited dipolar exciton fluid expands rapidly to uniformly fill the trap with densities ($\sim 10^{11}/cm^2$) that are much higher that can be achieved without the trap under the same conditions.

In this density and temperature regime, the De-Broglie temperature, the classical nearest-neighbor dipole-dipole interaction term for a square dipolar exciton lattice in equilibrium, and the harmonic potential for small vibrations in such lattices, are of the same order of magnitude, which can lead to some very interesting consequences in terms of the possible thermodynamic phases of the excitons, such as a possible competition of the quantum superfluid phase with the exciton crystal phase. We present new intriguing temperature-dependent experiments in the context of degenerate exciton fluid formation.

[1] R. Rapaport et. al., Phys. Rev. B 73, 033319 (2006).

[2] Z. Voros et. al., Phys. Rev. Lett. 94, 226401 (2005).

[3] Chen et. al., condmat/0601719 (2006).

[4] R. Rapaport et. al., Phys. Rev. B 72, 075428 (2005).

TuM1d.3 Tue 9:45 Rittersaal

Trapping of 2D excitons and polaritons — DAVID SNOKE[1], •ZOLTAN VOROS[1], RYAN BALILI[1], LOREN PFEIFFER[2], and KEN WEST[2] — [1]3941 OHara St., Pittsburgh, PA 15260, USA — [2]700 Mountain Ave., Murray Hill, NJ 07974, USA

We report on the successful trapping in two related, but quite different two-dimensional systems: indirect excitons in coupled quantum wells, with very long (50 μs) lifetime, and polaritons in microcavities, with short (ps) lifetime. The trapping mechanism is based on the deformation of the band structure when a uniaxial external stress is applied [1]. In both cases we show throught optical measurements of transport that the particles drift several hundred microns. In the case of excitons in coupled quantum wells, we demonstrate that excitons react to the force of the trap and fill it up and come to thermal equilibrium, resulting in a Gaussian density profile, which, in principle, can be used to measure the temperature of the exciton gas, which is not easily accessible by other experimental means.

In the case of polaritons, which are mixed states of a quantum well exciton and a microcavity photon, the trapping comes about through the excitonic part. Starting with the quantum well exciton energy higher than the cavity photon mode, stress is used to reduce the exciton energy and bring it into resonance with the photon mode. In this way, an in-plane harmonic potential for the polaritons is created, which allows trapping, we which observe as a drift of polaritons into the trap [2]. This method also overcomes a common experimental problem with microcavities. Due to a wedge in the wafer, usually only a small part of the sample fulfills the strong coupling condition, while active tuning using applied stress can bring the exciton energy close to resonance with the cavity mode at any arbitrary point on the wafer.

In both cases, the trapping opens up the possibility of Bose-Einstein condensation analogous to trapped atoms. However, we will also point out the differences, and the prospects for observation of Bose-Einstein condensation of these particles in the future.

This work has been supported by the National Science Foundation under Grant No. 0404912 and by DARPA under Army Research Office Contract No. W911NF-04-1-0075.

[1] V. Negoita, D.W. Snoke and K. Eberl, Applied Physics Letters 75, 2059 (1999).

[2] R. B. Balili, D. W. Snoke, L. Pfeiffer, and K. West, App. Phys. Lett. 88, 1 (2006).

TuM1d.4 Tue 10:00 Rittersaal

Drift mobility of long-living excitons in coupled GaAs quantum wells — ANDREAS GÄRTNER[1], •ALEXANDER W. HOLLEITNER[1], JÖRG P. KOTTHAUS[1], and DIETER SCHUH[2,3] — [1]Center for NanoScience (CeNS) and Department für Physik, Ludwig-Maximilians-Universität München, Germany — [2]Institut für Angewandte und Experimentelle Physik, Universität Regensburg, Germany — [3]Walter Schottky Institut, Technische Universität München, Germany

Photo-generated electron-hole pairs in quantum well devices can be manipulated in lifetime and position via a mesoscopic voltage-controlled electrostatic landscape. Whereas exciton ionization and spatial separation of electron-hole pairs by large in-plane electric fields enable us to store and release optical images at will [1, 2], the quantum-confined Stark effect allows us to create long-living excitons and study their dynamics on mesoscopic length scales [3,4]. Here we employ the quantum confined Stark effect in a coupled double quantum well to generate spatially indirect excitons with lifetimes exceeding 500 ns and to study their motion induced by a controlled spatial variation of the out-of-plane electric field. The confinement of such long-living excitons into artificial traps aims at observing Bose-Einstein condensation of excitons [5,6].

With spatially and time-resolved photoluminescence we study the dynamics of spatially indirect excitons generated in a GaAs-AlGaAs double quantum well at low temperatures. Temporal variation of the gate voltages applied to interdigitated gate electrodes induces excitonic motion in the quantum well plane, perpendicular to the narrow gate electrodes via the spatial variation of the quantum-confined Stark effect [3]. Thus we can establish long lifetimes of mobile excitons. Macroscopic drift of excitons is studied employing a laterally graded electrostatic potential induced via a current-carrying resistive gate [4]. This allows us to determine the drift mobilities of such long-living excitons. Across several hundreds of microns a drift mobility of 100,000 $\mathrm{cm}^2/\mathrm{eVs}$ is observed for temperatures below 10 K. With increasing temperature the excitonic mobility decreases due to exciton-phonon scattering. Artificial stressors prepared on top of the double quantum well induce an additional variation of the excitonic potential and cause trapping of excitons, e. g. to narrow ring-like regions around the stressor perimeter. Suitable combinations of these trapping schemes will be discussed that create the potential for possible exciton condensation.

[1] J. Krauß et al., Phys. Rev. Lett. 88, 036803 (2002).

[2] J. Krauß et al., Appl. Phys. Lett. 85, 5830 (2004).

[3] A. Gärtner, D. Schuh, J. P. Kotthaus, Physica E (in press), cond-mat/0509142.

[4] A. Gärtner, A. W. Holleitner, J. P. Kotthaus, D. Schuh, cond-mat/0602586.

[5] L. S. Levitov et al., Phys. Rev. Lett. 94, 176404 (2005).

[6] Z. Vörös et al., Phys. Rev. Lett. 94, 226401 (2005).

TuM1d.5 Tue 10:15 Rittersaal

Towards Bose-Einstein condensation of excitons in coupled quantum wells: Combined treatment of disorder and exciton-exciton interaction — •Roland Zimmermann — Institut für Physik der Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin, Germany

Spatially indirect excitons in coupled quantum wells are a promising candidate to reach Bose-Einstein condensation in semiconductors. Experiments employing a lateral trap have shown under high excitation a blue shift and a broadening of the exciton photoluminescence line [1]. The blue shift is induced by the strong dipole-dipole repulsion between indirect excitons, while the finite linewidth at low excitation is due to disorder.

The standard Hartree Fock approach gives a blue shift but is not able to produce any line broadening. We have developed recently a T-matrix theory which treats exciton-exciton interactions in a dynamical way [2] and can model the density-dependent linewidth. Here, we combine this approach with a proper treatment of disorder [3] via a modified coherent potential approximation. The total self energy $\Sigma(k,\omega)$ is calculated self consistently, and its imaginary part gives an increasing linewidth with rising density. While the disorder-related broadening diminishes (screening effect), the exciton-exciton scattering takes over. At still higher densities, however, the PL linewidth shrinks again dramatically which indicates the approach towards condensation. In such a strongly nonideal Bose system, condensation sets in if the chemical potential reaches the quasiparticle position at zero momentum, $\mu = \mathrm{Re}\Sigma(k=0,\mu)$. This is accompanied by a complete undamping since $\mathrm{Im}\Sigma(k,\mu) = 0$ holds strictly. For the AlGaAs coupled quantum well used in [1], we derive the corresponding phase boundary in the density-temperature plane. Since the predicted linewidth shrinkage has not been observed yet, we conclude that in the experiment the exciton gas may not have cooled down to lattice temperature.

Finally, we present calculations for the angular emission profile. Close to condensation, a narrow peak normal to the quantum well plane evolves. If seen in experiment, this would be a rather direct manifestation for off-diagonal long range order among excitons.

[1] D.W. Snoke et al., Solid State Comm. 134, 37 (2005).

[2] R. Zimmermann, cond-mat/0602601.

[3] R. Zimmermann, Solid State Comm. 134, 43 (2005).