The Mystery of the Ring: Emission from Excitons in quantum wells.

Formation Mechanism and Low-Temperature Instability of Exciton Rings
Authors: L.V.Butov et al.

Charge Separation of Dense Two-Dimensional Electron-Hole Gases: Mechanism for Exciton Ring Pattern Formation.
Authors: R.Rapaport et al.

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An electron and a hole optically excited within a semiconductor are oppositely charged, and bind together to form a bosonic exciton. Since the mass of this particle is typically small, there has long been interest in the possibility of obtaining a Bose-Einstein condensate (BEC) at cryogenic temperatures. Experimentally this has proved challenging, because a cold equilibrium gas needs to be prepared on a shorter time scale than the excitons can decay. One of the most promising experimental systems has been coupled semiconductor quantum wells. In these systems electrons and holes may be optically excited, and by applying an electric field perpendicular to the wells, induced to be trapped in neighbouring quantum wells. Here the e-h pairs are close enough (a few nm) to be electrically bound, but separated by a large tunnelling barrier to prevent rapid recombination. A typical experiment thus involves optical excitation well above band gap, and the subsequent observation (with both spatial and spectral resolution) of the weak recombination emission of the (with good fortune, thermalised) indirect exciton when the electron and hole tunnel through the barriers.

Consequently, considerable interest was aroused a couple of years ago by the discovery of rings of exciton luminescence by two different groups [1,2]. When light was focussed to a small spot (few microns), as well as the prompt luminescence in the vicinity of the pump, a second ring of luminescence appeared as distant as 1mm away from the source. The intervening region is mostly dark, except that Butov et al [1] also observed bright spots of emission from localised spots in the sample. These results provoked considerable discussion, and exotic thoughts about dark condensates with rapid transport although no good calculation has shown that excitonic condensation prevents recombination significantly. Two recent papers recommended here have now solved most of the puzzles by means that are more prosaic.

The original results were always problematic to interpret as exciton transport [5]: the rings could be seen at temperatures well exceeding the exciton binding energy; the exciton lifetime and thermalisation time is well-known in these systems, and much too short to allow for transport over the long distances seen; and tellingly, only low-energy pumping led to the formation of rings; the design of the experiments mean that there is a substantial leakage current through the devices, so that there are sources of free carriers (both injected the electrodes, and an imbalance of trapping of one carrier species over the other generated by optical pumping). Both groups now conclude that while the emission from the rings is indeed excitonic (this is convincing because of the spectral signature), the transport is from single carrier species with recombination occurring where the charges meet. The sharp rings thus mark the boundary between electron-rich and hole-rich regions. This is backed up by detailed transport modelling and new experiments to test the geometric effects – including the generation of rings in *single* quantum wells in the second paper above, coalescing droplets , and the effects of homogeneous excitation in shrinking the rings in the first paper above.

All groups agree however, that the excitons so formed are cold, and so although the existence of the rings has nothing to do with exciton condensation, they may be a source of cold and perhaps dense excitons. Are these excitons reaching quantum degeneracy? That is not known, though the evidence may rest in terms of the one phenomenon seen in experiment that is not yet understood. At low temperatures, the rings have an instability to the formation of regular beads of light emission. There is no reason not to believe that this instability can be explained by some standard nonlinear mechanism, but it turns out to be much easier to generate the phenomenology seen in experiment if the density approaches the quantum regime [3].

[1] L.V. Butov *et al* Nature **418**, 751 (2002).
[2] D. Snoke *et al.*, Nature **418**, 754 (2002).
[3] L. S. Levitov, B. D. Simons, L. V. Butov cond-mat/0403377