Multi-excitonic complexes in single, mesoscopic-size semiconductor islands

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The possibility of obtaining cold, tunable-density, two-dimensional electron-hole gas has stimulated investigations of double quantum well structures such as, for example, GaAs/AlAs hetero-wells with built-in type II interfaces. Luminescence spectra of such systems are known to exhibit a number of fascinating properties which have been interpreted as the observation of a precursor of the Bose condensate of excitons or alternatively are assigned to effects of trapping of photoexcited carriers in naturally built-in quantum-dot like objects formed by potential fluctuations caused by the interface roughness.

Recently we have shown that broad, indirect macro-luminescence of a GaAs/AlAs double quantum well structure can be dominated by sharp emission lines spreading up to 200meV below the direct Γ-Γ transition. These lines become clearly resolved when high magnetic fields are applied in the direction perpendicular to the quantum well plane. Time resolved experiments showed that the decay time of the sharp lines is in the μs range, which is quite different from that observed for direct (Γ-Γ) as well as indirect Γ-X transitions showing characteristic decay times in the ns and ms range, respectively. The appearance of these lines is not well understood, although they have been tentatively attributed to natural quantum-dot-like objects.

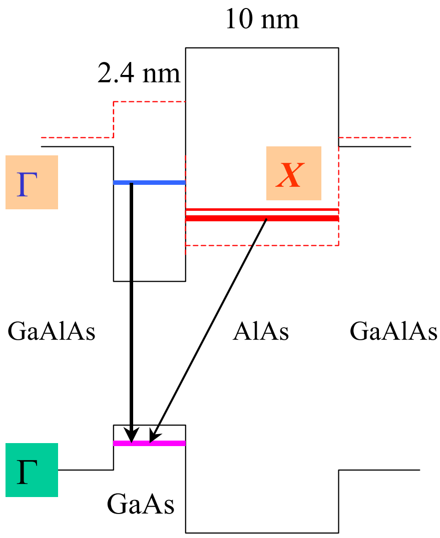

Figure The schematic diagram of the investigated structure

In order to explain the nature of this intriguing emission several types of experimental techniques, including time resolved luminescence, micro-luminescence mapping and micro-luminescence experiments in high magnetic fields have been employed.

Reducing the excitation spot size allowed us to detect well defined emission from single mesoscopic objects. For very low excitation powers only a single emission line is observed. With increasing excitation power an additional single line at an energy of about 3 meV below the initial emission appears. Such a doublet structure is similar to that observed in the micro-luminescence of natural GaAs quantum dots, and can be assigned to neutral and charged excitons. In our case, further increase of the excitation power leads to the appearance of additional low energy lines which we attribute to the formation of more complex excitonic molecules. Such a behavior is well reproducible when studying various parts of the sample in a broad energy range.

The application of a magnetic field allowed us to distinguish the lines as being of different physical origin. The emission line attributed to the neutral exciton splits into two well resolved Zeeman components, showing a significant diamagnetic shift. The magnetic field behavior of the low energy part of the spectrum, connected with other excitonic complexes, is more complicated. They split into several components. Some of them gain in intensity in a strong magnetic field and finally become dominant in the spectrum.

The observed effects are discussed in a context of the specific character of the GaAs/AlAs interface for which the GaAs well width fluctuations and/or gallium inter-diffusion into the AlAs layer favor the formation of mesoscopic islands. It is argued that such laterally confined objects can serve as an efficient recombination channel for indirect excitons diffusing in the plane of the GaAs/AlAs QW structure.