Carrier confinement in stacks of InAs/GaAs sub-monolayer quantum dots: quantum dots or quantum wells?

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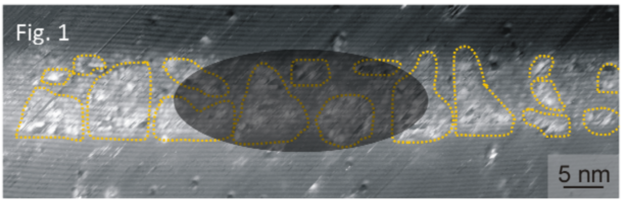
Sub-monolayer quantum dots (SML-QDs) are formed by cycled deposition of <1 ML of InAs and a few MLs of GaAs. Cross-sectional scanning tunneling microscopy (X-STM) reveals that the samples comprise In-rich agglomerations with a large distribution of shapes and sizes (Fig. 1), embedded in an InGaAs quantum well (QW) [1]. Paradoxically, SML-QD photoluminescence (PL) is very bright and narrow (6 to 9 meV at 4 K), and SML-QD vertical-cavity surface-emitting lasers (VCSELs) can operate at up to 30 Gb/s [2]. Indeed, the very nature of the confinement is unknown: is the system zero- or two-dimensional?

We have used magneto-PL measurements at temperatures between 1.5 and 400 K in Faraday and Voigt geometry up to 17 T to probe the excitonic confinement of 3 SML-QD samples with a 10-fold stack of 0.5 ML of InAs separated by 1.5, 2.0 and 2.5 ML of GaAs. At low temperature the exciton Bohr radius is found to be 15 to 16 nm in all samples, i.e. the exciton extends laterally across several agglomerations (Fig. 1). Furthermore, the dependence of both the PL linewidth and the (Voigt geometry) diamagnetic shift on GaAs spacer thickness strongly implies that the vertical exciton extent is limited by the stack height (Fig. 1). *These results support the interpretation that the samples are quantum wells*. *In contrast, magneto-PL measurements at 350 to 400 K demonstrate dot-like states*: In high magnetic field (Faraday geometry) excited-state luminescence peaks become resolved, and display a field dependence that can be described by a Fock-Darwin spectrum (Fig. 2).

These paradoxes can be resolved by attributing *different dimensionalities of confinement to electrons and holes*. The agglomerations are too small to confine electrons, which are relatively light, so the electron wave-function is bounded vertically by the SML-QD stack, and the electrons see an InGaAs QW. This defines the exciton extent, and results in line-widths that are typical for (disordered) QWs [3]. The much heavier holes, on the other hand, are confined in the dot-like In-rich agglomerations with confinement energies ~9 meV.



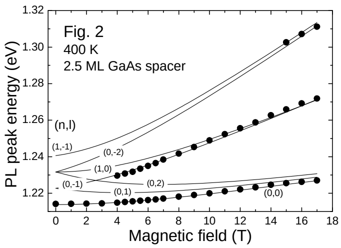


Fig. 1: Typical X-STM image of a SML-QD sample. The In-rich agglomerations are shown with dotted lines, while the shaded ellipse depicts the extent of the exciton (electron) wave function. Fig. 2: Magneto-PL peak positions (symbols) at 400 K for the sample with 2.5 ML GaAs spacers. The lines show the Fock-Darwin states. Similar behaviour was observed in all 3 samples.

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