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Ultra-Low Density GaAs Quantum Dots by Nanohole Filling

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We discuss the fabrication, as well as structural and optical properties of GaAs quantum dots with an ultra-low density of less than 10^6 dots per cm^2 uniformly over the whole wafer. We use the self-assembled local droplet etching (LDE) technique to drill nanoholes into AlGaAs surfaces and fill these holes partially with GaAs to form GaAs QDs of adjustable size in an AlGaAs matrix. The LDE is performed in a conventional molecular beam epitaxy system. First, group-III metal droplets, in our case Al, are deposited on a semiconductor surface at usual III-V MBE growth temperatures in Volmer-Weber growth mode under a very low arsenic background pressure F_{As}. After droplet deposition the sample is annealed, still without As supply. During annealing the Al droplets are transformed into nanoholes surrounded by an AlAs wall. At lowest possible F_{As} this leads to holes with a bimodal depth distribution, i.e., a relatively high number of shallow holes exists among some deep ones with a total density in the 10^8 per cm^2 range, as is visible in Fig. 1(a). By optimizing the As flux during the droplet deposition step, the formation of shallow holes can be suppressed, leading to only deep nanoholes, with an increased depth of ~30 nm and an ultra-low density typically in the 10^6 dots per cm^{-2} range (Fig. 1(c)). Apart from the influence of F_{As} on the hole density and depth (Fig. 1(d))[1], we also report on the influence of the process temperature [1] and droplet material amount [2] studied by atomic force microscopy (AFM).

By filling of the nanoholes with GaAs we obtained well separated, strain-free GaAs QDs. The ground-state emission energy of these QDs has been adjusted over an energy range from 1.56 eV up to 1.68 eV by the hole filling level [1]. The QDs show clear excitonic features with linewidths down to 100 µeV, setup resolution limited. High excitation power photoluminescence measurements demonstrate that also the quantization energy is precisely adjustable (Fig.1 (e-g)) [2].

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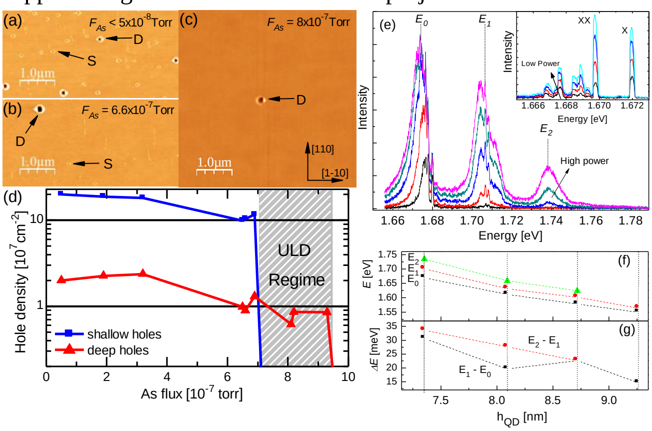

Fig.1: (a)-(c) AFM images of LDE samples with varied arsenic flux F_{As} during droplet deposition as indicated. (d) Density of shallow and deep holes in dependence of F_{As}. The lines are guides to the eye. [1] (e) High excitation power single-dot PL spectra at T=6 K from a single 7.3 nm high QD, with three broadened quantized shells $E_0 \ldots E_2$. In the inset, a low excitation power series of a dot is shown, were exciton X and biexciton peaks XX can be clearly identified by their power dependence. (f) Emission energies $E_0 \ldots E_2$ of the QD shells for samples with different QD height h_{QD}. (g) Comparison of the quantization energies ΔE in dependence of h_{QD} [2].

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