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Micro-photoluminescence of capped and uncapped ordered single InAs quantum dots on GaAs (311)B

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Abstract. Micro-photoluminescence (PL) of capped and uncapped ordered single InAs quantum dots (QDs) on patterned GaAs (311)B substrates exhibits distinct emission lines which are broadened for uncapped QDs. This indicates strong interaction with surface states paving the way towards high-sensitivity sensor applications.

Keywords: A1. Nanostructures; A3. Molecular beam epitaxy; B1. Nanomaterials; B2. Semiconducting III–V materials
PACS: 81.05.Ea; 81.15.Hi; 81.07.Ta; 81.07.Vb; 81.16.-c; 81.07.-b

INTRODUCTION

Self-assembled semiconductor quantum dots (QDs) with high structural and optical quality have been extensively investigated in recent decades. However, position control of single and ensembles of QDs still remains a challenge. We have presented complex architectures of laterally ordered QD arrays formed by self-organized anisotropic strain engineering of InGaAs/GaAs superlattice (SL) templates combined with step engineering on artificially patterned GaAs (311)B substrates. The ordering by self-organized strain engineering is based on anisotropic adatom surface migration during annealing and strain correlated growth during stacking in SL template formation to develop a two-dimensionally strain modulated surface. As a result, arrays of well isolated InAs QD molecules and single QDs form on top due to local strain recognition. On patterned substrates the anisotropic adatom surface migration during annealing is distinctly modified due to the presence of steps and facets to guide the self organization process of the SL template creating more complex QD arrangements such as zig-zag stripes and isolated single QD rows, as well as QD-free regions over macroscopic length scales [1]. Here we present micro-PL studies of capped and uncapped laterally ordered single InAs QDs to reveal the optical quality on the patterned substrates. Distinct emission lines are observed from individual QDs which are broader for the uncapped QDs. This indicates strong interaction with surface states which has great potential for high-sensitivity sensor applications [2].

SAMPLE STRUCTURE

The samples were grown by solid source molecular beam epitaxy (MBE) on stripe and zig-zag mesa patterned GaAs (311)B substrates. After oxide removal, the growth commenced with a 200 nm thick GaAs buffer layer grown at 580 ºC, followed by a ten periods InGaAs/GaAs SL template, a 15 nm GaAs spacer and an InAs layer on top for (single) QD formation. The details of the SL template and QD formation on planar and patterned substrates can be found elsewhere [1].

The structural properties of the samples were characterized by tapping-mode atomic force microscopy (AFM) in air. A QD sample was capped by 100 nm GaAs. A He-Ne laser operating at 632.8 nm with excitation power densities of 35 μW/cm² (for capped QDs) and 13 μW/cm² (for uncapped QDs) was used to excite the samples through an optical microscope objective which also served to collect the PL with a spatial resolution of ~ 2 μm

RESULTS AND DISCUSSION

Figure 1 shows the temperature dependent micro-PL of GaAs capped (a) and uncapped (b) single QDs on the SL template (the AFM image of uncapped QDs

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is shown in the inset of Fig. 1 (b)). The respective emission of the SL template and capped QDs is centered at 1.34 eV and 1.275 eV for temperatures below 10 K while the emission of the uncapped QDs is shifted to around 1.0 eV. The strong shift of the PL to lower energies (~250-280 meV shift) for the uncapped QDs (which has also been observed for large ensembles of random QDs) is attributed to elastic strain relaxation, hence, bandgap narrowing (~200 meV) and strong coupling/interaction of the QD energy states with surface states reducing the QD bandgap energy (~70-80 meV) [3]. Temperature dependent micro-PL reveals thermally activated carrier transfer from the SL template to the capped (QD PL intensity increases up to 60 K) and uncapped (QD PL intensity increases up to 25 K) QDs [4]. The PL intensity decreases for uncapped QDs at relatively low temperatures indicating the presence of nonradiative carrier recombination centers. However, up to 25 K the PL intensity of capped and uncapped QDs is comparable.

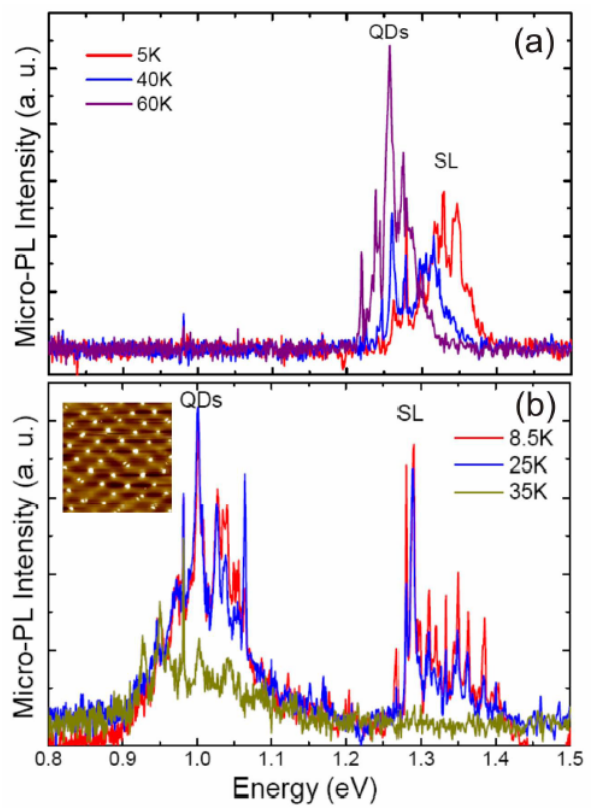

FIGURE 1. Temperature dependent micro-PL of (a) capped and (b) uncapped single InAs QDs on patterned GaAs (311)B substrates. Inset: AFM image of uncapped single InAs QDs. The scan field is 2 x 2 μm².

Figure 2 compares the micro-PL spectra of the capped (a) and uncapped (b) QDs taken at low temperatures, exhibiting well distinguished emission lines from individual QDs. The linewidths of the uncapped QDs (3 – 5 meV) are distinctly larger than the resolution limited linewidths of the capped QDs (1 meV for this measurement system). The larger linewidths of uncapped QDs confirm strong interaction of QD energy states with surface states which causes temporal variations of the PL emission energies. In contrast to ensemble measurements [5], structural variations are not relevant to broaden the emission for single QDs verifying that the broadening in Fig. 2 (b) is originating from the interaction with surface states.

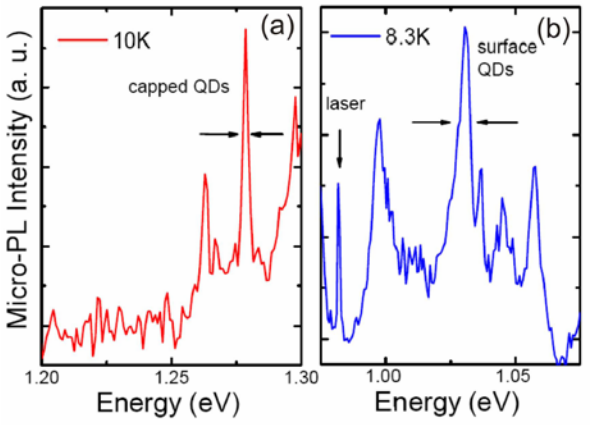

FIGURE 2. Micro-PL at low temperature of (a) capped and (b) uncapped single InAs QDs on patterned GaAs (311)B substrates with enlarged energy scale. In spectrum (a) the linewidths are ~1 meV, limited by the micro-PL setup and in spectrum (b) the linewidths are ~3 meV.

CONCLUSION

In conclusion, micro-PL of capped and uncapped laterally ordered single InAs QDs grown on patterned GaAs (311)B substrates was presented. Distinct emission lines have been observed from individual QDs which are broader for uncapped QDs. This was attributed to strong interaction with surface states paving the way towards high-sensitive sensor applications.

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