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Tuning the emission properties of self-assembled InAs/InP(001) quantum dots

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Because of their promising performances such as high characteristic temperature and low threshold current density, lasers based on InAs/InP quantum dots (QDs) are attractive building blocks for the next generation of optical networks operating in the 1.5 µm range.[1] As the development of these technologies requires the monolithic integration of different lasers on a single chip, spatially selective band gap tuning of QD structures is becoming a critical issue. On the other hand, self-assembled InAs quantum dots (QDs) grown on InP are characterized by a naturally broad emission, therefore making this materials system very promising for superluminescent diode in optical coherence tomography.[2] For this application, the achievement of higher imaging resolution requires further broadening of the QDs emission, which can also be achieved through spatially selective bandgap tuning.

Thermally-induced-intermixing, in which atomic interdiffusion at QD/barrier interfaces modifies the quantum confinement profiles, has proven to be a generic approach for the adjustment of energy levels after the growth of QD-based structures. To achieve spatial selectivity, several techniques based on the enhancement of interdiffusion through the inclusion of point defects in capping layers such as ion implantation[3] and grown-in defects (GID)[4] have been proposed. In this work, we study the photoluminescence (PL) properties of InAs/InP QDs subjected to these two defect-mediated intermixing techniques. It is shown that these approaches are very promising for the spatially selective adjustment of the emission properties of InAs/InP QDs by providing large and controllable blueshifts in the PL spectra.

Self-assembled InAs QDs were grown on InP(001) by chemical beam epitaxy in a Stranski–Krastanov mode, which involves a strain driven transition from 2 to 3 dimensional growth after deposition of few InAs monolayers (MLs). Samples submitted to ion implantation consisted in a single InAs QD layer capped with 200 or 800 nm-thick InP layer. Implantation was realized with P^+ ions at an energy of 30 keV with fluences Φ ranging from 10^{11} to 10^{15} cm^{-2}. According to SRIM 2000 simulations, the implantation damages were located in the top 120 nm of the InP capping layer.[5] On the other hand, GID sample structure consisted in single InAs QD layer covered with a 800 nm-thick InP layer and terminated with a 33 nm-thick InGaAs cap. The topmost 760 nm-thick InP layer was grown at reduced temperature and thus contained the GID. All samples were annealed at temperatures (T_a) ranging from 400 to 750 °C for annealing time (t_a) of 60 s. PL measurements were performed at 77 K on as-grown samples and following each anneal.

Figure 1 shows the emission spectra obtained from QDs samples before and after (a) ion implantation and (b) GID mediated intermixing. The as-grown samples are characterized by a broad emission peak centered at around 850 meV, arising from the superposition of up to 9 peaks which are attributed to QD families having the same thickness in terms of an integer number of MLs.[6] Figs. 1(a) and (b) reveal that under annealing the overall QD emission spectra exhibit a blueshift whose magnitude increases with T_a. It is important to note that the magnitude of the shift obtained for given annealing conditions is also proportional to implantation fluence and thickness of the GID layer. PL shift of up to 250 meV can be obtained after annealing at 600 and 750 °C in implanted and GID samples respectively.

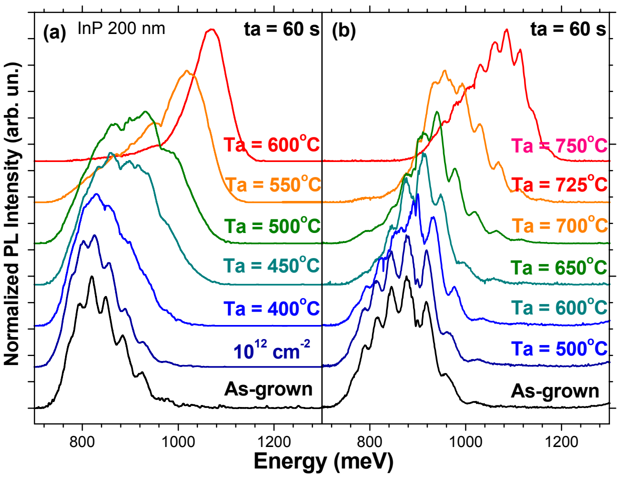

FIG 1. PL spectra from as-grown and annealed QDs as a function of annealing temperature T_a for (a) implanted sample with $\Phi = 10^{12}$ cm^{-2} and for (b) GID sample.

Figure 1 also reveals that the two tuning techniques are characterized by markedly different behaviors. The PL spectra from implanted samples (Fig 1(a)) exhibit significant bandwidth broadening as well as the progressive rise of a high-energy shoulder that slowly transforms into a much narrower peak, similar to that from a QW emission. In contrast, PL spectra from GID samples (Fig 1(b)) show that QD families are shifting at comparable rates, thus preserving the overall emission bandwidth. One further notes that the T_a threshold for observable PL shift are ~400 and 600 °C for implanted and GID samples, respectively. Since no significant PL shifts could be obtained below 725°C in the case of untreated samples,[6] ion implantation and low temperature InP deposition are therefore very promising for spatially selective tuning of QDs emission.

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