

Iterative Bandgap Engineering in Selected Areas of InGaAs/InGaAsP Quantum Semiconductor Wafers

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The need to fabricate quantum well (QW) semiconductor wafers with regions of different bandgap materials has been well documented in literature. Such microstructures are of high interest, e.g., for the fabrication of monolithically integrated photonic devices. In addition to conventional selective-area epitaxial growth techniques, the post growth wafer processing based on intermixing of the QW and barrier materials, known as quantum well intermixing (QWI), has been widely investigated for that purpose. However, the QWI approach has not been able to deliver precision and reproducibility required for the fabrication of advanced industrial devices. The underlying problem is related to the difficult technology of III-V semiconductors and limitations in using calibration procedures, such as those routinely used in the fabrication of Si-based devices by microelectronics industry. To address QWI in selected areas of QW or quantum dot (QD) wafers, we have been investigating a laser-rapid thermal annealing (Laser-RTA) technique [1]. The ultimate advantage of such an approach is that it offers the possibility to carry out diagnostics, e.g., photoluminescence (PL) mapping, without removing investigated wafers from a laser processing station. For instance, emission wavelength of a QW could be modified in several Laser-RTA steps, similar to the laser-based method of resistor or capacitor trimming used by microelectronics. However, specialized diagnostics, such as low-temperature study, often require the wafer to be removed from the laser workstation. Being able to reinstall the wafer at exactly the same location is key to the success of such a multi-step processing approach.

In this communication, we discuss the implementation of a Laser-RTA technique for iterative bandgap engineering in selected areas (iBESA) of InGaAs/InGaAsP QW wafers. We demonstrate the potential of the iBESA approach for tuning emission wavelength of individual QD.

The Laser-RTA system consists of two infrared lasers used for simultaneous heating of semiconductor

wafers from the back (980 nm 150 W laser diode) and front (Nd:YAG TEM00 30 W laser) sides. The role of the laser diode is to increase the wafer background temperature to near the QWI threshold, and reduce the level of power required from the Nd:YAG laser for the intermixing process [1]. Samples investigated in this experiment consisted of five 6-nm-thick InGaAs QWs ($\lambda_{QW} = 1.54 \mu\text{m}$) separated by 10-nm-thick InGaAsP barriers. The structure was grown on InP (001) substrate and the active region was located approximately 1000 nm below the surface. An x-y-z-theta computer interfaced stage was used to control the position of the sample. A video camera and a LabVIEW based software implemented for that purpose allowed for the manipulation of the orientation of samples, so each time they were removed from the stage they could return to the previously defined 'home' position. The translational and rotational precision of this manipulation was 5 μm and 0.01 deg, respectively. An example of the PL map of an InGaAs/InGaAsP QW wafer showing an array of 20 sites that, initially, were blueshifted by an arbitrary amount of $\Delta\lambda_x$ is shown in Fig. 1. It can be seen that following a 2-step iBESA processing, the sites emit at a wavelength identical within $\pm 2 \text{ nm}$, which is comparable with the precision of the applied PL measuring instrument. We will discuss the application of this approach for tuning emission wavelength of individual InAs QDs.

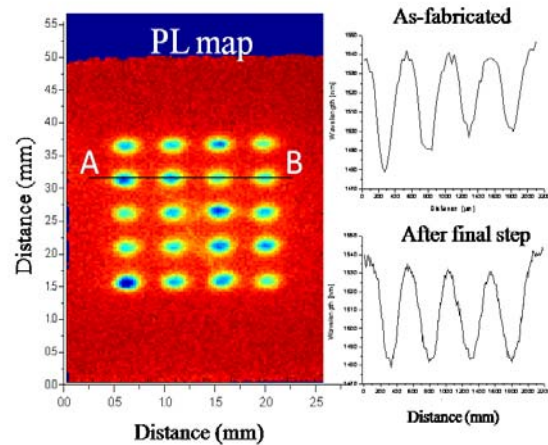


Fig. 1. Photoluminescence map of a QW InGaAs/InGaAsP wafer showing an array of 20 sites each initially blueshifted by an arbitrary amount of $\Delta\lambda_x$. A multi-step iBESA processing allows fine tuning of emission wavelength at individual sites. The equalization of emission wavelength in the shown example has been achieved following a 2-step iBESA processing.

[1] R. Stanowski, J.J. Dubowski, Appl. Phys A94, 667 (2009).

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