Investigation of quantum efficiency of A3B5 laser heterostructure after FIB milling

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Abstract. Al-containing layers oxidization was eliminated using UHV FIB system and thus, only ion implantation and amorphisation influence on quantum efficiency of A3B5 laser heterostructures should be investigated.

1. Introduction

Focused Ion Beam (FIB) nanofabrication is one of the fundamental techniques in research, and production development areas. FIB milling is widely used in integrated photonics as a rapid and flexible prototyping method for structures consisting of Si planar waveguides or Si photonic crystal based elements, because it is maskless direct etching on nanoscale [1].

The most important problem in silicon photonics is an integration of light emitters into planar photonic chip [2]. Hybrid technology like wafer bonding based on Si substrate is not a suitable solution for small and reliable active elements like laser or light emitting diodes [3]. Otherwise A3B5 laser heterostructures are used for small (less than 10 µm) integrated light emitters [4]. In application to A3B5 semiconductors FIB etching is used for manufacturing microresonators [5], subwavelength gratings [6], near-field couplers [7] and etc. However, FIB milling process is not suitable for fabrication of light emitters because of etching-induced defects such as, ion implantation, material amorphisation and deep oxidization of A3B5 semiconductor material. Oxidization appears because of low vacuum in a standard FIB chamber and high etching temperature. Both types of defects lead to crystal imperfections in the active layer of the structure, and therefore to nonradiative carrier recombination and low quantum efficiency of light emitters.

2. Experiment

2.1. Milling of laser heterostructure.

In order to investigate high energy ions influence on quantum efficiency we decided to conduct an experiment on molecular beam epitaxy grown $Al_{0.4}Ga_{0.6}As/GaAs$ laser heterostructure with $In_{0.2}Ga_{0.8}As$ quantum well (fig. 1 a). To prevent oxidization of Al containing layers we used originally designed ultra-high vacuum (UHV) cross-beam FIB/SEM (scanning electron microscopy) system equipped with Orsay Physics Ga ion and electron columns. We produced trenches on the laser

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structure with different depths: 120, 250 and 550 nm with exposure time 2, 4 and 10 ms correspondingly. Measured trenches width is close to 100 nm. SEM image of the cross section for depth measuring is shown on figure 1, b. Two trenches are located over the quantum well, and the third trench crosses it (fig. 1 a). Beam parameters were 30 kV acceleration voltage and 50 pA probe current. Optical characteristics were investigated using micro photoluminescence (PL) technique with 671 nm pump lasing wavelength focused by 0.5A objective in 40 µm spot diameter.

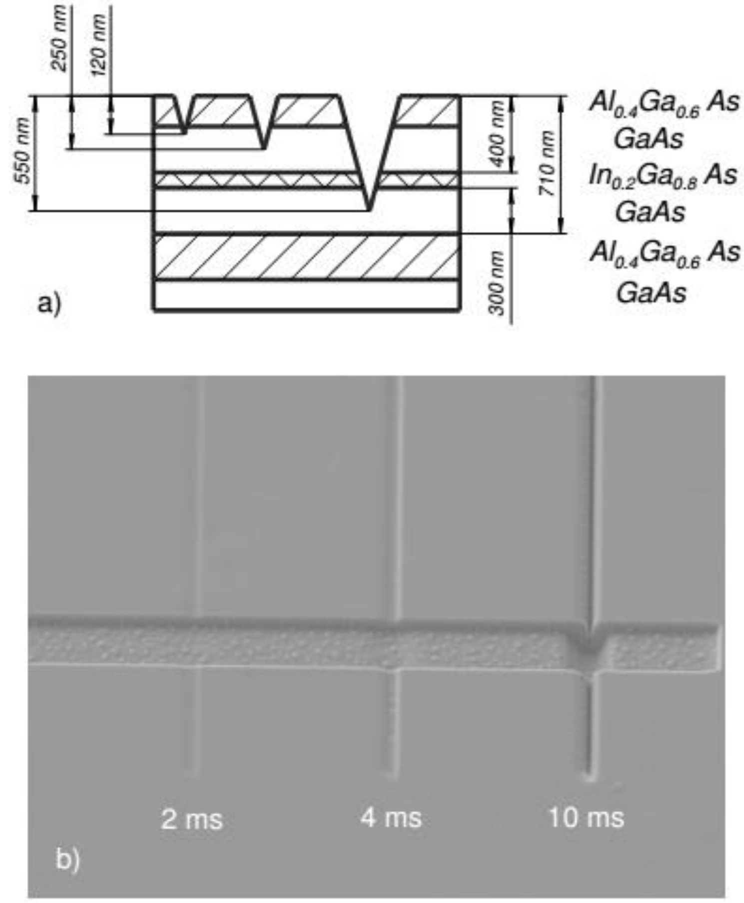

Figure 1. a – laser heterostructure scheme, b – etched trenches with 120, 250 and 550 nm depth, SEM image.

2.2. Measurement results and discussions

Figure 2 represents spatial distribution of micro photoluminescence (PL) intensity from the bulk structure and etched trenches. Experimental data is represented without mathematical processing and asymmetry of curves appears from aberrations of the optical system. The luminescence intensities from trenches 1 and 2 are close to each other and discern from trench 3. Assuming that luminescence from bulk structure is 100 % then trenches 1 and 2 have close to 97 % intensity and 3rd trench has 93 %. Spot of excitation is larger than trench width and radiation was collected from all layers, hence this graph is mostly qualitative. For quantitative examination the luminescence spectra were measured (figure 3). Low energy peak corresponds to luminescence from quantum well and high energy peak from waveguide layers. From this graph we clearly see that induced during FIB etching structural damages in quantum well lead to radical decrease of quantum efficiency, 60 % in comparison to the bulk structure. However, the light intensity decrease from trenches 1 and 2 (96 % and 93 %, correspondingly) is observed only in waveguide layer. Luminescence suppression by the shape of the etched surface due to the total internal reflection is not significant and hence not discussed in detail.

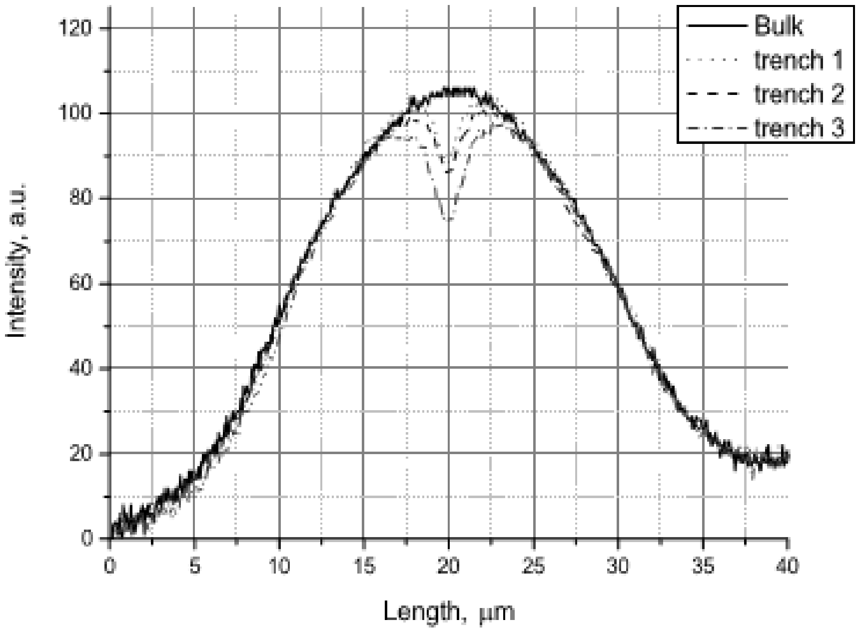

Figure 2. Spatial distribution of micro PL intensity. Bulk – 100 %, trench 1 and 2 – 97 %, trench 3 – 93 %.

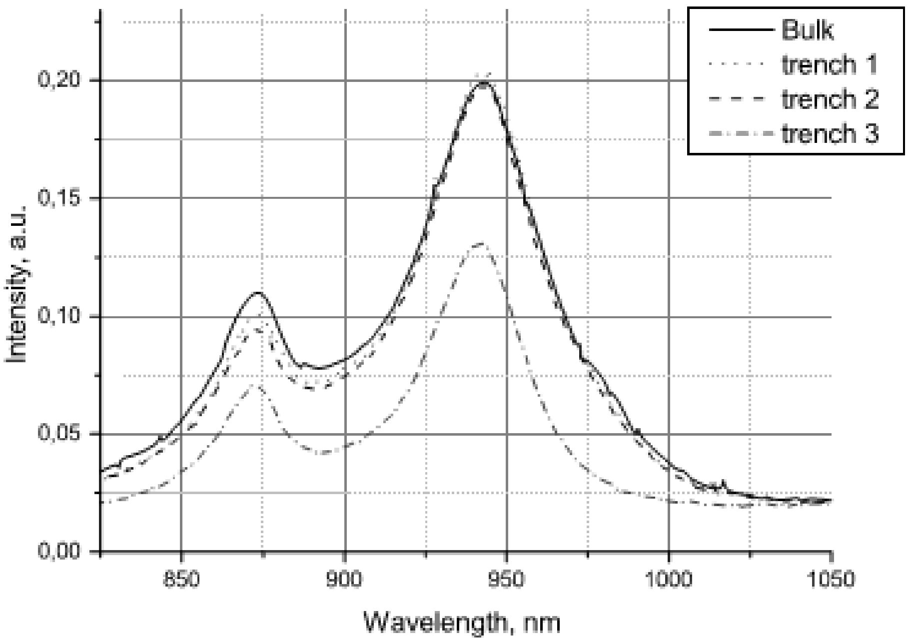

Figure 3. Micro PL spectra, intensity from bulk – 100 %, trenches: 1 – 96 %, 2 – 93 %, 3 – 60 %.

3. Conclusion

Several trenches on A3B5 laser heterostructure were etched using the UHV FIB system. Influence of radiation defects on luminescence efficiency of quantum well was investigated. As the result we can state that typical laser heterostructure can be etched in oxygen less atmosphere by 30 keV Ga FIB up to quantum well layer without decreasing of luminescence efficiency. Considering that width of FIB milling in A3B5 materials is less than 100 nm, this approach can serve as technological basic for light emitting elements in integrated nanophotonics.

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