Impurity Free Intermixing for Optoelectronic Device Integration

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Monolithic integration is a key issue of future optoelectronic device technology, with important applications in the area of optical communications. The bandgap control in different regions of the device is essential in order to achieve this goal. Although selective area regrowth has proved to be effective, the technique is complicated and costly. The technological simplicity of the intermixing process makes it highly attractive, but its main challenge is related to reproducibility. Intermixing can be achieved by ion implantation, can be induced by impurities such as Si or Zn during diffusion or by using dielectric capping layers in impurity free intermixing. Impurity free intermixing is attractive for laser diode applications since the amount of introduced defects is expected to be lower than for the other methods. The band gap shift depends on many variables such as annealing atmosphere, nature of the cap layer (SiO_2, Si_3N_4) and its deposition parameters, stress, position of the active region under the surface and doping.

Significant progress in the understanding of the influence of different factors affecting the intermixing process was achieved lately for undoped structures [1-4]. But a typical laser structure needs a high doping level ($p \approx 1.e20\ cm^{-3}$) in the top most contact layer. One of the purposes of this paper is to study the differential intermixing in InGaAs/GaAs/AlGaAs MOCVD Zn doped and undoped laser diode structures, in order to understand the influence of Zn doping. We use a thin p-clad ($t = 0.3\ \mu m$) asymmetric structure with a low value of the absorption coefficient, $\alpha \approx 2 - 3\ cm^{-1}$. Ga doped and undoped spin on glass were used as cap layers. The active region is 0.6 μm below the surface.

For the undoped structure, capping with undoped spin on glass enhances the blue shift of the band gap with respect to annealing using Ga doped spin on glass or the uncapped surface. The blue shift is 13 nm at 900 ^{o}C and 50 nm at 925 ^{o}C. If 0.3 μm are etched away and the sample is annealed at 900^{o} C with no cap, we find a 30 nm blue shift with respect to the annealed, unetched sample. This suggests a new method to achieve the needed blue shift for integration between a laser diode and a waveguide, by etching away some of the material outside the active (lasing) part of the device. The scheme is demonstrated for the doped structure for a device having passive loss of 7 cm^{-1}. This loss can be reduced by further optimizing the differential intermixing, since the relative value of the blue shift is reduced in doped laser structures, as it will be shown below.

For the Zn doped (normal) laser structures, the behavior is considerably more complex. For samples annealed with undoped spin on glass, the blue shift with respect to the as grown sample is 20 – 30 nm at 900 ^{o}C and 35 – 45 nm at 925 ^{o}C but there is little differential blue shift between annealing with and without the undoped spin on glass cap. Lower energy PL peaks, associated with the presence of Zn in the not intentionally doped active region are seen after intermixing. Annealing with Ga doped spin on glass is accompanied by a significant broadening of the PL peak. C-V profiles and results on laser diode devices show that this is due to the considerable Zn in-diffusion in the unintentionally doped layers of the laser diode. A significant higher absorption ($\alpha \approx 8\ cm^{-1}$) and increased series resistance is found for these devices.

The samples annealed with undoped spin on glass show less broadening of the PL peak and less Zn in-diffusion but samples annealed with no cap show minimal Zn migration and best performances: their absorption coefficient is as low as for the as grown structure and series resistance is not increased, while the blue shift with respect to the as grown sample is 35 – 40 nm.

If the highly Zn doped layer is etched away, the PL blue shift is comparable with the one corresponding to similarly etched undoped structure.

These results can be understood if we have in mind that in undoped structures group III vacancies, either injected at the cap semiconductor interface or present due to annealing under As rich conditions are the point defects that mediate the atomic inter-diffusion process, while the main point defects associated with intermixing in highly Zn doped layers are group III interstitials. Group III vacancies and interstitials annihilate each other. Thus, Ga doped spin on glass, which suppresses intermixing, is not a good option for Zn doped structures because it leads to considerable (unwanted) Zn in – diffusion.

Finally, a different scheme of optoelectronic integration is discussed. If no feed back is provided at the end of the active section, the lasing will depend on the feed-back at the end of the passive section. It is desirable to uncouple lasing in the active region from what follows in the passive section and after that. It was shown that it is possible to achieve integration by using a specially designed structure as in [5,6]. The approach proposed here uses a structure that supports only one mode in the active part of the device, with a theoretical coupling efficiency of 75 %, as compared with the 50 % coupling efficiency reported in ref. [5,6]. The mirror reflectivity at the partially etched facet is computed and discussed.

References

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