Effect of Al−content reduction in (AlGa)As cladding layers of MOVPE grown high−power laser diodes

Andrzej Malag [1)], Anna Kozlowska [1)], Marek Wesolowski [1)]

1) Institute of Electronic Materials Technology, 133 Wolczynska Str., 01−919 Warsaw, Poland

It has been generally accepted to consider AlGaAs/GaAs heterostructures as lattice−matched. Due to the small lattice constant difference between AlAs and GaAs however, the lattice−mismatch in e.g. $Al_{0.7}Ga_{0.3}As/GaAs$ heterojunction is $\Delta a/a$ = 1E−3 [1]. This magnitude is, for instance, only one−fourth of that for doubtless lattice−mismatched $GaAs_{0.88}P_{0.12}/GaAs$ junction ($\Delta a/a$ = 4.3E−3, tensile−strained GaAsP layer with P−content designed for λ = 808 nm emission). This means that in heterostructures containing thick $Al_xGa_{1-x}As$ cladding layers with high x−values one can expect some small perturbations during the epitaxial growth, leading to the QW active region performance deterioration. This is in significant degree dependent on the optimisation of the MOVPE growth conditions, but in general, it would be a good idea to decrease the Al−content in claddings if possible. This would be advantageous not only because of the lattice mismatch decrease, but also because of oxygen and carbon incorporation reduction, dopant activation energy decrease and so on.

This idea can be realised using the double−barrier SCH (DBSCH − MQW or SQW) heterostructure in the laser diode (LD) design. The main feature of DBSCH is the presence of two thin, wide−gap (high x) $Al_xGa_{1-x}As$ barrier layers inserted between waveguide and cladding layers which allows to set the x−values in the claddings relatively low. The role of the barrier layers is twofold, to control the waveguiding properties and to maintain the carrier confinement [2]. QW−DBSCH can be also considered as a conventional QW−SCH with x−values decreased in almost whole cladding layers except some thin, high−x sublayers remaining at both cladding−waveguide interfaces. This is shown in Fig.1.

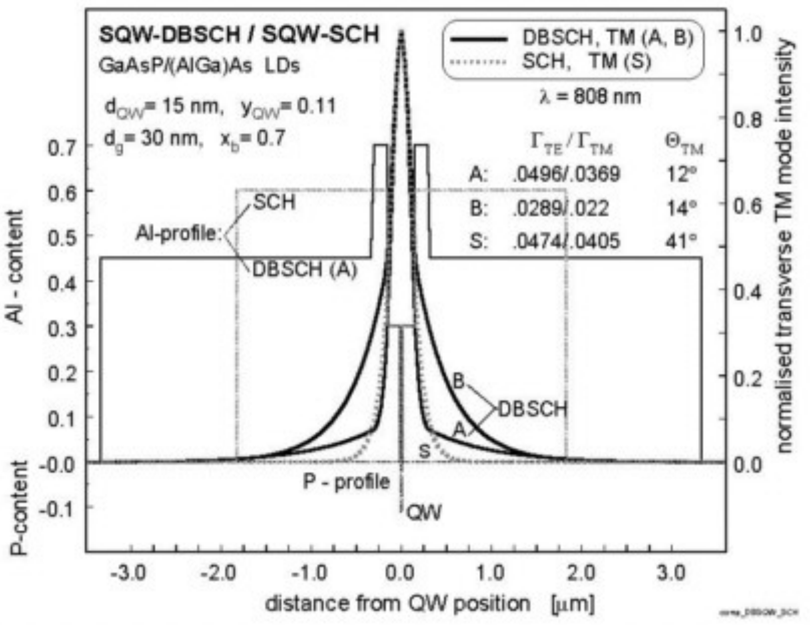


Fig.1.

Two design versions of SQW DBSCH are shown, differing to each other in the barrier and waveguide layers parameters: in the version *A* (Fig.1) the barrier thickness t_b= 150 nm, the waveguide thickness and composition t_w= 140 nm and x_w= 0.3, respectively, and, analogously, t_b= 30 nm, t_w= 130 nm and x_w= 0.35 in the version *B*. Other parameters, common for both versions are inserted in Fig.1. The third structure (*S*) shown in Fig.1 is conventional SQW SCH with similar waveguide and active layer (tensile−strained GaAsP QW). The main difference is in the parameters of the cladding layers: t_c= 1.5 µm, x_c= 0.6 for SCH and t_c= 3 µm, x_c= 0.45 for DBSCH. Calculated optical field intensity distributions of the fundamental (only maintained) transverse TM mode in the waveguide and at the LD facets are also shown for three structures under investigation. TM polarised emission is the only one taken into account as dominant in tensile−strained QW LDs. The difference between *A* and *B* profiles indicates the possibility of the optical field distribution tailoring by DBSCH design.

Electro−optical characteristics of the double−barrier heterostructure high power LDs (including a low beam divergence perpendicular to the junction plane) have been described earlier [3−5]. Here we would like to present the influence of Al−contents in claddings on the quality of the laser heterostructure. One of the ways for that is by comparison of spectral characteristics of LDs manufactured from the heterostructures grown according to the three design versions described above.

The GaAsP(QW)/AlGaAs SQW−SCH (ver. *S*) and two SQW−DBSCH (vers. *A* and *B*) heterostructures have been grown under the same conditions. The MOVPE growth was pursued in the horizontal flow AIXTRON R&D 200 halogen heated reactor with TMGa, TMAl as group III sources, AsH_3 and PH_3 as group V source, DMZn as acceptor doping and SiH_4 as donor doping sources. TMGa source was kept at 0°C. Applied growth temperature was 710°C, pressure 20 mbars and V/III ratios in the range 350−500. The highly *p*−doped GaAs cap layer was grown in lower temperature of 670°C to improve Zn incorporation. Growth interruptions for the gas flow stabilization at the GaAsP quantum well interfaces were minimized to 4s to avoid the interfacial defect generation.

Wide−stripe LDs of various cavity lengths have been fabricated using H^+ implantation for the stripe definition and CrPt and AuGeNi metallizations as *p*− and *n*−contacts, respectively. The pulsed (400 ns, 5 kHz) spectral characteristics were measured for sets of LDs made from each of the grown heterostructures and representative results are seen in Fig.2 and Fig.3. Exemplary spectrum of SCH LD shown in Fig.2 is rather wide and irregular. Sometimes LD spectra from this set consist of few separate groups. This indicates some nonuniformities in the active region (spectra of CW operation are usually more regular due to stable excitation conditions). On the contrary, spectra of DBSCH LDs are regular (single enveloped) for wide range of cavity lengths (*L*), as seen in Fig.3. Comparison of spectral characteristics of DBSCH devices of the *A* and *B* versions (Fig.3a and Fig.3b, respectively) shows the best quality of the heterostructure with thinner barrier layers (*B*), that means, with lowest cumulative Al content in claddings (including barriers).

There is an interesting difference in the lasing spectrum shift as a function of cavity length (*L*) for both DBSCH LD versions. For the thin barrier (*B*) version the spectra of short cavity LDs are strongly short−wavelength shifted indicating high quasi−Fermi levels separation and therefore high electronic threshold gain. The short−wavelength shift for the *A* version DBSCH LDs of similar *L* is much weaker. This can be explained by the confinement factor (Γ) difference in the heterostructures design, as given in Fig.1. For the TM−polarised fundamental mode the calculated Γ = 0.037 for the *A*−version and Γ = 0.022 for the *B*−version LDs. For a similar threshold modal gain (for similar *L* values) the electronic gain should be therefore distinctly higher in ver. *B* LDs, leading to a faster short−wavelength shift. On the other hand, for the same QW thickness (d_{QW} =15 nm for both versions), lower d/Γ value for the version *A* should cause lower threshold current density (J_{th}). The measured differences in J_{th} values are rather small however: approx. 800 Acm^{-2} (ver. *A*) and 900 Acm^{-2} (ver. *B*) for *L*= 0.25 mm LDs, while for $L \longrightarrow \infty$ $J_0 \cong 110$ Acm^{-2} for both versions. This result, together with measured lower internal quantum efficiency of ver. *A* LDs (η_i = 0.82) compared to those of ver. *B* (η_i = 0.94) confirms the earlier conclusion about superior quality of the thinner barriers (lower cumulative Al−content) DBSCH.

Different d/Γ values should also result in different emitted beam divergences perpendicular to the junction plane $\Theta_\perp$ (TM). In spite, the modelling results given in Fig.1 (the commercial "Photon Design" software [6] has been used) predict similar beam divergences Θ_{TM} = 12° and 14° for the *A* and *B* versions, respectively. Here Θ_{TM} is FWHM of the far−field (FF) beam intensity distribution, which is proportional to the Fourier transform of the *A* and *B* optical field intensity profiles. Low Θ_{TM} despite low d/Γ value (0.4 µm) for the *A*−version is due to the wide 'tails' at a low intensity level of the *A* field profile. This profile is 'irregular' in the sense that it is far from Gaussian−like profile of conventional SCH design (e.g. the profile S). The generally wider *B* profile of higher d/Γ = 0.68 µm is more regular in this sense. The DBSCH design leading to similar Θ_{TM} with different d/Γ values

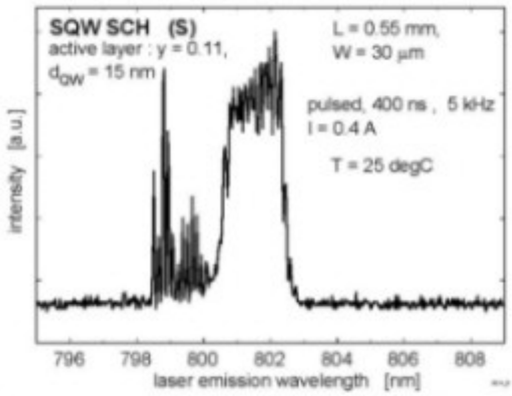


Fig.2.

Fig.3a.

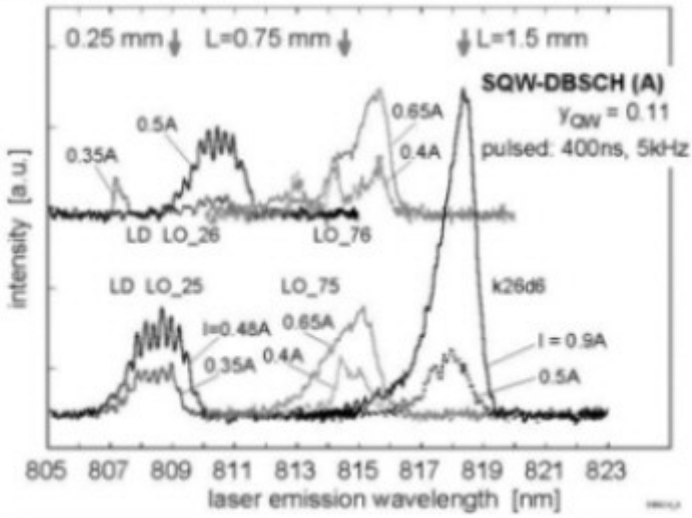
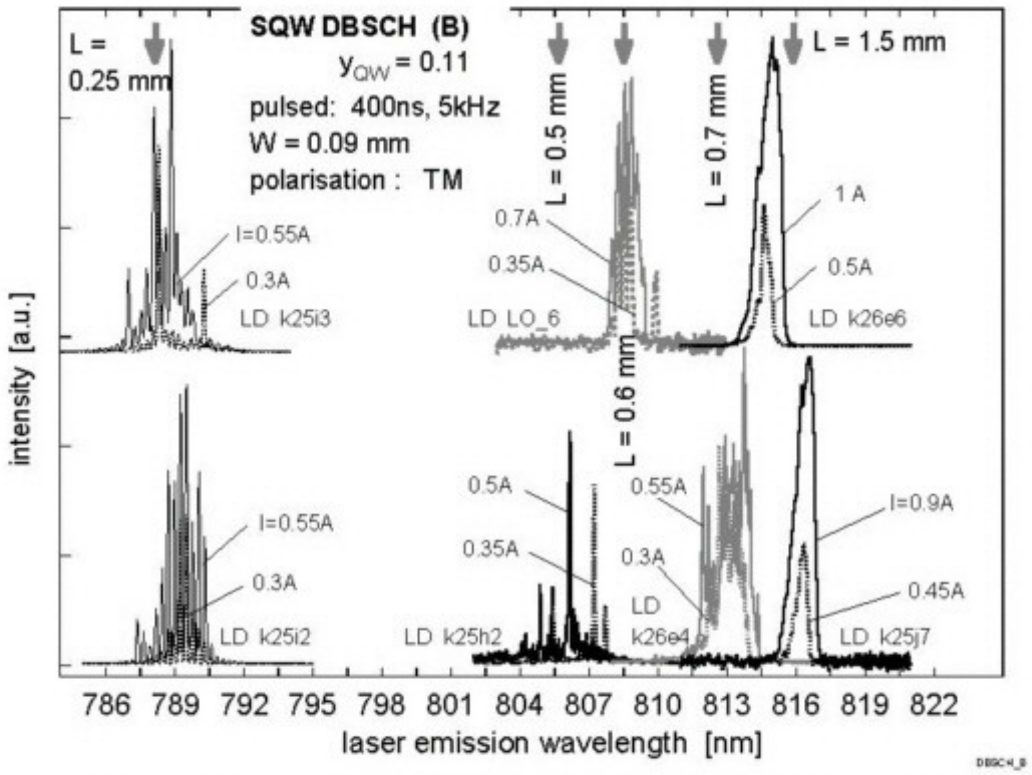


Fig.3b.



should result in different catastrophic optical damage (COD) levels.

Relatively good agreement between theoretical model and experimental results has been obtained for the *B* version, where $\Theta_{\perp}$ = 17° (TM, CW) has been recorded (Fig.4a), close to best results for the double−barrier LD design [4,5]. The difference can be attributed to some small deviations of the experimental structure with respect to the designed one (the transverse field distribution is quite sensitive to the barrier layers parameters) and to the thermal index guiding due to the temperature distribution perpendicular to the junction plane [7]. The later effect, not included in the modelling can be important in weakly guiding DBSCH. Concerning the *A* version, the recorded beam divergence $\Theta_{\perp}$ = 19° (TM; Fig.4b) is distinctly wider than predicted by modelling. This suggests that the low d/Γ parameter is better indication in this case (the optical field profile far from the Gaussian), and especially for TM modes, where modelling is generally less precise than for TE polarisation [6].

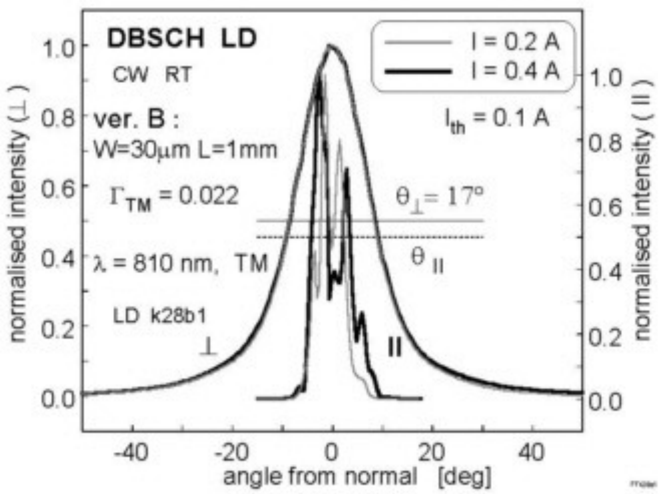


Fig. 4a.

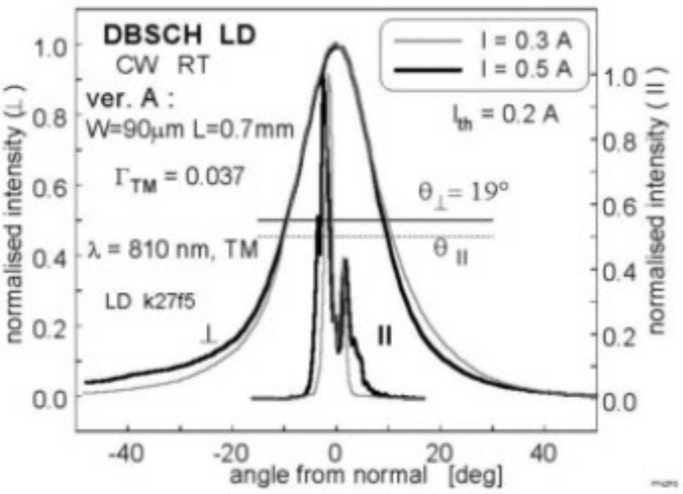


Fig. 4b.

In conclusion, the DBSCH with possibly thin barrier layers of high Al−content (version *B*) seems to be appropriate solution for high power LDs not only because of potentially better growth quality (with respect to conventional SCH), but also because of high d/Γ value, resulting in lower beam divergence and higher COD level, still with acceptably low threshold current density.

References

[1] E.g. the EMF Band Gap Calculator, CD−ROM, EMF, April 2002.
[2] A. Malag, B. Mroziewicz, J. Lightwave Technology, 1996, 14, 6, pp.1514 − 1518.
[3] A. Malag, W. Strupinski, J. Crystal Growth, 1997, 170, pp.408 − 412.
[4] G. Lin et al., IEEE Photon. Technol. Lett.,1996, 8, pp.1588 − 1590.
[5] A. Malag, W. Strupinski , E. Jezierska , Proc. of EW MOVPE VIII, Prague, 1999, p.253.
[6] Photon Design, http://www. photond.com
[7] E. Duda et al., IEEE J. Quant. Electron., 1979, QE−15, 8, pp.812−817.