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LOW THRESHOLD ROOM TEMPERATURE AlGaAs/GaAs GRIN SCH SQW LASERS GROWN BY MBE*

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Low threshold room temperature AlGaAs/GaAs graded-index separate-confinement heterostructure single quantum well (GRIN SCH SQW) lasers were prepared by MBE. The influence of the growth temperature on the laser parameters was studied. Due to the high temperature MBE growth and the use of p-contact layer in the form of thin quasi-metallic beryllium layer significant reduction of the threshold current was achieved.

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In the case of AlGaAs/GaAs GRIN SCH SQW lasers it has been found that the threshold current density, J_{th}, is critically dependent on growth parameters and shows W-shape dependence on the substrate temperature with minima at 375°C and 650°C [1] or at 740°C and 820°C according to other source [2]. The authors of both quoted papers [1, 2] also showed that QW photoluminescence (PL) intensities were in excellent correlation with J_{th} when growth temperature was changed and the quality of the AlGaAs cladding layer played a more decisive role than the active layer quality. Contrary to that Weisbuch et al. [3] reported that the quality of QW was more sensitive to the growth temperature than the AlGaAs cladding layer. Let us notice that the controversial results can be understood if we assume that an improvement in the quality of the heterointerface itself can be the explanation for the improvement of lasers parameters. In this paper we present results of systematic investigations of the influence of growth temperature on optical properties of GRIN SCH SQW structures and parameters of laser diodes made of these structures.

The single quantum well laser structures grown on (100)-oriented n^+-GaAs substrates consisted of: a 0.5 μm GaAs buffer layer ($n_{\mathrm{Si}} = 2 \times 10^{18}$ cm^{-3}), a 1–1.5 μm $Al_{0.7}Ga_{0.3}As$ cladding layer ($N_{\mathrm{Si}} = (0.5\text{–}1) \times 10^{18}$ cm^{-3}), a 0.1–0.15 μm undoped $Al_xGa_{1-x}As$ waveguide layer with an Al composition varying linearly from 0.7 to 0.25, a 50–80 Å undoped GaAs active layer, a 0.1–0.15 μm undoped $Al_xGa_{1-x}As$ waveguide layer ($x = 0.25\text{–}0.7$), a 1–1.5 μm $Al_{0.7}Ga_{0.3}As$ confinement

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layer (P_{Be} = $(0.5-1)\times10^{18}$ cm^{-3}), and a 0.25 μm GaAs contact layer (p_{Be} = 3×10^{19} cm^{-3}). The presence of quasi-metallic Be layer ($p_{Be} > 1 \times 10^{20}$ cm^{-3}) on the top of the final structure was essential for the fabrication of good quality ohmic contacts.

Despite minor variations in the structure design the main factor that differentiates them was that they were grown at various growth temperatures. Except for the bottom n^+-GaAs and the top p^+-GaAs cap layers, nearly entire structure #96 was grown at the temperature typical of early realizations of semiconductor lasers. The n- and p-doped cladding and 75% of the thickness of GRIN regions were grown at 630°C, and the GaAs active region was grown at 580°C. The growth temperature was ramped between 630 and 580°C during growth of the remaining 25% of the GRIN regions adjacent the quantum well. The technological process of the structure growth was designed to minimise Si diffusion into the quantum well. In the case of the structure #121 and #84 a growth temperature decrease from 630 to 616°C in the region of the quantum well resulted from shuttering the Al effusion cell. The confinement and GRIN layers in the structures #125 and #122 were grown at 680°C. The growth temperature decrease from 680 to 630°C during growing the quantum well in #125 was entirely compensated in the case of #122 and the whole structure was grown at elevated temperature of 680°C.

The broad-contact, ridge-waveguide lasers were fabricated from the grown wafers. The spacing between boundary of the GRIN layer and the lower surface of the ridge was 0.4–0.5 μm. Chips were mounted in the p-side up configuration on Cu heat sinks.

After the epitaxial growth the laser structures were first examined using photoluminescence spectroscopy. Room-temperature PL measurements using a low excitation intensity were conducted on the structures with the p-GaAs cap layer etched away. The observed light emission corresponded to the recombination of electrons and heavy holes in the $n = 1$ states. The peak PL intensities from the samples studied are compared in Fig. 1. They show a substantial dependence on the substrate temperature with clear trend to increase in the intensity with the increase in growth temperature. It is evident that optical quality of quantum well improves with the increase in both GaAs growth temperature as well as $Al_{0.7}Ga_{0.3}As$ cladding layers growth temperature. This is consistent with the fact that defects generated during the growth of the lowest $Al_{0.7}Ga_{0.3}As$ layer can propagate into the QW thus lowering its quality [4]. Simultaneously, deep level transient spectroscopy (DLTS) spectra were measured on devices prepared from the same wafers. As evidenced by the spectra, a deep trap with the thermal activation energy of 0.78 eV below the conduction band was commonly present in the structures studied. On the basis of its thermal characteristic, the trap was found to be very similar to the trap at $E_C - 0.76$ eV observed in $Al_xGa_{1-x}As$ and identified as the main PL killer related to oxygen or the aluminium–oxygen complex [5]. We have found that the trap shows an accumulation at heterointerface as determined from its concentration profile [6]. Its concentration strongly decreases with the increase in the growth temperature and the trap could be hardly seen in the sample #122 grown entirely at the highest temperature used, i.e., 680°C. On the basis of the results presented we argue that the trap is responsible for the QW

PL intensity decrease in structures grown at lower substrate temperatures.

The lasing properties of the AlGaAs/GaAs lasers were characterised by determining the threshold current, I_{th}, of broad-contact, ridge-waveguide lasers. The lasers with different cavity length were prepared by successive cleaving of the same bar. The length of resonator was varied from $L = 200$ μm to 900 μm. After each cleavage I_{th} of 5–10 laser diodes was measured at room temperature under pulsed current conditions (200 ns pulse at 0.1 percent duty cycle). In Fig. 2 the average values of I_{th} of lasers made of the various wafers are plotted against the cavity length. Let us notice in Fig. 2 a substantial decrease in the average threshold current, $\langle I_{th} \rangle$, with increasing growth temperature of both cladding layers and active region of the lasers. On the basis of the results of the PL and DLTS measurements the decrease in $\langle I_{th} \rangle$ together with the decrease in the slope of the $\langle I_{th} \rangle$ versus L dependence can be interpreted as a result of decreasing (interface) recombination velocity. This is in a qualitative agreement with calculations of Sieh et al. [7]. In Fig. 2 data for lasers made of the wafer #96 are not included (since they did not operate).

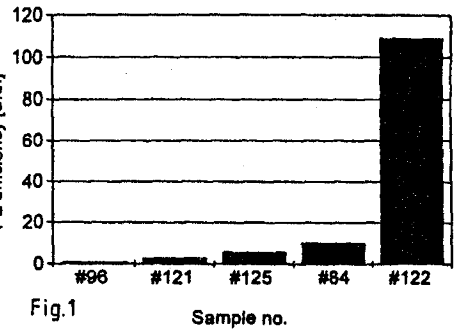

Fig.1

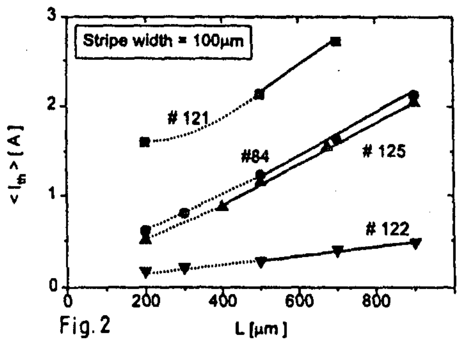

Fig. 2

Fig. 1. QW peak PL intensity at 300 K for a series of GRIN SCH SQW structures grown at different substrate temperatures.

Fig. 2. Average threshold current, $\langle I_{th} \rangle$, as a function of the cavity length, L, for lasers prepared from the wafers grown at different substrate temperatures. Continuous lines represent the fit to experimental data by the method of least squares; dashed lines are drawn to guide the eye.

Worth noting is an anomalous rise of the threshold current at a short cavity length which has been usually interpreted as a result of the limited confinement factor Γ in SQW structures [7]. Taking into consideration the fact that the confinement factor Γ is the same in structures #121, 125, and 122, that the effect is clearly seen in lasers #121, and it is rather weak in the remaining lasers at the cavity lengths used, the cause of the anomalous rise can be most probably attributed to the increase in the value of recombination velocity with decreasing growth temperature.

Summarising, the results of our investigations show that defects in the QW laser structures should be assumed to play important role in limiting the gain of the lasers. We have found that the QW PL intensities are in excellent correlation with threshold currents of the lasers, indicating that in the GRIN SCH SQW structures prepared by MBE the laser performance is determined by the quality of regions placed near the active layer. There is no doubt that decrease in I_{th} as a function of the growth temperature is caused by the decrease in the leakage current flowing through the nonradiative recombination centres accumulated at the AlGaAs/GaAs interface and whose presence has been determined by the DLTS measurements.

The lasers prepared from the wafer #122, grown at the highest temperature employed, i.e., 680°C, showed the best performance. In their case extrapolated transparency current density, J_0, was equal to 44 kA/(cm^2 μm)($J_0 d = 350$ A/cm^2, where d is the active layer thickness) and differential gain coefficient was equal to 0.03 cm μm/A. The intrinsic mode losses as low as 7 cm^{-1} and internal quantum efficiency close to unity were estimated for those lasers [8]. The power emitted per one facet at $\lambda \approx 835$ nm just before laser degradation was equal to 5 W. Threshold current density was low enough to permit junction-side-up operation to continuous wave optical power of 140 mW per facet. There was practically no difference between the threshold current for pulsed and continuous wave operation of the lasers.

References

[1] S. Miyazawa, Y. Sekiguchi, N. Mizutani, *Jpn. J. Appl. Phys.* **30**, L1935 (1991).

[2] S.V. Iyer, H.P. Meier, S. Ovadia, C. Parks, D.J. Arent, W. Walter, *Appl. Phys. Lett.* **60**, 416 (1992).

[3] C. Weisbuch, R. Dingle, P. M. Petroff, A.C. Gossard, W. Wiegmann, *Appl. Phys. Lett.* **38**, 840 (1981).

[4] Y.L. Sun, R. Fischer, M.V. Klein, H. Morkoc, E.E. Mendez, *Thin Solid Films* **112**, 213 (1984).

[5] K. Akimoto, M. Kamada, K. Taira, M. Arai, N. Watanabe, *J. Appl. Phys.* **59**, 2833 (1986).

[6] J. Kaniewski, M. Wesołowski, K. Regiński, J. Muszalski, M. Kaniewska, *Third Seminar on Surface and Thin Layer Structures, Spała (Poland) 1995*, to be published in *Electron Technol.*, 1996.

[7] C. Sieh, R. Engelmann, J. Mantz, K. Alvai, C. Shu, *Appl. Phys. Lett.* **54**, 1089 (1989).

[8] M. Kaniewska, K. Regiński, J. Muszalski, D. Kryńska, A. Litkowiec, M. Bugajski, *Third Seminar on Surface and Thin Layer Structures, Spała (Poland) 1995*, to be published in *Electron Technol.*, 1996.