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EFFECT OF NITROGEN CONCENTRATION ON THE OPTICAL AND ELECTRICAL PERFORMANCE OF $GA_{0.66}IN_{0.34}N_YAS_{1-Y}$/GAAS QUANTUM WELL LASER DIODES

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ABSTRACT

Design optimization of $Ga_{0.66}In_{0.34}N_yAs_{1-y}$ quantum well (QW) for long wavelength semiconductor laser is conducted by using RSoft LaserMOD. The effect of different nitrogen (N) concentration ranging from 2.0 to 3.2 % with a stepped of 0.3 % in $Ga_{0.66}In_{0.34}N_yAs_{1-y}$ QW system is investigated in term of its electrical and optical performances. It was found that the increment of N concentration up to 2.6% significantly elongating the emission of lasing wavelength (λ) up to 1.44 µm, elevating the output power (P_{out}) to 83.5 mW and reducing the threshold current density (J_{th}) to 431.25 A/cm^2.

KEYWORDS: GaInNAs, Quantum Well (QW), Laser Diodes (LD), Nitrogen Concentration

INTRODUCTION

The GaInNAs/GaAs system has attracted great interest in optical communications field since it was proposed back in 1995 by Kondow et al. [1, 2]. GaInNAs material posses interesting properties compared to the conventional III-V alloys (AlGa As, GaInAs and GaIn AsP) such as a large bandgap bowing [3] and an increase in the electron effective mass [4]. Generally, GaInNAs is a light-emitting material with a bandgap energy suitable for near-infrared LDs (1.3-1.55 µm and longer wavelengths) and can be grown pseudomorphically on GaAs substrate resulting in a type 1 band lineup which is essential in improving electron confinement in the QW layer and hence offers many advantages in terms of lasing performances.

The operating λ of GaInNAs can be extended by increasing the N concentration in the GaInNAs QW [5-7]. Previous reported work suggests that the N incorporation leads to the strong redshift of the bandgap when the N concentration is increased to above 0.01% [8]. However, this is typically accompanied by a very large degradation of all laser characteristics, in particular a very large increase in J_{th} [9-10]. This deterioration is suggested to be due to some possible reasons including the existence of a larger miscibility gap in the alloy phase diagram of GaInNAs materials [11], interface roughness, and N compositional inhomogeneity [12-14]. Therefore, it is important to optimize N concentration in GaInNAs in order to realize LD operating at longer λ emission and having low threshold current (I_{th}) and J_{th}. In this work, the effect of N concentration increment on the optical and electrical performance of $Ga_{0.66}In_{0.34}N_yAs_{1-y}$ QW LD is presented.

DEVICE DESIGN AND SIMULATION

Figure 1 show schematically the studied structure of GaInNAs broad area laser (BAL) which is based on previous work of W. Li et al. [15] with the cavity length of 1600 µm and a stripe width of 20 µm. The active region consists of a single $Ga_{0.66}In_{0.34}N_yAs_{1-y}$ (y = 0.02, 0.023, 0.026, 0.029, and 0.032) layer sandwiched between two $GaN_{0.02}As_{0.98}$ barriers. The waveguide layer is made of GaAs. Both n-type and p-type $Al_{0.3}Ga_{0.7}As$ cladding layers and doped with $5x10^{17}$ and $9x10^{17}$ cm^{-3}. Finally, p+ GaAs contact layer is heavily doped to $3x10^{19}$ cm^{-3} in order to minimize the contact resistance. The modeling of LD epitaxial structure and device design are performed by using RSoft LaserMOD software [16] for analyzing the optical and electrical characteristic of the $Ga_{0.66}In_{0.34}N_yAs_{1-y}$ QW LD.

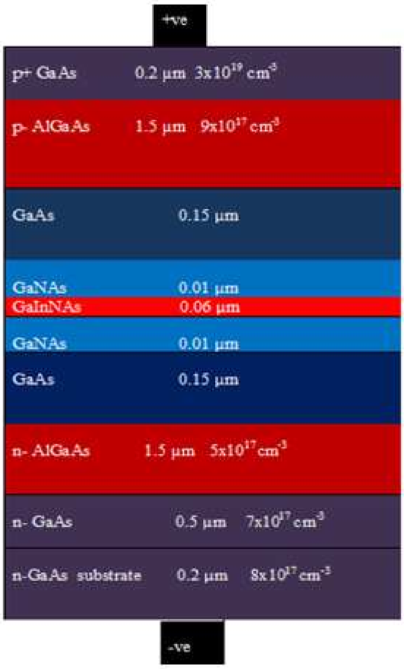

Figure 1: Schematic of the GaInNAs QW LD

RESULTS AND DISCUSSIONS

Optical Properties

Material gain of $Ga_{0.66}In_{0.34}N_yAs_{1-y}$ QW as a function of wavelength for various N concentrations is presented in Figure 2. It was found that as the percentage of N increased from 2.0 to 3.2%, the gain peak broadens and the wavelength red-shifted from 1.32 to 1.48 µm. However as higher N concentration is incorporated into the QW, the peak material gain is significantly increased indicating a great amount of carrier density is needed in the BAL in order to start lasing action. The increased in peak material gain profile reflects J_{th} profile which will be discussed later in Figure 6. This degradation is suggested to be caused by the in homogeneity of compositions [12-14] in the structure.

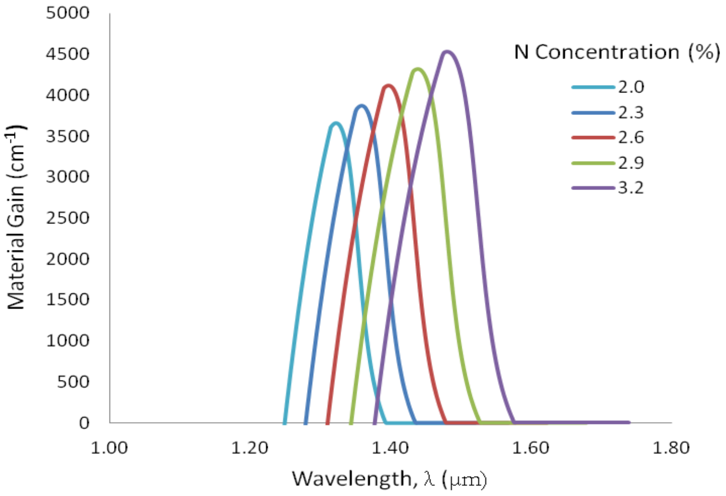

Figure 2: Material Gain of Ga$_{0.66}$in$_{0.34}$n$_y$as$_{1\text{-}Y}$ QW with Different N Concentrations

Figure 3 illustrates the photoluminescence (PL) spectrum for Ga$_{0.66}$In$_{0.34}$N$_y$As$_{1\text{-}y}$ QW at different N concentrations. Here, it was found that the increment of N concentration from 2.0 to 3.2 % also broadens and red-shifted the peak wavelength emission from 1.32 to 1.48 μm which correlated with the previous plotted material gain profile. However the intensity is slightly dropped when N concentration is increased. The broadening of the peak wavelength emission and dropped intensity might be the result of crystalline quality deterioration, N out-diffusions and phase segregations [17, 18].

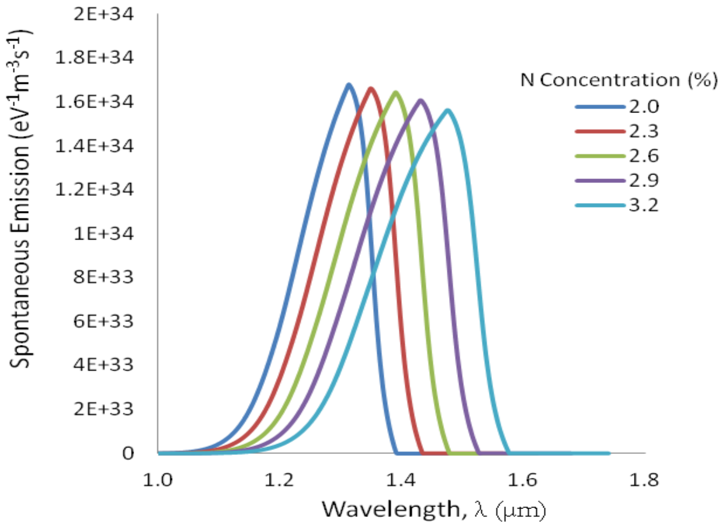

Figure 3: PL of Ga$_{0.66}$In$_{0.34}$n$_y$as$_{1\text{-}Y}$ QW with Different N Concentrations

Electrical Properties

Figure 4 illustrates the graph of P_{out} versus I_{th} of Ga$_{0.66}$In$_{0.34}$N$_y$As$_{1\text{-}y}$ QW at different N concentration ranging from 2.0 to 3.2%. This graph indicates the I_{th} is decreased from 162 to 138 mA with increasing N concentrations from 2.0 to

2.6% respectively. However at above 2.6% of N concentration, I_{th} is increased until reached the maximum of 162 mA at 3.2% of N concentration. This is could be due to the result of lower potential barrier in the valence band with further increase of N concentration which causes higher holes leakage and hence influencing the I_{th} to be increased [19,20]. In term of P_{out}, as N is increased to 2.6 %, a maximum value of 83.5 mW is recorded, however as N is further increased to 3.2 % the value slightly deteriorated to 70.24 mW.

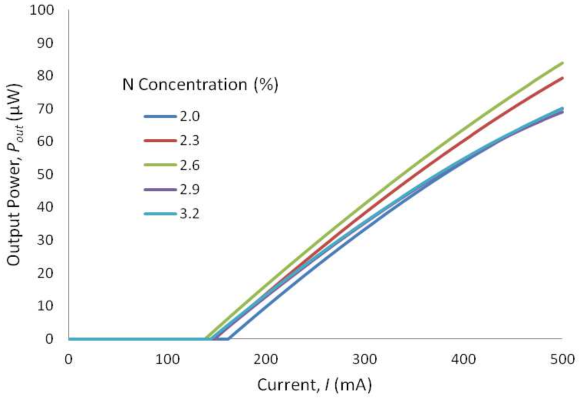

Figure 4: The P_{out} versus *Ith* of $Ga_{0.66}in_{0.34}n_{y}as_{1-Y}$ Qw LD for Different N Concentrations

Figure 5 illustrates the pattern P_{out} and J_{th} of $Ga_{0.66}In_{0.34}N_yAs_{1-y}$ QW as a function N concentration. All J_{th} values are calculated using $J_{th} = I_{th}/A$ where I_{th} is threshold current measured in mA and A is the area of LD = width x cavity length measured in cm^2. Here it was found that there are two dissimilar patterns describing N concentration is increased from 2.0 to 2.6 % and from 2.6 to 3.2 %. First, J_{th} is found to decrease from 504.69 to 431.25 A/cm^2 correspond to increment of N concentration from 2.0 to 2.6 % then increased from 431.25 to 506.25 A/cm^2 correspond to increment of N concentration from 2.6 to 3.2%. As stated earlier, the increment of J_{th} might be caused by the deterioration of crystalline quality of GaInNAs QW at higher N concentration. Furthermore this degradation is suggested to be originated from the reduction of the carrier injection efficiency which is related to carrier recombination losses in the barriers, the optical absorption losses and the defect-related recombination coefficient which are found to increase at larger N concentration [13]. Based from the simulated profiles it is found that the lowest J_{th} and highest P_{out} are 431.25 A/cm^2 and 83.5 mW at recorded at 2.6% of N concentration.

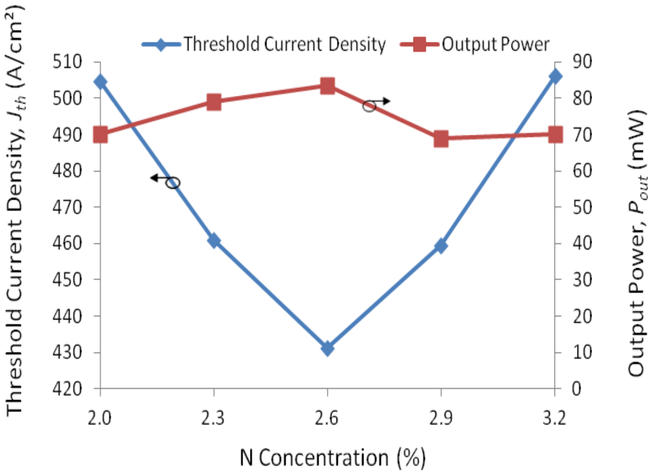

Figure 5: P_{out} and J_{th} Curve as a Function of N Concentrations

Figure 6 shows the external differential quantum efficiency (η_d) calculated for the $Ga_{0.66}In_{0.34}N_yAs_{1-y}$ QW at different N concentrations. The η_d is calculated using $\eta_d = 2(\Delta P/\Delta I)\ [q\lambda/\hbar c]$ where $\Delta P/\Delta I$ is slope of *PI* curve or slope efficiency, $\hbar$ is Planck's constant, q is electric charge, c is the speed of light, and λ is the lasing wavelength of the device. η_d is used to indicate the efficiency of a laser device in converting the injected electron hole pairs (input electric charges) to photon emitted from the device (output light) [21]. It was found that η_d increased gradually with increasing N concentration from 2.0 to 2.6% but decreased when is above 2.6 %. The highest η_d of 27% is recorded at 2.6% of N concentration. However here the internal quantum efficiency η_i is not calculated since no variation in term of cavity length is made throughout this study.

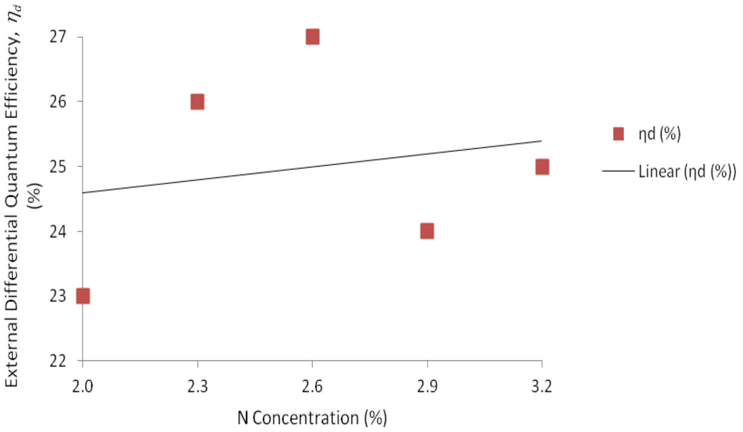

Figure 6: η_d of $Ga_{0.66}In_{0.34}N_yAs_{1-y}$/GaAs QW with Different N Concentrations

CONCLUSIONS

Comprehensive analysis involving electrical and optical performances of $Ga_{0.66}In_{0.34}N_yAs_{1-y}$/GaAs QW LD have been studied based on different nitrogen concentrations ranging from 2.0 to 3.2%. Improvement in term of the λ emission and P_{out} are obtained with only a small incorporation N in $Ga_{0.66}In_{0.34}N_yAs_{1-y}$ QW. In this simulation works, the optimal value of N concentration in $Ga_{0.66}In_{0.34}N_yAs_{1-y}$ QW is suggested to be at 2.6% resulting in λ emission of 1.44 µm, P_{out} of 83.5 mW, and a low J_{th} of 431.25 A/cm^2.

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REFERENCES

1. M. Kondow, K. Uomi, A. Niwa, T. Kitatani, S. Watahiki, and Y. Yazawa, A novel material of GaInNAs for long-wavelengthrange laser diodes with excellent high-temperature performance, in Proceedings of the International Conference on Solid State Devices and Materials, Osaka, Japan, 1995.
2. M. Kondow, K. Uomi, A. Niwa, T. Kitatani, S. Watahiki, Y. Yazawa, GaInNAs: a novel material for long-wavelength-range laser diodes with excellent hightemperature performance, Jpn. J. Appl. Phys., vol. 35, 1996, pp. 1273–1275.
3. T. Kitatani, M. Kondow, K. Nakahara, M.C. Larson, Y. Yazawa, M. Okai", K. Uomi, Nitrogen incorporation rate, optimal growth temperature, andAsH3 flow rate in GaInNAs growth by gas-source MBE using N radical as an N source, J. Cryst. Growth, vol. 201, no. 202, 1999, pp. 351–354.
4. P. N. Hai, W. M. Chen, I. A. Buyanova, H. P. Xin, C. W. Tu, Direct determination of electron effective mass in GaNAs/GaAs quantum wells, Appl. Phys. Lett., vol. 77, 2000, pp. 1843–1845.
5. S. Sato, Y. Osawa, T. Saitoh, and I. Fujimura, Room-temperature pulsed operation of 1.3 µm GaInNAs/GaAs laser diode, Electron. Lett., vol. 33, no. 16, Jul. 1997,pp. 1386–1387.
6. E. Tournie, M.-A. Pinault, M. Laugt, J.-M. Chauveau, A. Trampert, and K. H. Ploog, GaInNAs/GaAs quantum wells grown by molecularbeam epitaxy emitting above 1.5 µm, Appl. Phys. Lett., vol. 82, 2003, pp. 1845–1847.
7. M. Fischer, M. Reinhardt, and A. Forchel, GaInAsN/GaAs laser diodes operating at 1.52 µm, Electron. Lett., vol. 36, no. 14, Jul. 2000, pp. 1208–1209.
8. T. Makimoto, H. Saito, T. Nishida, and N. Kobayashi, Excitonic luminescence and absorption in dilute GaAsN alloy (x<0.3%), Appl. Phys. Lett., vol. 70, 1997, pp. 2984–2986.
9. J. S. Harris, The opportunities, successes and challenges for GaInNAsSb, J. Cryst. Growth, vol. 278, May 2005, pp. 3–17.
10. A Hierro, J. M. Ulloa, E. Calleja, B. Damilano, J. Barjon, J. Y. Duboz, and J. Massies, Room temperature performance of low threshold 1.34-1.44 µm GaInNAs/GaAs quantum-well lasers grown by molecular beam

epitaxy, IEEE Photonics Technol. Lett., vol. 17, 2005, pp. 1142–1144.

11. J. Neugebauer and C. G. Van de walle, Electronic structure and phase stability of GaAs N alloys, Phys. Rev. B, vol. 51, no. 16, Apr. 1995, pp. 10568–10571.
12. A. Buyanova,W. M. Chen, G. Pozina, J. P. Bergman, B. Monemar,X. P. Xin, and C. W. Tu, Mechanism for low-temperature photoluminescence in GaNaAs/GaAs structures grown by molecular-beam epitaxy, Appl. Phys. Lett., vol. 75, no. 4, Jul. 26, 1999. pp. 501–503.
13. J. M. Ulloa, A. Hierro, M. Montes, B. Damilano, M. Hugues, J. Barjon, J.-Y. Duboz, and J. Massies, Impact of N on the lasing characteristics of GaInNAs/GaAs quantum well lasers emitting from 1.29 to 1.52 µm, Appl. Phys. Lett., vol. 87, 2005, pp. 251109–251111.
14. S. M. Mitani, M. S. Alias, A. A. Manaf, F. M. Exhsan and A. F. A. Mat, Optimized optical variables of 1.3µm GaInNAs/GaAs quantum well semiconductor laser, International Conference on Photonics (ICP), July 2010, pp. 1–4,.
15. W. Li, T. Jouhti, C. S. Peng, J. Konttinen, P. Laukkanen, E. Pavelescu, M. Dumitrescu, and M. Pessa, Low-threshold-current 1.32-µm GaInNAs/GaAs single-quantum-well lasers grown by molecular-beam epitaxy, Appl. Phys. Lett., vol. 79, no. 21, 2001, pp. 3386–3388.
16. RSoft Design Group, Inc., LaserMOD, 1999-2006.
17. S. G. Spruytte, M. C. Larson, W. Wampler, C. W. Coldren, P. Krispin, H. E. Petersen, S. Picraux, K. Ploog, J. S. Harris, “Nitrogen incorporation in group III–nitride–arsenide materials grown by elemental source molecular beam epitaxy,” J. Cryst. Growth, vol. 227-228, 2001, pp. 506–515.
18. W. Li, M. Pessa, T. Ahlgren, J. Dekker, Origin of improved luminescence efficiency after annealing of Ga(In)NAs materials grown by molecular-beam epitaxy, Appl. Phys. Lett. vol. 79, 2001, pp. 1094–1096.
19. M. Weyers, M. Sato, H. Ando, Red shift of photoluminescence and absorption in dilute GaAsN alloy layers, Jpn. J. Appl. Phys, vol. 31, 1992, pp. 853–855.
20. C. K. Kim, T. Miyamoto, Y. H. Lee, Design considerations of GaInNAs-GaAs quantum wells: effects of indium and nitrogen mole fractions, Jpn. J. Appl. Phys, vol. 37, 1998, pp. 5994–5996.
21. K.S. Mobarhan, Test and characterization of laser diodes: determination of principal parameters. Newport Corporation, 1995.