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Low thermal resistance 780nm GaInPAs/GaInP 40ch VCSEL array for laser printers

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Abstract: *We have developed a 780nm 40ch VCSEL array for laser printers. Low thermal resistance has been achieved by improving the layer construction, with the result that laser power changing due to self-heating and thermal interference in the array have been stabilized. Moreover, single-mode high power and stable polarization have been achieved by GaInPAs strained quantum wells grown on 15° off GaAs substrate and anisotropically-shaped transverse mode filter on the output surface.*

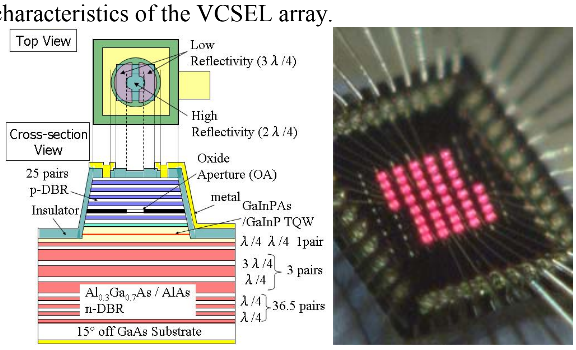
1. Introduction

A vertical-cavity surface-emitting laser (VCSEL) array has been applied for a multi-beam light source for laser printers [1]. For high-speed printing, higher power operation is required; however, the laser power changing and aging degradation due to self-heating become problems as the output power increases. Heat generated in active region tends not to disperse because distribution Bragg reflectors (DBR) are composed of materials which have higher thermal resistivity. Furthermore, in a high-density VCSEL array, the above problems are also affected by the thermal interference in the array. It has been reported that the thermal resistance has been reduced drastically by improving the mounting configuration [2] or Cu-plated heatsinks [3]. Moreover, it has been proposed that adopting AlAs layers for low refractive index layers of lower DBR to reduce the thermal resistance [4]. In this report, we have considered to reduce the thermal resistance more significantly by thickening AlAs layers near the active region.

In addition, polarization stability is also required because the laser printing system includes polarization sensitive optical elements. It is effective adding anisotropy to the optical gain or the cavity reflectance to control the polarization angles. For this purpose, several methods have been proposed on 780nm VCSELs such as using 2° off GaAs substrate [1], or adding anisotropic stress to the active region by oxidizing AlAs layers in the DBR [5]. In this report, we have also considered stabilizing the polarization characteristics by adopting strain-induced GaInPAs quantum wells grown on 15° off GaAs substrate, and anisotropy transverse mode filter formed on the output surface. GaInPAs quantum wells have advantages that the strain is easy to be induced compared to AlGaAs quantum wells, which is usually adopted for 780nm VCSEL, as the result anisotropic high optical gain can be obtained. The anisotropically-shaped mode filter provides both suppressing higher-order transverse modes and stabilizing polarization angles. Moreover, complicated manufacturing process is not necessary such as high contrast gratings because the anisotropy is introduced in fabricating process of the mode filter.

2. Experiment

A schematic of proposed VCSEL is shown in Fig.1. A 40.5pairs lower n-DBR, a one λ-cavity spacer containing compressively strained GaInPAs three quantum wells and GaInP barriers, and a 25pairs upper p-DBR were grown epitaxially on n-GaAs substrate using MOCVD. The substrate was misoriented from (100) plane by 15° toward the <111A> direction. We adopted AlGaInP spacer layers so as to obtain etching selectivity to AlGaAs, and we fabricated a mesa structure whose bottom was in the spacer layer. This structure made it possible to adopt AlAs layers, which was the lowest thermal resistance than AlGaAs layers, for the lower DBR. In addition, we adopted three AlAs layers of 3λ/4 thick near the active region as shown in Fig.1(a) to disperse heat generated by active region in a transverse direction. On the output surface, we formed a metal aperture and transverse mode filters composed of SiN films. The SiN films were patterned in the shape of high reflectivity (2λ/4 thick) in the central region and low reflectivity (3λ/4 thick) in the peripheral region. Furthermore, the low reflectivity regions were partially removed like a slit as shown in Fig.1 so as to add the anisotropy between orthogonal directions. 40 channels of VCSELs were arrayed in about 0.1mm^2 as shown in Fig.1(b). We evaluated the thermal characteristics and the polarization characteristics of the VCSEL array.



(a) Schematic design (b) 40ch VCSEL array
Fig. 1. Structure

3. Result

We show the thermal characteristics firstly. In order to evaluate advantages of proposed structure, we fabricated reference structures which had different composition of lower DBR as shown in Fig.2. The lower DBR of #1 structure was composed $Al_{0.3}Ga_{0.9}As/Al_{0.9}Ga_{0.1}As$ which was usually adopted for 780nm VCSEL, and that of #2 structure was composed of $Al_{0.3}Ga_{0.7}As/AlAs$ whose layers were every λ/4 thick. We estimated the thermal resistance of each structure by the variation of oscillation wavelength to temperature [6], and 3872(#1), 3102(#2) and 2867(#3)[K/W] (OA=20μm^2) were obtained respectively. The thermal resistance of #3 structure was reduced of 26% compared to #1, and 7.6% compared to #2. I-L curves of each structure are shown in Fig.3. Increasing of the saturation power of #3 structure indicates that the temperature at active region decreased. Fig.4 shows the droop characteristics, which represent the laser power changing due to self-heating, when the current of emitting 1.5mW at CW operation was injected and the beam was modulated under 1kHz at 60°C. Droop characteristics are important as a light source for laser printers because the laser power changing causes unevenness of printed images. As shown in Fig.4, the power changing of #3 structure was drastically improved. The light intensity ratio between shortly after turn-on and 10μsec later ($\Delta V=(V_1-V_2)/V_2$) decreased of 90% compared to #1 structure.

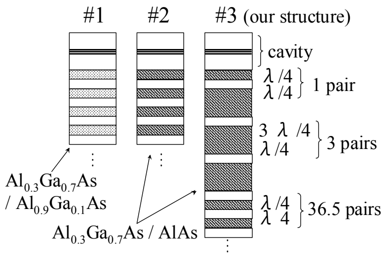


Fig.2. Structure of lower DBR near the active region

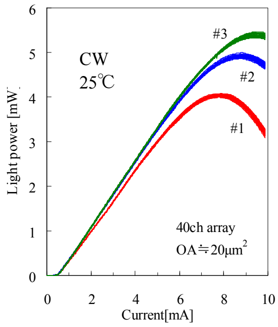


Fig.3. I-L curve

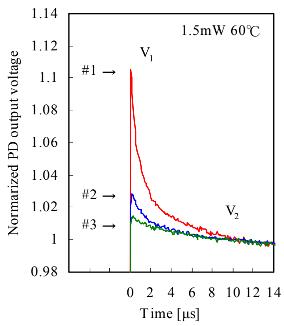


Fig.4. Droop characteristic

Secondly, we have evaluated the polarization characteristics of proposed structure. The evaluated VCSEL array (OA=18μm^2) showed side-mode suppression ratio (SMSR) of over 35dB up to 3mW. The polarization angles were well controlled as shown in Fig.6. Each beam was polarized to the [0-11] angle (standard deviation of the array σ<0.85deg) in the range of 0.5-4.0mW, and orthogonal polarization suppression ratio (OPSR) of more than 20dB was obtained. (σ<0.11dB in the range of 0.5-3.0mW) In order to evaluate the polarization control effect of anisotropically-shaped mode filters, we also fabricated an isotropy-shaped mode filter, which was like a circular ring. In such cases, OPSR decreased compared to those without mode filters, and the polarization angles were switched to orthogonal direction in several cases. On the other hand, there were no polarization switched beams in proposed structure which had anisotropically-shaped filters whose low reflectivity region was partially removed like a slit in the substrate inclined direction (See Fig.5). It indicates that the anisotropy distribution of reflectivity on the output surface contributed to the polarization stability. Even though the mode filters had anisotropy, higher order transverse modes were well suppressed. As shown in Fig.7, SMSR of over 30dB up to 3mW was obtained in large range of OA areas from 15μm^2 to 50μm^2. Moreover, far field pattern of the beams were Gaussian. In addition, long-term reliability of the polarization characteristics was obtained. Even after all 40 beams emitted 1.5mW (APC operation) simultaneously for 500 hours at the state of 80°C, polarization stability were obtained for 40 beams.

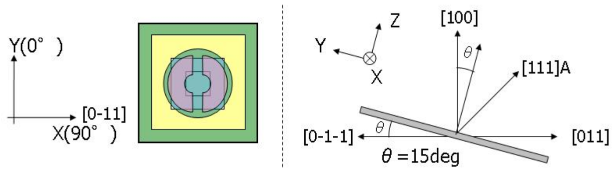


Fig.5. Definition of polarization angle

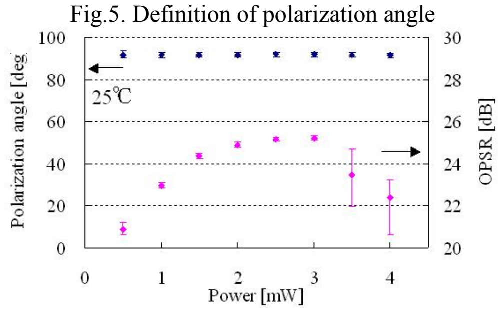


Fig.6. Polarization characteristics (40ch array)

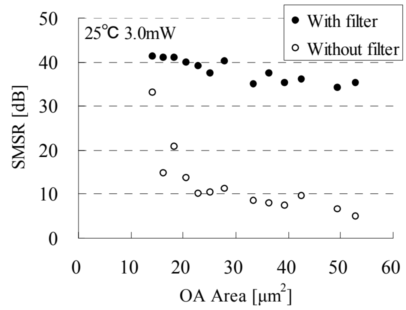


Fig.7. Comparison of SMSR between with and without mode filter

4. Conclusions

We achieved reduction of the thermal resistance by improving the layer construction of the cavity spacer and the lower DBR. As a result, we obtained the VCSEL array whose laser power changing due to self-heating and thermal interference in the array were stabilized. Moreover, high-power single-mode operation and stable polarization characteristics were achieved by GaInPAs strained quantum wells grown on 15° off GaAs substrate and anisotropically-shaped transverse mode filter. This VCSEL array enables to enhance the printing speed with higher resolution by virtue of stable high power operation.

References

[1] N. Mukoyama *et al.*, "VCSEL array-based light exposure system for laser printing", Proc. of SPIE, Vol.6908, 69080H, 2008

[2] H. Roscher *et al.*, "Low thermal resistance Flip-chip bonding of 850nm 2-D VCSEL arrays capable of 10Gbit/s/ch operation", Lasers and Electro-Optics Society, The 16th Annual Meeting of the IEEE, pp.511, 2003

[3] A. N. Al-Omari *et al.*, "Low thermal resistance high-speed top-emitting 980-nm VCSELs", IEEE Photon. Technol. Lett., vol. 18, No.11, pp. 1225-1227, 2006.

[4] K. M. Lascola *et al.*, "Structural dependence of the thermal resistance of vertical cavity surface emitting lasers," IEEE/LEOS Summer Topical Meeting, pp.79, 1997.

[5] O. Maeda *et al.*, The 55th Spring Meeting of the Japan Society of Applied Physics and Related Societies, 30a-ZQ-1, 2008

[6] R. Pu *et al.*, "Thermal resistance of VCSEL's bonded to integrated circuits," IEEE Photon. Technol. Lett., vol. 11, No.12, pp. 1554-1556, 1999