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Astigmatism of Ridge Stripe InGaAlP Laser Diodes

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Astigmatism of transverse mode stabilized InGaAlP laser diodes with ridge stripe structure strongly depends on the laser structure, especially on the active layer thickness which influences the noise characteristics. The astigmatism dependence, for index-guided lasers and the gain-guided lasers, on the active layer thickness show opposite relations. Both the index-guiding effect and gain-guiding effect are found to appear, depending on the ridge stripe structure dimensions.

1. Introduction

Transverse mode stabilized InGaAlP laser diodes have attracted much interest as light sources for optical information processing systems, such as high-density optical disc systems and high-speed laser printers[1]. Coexistence of the index-guiding effect and gain-guiding effect in ridge stripe InGaAlP lasers leads to stable fundamental-mode oscillation and low noise characteristics versus optical feedback[2]. For such a waveguide structure, the astigmatism strongly depends on the structure dimensions, because the effective refractive-index difference in a direction parallel to the junction is considerably influenced by the ridge stripe structure. It has been confirmed, by theoretical analysis, that astigmatism depends on the stripe width at the bottom of the ridge, as well as the distance between the active layer and the light-absorbing layer outside the stripe[3,4]. However, the astigmatism, as a fucntion of the active layer thickness, which strongly affects the noise characteristics, has not been investigated systematically. In this paper, the dependence of astigmatism in the ridge stripe InGaAlP lasers on the active layer thickness is described. Comparison of index-guided lasers and gain-guided lasers is also discussed.

2. Experimental Results and Discussion

Figure 1 shows a cross-sectional view of InGaAlP lasers with (a) ridge stripe structure and (b) gain-guiding structure, where d is the active layer thickness and h is the distance between the active layer and the current-blocking layer outside the stripe. The n-GaAs current blocking layer also acts as a light-absorbing layer for oscillating light-waves. The optical mode confinement is realized through a complex refractive index step along the junction plane. This waveguide mechanism affects the transverse mode characteristics of the ridge stripe lasers.

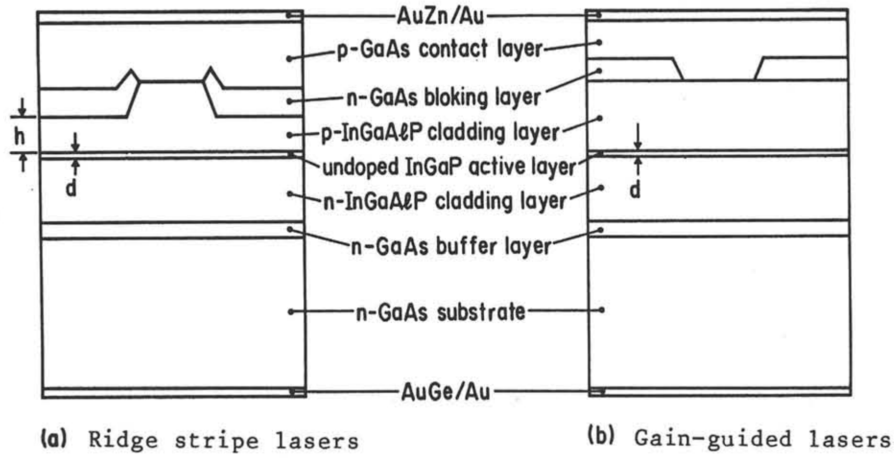

Fig. 1 Cross-sectional view of InGaAlP laser diodes

Generally, the astigmatism of laser diodes is determined by the complex amplitude profile for the waveguide mode in a direction parallel to the junction plane[5]. Figure 2 shows calculated examples of optical mode profiles for InGaAlP lasers with (a) ridge stripe structure and (b) gain-guiding structure, using a two-dimensional device simulator[6]. Solid and broken lines show amplitude and phase profiles for the waveguide mode, respectively. This phase profile has an effect on the output beam astigmatism. The astigmatism of index-guided lasers is expected to be smaller than that of the gain-guiding structure, because the phase change in the stripe region for index-guide lasers is smaller.

Figure 3 shows experimental results for astigmatism measured by knife-edge scan techniques. It is found that the astigmatism becomes larger for a thicker active layer in the ridge stripe lasers.

The optical confinement factor becomes larger, when the active layer thickness increases. As a result, the influence of the n-GaAs light-absorbing layer decreases and waveguide mechanism becomes virtually completely gain-guiding. In the same way, an increase in h in Fig. 1 (a) leads to an increase in the astigmatism.

For the gain-guided lasers, the relation between the astigmatism magnitude and the active layer thickness was found to show opposite characteristics, compared with the ridge stripe lasers. This phenomena originates in the relation between gain profile and active layer thickness. In the gain-guided lasers, the current spreading width depends on the threshold current, which is determined by the active layer thickness. Consequently, the astigmatism, determined by the gain distribution, depends on the active layer thickness.

A laser with gain-guiding structure can be considered as one of the ridge stripe lasers, with sufficiently large distance h from the active layer. As described above, the astigmatism dependences on the active layer thickness show contrary characteristics between the ridge stripe structure and gain-guiding structure. It

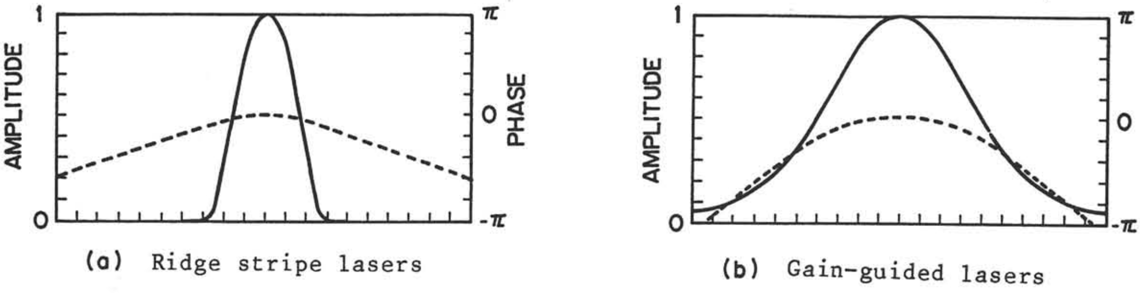

Fig. 2 Waveguide mode profiles for InGaAlP laser diodes

means that a transition region exists from the index-guiding region to the gain-guiding region in the ridge stripe lasers.

The astigmatism for the lasers of both structures have been calculated by computer simulation. In the simulation, astigmatism ΔZ has been calculated by the following equation:

$$\Delta Z = \int (\lambda/2\pi \sin\theta).(d\psi/d\theta).A^2 d \;/\; \int A^2 d\theta \qquad (1)$$

where $A(\theta)$ and $\psi(\theta)$ are the amplitude and phase distributions, respectively, as a function of far-field angle . Figure 4 shows calculated examples of the astigmatism. As shown in the Figure, the results of the numerical calculation agree with the experimented results, shown in Fig. 3.

For ridge stripe lasers, the astigmatism dependence on the active layer thickness is found to change in the regions of the large active layer. In these regions, the waveguide mechanism can be considered to be mostly gain-guiding, and the astigmatism mainly depends on the gain distribution. The transition region, between index-guiding and the gain-guiding, appears in the thinner active layer for larger h. When h is large enough, gain-guiding effect is dominant for any active layer thickness.

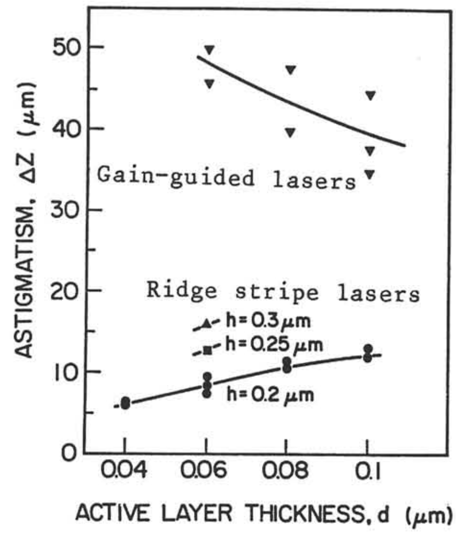

Fig. 3 Measured astigmatism dependence on the active layer thickness

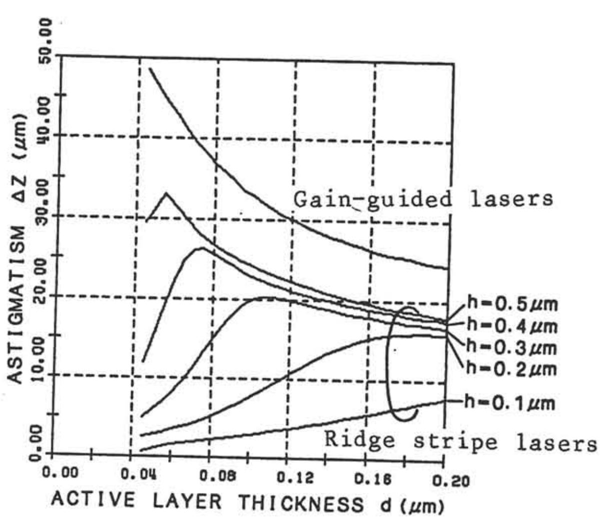

Fig. 4 Calculated astigmatism dependence on active layer thickness

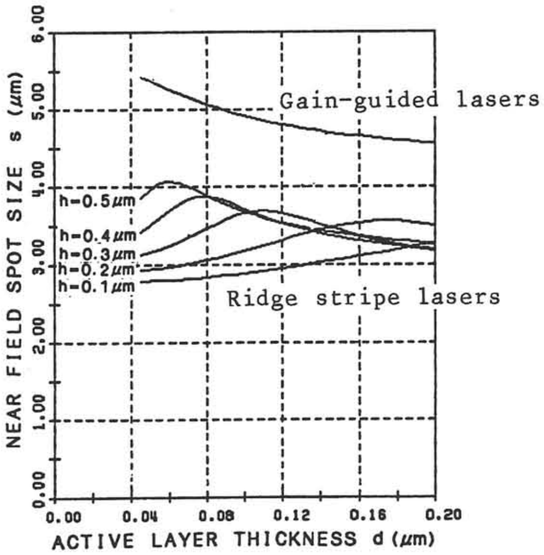

Fig. 5 Calculated spot size dependence on active layer thickness

Figure 5 shows calculated examples of the spot size S, parallel to the junction at the end facet of the cavity. As shown in Fig. 5, the spot size increases as h becomes larger. The spot size dependence on the active layer thickness shows characteristics similar to those for astigmatism. For small h, transverse-mode is formed by the structure-dependent effective refractive index distribution, whereas, for large h, transverse-mode is strongly affected by the gain profile along the active layer, which is determined by current distribution. In the gain-guiding regions, the threshold current is raised by increasing the active layer thickness. As a result, current spreading width becomes small, similarly to the spot width becoming smaller.

3. Conclusion

It has been shown that astigmatism, in the transverse mode stabilized InGaAlP laser diodes, with the ridge stripe structure depend on structure dimensions. Astigmatism dependence on the active layer thickness is found to show opposite characteristics for the ridge stripe structure and the gain-guiding structure, as determined by the measurements and simulations. The relation between the structure dimensions and the waveguiding mechanism, which affect the transverse mode and noise characteristics, has been made clear.

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Reference

1. H. Okuda, H. Siozawa, K. Itaya, M. Ishikawa, Y. Watanabe, K. Nitta, G. Hatakoshi, M. Okajima, and Y. Uematsu; Extendent Abstracts (The 36 Spring Meeting, 1989); The Japan Society of Applied Physics and Related Societies, 1p-ZC-4, 3 (1989) 886.
2. G. Hatakoshi, M. Ishikawa, Y. Watanabe, and Y. Uematsu; Electron, Lett. 25 (1989) 125.
3. A. Shimizu and T. Hara; IEEE J. Quantum Electron. QE-23 (1987) 293.
4. G. Hatakoshi, M. Ishikawa, H. Nagasaka, Y. Watanabe and Y. Ohba; National Conference Record, 1986 Optical and Radio Wave Electronics The Institute of Electronics, and Communication Engineers of Japan, 2 (1986) 2-41
5. D.D. Cook and F. R. Nash; J. Appl. Phys, 46, (1975) 1660.
6. G. Hatakoshi, M. Kurata, E. Iwasawa, and N. Motegi; Trans. IEICE Jpn. E71 (1988) 923.

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