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# Effect of Residual Stress in Thin Films on the Radiation Spectrum of a Semiconductor Laser

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## 1. Introduction

A wavelength division multiplexing system is a basic infrastructure for the next coming optical fiber network. Since multi-channel signal processing is indispensable for the high speed and large density communication, the half width of intensity of a laser beam should be less than 1 nm. In order to achieve this high quality laser beam, the fluctuation of strain in a laser chip has to be less than 3 ppm. This is because that the band gap of the laser chip that determines the wavelength of the laser beam is varied with the strain in the laser chip, and the sensitivity of the change is about 300-nm/0.1%-strain[1)]. Since an intrinsic stress higher than 1 GPa often occurs in thin films used for electrode and passivation films[2)3)], the final residual strain in an active layer of the chip varies significantly depending on their deposition process, and thus, changes the radiation spectrum of the laser chip. Therefore, it is very important to control the final residual strain in the active layer to assure the precise optical characteristics of the laser chip[4)]. In this study, the effect of strain on the radiation spectrum of a laser chip was evaluated experimentally and the effect of the intrinsic stress in the electrode and passivation films on the final residual strain in the laser chip was analyzed quantitatively.

## 2. Residual strain analysis considering the intrinsic stress of thin films

The residual stress in thin films used for a laser structure as isolation or mirrors was measured and it was found that the residual stress often exceeds 1 GPa and such a high stress gives rise to high strain in the active layer of a laser chip. The final residual strain caused by the thin film stress was analyzed by a three-dimensional finite element method as shown in Fig. 1. The residual strain varies drastically depending on the intrinsic stress of a $Si_3N_4$ film which is used for passivation as shown in Fig. 2. After the deposition of the passivation film, the residual strain at a center of an active layer of a laser chip varies from about -0.12% to +0.03% when the intrinsic stress of the film was changed from -1 GPa to +1 GPa. The change rate of the strain is about 80-ppm/1-GPa. This means that the wavelength of a laser beam shifts by about 240-nm/1-GPa. In addition, there is a distribution of strain in the active layer. The maximum amplitude of the strain distribution reaches about 0.07% when the intrinsic stress of the passivation film is -1 GPa. The amplitude is a strong function of the intrinsic stress. The width of the radiation spectrum is expanded by about 180-nm/1-GPa due to this strain distribution in the active layer caused by the thin film stress.

The strain distribution is also formed by the residual stress of the mirror films. The sharp strain gradient occurs in the area within 5 μm from the edge of the laser chip as shown in Fig. 3. The amplitude of the strain is also a strong function of the intrinsic stress of the mirror film, and it is about 0.07% when the intrinsic stress is -1 GPa. This strain distribution deteriorates the quality of the laser beam by increasing the recombination rate of light in the active layer and thus, by increasing Joule heat. Since the band gap of the active layer is controlled by the mismatch of the lattice constant among the stacked nano-meter-thick layers in the

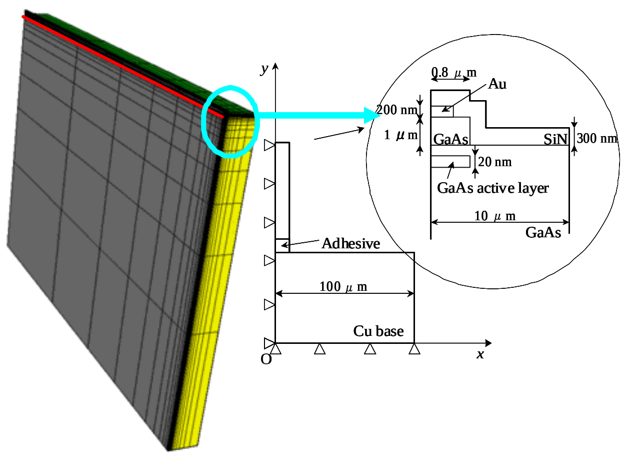


Fig. 1 Finite element analysis model of a laser chip.

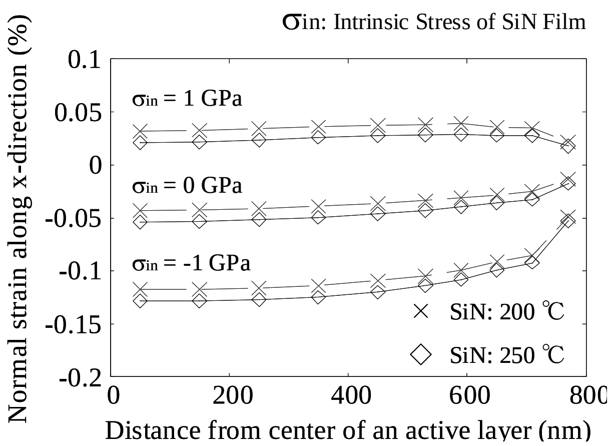


Fig. 2 Change of a strain distribution in an active layer of a laser chip due to the intrinsic stress of a $Si_3N_4$ film

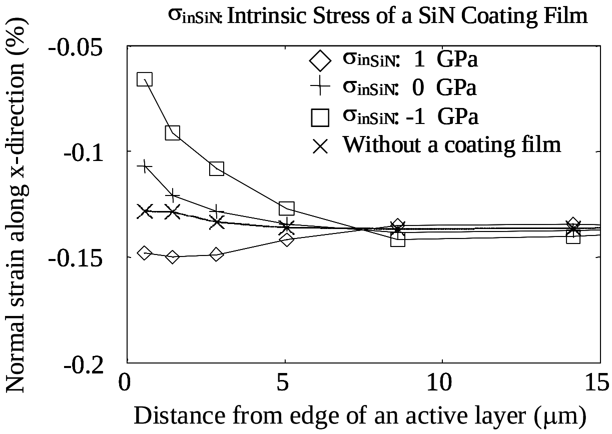


Fig. 3 Change of a strain distribution in an active layer of a laser chip due to the intrinsic stress of a mirror film

substrate, these additional strains caused by intrinsic stress of passivation and mirror films change it seriously. The residual strain changes further during the assembly process of a package or a module of the laser chip. The final spectrum of the laser chip may vary significantly depending on its fabrication process.

## 3. Effect of mechanical strain on the radiation spectrum of a laser chip

In order to confirm the effect of such an additional strain on the radiation spectrum of a laser beam, mechanical stress (starin) was applied directly to a laser chip and the change of the spectrum of the laser chip under the applied strain was measured. A four-point bending test was used for applying mechanical stress to a laser chip as shown in Fig. 4. An AlGaAs laser chip with wavelength of about 830 nm was used for the measurement. The laser chip was mounted on a thin copper plate by soldering. The plate was bended as is shown in Fig. 4. The applied surface strain was monitored by strain gauges attached on the plate. It was confirmed that the radiation spectrum of a laser chip, such as wavelength and width of the spectrum, changes almost linearly with the amplitude of the applied uni-axial strain. Figure 5 shows that the wavelength of the laser chip under an uni-axial tensile strain decreases and a width of the spectrum of the laser chip at the threshold current increases with the increase of the magnitude of the applied strain. Also, the peak wavelength of the laser chip decreases almost linearly with the applied tensile strain. The change rate of the wavelength under an uni-axial tensile strain was about 0.4-nm/μstrain. This sensitivity agrees well with the theoretically predicted result[1]. These results clearly indicate that the control of the mechanical strain in a laser chip is the important factor that determines both the reliability and quality of the laser chip.

## 3. Conclusions

The radiation spectrum of a laser chip is changed seriously by mechanical stress (strain) caused by thin-film

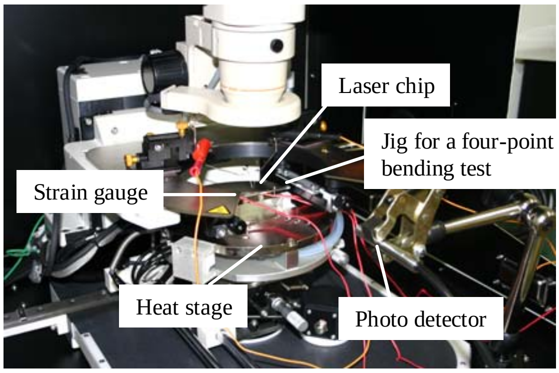


Fig. 4 Measurement of a radiation spectrum of a laser chip under a four-point bending test

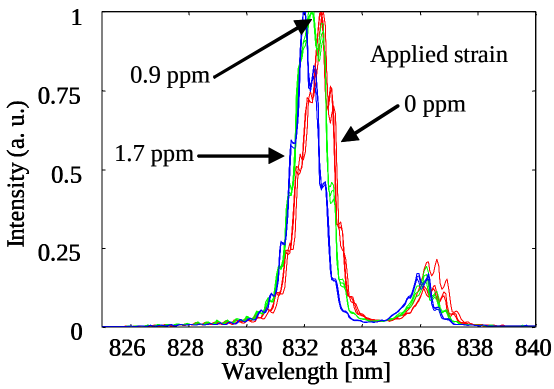


Fig. 5 Change of a radiation spectrum of a laser chip under an applied uni-axial strain

processes and packaging. It is very important to minimize the change of the strain distribution in an active layer of a laser chip caused by residual stress in thin films used for mirrors and passivation to improve and assure the reliability of the laser chip. Packaging-induced stress should be another important factor that determines the final performance or reliability of products.


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## References


[1] H. Carrère, et al. Journal of Physics: Condensed Matter, Vol.16, (2004), pp. 3215-3227.

[2] H. Miura, N. Saito, and N. Okamoto, Simulation of Semiconductor Devices and Processes, vol. 5, Springer-Verlag, Wien, (1993.9) pp. 177-180.

[3] H. Miura, K. Ohshika, H. Masuda 1996 Int. Conf. on-Simulation of Semiconductor Processes and Devices '96 (SISPAD'96), (1996.9) pp. 49-50.

[4] H, Miura and S. Ikeda, IEICE Trans. on Electronics, Vol.E82-C, No. 6, (1999.6) pp. 830-838.