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Mechanical Stress Surpressed AlGaAs High Power TJS Laser Diodes

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Mechanical stress compensation in bonding procedure has been discussed for AlGaAs high power lasers. Theoretical stress distribitions in laser chips are estimated and actual strain fields are observed by photoelastic method. Stress and strain depend on thickness of submount. The improved bonding condition by compensating the mechanical stress is described.

The laser diode fabricated by the new bonding condition has no sudden failure mode and has long operating life.

1. Introduction

Life of AlGaAs small power laser diodes has been remarkably improved as 10^6 hours at room temperature.[1] The failure rate, however, is relatively high as yet because of insufficient control of sudden degradation. On the other hand, there are few reports with respect to the life and degradation modes of high power lasers more than 10 mW.

The prime factor of sudden degradation in laser is almost a rapid increase of dislocation in active region through climb motion as dark line defects.[2] Dislocation slip induced by strain seems to be the primary stage of the degradation.[3), 4] Dislocation invades into the active region during several procedure such as crystal growth and fabrication process. Among them, the strain induced during bonding procedure seems to cause dislocation slip. The strains in bonding are primarily caused by different thermal expansion coefficients of GaAs crystal, Si submount and Cu heat sink block.

We have examined mechanical stress of high power lasers[5] in bonding procedure. The stress distributions in laser chips are theoretically estimated by the finite element method. And the theoretical results are compared with the results of the photoelastic measurements.[6] The improved bonding condition which enables to compensate the effect of mechanical stress is discussed. In this paper, we describe the effect of mechanical stress in bonding procedure and demonstrate the results of life test of high power TJS lasers fabricated by the new bonding condition.

2. Stress Distribution and Strain Fields

Diodes tested in this work are junction up high power lasers.[5] Laser chips are mounted on Si submount on heat sink of Cu block in junction up configuration. The stress distribution in laser chips are simulated by the finite element method. The finite element mesh of the structure is shown in Fig.1.

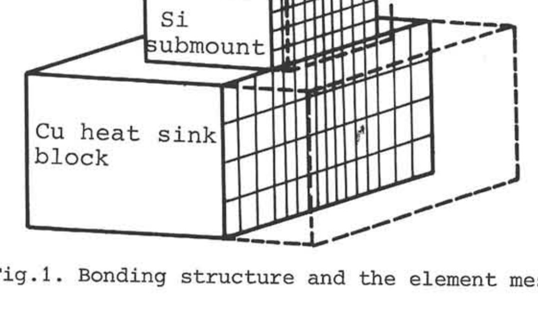

Fig.1. Bonding structure and the element mesh

In the calculation, Au-Si solders located at interfaces of chip/Si and Si/Cu block are neglected. Figure 2 shows the theoretical results displaying series of distribution of principal stresses in laser chips. The distribution and the strength of stress remarkably depend on the thickness of Si submounts. Calculated stresses are highly tensile at the thickness of Si submount more than 250 µm. As the thickness is reduced, the maximum principal stress decreases. Further reduction of the thickness brings the minimum stress and additional reduction causes increase of compressive stress in the chip. Figure 3 shows the stress variations near active region A and edge portion B replotted against the thickness of submount. The minimum principal stress is obtained at about 120 µm thickness of submount as shown in Fig.3.

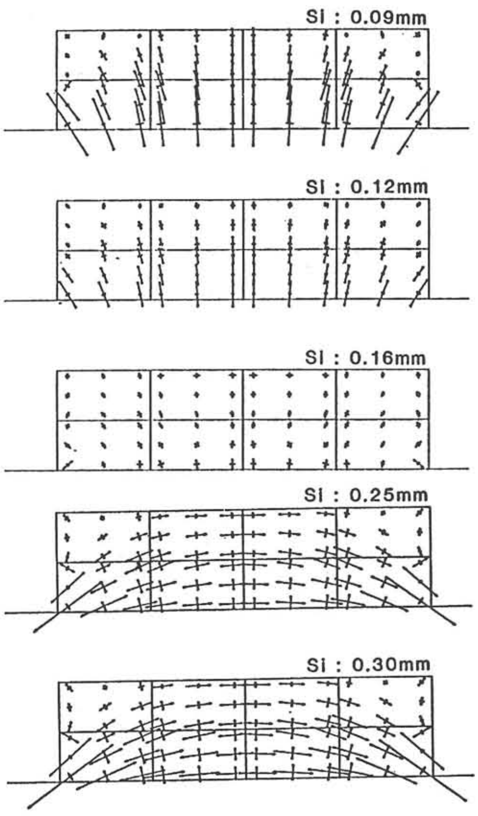

Fig.2. Theoretical stress distribution

The strain in the chip is observed by the photoelastic method. The block diagram of measurements is shown in Fig.4. The laser diode, which is placed between a polarizer and an analyzer, is observed by the transmitted light through the cleaved facets of chips. The transmitted light is detected through an infrared TV camera and is displayed in a CRT. Strain fields are measured as bright region. Figure 5 shows examples of measured strain fields of the lasers with various thickness of Si submount. In the case of 280 µm thickness of submount, the sharply bright areas are observed, so highly strained regions exist. The strain fields decrease by reduction of the thickness of submount as expected by the calculation.

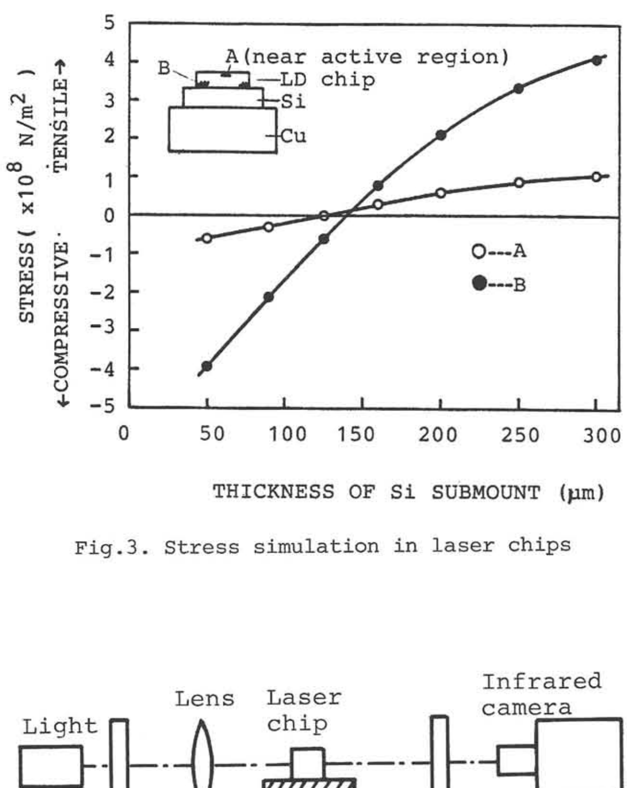

Fig.3. Stress simulation in laser chips

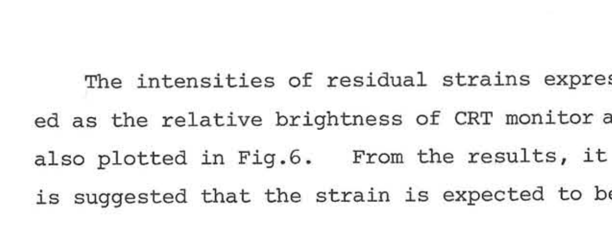

Fig.4. Block diagram of strain measurements

The intensities of residual strains expressed as the relative brightness of CRT monitor are also plotted in Fig.6. From the results, it is suggested that the strain is expected to be minimized when the thickness of submount is about 120 µm. This is in good agreement with the theoretical results. Therefore, these results suggest that the effect of stress in bonding is able to be eliminated successfully by optimizing the thickness of Si submount.

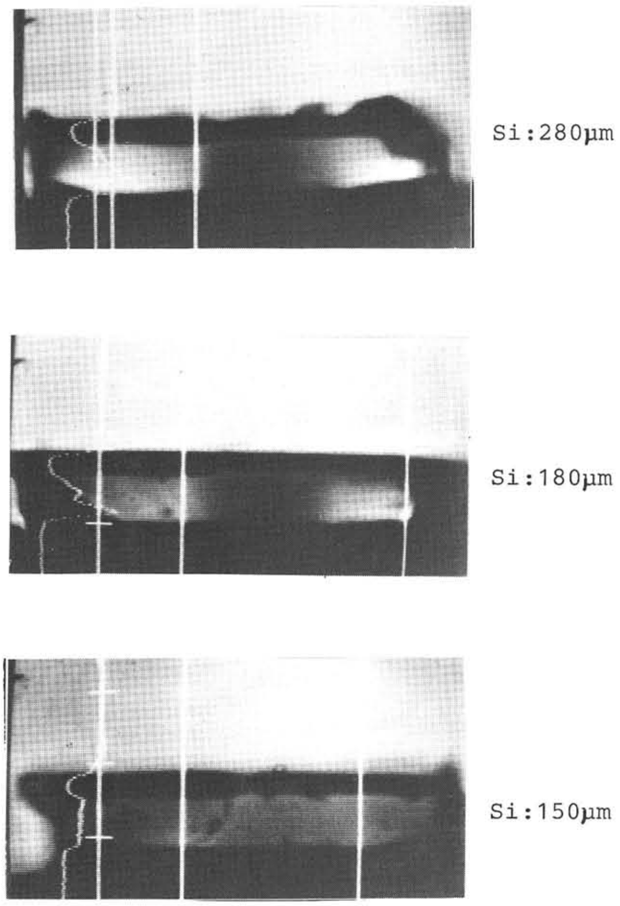

Fig.5. Measured strain fields of lasers with various thickness of submounts.

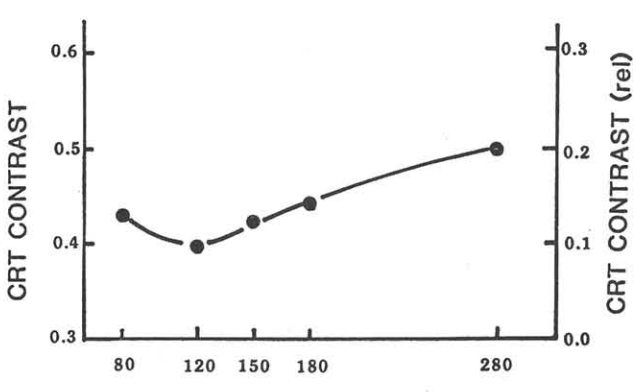

Fig.6. Residual strain by photoelastic intensities.

3. Life Tests of Lasers

We preliminaly tested the life of high power lasers with various thickness of Si submount at 50 °C. In tests, light output is constantly controlled by automatic power control circuits at cw power of 15 mW. Samples which showed the operating current more than 1.1 times the initial values were judged as failure in the tests. The typical wavelength of tested lasers is 830 nm. Variations of operating current versus aging time are shown in Fig.7.

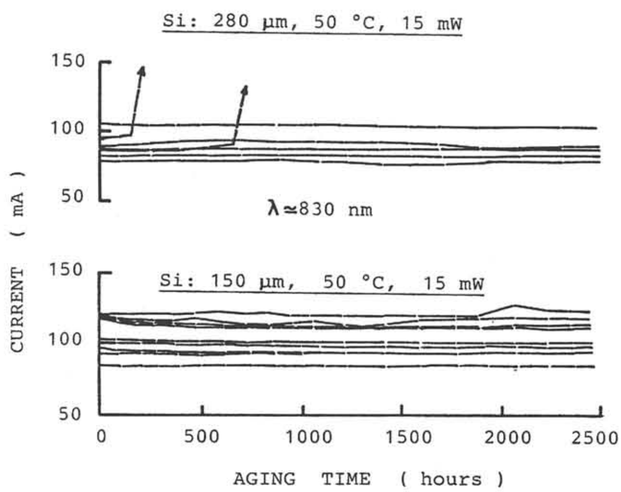

Fig.7. CW operating life tests of laser diodes with 150 µm and 280 µm submount thickness.

All diodes fabricated by optimizing the thickness of submount to about 150 µm are operating well with no obvious change of the current, while two of six diodes with 280 µm thickness of Si failed in less than 1000 hours. Sudden failure modes at early stage has no observed in the compensated diodes. Figure 8 shows the estimated MTTF of lasers with various thickness of Si submounts. The MTTF was estimated by the equation (1).

$$\mathrm{MTTF} = \frac{\text{accumulated operating time}}{\text{number of failure diodes}} \quad \text{-----} \quad (1)$$

At the present stage, the MTTF of the diodes with 150 µm Si submount thickness is about

2.2×10^4 hours at 50 °C. This is the best value of the tested three cases as shown in Fig. 8.

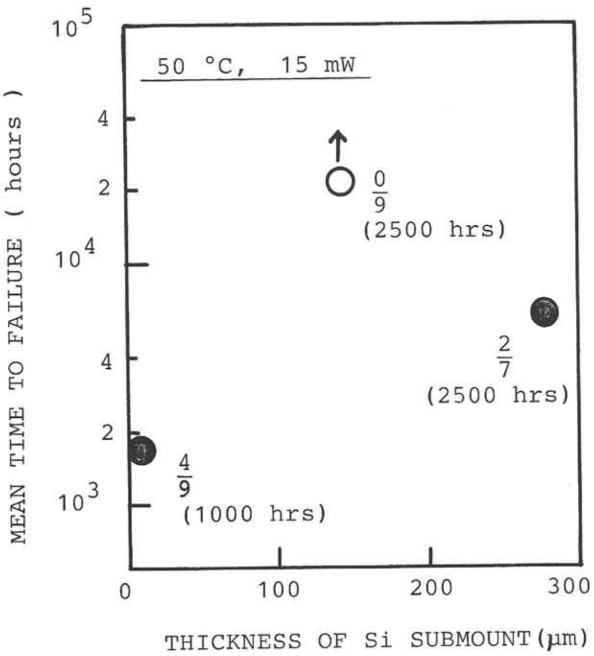

Fig.8. MTTF of high power laser diodes vs. thickness of Si submount.

4. Conclusion

Mechanical stress compensation in bonding procedure has been discussed for AlGaAs high power laser diodes. The theoretical stress distributions are in good agreement with measurements of photoelastic strain fields.

A balancing of the stresses in the three layered structure is responsible for the stress compensation. It was confirmed that the mechanical stresses in laser chip can be compensated by optimizing the thickness of Si submount. Therefore, not only selection of submount materials with thermal expansion coefficients close to GaAs, a fine balancing of sizes in the diodes is consequently necessary for accomplishing stress compensation.

The stress compensated high power laser diodes by optimizing the thickness of Si submount are operating well with no sudden failure modes. The improved lasers have reproducibly the long operating life.

Acknowledgement

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