Digest of Tech. Papers *The 11th Conf. (1979 International) on Solid State Devices, Tokyo*

B—3—9 Slow Degradation Mechanism of GaAlAs Light-Emitting Diodes

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The slow degradation of GaAlAs lasers and light-emitting diodes (LEDs) could be due to an increase in the density of nonradiative centers in the active region.[1] On the other hand, the conclusive evidence to support this speculation has not been given. This paper is the first report of the explicit correlation between the deep level densities in the active layer and the slow degradation of GaAlAs LEDs.

The structure of the LEDs used in this experiment is shown in Fig. 1. The crystal was grown by a liquid phase epitaxial method. The hole concentration in the active layer was 1×10^{16} cm^{-3} and the thickness of this layer was 2 μm. The densities of deep levels were measured using the method of deep level transient spectroscopy (DLTS).[2] The LEDs were operated at the ambient temperature of 180 °C and at the current density of 200 A/cm^2.

The change of output power during the aging is shown in Fig. 2. Dark line defects or dark regions were not observed in the active layer after the operation of 4000 hours. Typical DLTS spectra of the LEDs before and after aging are shown in Fig. 3. Any trap with the density of more than $\sim 5 \times 10^{12}$ cm^{-3} was not detected in the active region before aging. As the aging proceeds, three kinds of hole traps designated A, B, and C appeared and the densities of traps A and B increased. The thermal activation energies of A, B, and C are 0.43, 0.76, and 0.44 eV, respectively. Figure 4 shows the density changes of traps A and B as a function of aging time. In Fig. 4, we see that the density of trap A increased four or five times larger than that of trap B. Figure 5 shows the changes of cutoff frequency as a function of aging time. The cutoff frequency is directly related with the densities of nonradiative centers in the active layer. Neglecting the nonradiative recombinations in the space-charge layer and near the p-n junction, the cutoff frequency may be simply written as

$$2\pi f_c = B_r p + \sigma_{nA}\langle v_n\rangle N_{TA} + \sigma_{nB}\langle v_n\rangle N_{TB}, \qquad (1)$$

where B_r is the radiative constant, p is the concentration of holes in the active layer, σ_{ni} is the electron capture cross section of hole trap i, $\langle v_n\rangle$ is the thermal velocity of electrons, and N_{Ti} is the density of hole trap i. Solid line in Fig. 5 shows the calculated results of the cutoff frequency using Eq. (1) by the method of least squares. The obtained values of B_r, σ_{nA}, and σ_{nB} are $(5 \pm 5) \times 10^{-10}$ $cm^3 s^{-1}$, $(2 \pm 1) \times 10^{-14}$ cm^2, and $(1 \pm 4) \times 10^{-14}$ cm^2, respectively. The value of B_r is nearly the same as that measured by Casey and Stern.[3] The values of σ_{nA} and σ_{nB}, however, are two or three orders of magnitude larger than those reported by Lang and Logan.[4] The difference of these values cannot be understood at this stage. If we accept the values of σ_{nA} and σ_{nB} obtained in this experiment, the change of the cutoff frequency with the degradation of the LEDs is well explained by the changes of the densities of deep traps A and B. Furthermore, the rates of the nonradiative recombinations $U_{nr} = \sigma_n\langle v_n\rangle N_T$ through the deep levels A and B are estimated to be 1×10^8 s^{-1} and 2×10^7 s^{-1}, respectively, at the aging

time of 3240 hours. The effect of the level B on the change of the cutoff frequency is five times smaller than that of the level A. Therefore, the degradation of the LEDs is mainly due to the increase of the deep level A.

To summarize, we observed the density changes in deep levels in the active layer associated with the degradation of GaAlAs LEDs for the first time. It was found that the slow degradation of the GaAlAs LEDs was caused by the increase of the deep level A in the active layer.

The authors wish to thank M. Fujimoto of NTT for encouragements. They also wish to thank Y. Toyama, T. Kotani, and Y. Komatsu for helpful discussions.

References

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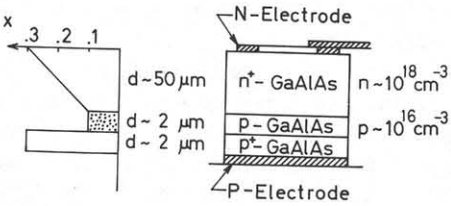

Fig. 1 The structure of GaAlAs LEDs used in this experiment.

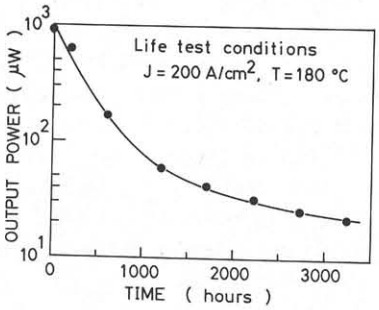

Fig. 2 Output power of the GaAlAs LEDs as a function of aging time. It was measured at 20 °C and at 40 A/cm².

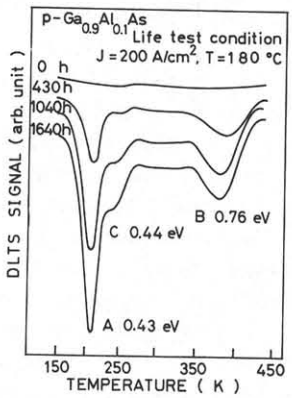

Fig. 3 DLTS spectra of the GaAlAs LEDs before and after aging

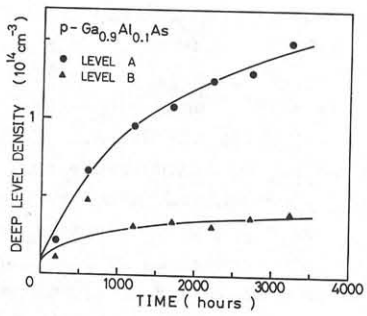

Fig. 4 Densities of hole traps A and B as a function of aging time at 180 °C.

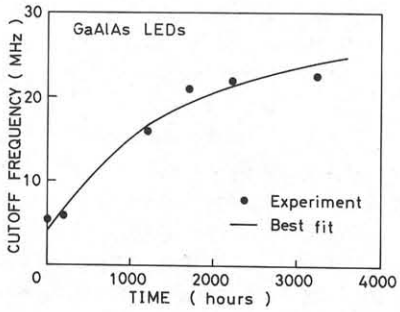

Fig. 5 Cutoff frequency of the GaAlAs LEDs as a function of aging time at 180 °C.