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INVITED: SPECTRAL AND SPATIAL BEHAVIOR OF LUMINESCENCE FROM THE ACTIVE LAYER OF GaAs-$Ga_{1-x}Al_xAs$ DOUBLE HETEROSTRUCTUER LASER DIODES

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Performances of GaAs-$Ga_{1-x}Al_xAs$ double heterostructure(DH) laser have been much improved so far by progress of the crystal growing and device fabrication technique, and by elaboration of the device geometry, e.g., by introduction of the improved stripe geometry with a laterally confined optical cavity.[1,2,3] However, for the further elucidation of lasing mechanisms as well as for the establishment of the reliability of the device, it would be indispensable to characterize and evaluate the nature of the active layer of DH laser diodes in more detail.

In this report we describe a method of the direct and nondestructive observation of luminescence from the active layer of DH laser diodes, applied, firstly, to measurements of the spectral luminescent response, and next, to observations of the spatial inhomogeneity in the active layer of GaAs-$Ga_{1-x}Al_xAs$ DH lasers in relation to their lasing performance and reliability.

The essence of the method lies in photoluminescence(PL) and/or electroluminescence(EL) observations of the active GaAs layer from the top surface of DH laser through the "window" of the upper $Ga_{1-x}Al_xAs$ layer, utilizing a difference of the bandgap between GaAs and $Ga_{1-x}Al_xAs$.[4,5] Samples used were similar to conventional DH lasers except that the top GaAs layer were lacking, so that they had simple three-layered structure. Several techniques of device fabrication to facilitate observations were developed. Two modes of observations were employed. The one is the measurement of PL or EL spectrum, making use of a He-Ne laser with 25 mW output as an excitation source, a grating spectrometer, and a cooled photomultiplier. The other mode is the observation of the spatial (two-dimensional) pattern of PL or EL brightness. In the case of the PL pattern observation, the sample was illuminated uniformly by a defocused laser beam from a krypton-ion laser with 200mW output. The visual image of the luminescence pattern was formed, through a microscope and a Si-target vidicon, upon a TV monitor.[6]

By using the spectral observation mode, measurements were made on the temperature- and excitation-dependence of luminescence spectra of the three-layered DH laser diodes with undoped, and Si-doped, active layers. Experimental results were interpreted in terms of the exponential band tailing and the carrier compensation effect. It is worth noting that J_{th}/d, the ratio of the threshold current density to the thickness of the active layer, of the undoped samples with relatively narrow PL halfwidth ($\Delta h\nu \approx$30meV at 300 K) were $\sim$3 kA/cm$^2\mu$m, being quite comparable to those of the diodes with heavily doped and closely compensated active layer, in contrast to theoretical predictions.[7,5]

Next, using the second mode of PL observation method stated above we discriminated various kinds of inhomogeneities within the active layer. Except for the drastic defects which penetrated up to the top surface, most of them were not observable at the top surface, while resonable correspondences were assigned to the morphological defects in the active layer observed under microscope after etching-off of the top layer. It was experimentally confirmed from these observations together with lasing characteristics that an anomalous increase of the threshold and a shift of the lasing mode to a higher order one were generally caused by existence of the inhomogeneity.[8]

Finally, as a most important application of the method, successive and non-destructive observations on the change of EL patterns in the process of gradual degradation of three-layered diodes were performed. It was recognized that a number of linear dark regions grew mostly from edges of the diode and the electrode, and also from some internal defects.[9,10] Simultaneous measurements of lasing characteristics along with these EL patterns clearly demonstrated a close relationship between the internal and external symptoms of the gradual degradation, eventually allowing us to infer the physical mechanism of the phenomena.

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