GaAs-GaAlAs distributed-feedback diode lasers with separate optical and carrier confinement

K. Aiki, M. Nakamura, and J. Umeda

Central Research Laboratory, Hitachi, Ltd., Kokubunji, Tokyo, Japan

A. Yariv,* A. Katzir,* and H. W. Yen*

California Institute of Technology, Pasadena, California 91125
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Remarkable reduction of the threshold current density is achieved in GaAs-GaAlAs distributed-feedback diode lasers by adopting a separate-confinement heterostructure. The diodes are lased successfully at temperatures up to 340°K under pulsed operation. The lowest threshold current density is 3 kA/cm^2 at 300°K.

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We have previously reported the operation of GaAs-GaAlAs double-heterostructure (DH) distributed-feedback (DFB) diode lasers in which the optical feedback was provided by a corrugated interface between the active layer and the outer p-GaAlAs layer.[1,2] Since the light and the carriers were confined to the active layer by the double heterojunction, the threshold current density at 80 °K was the lowest among those of the DFB diode lasers reported so far.[3-5] It was found, however, that the fabrication of a grating on the active layer caused the interface recombination centers which increased the threshold current density substantially at higher temperatures. For this reason, it was impossible to operate such lasers at around 300 °K at low current densities. Recombination centers existed even when the grating was made by chemical etching instead of by ion milling.

One of the solutions to this problem will be to use a separate optical and carrier confinement heterostructure (SCH). In the present work, we describe heterostructure lasers in which carriers are confined to the p-GaAs active layer while the light extends to the p-$Ga_{1-y}Al_yAs$ layer ($y \sim 0.17$) and the p-$Ga_{1-z}Al_zAs$ layer ($z \sim 0.07$) grown successively on the active layer. The grating is made on the p-$Ga_{1-z}Al_zAs$ layer to obtain the optical feedback. Since the active layer is separated from the corrugated interface, the threshold current density has been found to be low enough to operate the diode at higher temperatures. In this experiment lasers were operated successfully at room temperature.

In the fabrication of the DFB diode laser with separate confinement, an n-$Ga_{0.7}Al_{0.3}As$ layer (~ 2 μm thick), a p-GaAs active layer (~ 0.3 μm thick), a p-$Ga_{0.83}Al_{0.17}As$ layer (~ 0.1 μm thick), and a p-$Ga_{0.93}Al_{0.07}As$ layer (~ 0.2 μm thick) were grown successively by liquid phase epitaxy (LPE). The n layer was doped with Sn, and the p layers with Ge. Next, surface corrugations with a period of ~ 0.37 μm were made on the p-$Ga_{0.93}Al_{0.07}As$ layer by chemical etching through a photoresist mask produced by holographic photolithography. Finally, a p-$Ga_{0.7}Al_{0.3}As$ layer (~ 2 μm thick) and a p-GaAs layer (~ 1 μm thick), both doped with Ge, were grown on the corrugated surface by LPE. The SEM photograph of the corrugated waveguide with separate confinement is shown in Fig. 1, where the period Λ and the depth of the grating are 3700 Å and 1500 Å, respectively. In this figure, the injected electrons are confined to the p-GaAs active layer by the p-$Ga_{0.83}Al_{0.17}As$ layer. The p-$Ga_{0.93}Al_{0.07}As$ layer was necessary because it was difficult to grow GaAlAs uniformly on the exposed $Ga_{1-y}Al_yAs$ layer ($y > 0.1$) in the second LPE. The mole fraction of Al in the corrugated layer was chosen to be 0.07, so that the absorption of light could be reduced and the next p-$Ga_{0.7}Al_{0.3}As$ layer could be uniformly grown on it.

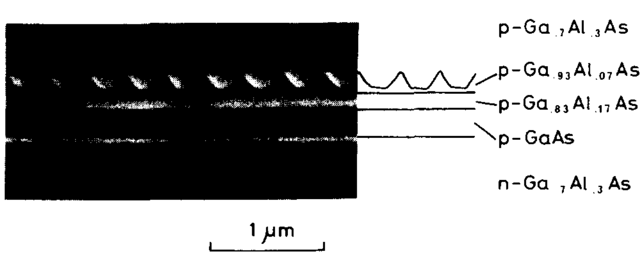

FIG. 1. SEM photograph of the SCH structure DFB laser. The period is 3700 Å.

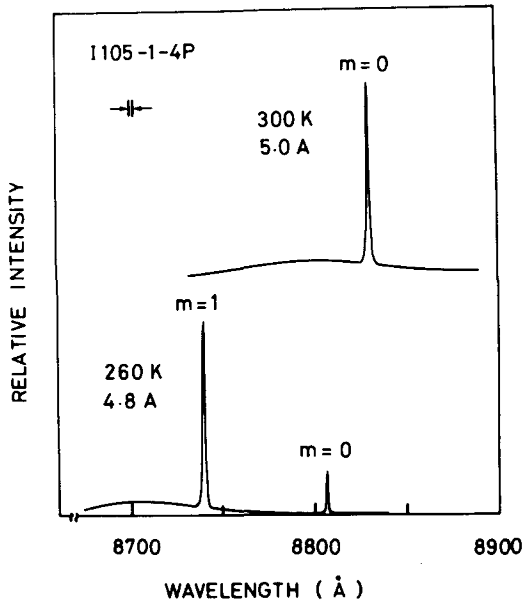

FIG. 2. Lasing spectra of a SCH structure DFB laser. m is the transverse mode number.

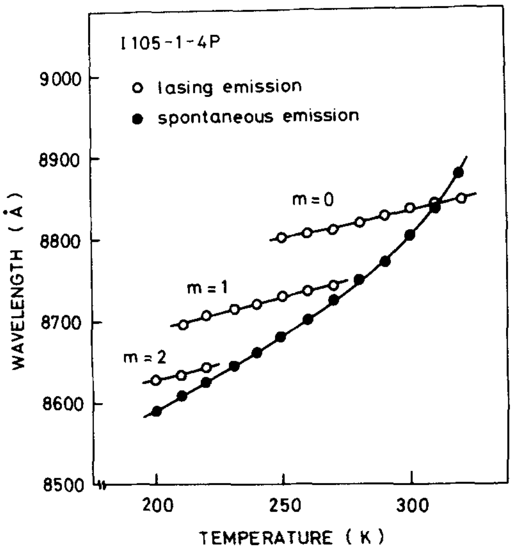

FIG. 3. Wavelength as a function of temperature. The open circles denote the lasing wavelength. The filled circles denote the peak wavelength of the spontaneous emission.

The diode had a mesa-stripe geometry so that the injection could be limited to a rectangular region. The width of the stripe was 50 μm. The length of the excited area, L, was 200–1000 μm. The details of the geometry are the same as those described before.[1,2] The lasing characteristics were investigated in a temperature range from 80 to 340 °K under pulsed operation. The duration and the repetition rate of current pulses were 50 ns and 100 Hz, respectively.

At 80 °K, the threshold current density J_{th} was ~500 A/cm^2 for $\Lambda = 3600$ Å and $L = 500$ μm. This is about the same as the J_{th}(80 °K) obtained in the DH structure DFB lasers. At 300 °K, the lowest threshold current density was 3 kA/cm^2 for $\Lambda = 3770$ Å and $L = 500$ μm. This is about 1/30 of the J_{th}(300 °K) of the DH structure DFB lasers.

The emission spectra of a typical SCH structure DFB laser are shown in Fig. 2, where $\Lambda = 3770$ Å and $L = 500$ μm. At 260 °K, we observed two peaks, the separation of which was 67 Å. These two peaks corresponded to the two transverse modes operating perpendicular to the junction plane, as was theoretically discussed in Refs. 6–8. From the study of the radiation pattern, the peak centered at 8807 Å was assigned to the lowest transverse mode ($m = 0$), and the peak centered at 8740 Å to the second transverse mode ($m = 1$). The threshold current density of the lowest transverse mode was higher than that of the second transverse mode at 260 °K. At 300 °K, the diode lased in the lowest transverse mode with a peak wavelength of 8829 Å.[9] As is shown in Fig. 2, the selectivity of the longitudinal mode was as remarkable in the SCH structure DFB laser as in the DH structure DFB lasers. The lasing wavelength of the diode is plotted as a function of the diode temperature in Fig. 3, where current pulses up to 10 A were applied to the diode. Three transverse modes were observed in total, and the wavelength of each mode had a temperature dependence of 0.6 Å/deg.

In some diodes an increase of the pumping current by a factor of 5 above threshold resulted in the appearance of two, or at most three, longitudinal modes. The peak room-temperature power was about 5 mW.

In conclusion, GaAs-GaAlAs DFB lasers with a SCH structure were operated at temperatures up to 340 °K under pulsed bias. cw operation will be possible in this structure by improving the heat sink of the diode.

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[9]It depends on the gain spectrum of the diode as well as on the coupling coefficient of each mode as to which transverse mode has the lowest threshold. The details will be discussed elsewhere.