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Fabrication and Characteristics of a Gain-Coupled Distributed- Feedback Laser Diode

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We propose a gain-coupled semiconductor distributed feedback laser structure, where complete single-longitudinal-mode oscillation is expected to automatically come about without any complicated scheme such as the quarter-wave phase shift. A preliminary GaAlAs/GaAs device with an oxide stripe structure is fabricated using two-step liquid phase epitaxy. An excellent single-longitudinal-mode property consistent with the theoretical prediction is achieved.

I. Introduction

The semiconductor distributed feedback (DFB) laser was made feasible by the introduction of the separate optical and carrier confinement structure.[1,2] Since then the predominant optical feedback mechanism in the DFB laser has been refractive index perturbation, which is usually provided by the diffraction grating formed on the transparent waveguiding layer adjacent to the active layer. This index-coupled DFB laser has an intrinsic problem of yielding a pair of longitudinal modes having equal threshold gain. For complete single-longitudinal-mode oscillation of such lasers, several schemes have been contrived,[3,4] yet they may add another intricacy to the fabrication process.

On the other hand, if the light is fed back by perturbation in gain or loss coefficient (i.e. gain-coupling), there uniquely exists the mode with minimum threshold gain,[5] and the complete single-longitudinal-mode oscillation will automatically come about. Here we propose a structure in which this principle is for the first time applied to the semiconductor DFB laser, and describe its fabrication process and oscillation characteristics.

II. Fabrication Procedure

A schematic drawing of the gain-coupled GaAlAs/GaAs DFB laser fabricated is depicted in Fig.1. For simplicity, we have employed the fundamental oxide stripe structure. The key point of our proposal is the use of the corrugated layer with composition being approximately the same as that of the active layer, namely GaAs in this case, instead of the usual transparent composition. As a result, the corrugation provides not

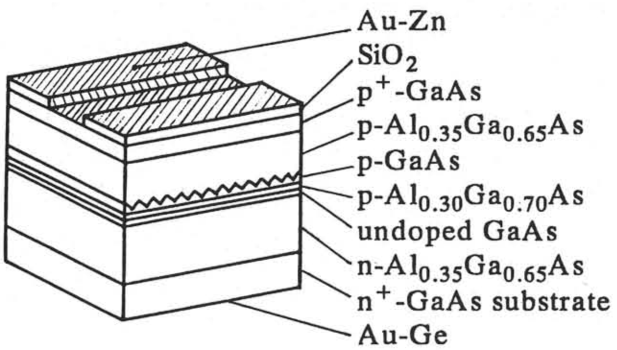

Fig.1 ***Schematic drawing of the gain-coupled DFB laser diode with oxide stripe structure***

only index modulation but also substantial perturbation in the net gain coefficient of the waveguide.

The actual sample was made by a two-step liquid phase epitaxy (LPE). During the first LPE step, n-GaAlAs lower cladding (1μm-thick), undoped GaAs active (0.2μm), p-GaAlAs carrier-confining (0.1μm), and p-GaAs "waveguiding" (0.15μm) layers were successively grown on an n^+-GaAs (100) substrate at 800°C. A second-order diffraction grating with a period of 255nm was engraved on the epitaxial wafer by reactive ion etching (RIE).[6] The second LPE step was for growing p-GaAlAs upper cladding (0.9μm), and p^+-GaAs contact (0.3μm) layers on the grating. After construction of 11μm-wide stripe geometry, the wafer was cleaved into each device with a cavity length of approximately 200μm. One of the cleaved facets was scratched to suppress Fabry-Perot modes.

III. Characteristics

Figure 2 shows light output power versus injection current characteristics under pulsed operation (500ns, 10kHz) at room temperature. Threshold current of 200mA at 20°C without any lateral confinement structure is considered to be normal. The external differential quantum efficiency per facet is measured as 30%. The kink is not observed below 10mW.

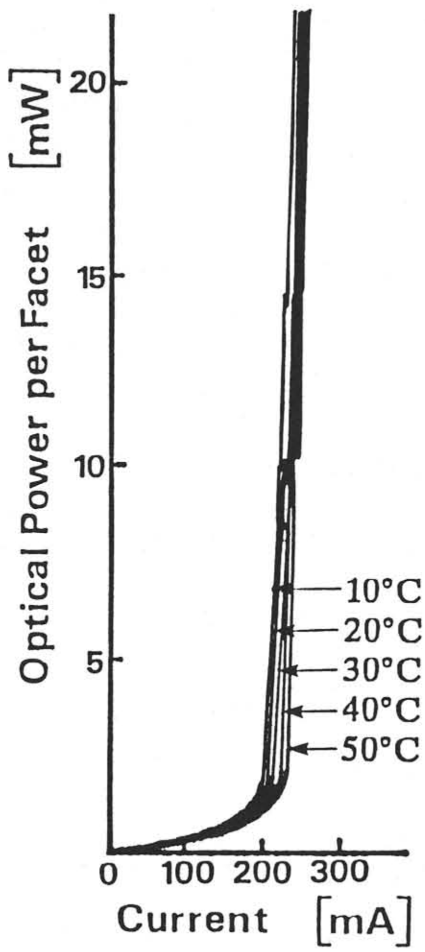

Fig.2 ***Light output vs. injection current characteristics at different temperatures***

Spectra at several injection levels of the same device at 10°C are shown in Fig.3. It should be noted that, in the spectrum near threshold, the stop band which is usually observed in the index-coupled DFB laser is not found, and the shape of the spectrum is symmetrical with respect to the lasing wavelength of 878nm. This symmetric spectrum characterizes our DFB laser, and is con-

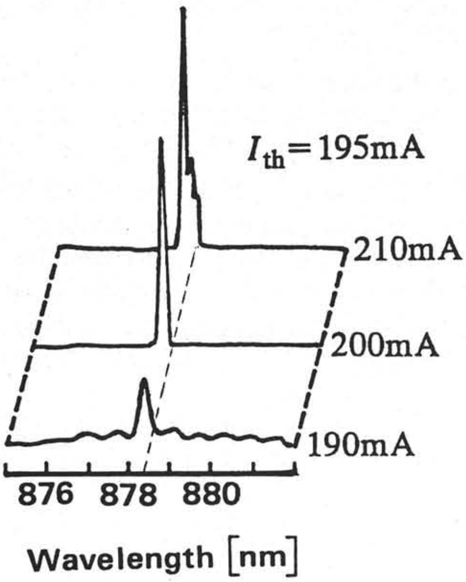

Fig.3 *Injection current dependence of the lasing spectrum at 10°C*

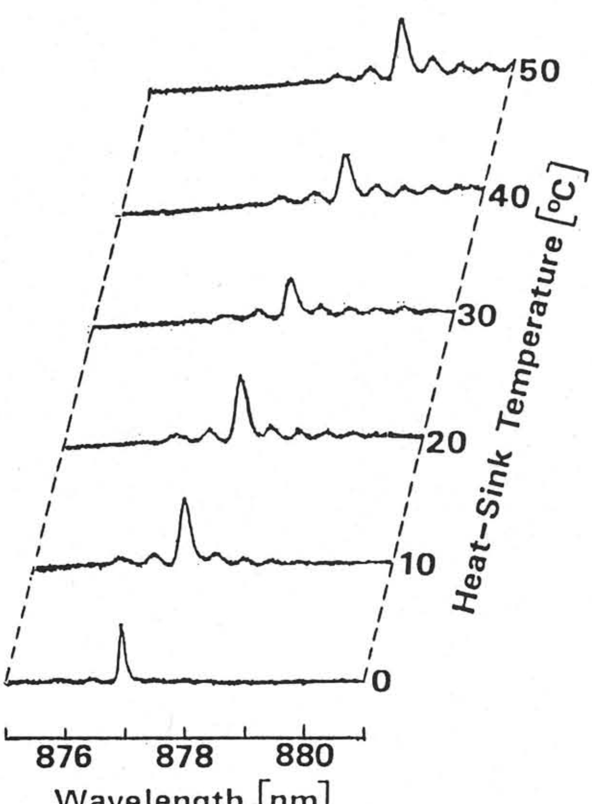

Fig.4 *Near-threshold spectra at different temperatures*

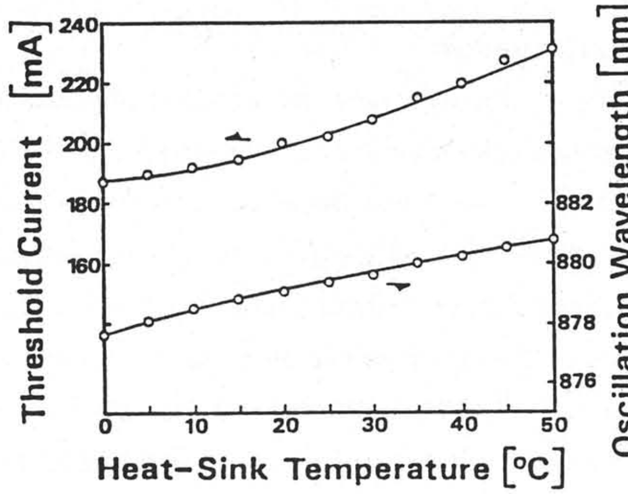

Fig.5 *Dependence of the threshold current and the lasing wavelength on heat-sink temperature*

sidered to be the evidence showing that the feedback is mainly carried out by gain modulation.[5] The feature is invariable with temperature as seen in Fig.4, where near-threshold spectra measured at different temperatures are illustrated.

Since there is no lateral mode control mechanism, complete single mode operation is kept within a limited current range around 200mA. Above that level first- and second-order lateral modes begin to lase successively, and the latter becomes dominant at 210mA as observed in Fig.3.

The temperature dependences of the threshold current and the lasing wavelength just above threshold are plotted in Fig.5. From the figure we understand that no mode hopping exists at least within 50K, our maximum variable range of temperature, and the device maintains the same DFB mode oscillation. This fact suggests that the coupling coefficient arising from gain perturbation is considerably large. Temperature coefficient of the lasing wavelength due to refractive index change is measured as 0.06nm/K.

IV. Conclusions

We proposed here an actual configuration realizing gain-coupling in semiconductor DFB lasers, by which the lasers are expected to automatically exhibit complete single-longitudinal-mode oscillation without any complicated scheme such as the quarter-wave phase shift. A preliminary GaAlAs/GaAs device with the oxide stripe structure was fabricated using two-step LPE. The excellent spectral property observed was consistent with the theoretical prediction, thus confirming us in its validity.

Acknowledgment

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