Extended Abstracts of the 1994 International Conference on Solid State Devices and Materials, Yokohama, 1994, pp. 136-138 S-I-11-2

Wavelength Filtering Operation in Absorptive-Grating Gain-Coupled DFB Laser

Tomohiro Otani, Tsurugi K. Sudoh, Yoshiaki Nakano, Kunio Tada, and Hiroki Ishikuro

Department of Electronic Engineering, University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo, 113, Japan

Optical wavelength filtering operation in a gain-coupled (GC) distributed-feedback (DFB) semiconductor laser has experimentally investigated for the first time. As a result, we have obtained useful characteristics such as 0.02nm transmission bandwidth, 14dB discrimination, zero insertion loss, and –12dBm saturation power.

1. Introduction

There is a tremendous interest toward an optical network utilizing wavelength division multiplex (WDM) scheme.[1] This seems particularly useful for enlarging data transmission capacity in subscriber loops. However, the WDM requires optical devices which are uncommon in the present optical communication. One of them is an optical wavelength filter that extracts a specific channel out of a number of wavelength-multiplexed channels.

Distributed feedback (DFB) semiconductor lasers biased below threshold can work as optical wavelength filters with gain as they selectively amplify and pass a wavelength band corresponding to the lasers' oscillation wavelength in incident light.[2,3] However, they often have parasitic pass bands associated with side modes, which significantly degrades wavelength discrimination ratio. As a result, this kind of filters is only useful within a limited wavelength range in the vicinity of the lasing mode.

The gain-coupled (GC) DFB laser is known to have a larger side-mode suppression ratio than the conventional DFB laser[4] and therefore is expected to have better characteristics if it is used as a wavelength filter. It was predicted that if the gain coupling was incorporated with a reflection-type wavelength filter with a distributed Bragg reflector (DBR), the filtering operation could be improved significantly.[5] This paper describes the first demonstration of transmission-type wavelength filtering operation in the GC DFB laser.

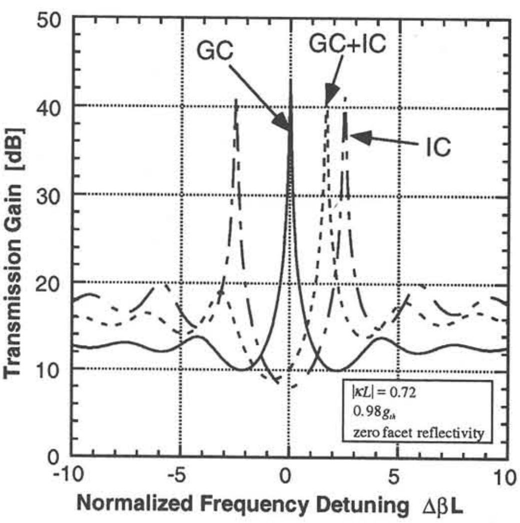

Fig. 1 Calculated transmission spectra of DFB lasers with pure index coupling (IC, $\kappa_i L$=0.72), mixed gain and index coupling (GC+IC, $\kappa_i L$=0.6, $\kappa_g L$=0.4), and pure gain coupling (GC, $\kappa_g L$=0.72).

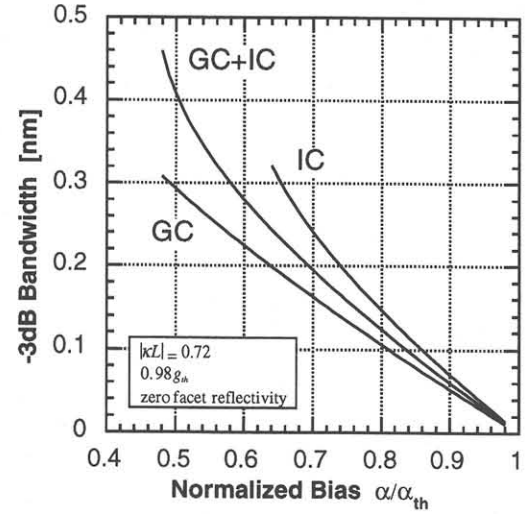

Fig. 2 Calculated transmission bandwidth of the DFB lasers in Fig. 1 as functions of normalized bias level (central wavelength is assumed as 840nm).

2. Analysis

Transmission characteristics of DFB lasers biased below threshold can be calculated by making use of the coupled mode equations.[6] Those for pure index coupling (IC), mixed gain and index coupling (GC+IC), and pure gain coupling (GC) have been calculated as shown in Fig. 1. Assumed gain coupling was of "absorptive grating" type where the periodic perturbations of gain and index were opposite in phase with each other. Values of normalized index- and gain-coupling constants, $\kappa_i L$ and $\kappa_g L$, were chosen in such a way that the absolute value, $|\kappa L| = \sqrt{(\kappa_i L)^2 + (\kappa_g L)^2}$, was kept constant (0.72). The gain was 0.98 times the threshold, and facet reflection was assumed to be zero.

In the conventional DFB laser with pure index coupling, there are two transmission bands on both sides of the Bragg stop band, which is apparently not preferable. On the other hand, incorporation of gain coupling gives rise to a single pass band. Moreover, as it approaches to pure gain coupling, the side-mode suppression becomes larger. The quarter wave phase shift could provide a single pass band but the above effect of side-mode suppression would not be expected.

Next, full width at half maximum (FWHM) of the transmission band for each laser in Fig. 1 was calculated and plotted in Fig. 2 as a function of pump strength. The pass bandwidth at the same bias level decreases as one increases gain coupling component. The bias condition to be used depends on the bandwidth required. However, one should note that a too small bias might result in a poor side-mode suppression in general. Therefore, a compromise between them should be considered.

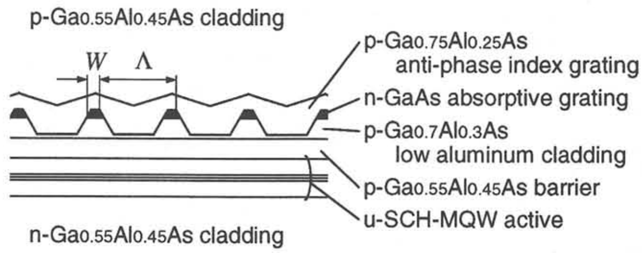

Fig. 3 Longitudinal cross section of the GC DFB MQW laser with a 3rd-order absorptive grating. Pitch Λ and duty cycle W/Λ of the grating are 376nm and approximately 0.2.

3. Experiment

Figure 3 shows schematic drawing of the longitudinal cross section of the device used here. It has periodic GaAs laid over the active layer along the laser axis which works as an absorptive grating, thus producing net gain perturbation. The active layer consists of three GaAs quantum wells with 8nm width. Cavity length was 200μm, and the facets were left as cleaved. Threshold current was 17.2mA at 20°C.

Transmission wavelength filtering operation of this GC DFB laser was characterized by using an experimental setup shown in Fig. 4. Variable wavelength light from a Ti-sapphire laser was injected from one facet of the GC DFB laser, and collected from the other facet via hemispherical-ended single-mode fibers. Polarization of the incident light was adjusted to be TE.

Figure 5 shows wavelength dependence of the transmission optical power at different bias levels. The incident power was fixed at –20dBm.

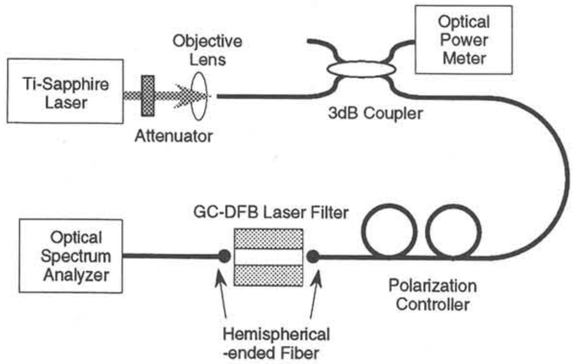

Fig. 4 Experimental setup for the measurement of wavelength filtering operation in the GC DFB laser.

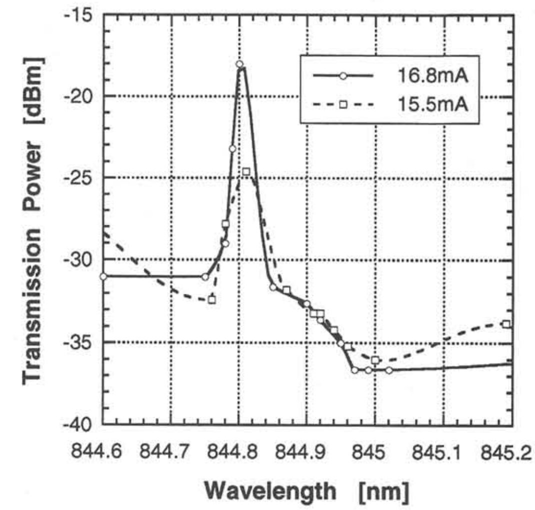

Fig. 5 Wavelength dependence of transmission optical power through the GC DFB laser at two different bias levels. Incident power was –20dBm.

The single wavelength transmission spectrum seen in the figure is a direct consequence of the single mode property of the GC DFB laser. The 3dB transmission bandwidth changes from 0.06 to 0.02nm as the bias is increased. The discrimination ratio simultaneously increases up to 14dB. This value seems significantly large for a laser with as-cleaved facets. It can be enlarged further if antireflection coating is applied on the facets.

Next, we measured transmission fiber-to-fiber gain at the peak wavelength as a function of input power when the laser is biased at 16.8mA. The result is illustrated in Fig. 6. In the low power regime, the gain of the laser filter compensated the input and output coupling loss to result in net zero insertion loss. 3dB saturation input power at this particular bias level was approximately –12dBm.

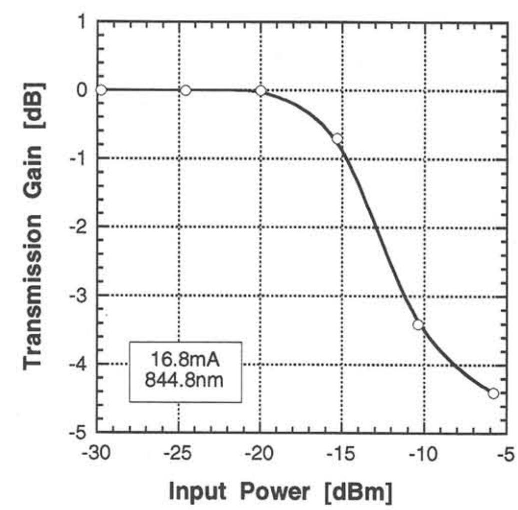

Fig. 6 Incidnet power dependence of fiber-to-fiber transmission optical gain measured at the peak wavelength. Bias current was 16.8mA.

4. Conclusions

We have analyzed transmission-type wavelength filtering operation in DFB lasers incorporating gain coupling, and have shown advantages over conventional DFB laser filters. Next, we have demonstrated optical wavelength filtering operation in an actual GC DFB laser for the first time, and obtained useful characteristics such as 0.02nm transmission bandwidth, 14dB discrimination, zero insertion loss, and –12dBm saturation power.

References

1) C. A. Brackett, IEEE J. Sel. Areas Commun. **8** (1990) 948.
2) K. Magari, H. Kawaguchi, K. Oe, and M. Fukuda, J. Lightwave Technol. **11**(1988) 2178.
3) T. Numai, IEEE J. Quantum Electron. **28** (1992) 1513.
4) For example, Y. Nakano, H.-L. Cao, K. Tada, Y. Luo, M. Dobashi, and H. Hosomatsu, Jpn. J. Appl. Phys. **32 pt. 1** (1993) 825.
5) J. Willems, K. David, G. Morthier, and R. Baets, IEE Proc.-J **39** (1992) 53.
6) H. Kogelnik and C. V. Shank, J. Appl. Phys. **43** (1972) 2327.