Extended Abstracts of the 18th (1986 International) Conference on Solid State Devices and Materials, Tokyo, 1986, pp. 177-180

High Frequency Response Characteristics of DFB-DC-PBH LDs

Hiroyuki Nishimoto, Masayuki Yamaguchi, Ikuo Mito and Kohroh Kobayashi

Opto-Electronics Research Laboratories, NEC Corporation

4-1-1, Miyazaki, Miyamae-ku, Kawasaki-city, Japan

Resonance frequencies for 1.3μm and 1.5μm DFB-LDs have been increased by setting the DFB lasing wavelength shorter than the gain peak wavelength. The reason is estimated to be due to the large differential gain in this region. As high as 21GHz resonance frequency has been obtained in 1.5μm DFB-DC-PBH LDs with a lasing wavelength 80Å shorter than gain peak wavelength under 30mW light output power conditions.

Introduction

Recently, there has been much interest in very high frequency modulation of InGaAsP semiconductor lasers. Especially, the distributed feedback laser diode (DFB-LD) is one of the promising light sources for high bit rate and long span optical fiber communication systems, because it can operate with single longitudinal mode oscillation under high frequency modulation.

There seem to be two important factors to be met in achieving high speed laser diodes. One is to reduce the parasitic capacitance to as small a value as possible[1][2]. -3dB frequency as high as 16GHz have been reported so far[1].

Another point is to increase the resonance frequency with respect to the laser bias level or output power level, because the modulation sensitivity for laser diodes decreases abruptly beyond the resonance frequency. The resonance frequency is governed by photon lifetime, differential gain and carrier lifetime etc.. In DFB-LDs, it is noticeable that the lasing wavelength can be set free from the gain peak to some extent. A lasing wavelength, different from the gain peak, is expected to bring about new effects in the parameters mentioned above.

This paper reports the experimentally obtained relationship between resonance frequency and the difference between lasing and gain peak wavelengths for 1.3μm and 1.5μm InGaAsP DFB-DC-PBH LDs.

Measurements

The DFB-LDs measured here were mesa type 1.3μm and 1.5μm DFB-DC-PBH LDs[3]. An illustration is shown in Figure 1. The first order grating was formed on a n-InP substrate using the ordinary holographic exprosure method. The active layer width, the active and guide layer thicknesses and the cavity length were 1.5μm, 0.1μm, 0.1μm and 300μm, respectively. For 1.5μm DFB-LDs, the anti-meltback layer was grown on an active layer less than 0.1μm thick. To reduce parasitic capacitance, two grooves were formed outside the double channel region and SiO_2 film was formed all over the surface, except for the 7μm wide contact region above the mesa. One of the facets of these

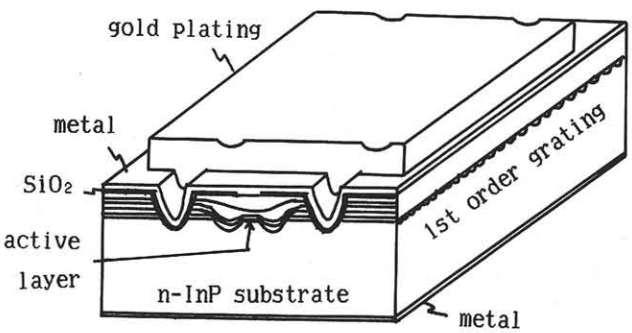

Fig.1 DFB-DC-PBH LD illustration

DFB-LDs was coated by SiN_x to an about 10% reflectivity to make asymmetric reflectivity combination for stable single longitudinal mode oscillation. Device structures mentioned above were the same among the samples, except for the grating periods, which were changed due to evaluating the device characteristics with regard to the difference between lasing and gain peak wavelengths.

The resonance frequencies were measured from the small signal frequency response characteristics, using a 26.5GHz bandwidth network analyzer (HP-8510). A 7GHz bandwidth InGaAs PIN photo diode was used as an optical detector. The resonance frequencies higher than 10GHz were measured by optical feed back method[4]. The gain peak wavelengths were measured from the spectra just below the threshold.

Results

Figure 2 shows the resonance frequencies for 1.3μm DFB-DC-PBH LDs versus bias level $\sqrt{I/I_{th}-1}$. Three cases are shown in Fig.2. Device parameters among these three DFB-LDs were almost the same, except for the grating period, as mentioned before. The different grating periods resulted in different DFB lasing wavelength. Since the composition of the active layers were set to be almost same, the different wavelength discrepancy between gain peak and DFB lasing wavelengths were achieved among these wafers. The three samples shown in Figure 2 showed a large difference in the resonance frequency at the bias level of 2 times the threshold current. Figure 3 shows the resonance frequencies versus the wavelength difference $\Delta\lambda$ between DFB lasing wavelength λ and gain peak wavelength λ_p, where $\Delta\lambda = (\lambda - \lambda_p)$. Resonance frequencies shown in this figure were obtained from the small signal frequency response characteristics measurement. Circles and triangles represent the resonance frequencies for 1.3μm and 1.5μm DFB-LDs, respectively. Both the 1.3μm and 1.5μm DFB-LD reasonance frequencies have been found to increase, when the lasing wavelength became shorter than the gain peak wavelength. The resonance frequency dependence on wavelength difference $\Delta\lambda$ was also measured at the condition of the constant output power. The tendency was the same as that of the constant bias level cases mentioned before. As the 1.5μm DFB-LD differential quantum efficiency was less than the 1.3μm DFB-LD efficiency, the higher bais current levels were required for 1.5μm DFB-LDs to guarantee the same output power. Accordingly,

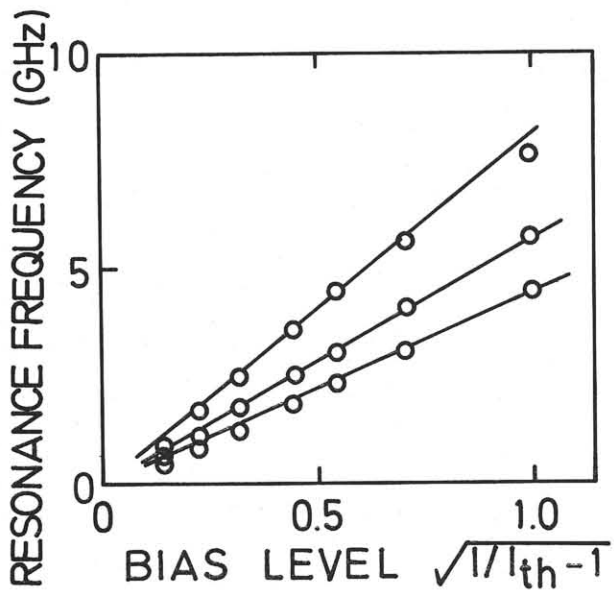

Fig.2 Resonance frequency versus bias level. Where the wavelength difference between the lasing wavelength and the gain peak wavelength $\Delta\lambda$ is different.

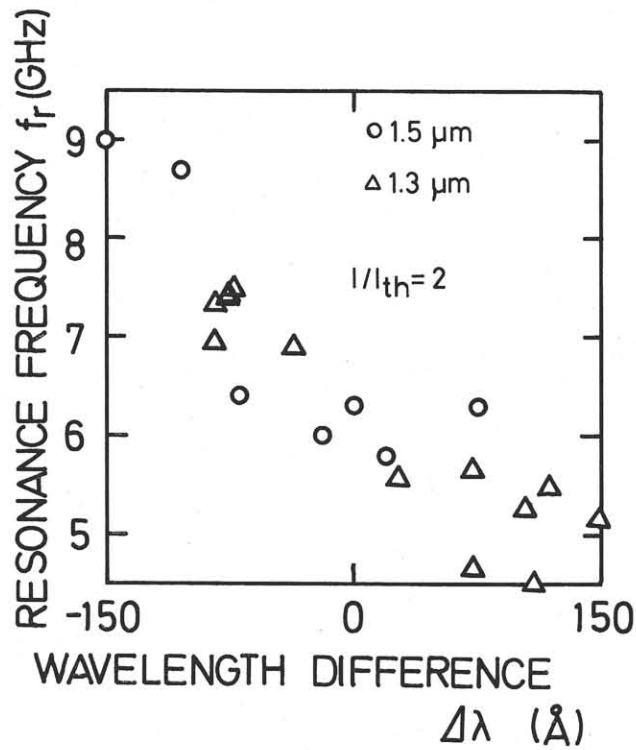

Fig.3 Resonance frequency at the bias level of 2 times of the threshold current versus the wavelength difference $\Delta\lambda$. (△) and (○) represents the results of the 1.5μm and 1.3μm DFB-DC-PBH LDs, respectively

1.5μm DFB-LD resonance frequencies were larger than those for 1.3μm DFB-LDs.

It was very interesting how large the resonance frequencies of DFB-DC-PBH LDs would be obtained. The frequency response of the detector system was limited around 10GHz. Therefore resonance frequency over 10GHz was measured by observing the satellite mode generated by an optical feed back[4], which was corresponding to the resonance frequency. Figure 4 shows resoncnce frequency versus the bias level $\sqrt{I/I_{th}-1}$. In this measurement, $\lambda/4$ shifted DFB-DC-PBH LDs[5] was used and wavelength difference $\Delta\lambda$ is about -80 Å. The resonance peak frequency increased with no saturation, according to the bias level increase. As high as 21GHz resonance frequency was obtained at a bias level of 13 times the threshold, where the front output power was 30mW.

Discussion

Resonance frequency f_r, is expressed as follows[6].

$$f_r=\sqrt{\frac{A\tau_p\Gamma N_{om}+1}{\tau_s\tau_p}(I/I_{th}-1)} \qquad (1)$$

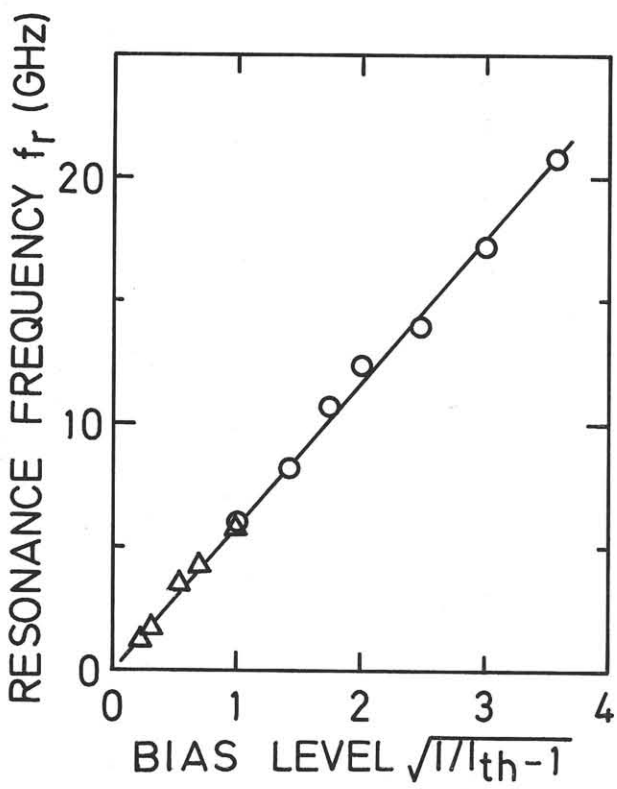

Fig.4 Resonance frequency versus bias level for $\lambda/4$ shifted 1.5μm DFB-DC-PBH LDs. (○) indicates measurement from small signal frequency response. (△) indicates measurement optical feed back method.

Where, A, τ_s, τ_p, Γ and N_{om} are differential gain, carrier lifetime, photon lifetime, filling factor and carrier density for transparency, respectively. The carrier lifetimes measured using the relation between oscillation delay time and bias level were about 1.5-1.8ns for 1.3μm DFB-DC-PBH LD. An attempt was made to remove the carrier lifetime influence in the resonance frequency. Figure 5 shows resonance frequencies normalized by the square root of carrier lifetime. The normarized value $\sqrt{\tau_s}f_r$ also increased when the lasing wavelength became shorter than the gain wavelength. The filling factor was considered to be almost the same, because active and guide layers in the measured DFB-LDs had the same thicknesses and composition. Furthermore, the photon lifetime and the carrier density for transparency were also considered as being the same, because the threshold current difference was small as shown in Figure 6. Therefore, the dependence on the resonance frequency described above can be attributed to the difference in differential gain A. As injection carrier density increases, the laser gain distribution moves for higher energy side (shorter wavelength). Accordingly, differential gain A is theoretically

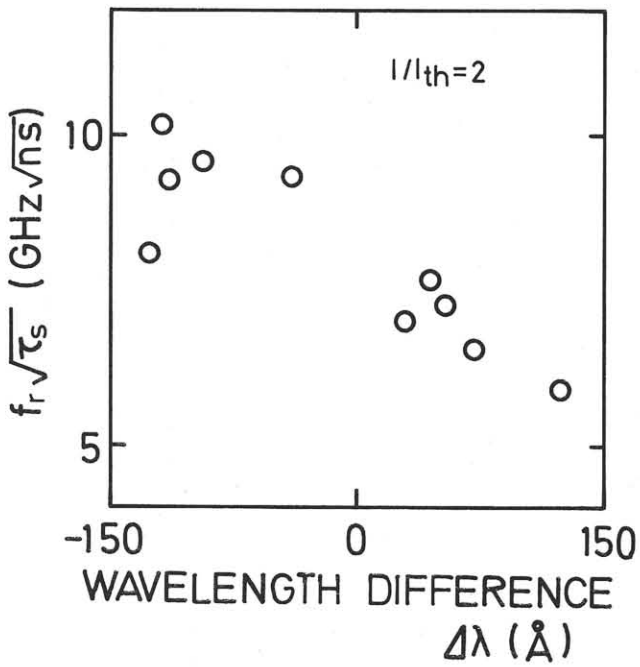

Fig.5 Product of resonance frequency and square root of carrier life time versus the wavelength difference $\Delta\lambda$ for 1.3μm DFB-DC-PBH LDs.

expected large in the shorter wavelength region and small in the longer wavelength region, with respect to gain peak wavelength. This explains the results in Figs.3 and 5. In rough estimation from the gain curves of injection carrier density dependence , differential gain A for the wavelength difference $\Delta\lambda$=-150 Å becomes about 1.5 times , compared to that for $\Delta\lambda$=0. As the resonance frequency is about proportional to the square root of A, it becomes 1.2 times. From Fig.3 the resonance frequency becomes about 1.3 times, through $\Delta\lambda$ change to -150 Å from 0 Å. The experimental results on the resonance frequency increase can be well explained by the detail theoretical calculation. In DFB-LDs, as one of the important parameters, the lasing wavelength for DFB-LDs should be advantageously set at shorter wavelength than gain peak wavelength, to improve the modulation bandwidth.

Conclusion

The high frequency response for DFB-LDs has been found to be improved by setting the lasing wavelength shorter than the gain peak wavelength. It seemed to be due to the differential gain increase. Using $\lambda/4$ shifted DFB-DC-PBH LDs with a lasing wavelength being 80 Å shorter than gain peak wavelength, as high as 21GHz resonance frequency was obtained at a bias level of 13 times the threshold current. It indicates the possibility of such a high speed modulation.

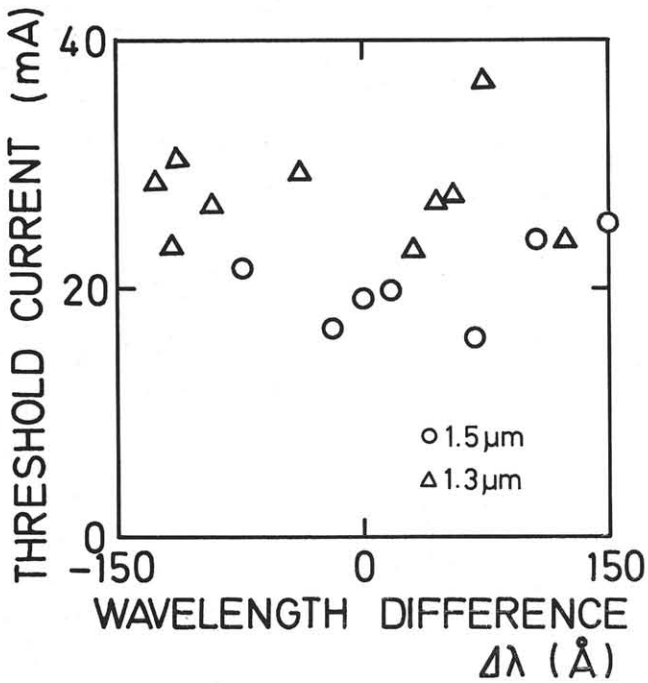

Fig.6 Threshold currents versus wavelength difference $\Delta\lambda$ for 1.3μm and 1.5μm DFB-DC-PBH LDs.

Reference

(1)J.E.Bowers, D.P.Wilt, B.R.Hemenway, T.J.Bridges and E.G.Burkhardt: "Design and implementation of high-speed InGaAsP constricted-mesa lasers" OFC/IGWO'86 WBB2 1986

(2)C.B.Su, V.Lanzisera, R.Olshansky, W.Powazinik, E.Meland, J.Schlater and R.B.Lauer: "15GHz direct modulation bandwidth of vapour-phase regrown 1.3μm InGaAsP buried-heterostructure lasers under CW operation at room temperature" Electron. Lett. 20th June 1985 Vol.21 No.13

(3)H.Nishimoto, S.Takano and I.Mito: "High frequency response of 1.3/1.5μm DFB-DC-PBH LDs" Inst. Electron. Commun. Eng. Jan., Digest of National Convention, 322, Nov. 1985

(4)G.P.Agrawal, N.A.Olsson and N.K.Dutta: "Effect of fiber-far-end reflection of intensity and phase noise in InGaAsP semiconductor lasers" Appl. Phys. Lett. 45(6) 15 September 1984

(5)I.Mito et.al, ECOC'86 to be published

(6)K.Y.Lau and A.Yariv: "Ultra-high speed semiconductor lasers" IEEE J. Quantum Electron., Vol.QE-21,No.2,February 1985