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Line Width for Semiconductor Ring Laser Diodes

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Abstract

A novel measurement method of lasing characteristics for a ring laser diode is proposed without branching optical lasing power. The lasing power and the line width as a function of the injection current have been measured with detecting the RF power by the terminal voltage change of a ring LD. The line width is estimated to be 55 kHz at I=1.75 Ith.

1. Introduction

Semiconductor ring lasers[1-5] have many capabilities of realizing new functional devices, such as retiming circuits, logic devices or optical ring gyros. We can measure the lasing characteristics, such as an optical power versus injection current and a line width, if we can branch the circulating optical power. Ordinary ring lasers have branching ports or output coupling ports; however, these branching ports are not essential to some functional devices such as optical ring gyros. There is not a way to measure the lasing power as a function of an injection current without branching the circulating power. Concerning the line width measurement, the Self Delayed Heterodyne method (SDH method) using an optical delay line[6] is well known as the high resolution measurement of laser line width. However, this SDH method has to branch the oscillating optical power to the delayed line arm. In a completely circulating ring laser, this method cannot be applied. In this paper, we propose the simple method to measure the lasing characteristics, such as a lasing power versus injection current and a line width of a laser output spectrum of a ring LD without branching the optical power.

2. Measurement Setup

Figure 1 shows the experimental setup for measuring lasing characteristics of a ring LD. The ring laser under test is a pig tailed LD amplifier module[7], whose ring resonator is about 3.9 m long single mode fiber and a connected by an optical connector. The LD chip is a BH-type InGaAsP/InP LD with anti reflection coating on both facets. The fiber ends have a tapered and hemi-spherical lens to optimize the coupling efficiency. The RF power detected by the terminal voltage change is analyzed to measure the lasing power versus injection current and the lasing line width by a RF spectrum analyzer. For verifying the usefulness of the proposed method, the

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lasing power is branched with a fiber coupler. The oscillation wavelength and its threshold current are 1.30 μm and 34 mA, respectively.

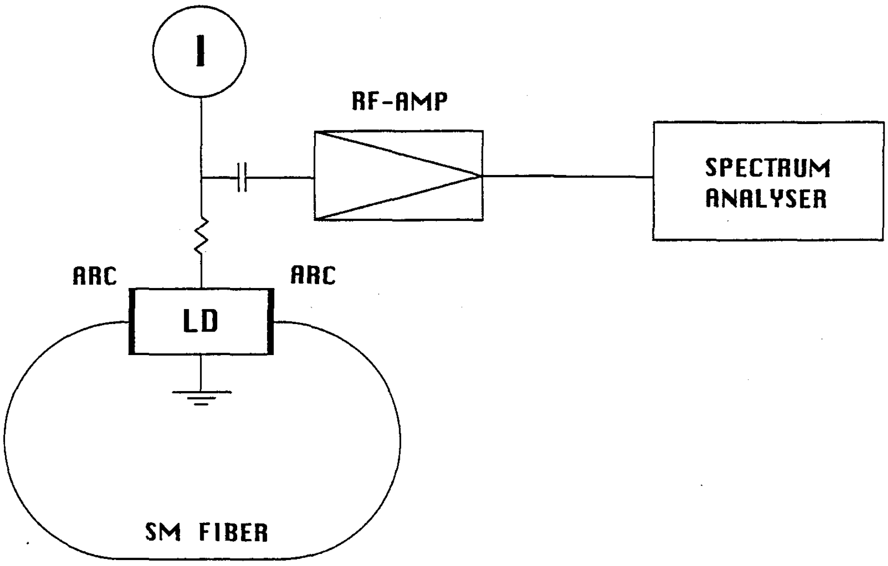

Fig.1 : Experimental setup for measuring lasing characteristics for a ring LD without branching optical power. ARC, anti reflection coating, LD, laser diode, and RF-AMP, RF amplifier.

3. Results

The V-I curve of an LD is usually used to detect a lasing threshold current. Figure 2 shows the measured V-I and L-I (Light output power versus injection current) curves. In this V-I

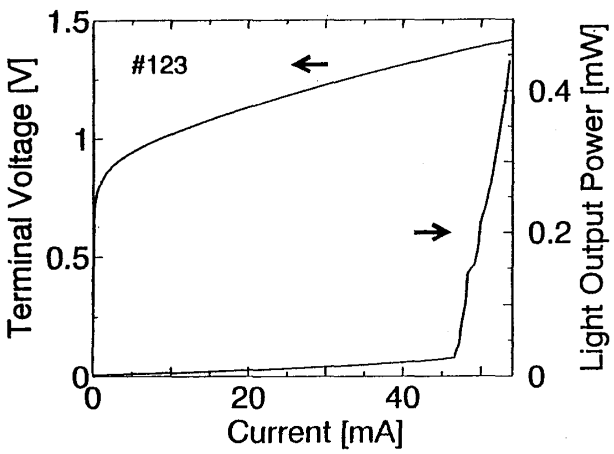

Fig.2 : Terminal voltage and light output power as a function of injection current.

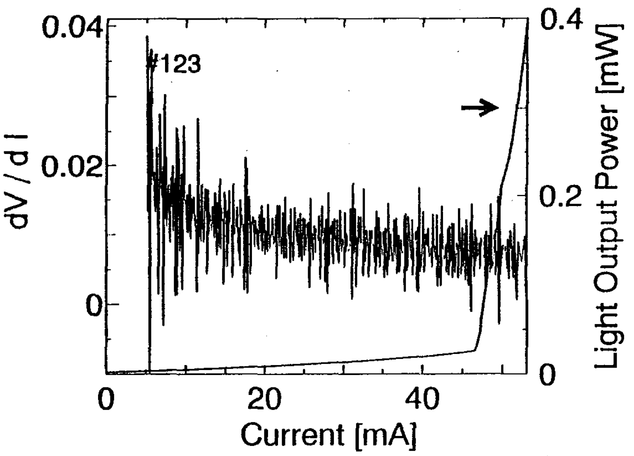

Fig.3 : Differentiated V-I curve and light output power as a function of injection current.

curve, we cannot detect a little voltage change around the threshold current. To enlarge the voltage change in V-I curve, the differentiated V-I curve (dV/dI-I) is shown in Fig.3. It is clear from this figure that we cannot detect the lasing characteristics from the DC-voltage change.

We can, however, analyze the lasing characteristics with the RF power detected by the terminal voltage change. Figure 4 shows an example of the measured RF spectrum in 0 to 500

MHz range. In this figure, more than 9 RF spectral components can be observed under the condition of I=1.2 Ith. These RF power components are proportional to the optical output power. Figure 5 shows the measured RF power and the light output power as a function of the

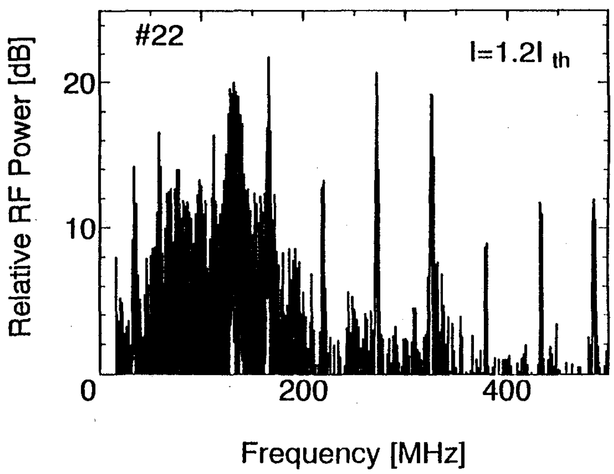

Fig.4 : Example of the measured RF spectrum in 0 to 500 MHz range.

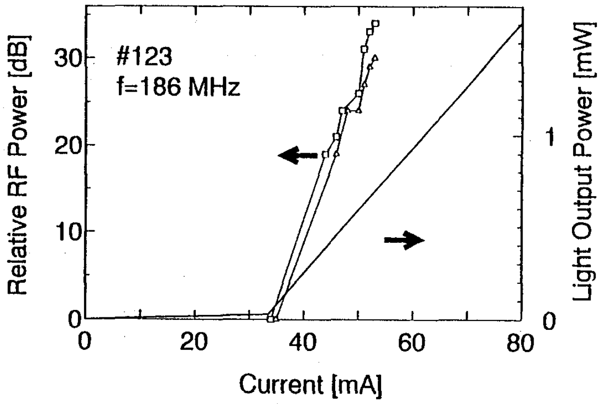

Fig.5 : Detected RF power at 186 MHz and light output power versus injection current.

injection current. The RF power is detected at 186 MHz. The square and triangular points closely correspond in both trials. The threshold currents of these RF-I curves and the L-I curve coincide well with each other. It is clear from this figure that the detected RF powers are proportional to the lasing output power. Therefore, we can analyze the internal lasing power with the RF power detected by the terminal voltage change without branching the lasing power.

It is clear from Fig.4 that the detected RF spectrum components have an equal frequency interval of about 60 MHz. These RF spectrum are cosidered to be the ring cavity modes which are composed of the fiber loop. The calculated ring cavity mode interval (FSR) is about 55 MHz where the fiber loop L=3.78 m. This results are well coincide with the measured value.

Furthermore, we can estimate the lasing line width with the detected RF spectrum. Figure 6

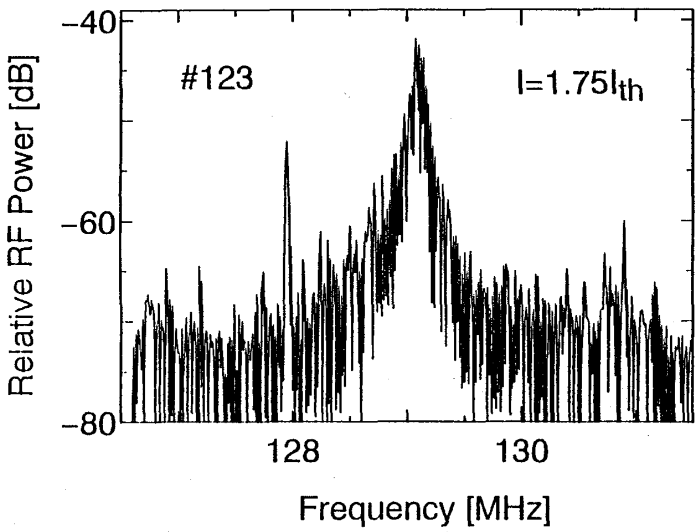

Fig.6 : RF line shape with the center frequency of 129 MHz at I=1.75 Ith.

shows the expanded RF spectrum with the center frequency of 129 MHz. The 3 dB down RF spectrum width (FWHM) is measured to be about 110 kHz. These sharp RF spectra seem to be caused by the beat power spectra between the ring cavity modes. This RF line shape resembles a Lorentzian and the FSR of this ring resonator of L=3.9 m is about 53 MHz. Thus, the line width of this ring resonator having high finesse is very narrow.

4. Discussion

We estimate the beat spectrum between the ring cavity modes assuming that the line shape of semiconductor laser is Lorentzian[8]. Figure 7 shows the assumed field spectra S(f) of two ring

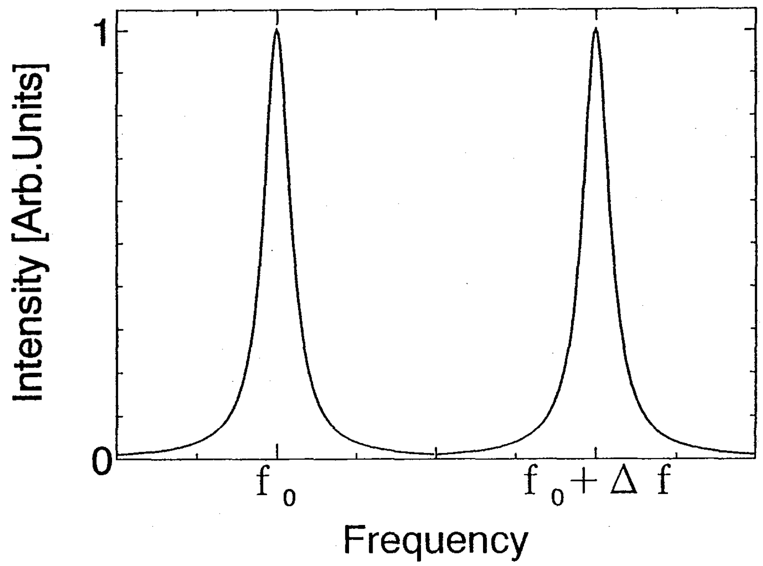

Fig.7 : Assumed Lorentzian line shape of two ring cavity modes separated Δf.

cavity modes whose center frequency is different from Δf. Two spectra of S(f) are given as follows:

$$S_1(f) = \delta f/2\pi\{(f-f_0)^2+(\delta f/2)^2\},$$
$$S_2(f) = \delta f/2\pi\{(f-f_0-\Delta f)^2+(\delta f/2)^2\}.$$

Then, the beat spectrum between the two spectra is derived from the calculation of the

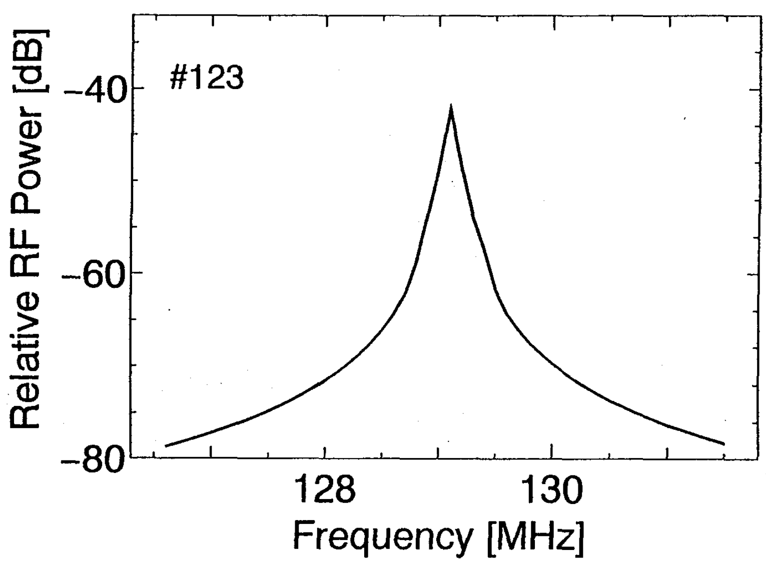

Fig.8 : Calculated beat spectrum under the condition of line width df=55 kHz and separating center frequency Δf=129 MHz.

combolution $S_1(f)$ x $S_2(f)$. Figure 8 shows calculated beat spectrum assuming δf=55 kHz and Δf=129 MHz. This calculated result is coincident with the measured RF spectrum as shown in Fig.9. The solid line shows the calculated spectrum. The measured spectrum is larger than the

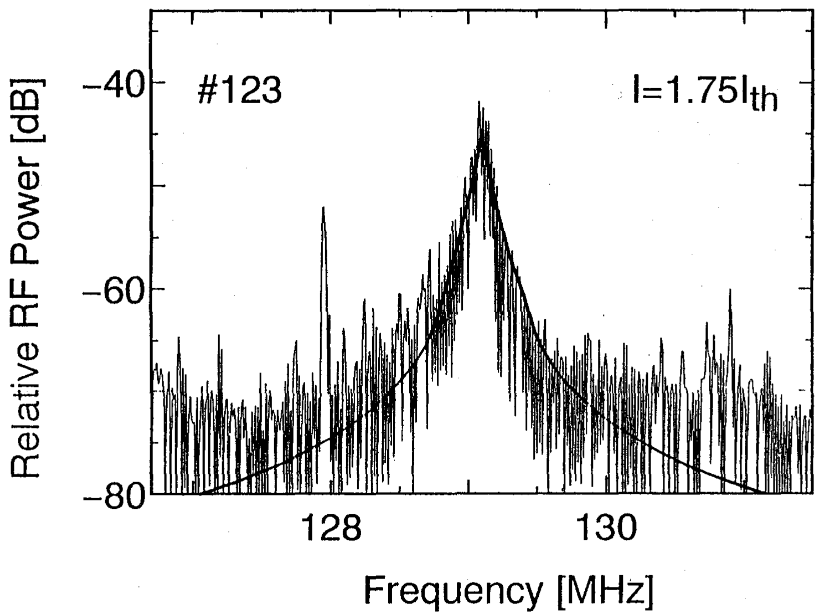

Fig.9 : Measured RF spectrum and calculated beat spectrum shown in a solid line. The noise spectrum is added at the floor of the line shape.

calculated one at the floor of the curve, because of a large noise level. However, the measured spectrum fits to the calculated Lorentzian near the peak of the spectrum. This result shows that these ring cavity modes have no correlation to one another[9]. Therefore, the line width of the ring laser is estimated to be 55 kHz at I=1.75 Ith. This narrow line width is caused by the high finesse and the long ring cavity. We verified that the other Fabry Perot LD which has a short pig tail has a rather broad line width of about 9.5 MHz at I=1.7 Ith.

Figure 10 shows the measured 3 dB down line width of the ring LD as a function of the injection current I. This figure shows that the line width is inversely proportional to the photon numbers[10] untill the injection current is less than about 1.5 Ith. However, the decrease of the line width is saturated near 2.0 Ith and the rebroadening phenomenon can be seen clearly under a high injection current condition. This line width rebroadening seems to be caused by the increase of the mode partition noise[11], or the nonlinear optical gain[12].

5. Conclusions

A novel measurement method of lasing characteristics such as a lasing power as a function of an injection current and a line width for ring laser diodes without branching the circulating optical power has been proposed. The RF power detected with the terminal voltage change is proportional to the lasing optical power. The detected RF power is attributed to the beat power spectrum between the lasing ring cavity modes. Since the lasing ring cavity modes have no correlation to one another, we can easily estimate the line width of a laser output spectrum. The line width of a ring LD is estimated to be 55 kHz at I=1.75 Ith. The rebroadening of the line width has been observed under a high injection current condition.

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