Drive Current Noise Induced Linewidth in Tunable Multielectrode Lasers

G.H. Duan and P. Gallion

***Abstract*—It is shown experimentally, for the first time, that the drive current noise could lead to an important increase of the linewidth and a Gaussian line shape of tunable multielectrode DBR lasers. As an example, the drive current noise induced linewidth (DCNIL) has been measured to be about 120 MHz using a standard dc source through a 50 Ω resistor to drive the Bragg section of a tested DBR laser. For tunable lasers with a electronic tuning efficiency of more than 1 GHz/mA ultralow noise current sources should be used to ensure a negligible DCNIL.**

Introduction

NARROW linewidth and wide wavelength tunability are two of the main characteristics of multielectrode lasers for applications in future coherent optical communication systems [1]. The linewidth has been shown to be determined by the fraction of the spontaneous emission coupled into the lasing mode, by the phase-amplitude coupling factor and by the carrier-density fluctuations in the inhomogeneous cavity [2]–[4].

Besides the above causes, the drive current noise could contribute to the linewidth in wavelength tunable lasers. In these lasers the current injection changes the refractive index and consequently the lasing wavelength. However, the injection current always has a noise component. The tuning mechanism will convert this drive current noise into lasing frequency fluctuations, which contribute to the measured linewidth. In this letter, experimental results showing the importance of the drive current noise induced linewidth (DCNIL) in a tunable DBR laser are reported for the first time.

Experimental Results

The two-electrode DBR laser used consists of a 1.5 μm InGaAsP active section and a passive 1.3 μm Bragg waveguide section fabricated by the Laboratoire de Bagneux, CNET. The DBR laser has a discontinuous tuning range of 6 nm for an injection current range of 0–70 mA. In the linewidth measurement setup, two optical isolators are used to provide more than 60 dB isolation. The active section is modulated sinusoidally at 500 MHz. The modulation index is adjusted to maximize the first FM sideband. The laser linewidth is deduced by measuring the 3 dB spectral width of the first FM sideband of the photocurrent using a modified delayed self-homodyne technique [5], [6].

Manuscript received November 26, 1990; revised January 17, 1991.

The authors are with the Department Communications, Ecole Nationale Supérieure des Télécommunications, 75634 Paris Cedex 13, France.

IEEE Log Number 9144501.

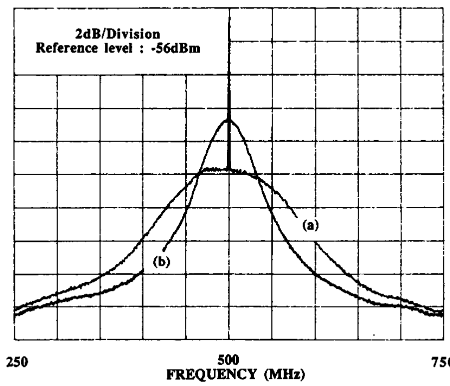

Fig. 1. Measured homodyne spectrum around the first modulation sideband using (a) the drive scheme 1 and (b) the drive scheme 2. The modulation frequency is 500 MHz. The central peak is the AM component.

To show the influence of the drive current noise, two drive schemes are used for the Bragg section. The first one consists of a standard dc source and a current limiting resistor of 50 Ω. The second one uses an LDX-3620 ultralow noise current source. The current noise density is about 5.2 nA/$\sqrt{\text{Hz}}$ at 50 Hz, 815 pA/$\sqrt{\text{Hz}}$ at 1 kHz, and 315 pA/$\sqrt{\text{Hz}}$ at 25 kHz. The rms value of the total current fluctuation is about 850 nA [7]. For the drive scheme 1, these values are estimated to be about one order of magnitude greater. An example of the measured homodyne spectrum is shown in Fig. 1. The drive current is 65.0 mA in the active section and 2.2 mA in the Bragg section. In Fig. 1, curve (a) represents the measured spectrum using drive scheme 1 and (b) using drive scheme 2. Curve (a) has a Gaussian shape, whereas (b) is a Lorentzian shape, as is expected by pure quantum phase noise theory [2]. It has been pointed out that the 3 dB spectral width of a self-homodyne spectrum is twice the spectral linewidth for a Lorentzian shape and $\sqrt{2}$ times the spectral linewidth for a Gaussian shape [5]. Taking this into account, the measured linewidths are 117 MHz with drive scheme 1 and 30 MHz with drive scheme 2.

The DCNIL is obtained by calculating the difference between the measurement results obtained with drive schemes 1 and 2. In Fig. 2, the DCNIL is plotted as a function of the injection current of the Bragg section in the current range 9.5–15 mA. The tuning efficiency is also shown in this figure. The DCNIL and the tuning efficiency increase with increasing tuning current in the Bragg section for a given longitudinal mode of the DBR laser. In the rest of the tuning current range the same behavior is observed.

1041-1135/91/0400-0302$01.00

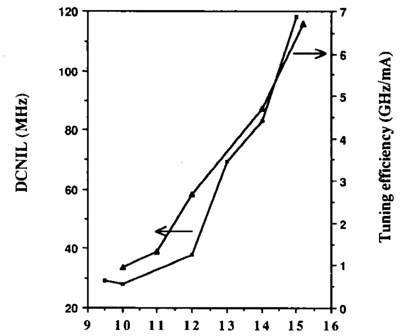

Fig. 2. (a) Drive current noise induced linewidth (DCNIL) and (b) tuning efficiency as a function of the Bragg section current.

Discussion

The drive current noise has various origins: the thermal noise of dissipative elements, the shot noise of the injection current through the pn-junction, fluctuations of the dc source, and the omnipresent $1/f$ noise. Generally, the resulting current noise spectral density is not white. The current noise leads to lasing frequency fluctuations by tuning mechanism. In the frequency domain, the lasing frequency fluctuation δf is related to the current noise δI by the current-frequency transfer function $H(\Omega)$ of the laser:

$$\delta f = H(\Omega)\delta I \tag{1}$$

where Ω is the analysis frequency. For a two-electrode DBR laser, the frequency tuning results mainly from the electronic effect in the Bragg section and from the thermal effect in the active section. In the case of current noise applied to the Bragg section, the transfer function is a low-pass filter of the first order [1]:

$$H(\Omega) = \frac{H_o}{1 + j\Omega/\Omega_C} \tag{2}$$

where H_o is the tuning efficiency or FM modulation efficiency in GHz/mA for $\Omega = 0$ and Ω_C is the cutoff angular frequency determined by the carrier lifetime in the Bragg section. For the tested DBR laser the measured response is very close to this theoretical prediction. The cutoff frequency is measured to be 150 MHz. By using (1) the FM noise spectrum $S_f(\Omega)$ is related to the current noise power spectral density $S_I(\Omega)$ by

$$S_f(\Omega) = |H(\Omega)|^2 S_I(\Omega). \tag{3}$$

The resulting FM noise spectrum is essentially low frequency noise. The corresponding field spectrum depends on the exact form of the FM noise spectrum. Generally the low frequency FM noise will render the line shape Gaussian rather than Lorentzian, as noted previously [8], [9]. Moreover the nonwhite nature complicates the evaluation of the linewidth. For a relatively flat current noise spectral density and an FM bandwidth larger than the intrinsic linewidth, the DCNIL is determined by the value of the FM noise spectrum at low frequencies. The DCNIL $\Delta\nu_{CN}$ is estimated by

$$\Delta\nu_{CN} \approx 2\pi H_o^2 S_I(0). \tag{4}$$

For most practical cases, the current noise induced FM noise spectrum is of the form $1/f$. The resulting linewidth has been discussed previously [8]. The estimation given in (4) should be considered as an upper bound of DCNIL in these cases. However, the high tuning efficiency will give a high DCNIL value for any form of $S_I(\Omega)$. The measured curves plotted in Fig. 2 confirm this theoretical prediction. This proves, on the other hand, the theory about the origin of the measured linewidth difference using drive schemes 1 and 2.

In previous publications many authors have reported an anomalous increase of the linewidth due to the injection of the current into the tuning section (see for example, [10]). The increase of the loss due to the current injection in this section tends to broaden the linewidth. However, the magnitude of increase observed is too high to be explained by this cause alone. The drive current noise, on the other hand, may well be one of the main sources of the reported linewidth increase.

The thermal tuning efficiency for the tested laser in the active section is approximately 1 GHz/mA, which is of the same order of magnitude as the electronic tuning efficiency in the Bragg section. However, in the case of the active section, our measurements show that the use of the ultralow noise current source does not affect the line shape and linewidth. This results from the fact that the thermal cutoff frequency (in the order of 100 kHz–1 MHz) is much smaller than the laser intrinisic linewidth.

Conclusion

The drive current noise of the tunable multielectrode laser is shown to have an important influence on the measured linewidth. The current noise generally results in a Gaussian line shape. The measured DCNIL increases with the increasing frequency tuning efficiency. The maximum DCNIL is measured to be about 120 MHz using a standard dc source and a 50 Ω resistor to drive the Bragg section of the tested DBR laser. The previous observed anomalous increase of the linewidth during the wavelength tuning could be explained by this supplementary contribution. The results imply that for tunable multielectrode lasers ultralow noise current sources should be used to eliminate the influence of the DCNIL.

Acknowledgment

The authors wish to thank Dr. Bouley of CNET Bagneux for providing the two-electrode DBR lasers and Dr. Erasme for our stimulating discussions.

References

[1] T. L. Koch and U. Koren, "Semiconductor lasers for coherent optical fiber communications," *J. Lightwave Technol.*, vol. 8, pp. 274–293, 1990.

[2] C. H. Henry, "Theory of the linewidth of semiconductor lasers," *IEEE J. Quantum Electron.*, vol. 18, pp. 259-264, 1982.

[3] G. H. Duan, P. Gallion, and G. Debarge, "Analysis of the phase-amplitude coupling factor and spectral linewidth of distributed feedback and composite-cavity semiconductor lasers," *IEEE J. Quantum Electron.*, vol. 26, pp. 32-44, 1990.

[4] J. Arnaud, "Linewidth of laser diodes with nonuniform phase-amplitude α-factor," *IEEE J. Quantum Electron.*, vol. 25, pp. 668-677, 1989.

[5] T. Okoshi, K. Kikuchi, and A. Nakayama, "Novel method for high resolution measurement of laser output spectrum," *Electron. Lett.*, vol. 16, pp. 630-631, 1980.

[6] R. D. Esman and L. Goldberg, "Simple measurement of laser diode spectral linewidth using modulation sidebands." *Electron. Lett.*, vol. 24, pp. 1393-1395.

[7] ILX Lightwave, technical note of LDX-3620 ultralow noise current sources.

[8] M. J. O'Mahony and I. D. Henning, "Semiconductor laser linewidth broadening due to 1/f carrier noise," *Electron. Lett.*, vol. 19, pp. 1000-1001, 1983.

[9] K. Kikuchi, "Effect of 1/f-type FM noise on semiconductor-laser linewidth residual in high-power limit," *IEEE J. Quantum Electron.*, vol. 25, pp. 684-688, 1989.

[10] Y. Kotaki and H. Ishikawa, "Spectral characteristics of a three-section wavelength-tunable DBR laser," *IEEE J. Quantum Electron.*, vol. 25, pp. 1340-1345, 1989.