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AMPLITUDE OR INTENSITY STABILITY IN SEMICONDUCTOR LASERS

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ABSTRACT

For the physicians, noise measurements on semiconductor laser diodes (SC-LD) provide accurate informations on stability and fundamental parameters which stand into rate equations describing the interaction between photons and electrons. But intensity fluctuations worry users of SC-LD coupled to optical fibres, in amplitude modulation analog transmission techniques.

In this paper, we first consider how the noise is characterized. Then we describe the measurement techniques and give results on different types of SC-LD.

I - INTRODUCTION

The semiconductor laser diodes, as well as other sorts of lasers, are light generators and their use in fibre optic transmission systems requires a high amplitude or intensity and phase or frequency stability. The discrete quantities that are photons and electrons and the discrete processes that are recombinaison and absorption give rise to fluctuations in the photon number and lead to an intrinsic noise source. This noise sets an upper limit to signal to noise ratio achievable in an optical communication system.

The first part of this contribution is devoted to description and measurements of the noise, the second part to comments of the results.

II - RELATIVE INTENSITY NOISE : R.I.N

The intensity noise of the laser output is usually expressed in terms of relative intensity noise (RIN) which is the ratio of the fluctuations $\langle \varphi^2 \rangle$ of the radiant power (mean square power Φ of the source) and of the squared average Φ^2 :

$$(1) \quad \text{RIN} = \frac{\langle \varphi^2 \rangle}{\Phi^2}$$

The experimental technique for measuring this quantity, based on single detector technique, can be described as follows : the noise spectral density of the photocurrent $\langle i^2 \rangle_{\text{ph}}$ at the output of a detector illuminated by a light source is the sum of two terms : the shot noise $\langle i^2 \rangle_{\text{sh}}$ due to discrete nature of photons and photoelectrons :

$$(2) \quad \langle i^2 \rangle_{\text{sh}} = 2.q.I_{\text{ph}}$$

and the excess noise ($RIN \times \mathfrak{I}_{ph}^2$) where RIN is the noise contribution factor specific to the light source, \mathfrak{I}_{ph} is the average photocurrent delivered by the light detector and q is the electron charge :

$$(3) \quad \langle i^2 \rangle_{ph} = \langle i^2 \rangle_{sh} + RIN \times \mathfrak{I}_{ph}^2$$

This excess noise also called "wave interaction noise" is related to the wave nature of the light and connected to beat noise of elementary waves.

III- EXPERIMENTAL ARRANGEMENT

The experimental arrangement described in reference [1] is based on a principle borrowed from millimeter wave technique. The signal (noise source) is chopped at low frequency. The detection of this low frequency modulation on the noise spectral lines located around 30MHz in a frequency band of 1MHz is achieved by a cascade of amplifiers, filters and quadratic crystal detector. For high frequencies (800MHz - 4GHz) the signal mixed with a local oscillator signal crosses extra FI filters before reaching the previously described middle frequency channel. The signal is finally fed into an automated synchronous amplifier.

At first we calibrate our experimental set up using an incoherent source. The surface emitting electroluminescent diodes transmit "thermal" light whose RIN is proportional to the coherence time. Their spectral width is high and the photocurrent obtained from the PIN diode they shine on is rather weak. Therefore they are very well suited for pure shot noise measurement.

When the photodetector is illuminated by a laser, the RIN is related to the noise spectral density by using (2) and (3) :

$$(4) \quad RIN = \frac{2q}{\mathfrak{I}_{ph}} \times \left(\frac{\langle i^2 \rangle_{ph}}{\langle i^2 \rangle_{sh}} - 1 \right)$$

Therefore RIN measurements results are only dependent on the exact value of \mathfrak{I}_{ph} and not on the conversion factor between noise level and voltage level at the output of the synchronous amplifier.

IV - MIDDLE FREQUENCY

In the middle frequency range (between 10 and 500MHz) and laser bias currents scaling up from 1.1 to $2 \times I_0$ (I_0 being the threshold current), we already showed [2] that RIN can be written as :

$$(5) \quad RIN = \frac{4 \times \beta \times \tau_{\phi}}{n_{pop}^2 \times (I/I_0 - 1)^3}$$

where I is the injection current, β is the amount of spontaneous emission coupled into the waveguide, τ_{ϕ} is the photon lifetime and n_{pop} is the population inversion factor.

The parameter β can be up to 25 times greater in gain-guiding lasers compared to index-guiding lasers. This is clearly confirmed by RIN measurements results in figure 1. The RIN decreases more abruptly in index-guiding than in gain-guiding devices in term of the relative current normalized to the threshold current. In gain-guiding lasers, gain saturation and intensity stability are more difficult to obtain. Thusfar noise measurements carried out at middle frequencies in semiconductor lasers reveal their ability to reach a stable state.

We now consider the relation between longitudinal mode distribution and noise level : a RIN increase of more than one decade occurs when a distributed feedback (DFB) laser gets two modes or when the envelope spectrum of a Pérot-Fabry laser exhibits a dip. In both cases a competition between two modes settles and causes an increase of total photon number

fluctuations. As shown in figure 2, radiant power fluctuations causing sharp peak along the RIN plot against the current relative to threshold are related to mode competition, while, for a single mode DFB laser, the RIN is smooth.

Noise measurements have been carried out on 30, 1.3 μm , InGaAsP index-guiding lasers (Pérot-Fabry and DFB types). Their structure are BH (buried heterostructure), BR (buried ridge), BC (buried crescent) and DCPBH (double channel planar BH). Their RIN measured at 20% above threshold, that is to say for a current value where no mode hopping occurs, stands in the range between 9×10^{-15} and $4 \times 10^{-14} (\text{Hz}^{-1})$. There is no obvious correlation between RIN value and laser structure.

In term of cavity length, for a set of Pérot-Fabry lasers built from the same wafer, we have observed that RIN values decrease as the length of the lasers increases, as shown on figure 3. An averaging of intensity fluctuations can be imagine in a long cavity laser. But the RIN improvement is rather slim : only 4 or 5dB between 100 μm and 400 μm length.

VI - HIGH FREQUENCIES

We follow the noise variations up to 4GHz. The interaction between the electromagnetic field and the population inversion in the laser cavity gives rise to a resonant peak in the RIN spectrum. The resonance frequency depends on the injected current according to the simplified relation :

$$(6) \quad F_R^2 = \frac{n_{\text{pop}}}{4\pi^2 \tau_\phi \tau_S} \times (I/I_0 - 1)$$

It can fill a RF band of 800MHz and peak 30dB above the other frequency noise components. A simple relation between the damping factor θ (related to the width of the resonance peak) and the squared resonance frequency can be derived from rate equations ([3], [4]):

$$(7) \quad \frac{\theta}{F_R^2} = 4\pi^2 \times \left(1 + \frac{\gamma}{A} \right) \times \tau_\phi$$

where γ and A denote the gain derivative with respect to the photons number and electrons number respectively. This ratio only depends on material parameters and is two or three times higher in conventional double heterostructure lasers (DH) than in multiple quantum wells lasers (MQW) - according to our measurements, 0.2ns for DH lasers and 0.6ns for MQW lasers. This high nonlinear damping due to spectral hole burning can limit the maximum bandwidth of MQW lasers.

VII - CONCLUSION

We have presented here noise measurement results on semiconductor lasers at middle and high frequencies and how they depend on the laser structure, the material properties and the irregular behaviour.

Acknowledgments

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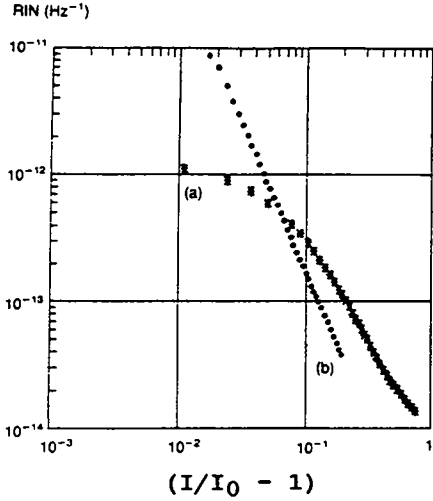


Figure 1 : RIN plots of
 (a) Gain guiding laser
 (b) Index guiding laser
 versus injection current.

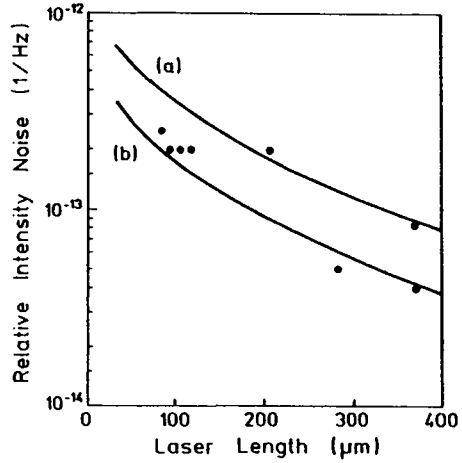


Figure 3 : RIN versus laser length
 for $I = 1.1 \times I_0$
 Dots : measured values
 Solid lines : theoretical curves with
 (a) $\beta = 0.026/L(\mu\text{m})$, (b) $\beta = 0.013/L(\mu\text{m})$.

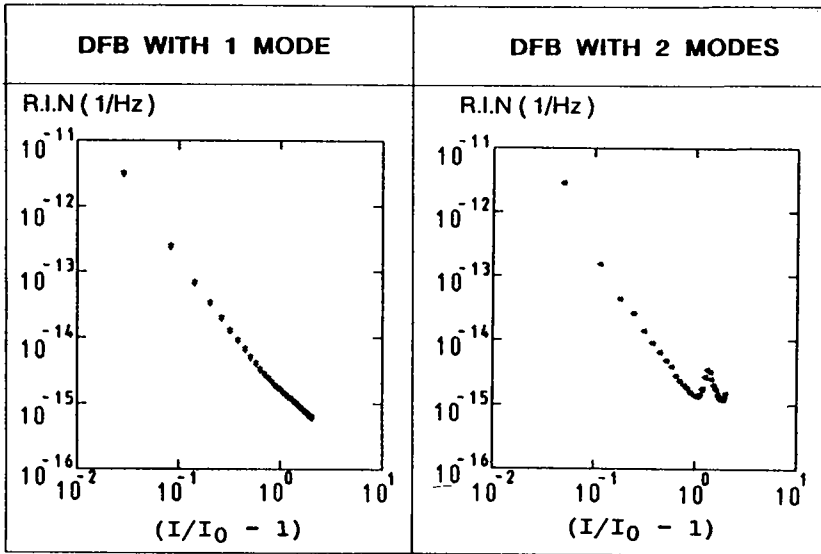


Figure 2 : RIN plots of
 (a) DFB with one mode
 (b) DFB with two modes
 versus injection current.