SPECTRAL BEHAVIOR OF LONG WAVELENGTH VCSELs

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ABSTRACT

For a long time, only a small wavelength range of Vertical-Cavity Surface-Emitting Lasers (VCSEL) was available. The current evolution in process technology allows the fabrication of long wavelength VCSEL that is interesting for Telecom systems because they offer a higher integration level than the existing optical sources at lower costs since they are fabricated in arrays. We propose to focus our investigation on the behavior of singlemode 1.55μm VCSEL. We aim at precisely knowing their spectral properties under direct modulation. We present a study about the linewidth measurement and the linewidth enhancement factor, also called the Henry - or the alpha - factor. Many studies have been reported but only a few of them are really efficient. Two different set-ups are presented here to extract alpha factor. The first one uses an interferometer based on the heterodyne technique and the second uses the dispersive properties of an optical fiber. We compare both results and discuss about each set-up.

Keywords: VCSEL, linewidth enhancement factor, heterodyne detection

1. INTRODUCTION

Since the last ten years, Vertical-Cavity Surface-Emitting Lasers (VCSELs) have been the most studied devices because of their important role in networks domain. Indeed, on-wafer testing, array fabrication and best optical fiber coupling make them key optical sources. Nevertheless, long-wavelength VCSELs have suffered for a long time from the inexistence of an efficient p-doped distributed Bragg reflector (DBR), for the bottom mirror. Fortunately, dielectric mirror technology has been developed, which seems to be the best choice to fabricate commercially available 1.55μm VCSELs.

The VCSELs, in this way, become excellent candidates for telecommunication networks, spectroscopy or even free space applications, thanks to their ocular safety wavelength.

Hence, it turns out to be important to precisely know their spectral properties under direct modulation. Effectively, the linewidth and the linewidth enhancement factor are two important parameters in telecomunication systems that finally degrade the quality of the transmission. That is why the spectral behavior of a such optical source must be measured. Several studies have been presented on this subject but it seems that a few characterisation methods are really efficient as it has been demonstrated.[1,2] One of the most accurate is the interferometric set-up. The measurement of the linewidth allows, with a fitting curve, the extraction of the linewidth enhancement factor or Henry factor α_H.[3] But this kind of extraction requires intrinsic parameters that are not commonly known. This technique is compared to another one that uses dispersive properties of an optical fiber by direct modulation of the source. The modulation response is influenced by the α_H factor which can be easily calculated. We hence compare both resuslts. The aim of the study is to present the extraction of the Henry factor of long-wavelength VCSELs by using two different techniques: static and dynamic ones.

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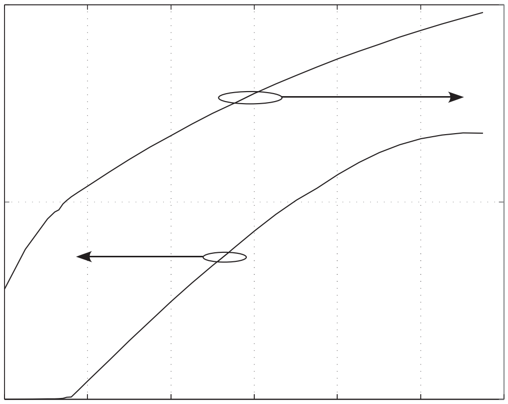
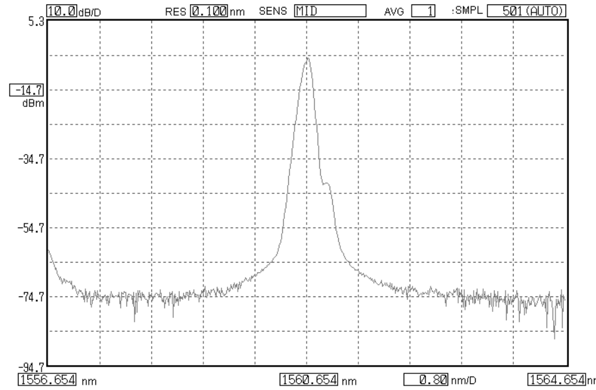
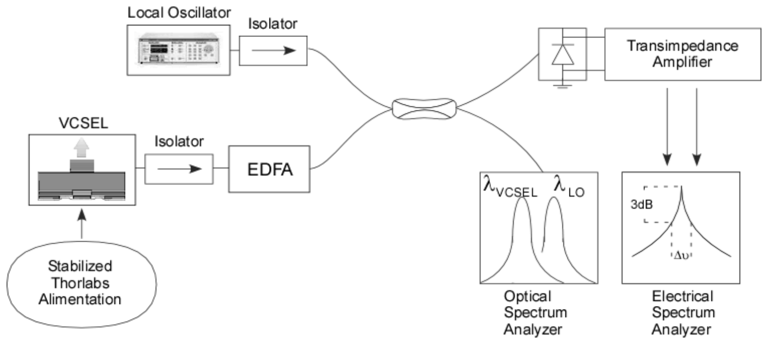




10.0 dB/D
RES 0.100 nm
SENS MID
AVG 1
:SMPL 501(AUTO)
5.3
-14.7
dBm
-34.7
-54.7
-74.7
-94.7
1556.654 nm
1560.654 nm
0.80 nm/D
1564.654 nm


Local Oscillator
Isolator
Transimpedance
Amplifier
VCSEL
Isolator
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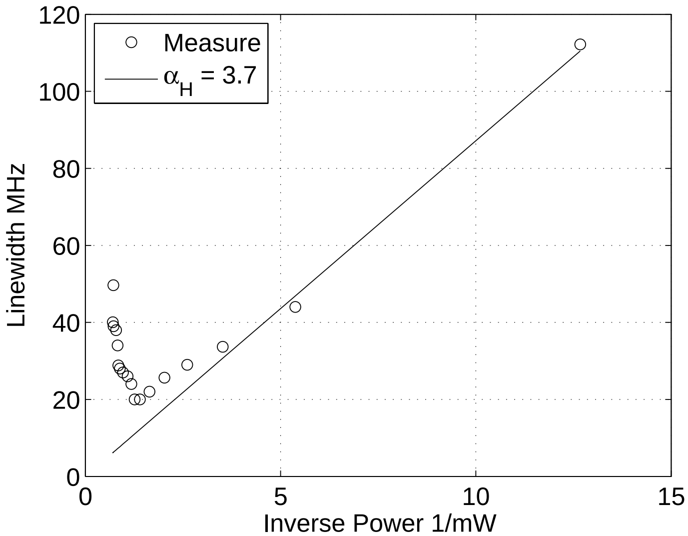


Figure 4. VCSEL Linewidth versus inverse optical power

Parameter	Symbol	Value
Confinement factor	Γ	0.0168
Group velocity	v_g	$7.50^9 m.s^{-1}$
Threshold gain	g_{th}	$2410 cm^{-1}$
External differential efficiencies	η_d	0.26
Internal differential efficiencies	η_i	0.8
Spontaneus emission factor	n_{sp}	1.6
Planck constant	h	$6.62^{-34} J.s$
Lasing frequency	ν	$1.92^{14} Hz$
Linewidth Enhancement Factor	a_H	3.7
Photon Lifetime	τ_p	$3^{-12} s$

Table 1. Intrinsic parameters of the VCSEL

This kind of measurement is cumbersome and many conditions must be known in advance to obtain a good value of the LEF. Moreover, some intrinsic parameters must be known to extract a representative value of the LEF and there is a degree of uncertainty on these parameters. Finally the extraction of the LEF gives an approximated value, 3.7 ± 0.3, that is not very accurate but realistic, that is not the case from other methods.[13] That is why this method is compared to the following one because it allows a direct extraction of the α_H factor.

4. OPTICAL FIBER DISPERSION SET-UP

The second set-up realised to extract the LEF uses the dispersion properties of an optical fiber.[14] Indeed, chromatic dispersion of optical fibers is responsible for deformation of an optical signal when it propagates through the fiber, inducing the apparition of extinction frequencies. The set-up implemented to measure the extinction frequencies of an optical fiber link employs a Vector Network Analyser (VNA) HP8510C coupled with an opto-electronic module HP83420A including a calibrated laser and a photodetector. Indeed, before each measurement, all the components that do not contribute to the test are taken into account in the calibration step to compensate for their effects. Figure 5 presents the extinction frequencies of the tested fiber.

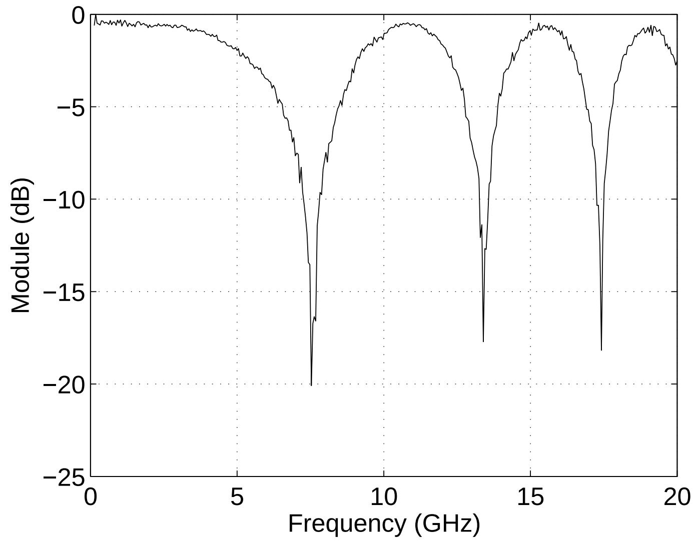


Figure 5. experimental extinction frequencies of singlemode fiber

The response measurement is carried out with exactly 60.964km of optical fiber in the range of 0.13-20 GHz. The longer the fiber, more is the number of significant extinction frequencies. The relation between extinction frequencies and fiber length is given by:[14,15]

$$f_u^2.L = \frac{c}{2.D.\lambda^2}\left(1 + 2.u - \frac{2}{\pi}arctan(\alpha_H)\right) \tag{3}$$

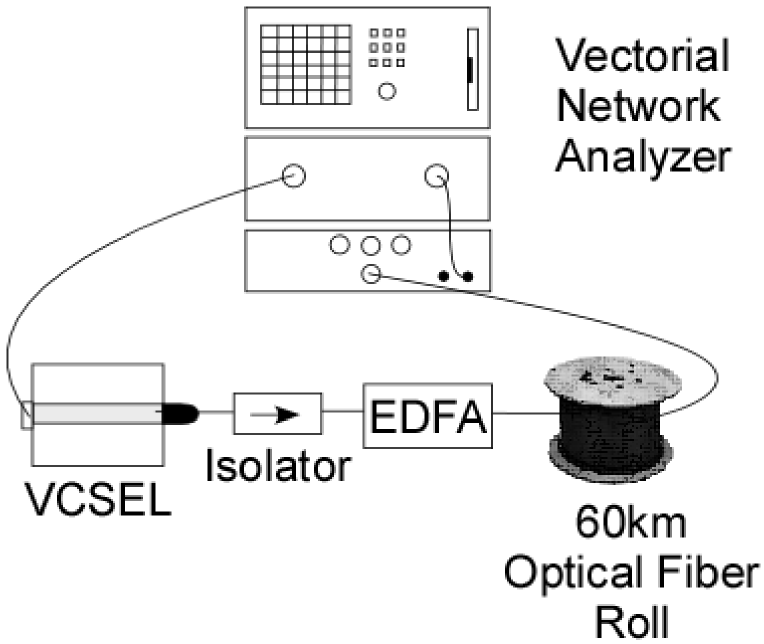
where f_u is the frequency of the u^{th} order, L is the fiber length, c the light velocity, D the fiber dispersion, λ the wavelength of the VCSEL and α_H the linewidth enhancement factor.
We see that extinction frequencies are directly affected by the α_H factor of the emitter. So, as the LEF increases, we see the extinction frequencies shifted towards lower values. We limit the study to the first extinction frequency, u = 0, and thus the relation (3) can be written as:

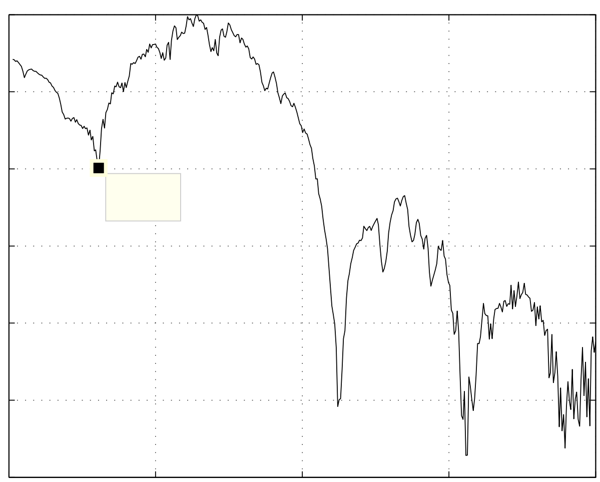
$$\alpha_H = tan\left(\frac{\pi}{2} - \frac{\pi.f_{ex1}^2.L.D.\lambda^2}{c}\right) \tag{4}$$

This measurement was realised with the set-up presented in figure 6.

The VCSEL is mounted on a 50Ω microstrip line and is directly modulated by a small-signal from the VNA. In order to realise the VNA calibration, we used a standard calibration kit (Short, Open and Load) mounted on TO-46 package. It allowed us to avoid a maximum of parasitics from the package module. Moreover, leads of the TO-46 case have been shortened to avoid resonant peak frequencies.[16] The optical signal then travels along the fiber and is detected by the calibrated photodetector of the VNA. When it is modulated, the optical field of the VCSEL is composed of the fundamental band surrounded by sidebands. Extinction frequencies expresses interference between the carrier and the sidebands of the signal.

By precisely calculating fiber properties, the α_H factor can be exactly found. The operating wavelength of the VCSEL is 1561nm, so we find a dispersion parameter of $D = 17.93ps/(nm.km)$. An Erbium Doped Fiber Amplifier (EDFA) is connected to the output of the VCSEL to have a better dynamic range. The result is presented in figure 4.


Vectorial
Network
Analyzer
EDFA
Isolator
VCSEL
60km
Optical Fiber
Roll



The first extinction frequency is then measured at 3.061GHz, as shown in figure 7. We calculate hence the LEF of the VCSEL: $\alpha_H = 3.72$. This value is in good agreement with values reported in the previous experimental investigation and in the literature.[11,12] Finally this method gives a very accurate value of the LEF of 3.72 ± 0.02 and is easier to implement.

The advantages of such a method can be stated as follows:

- the set-up is not difficult to implement so the measurement is fast.
- measurements can be done for each bias current: the VCSEL wavelength varies as a function of the bias current. The fiber dispersion parameter can be modified and the value of α_H can be found.
- the extraction of α_H factor does not need a preliminary measurement of $\Delta\nu$.
- the evolution of α_H factor as a function of temperature can be easily found.

5. CONCLUSION

The linewidth enhancement factor of a 1.55μm singlemode BTJ VCSEL has been extracted from measurements based on two different experimental techniques: the first one is based on a heterodyne interferometer and the second uses the dispersion properties of optical fibers. It has been shown that, if the second method gives the Henry factor by simple reading of extinction frequencies, the first method although more complicated, allows us to take into account the level of optical power delivered by the VCSEL. Experimental results from each set-up are in good agreement but the first one is valid only as long as the optical output power is less than 0.5mW, before the rebroadening. This rebroadening can be caused by the side mode that appears on the VCSEL spectra even if the side-mode suppression-ratio is 35dB. Moreover, it could be interesting in a future work to measure the linewidth of only the main mode after having filtered the side mode. The threshold behavior could be investigated too[13,17] using the Fokker-Planck model to fit the linewidth behavior.

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