Measurements of Reflectivities on Butt-Joint Active-Passive Interfaces in Extended Cavity Fabry-Pérot Lasers.

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A method and measurement results are presented for the determination of the reflectivity of butt-joint active-passive interfaces in a series of extended cavity Fabry-Pérot lasers. The method is based on the analysis of sub-threshold laser spectra. The small reflections at the two intra-cavity active-passive interfaces modify the mode structure of the laser. By fitting the calculated sub-threshold mode structure to the recorded data, values of the reflectivities are extracted. An average value of 2.10^{-4} *has been determined. The absolute value of those interface reflectivity is particularly important for the development of integrated mode-locked lasers.*

Introduction

Low butt-joint loss and low butt-joint reflection values on active-passive interfaces are essential in Photonic Integrated Circuits (PIC) [1]. Reflections down to 10^{-5} affect the operation of integrated lasers [2] and lead to a modification of the mode structure. The maximum reflection acceptable for a laser depends on its design. For instance, Multi-Wavelength Lasers (MWL) have been realized including an Array Waveguide Grating (AWG) [3] which operate properly with maximum intra-cavity reflections of 10^{-3}. However Mode Locked Lasers (MLL) [4] have a more strict requirement on intra-cavity reflections. For their development, measurements of small reflectivity values on butt-joint active-passive interfaces are needed. In this paper, we present a method and measurement results of the reflectivity of butt-joint active-passive interfaces in a series of extended cavity Fabry-Pérot lasers. An average value of 2.10^{-4} has been determined.

Method

An integrated Extended Cavity Laser (ECL) consists of a Semiconductor Optical Amplifier (SOA) waveguide connected to two passive waveguides terminated by cleaved mirrors [5]. Each device has a different length of SOA. The small reflections at the two intra-cavity active-passive interfaces (figure 1) modify the mode structure. This can be observed directly by studying the Fourier transform of the sub-threshold laser output spectrum. A typical transformed spectrum is plotted in figure 2, where the time axis has been translated into physical distance. Analyzing this graph, the highest peak corresponds to the longitudinal mode of the total cavity (3.736 mm). Other peaks belong to shorter cavity formed by the intra-cavity reflections. Only cavities containing at least one cleaved facet are observed; the possible cavity formed by the SOA alone (L2) is not visible. By fitting a simulated sub-threshold mode structure to the recorded data, values of the reflectivities have been extracted.

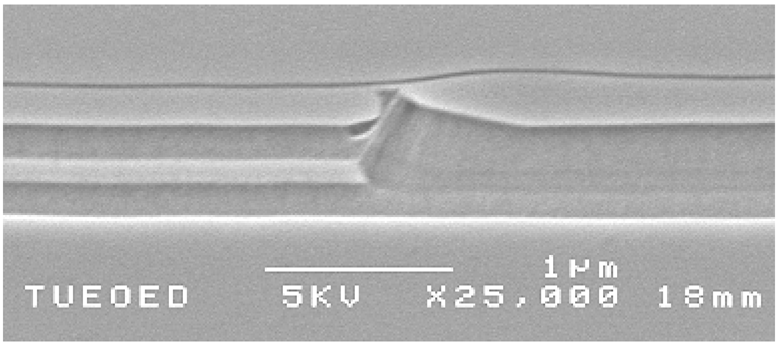

Figure 1 : SEM picture of an active passive butt-joint (011) plane.

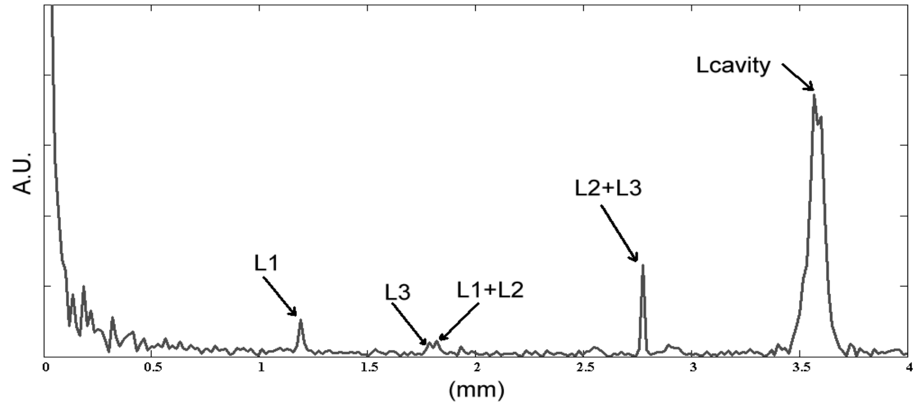

Figure 2 Fourier transform of an ECL spectra, I=36mA, Lsoa = 600µm

Modeling of the sub-threshold spectrum

The sub-threshold spectrum is modeled using the scheme plotted in figure 3, in which names of the different normalized fields are defined. We model the generation of the ASE from the SOA by introducing a low reflectivity beam splitter that couples light into the cavity from an external monochromatic source. The field E_1 in the cavity is then calculated for a range of wavelengths of the injected light. R_f represents the power reflectivity at the cleaved mirrors (R_f = 0.34). We have introduced different reflection coefficient at both interfaces between passive and active region to have more flexibility in our model. This takes into account that losses at the interfaces are neglected. The intra-cavity field is calculated using a transmission matrix formalism.

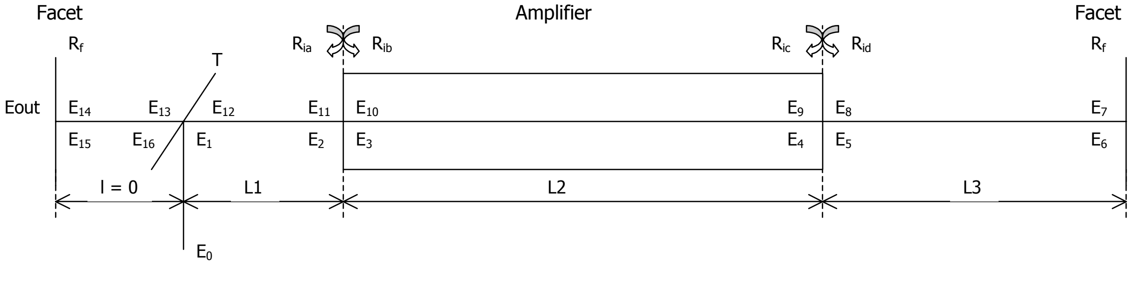

Figure 3: scheme of an ECL with definition of normalized fields and power reflectivity coefficients.

Details of the T-matrices are given below. In our model the wavelength dependence of the gain in the SOA *G(λ)* is assumed to be Gaussian. *Att* is the loss per meter in the passive waveguides.

$$T_{SOA}(L_{SOA},\lambda,Neff_{SOA}(\lambda),G(\lambda))=\begin{bmatrix} e^{-G(\lambda)+i\cdot\left(\frac{2\cdot\pi\cdot Neff}{\lambda}\cdot L_{WG}\right)} & 0 \\ 0 & e^{G(\lambda)-i\cdot\left(\frac{2\cdot\pi\cdot Neff}{\lambda}\cdot L_{SOA}\right)} \end{bmatrix}$$

$$T_{WG}(L_{WG},\lambda,Neff_{WG}(\lambda),Att)=\begin{bmatrix} e^{Att\cdot L_{WG}+i\cdot\left(\frac{2\cdot\pi\cdot Neff}{\lambda}\cdot L_{WG}\right)} & 0 \\ 0 & e^{-Att\cdot L_{WG}-i\cdot\left(\frac{2\cdot\pi\cdot Neff}{\lambda}\cdot L_{SOA}\right)} \end{bmatrix}$$

$$T_{Interface}(Ria,Rib)=\frac{1}{\sqrt{1-Ria^2}}\begin{bmatrix} 1 & -Ria \\ -Rib & \sqrt{1-Rib^2}\cdot\sqrt{1-Rib^2}+Ria\cdot Rib \end{bmatrix}$$

Dispersion in the different waveguides is included and assumed to be equal for the active and passive waveguides (*N1*). The difference between the effective group index of the active and passive waveguide has been measured separately (0.134).

$$Neff_{WG}(\lambda)=N_0^{WG}+\frac{N_1}{\lambda^2} \qquad Neff_{SOA}(\lambda)=N_0^{WG}+Const+\frac{N_1}{\lambda^2}$$

The theoretical spectrum is then broadened to simulate the finite bandwidth of the spectrum analyzer and fitted to the recorded data as follows. First, the coefficients of the effective group index are adjusted to fit the position of the modes along the spectrum. Adjusting the gain of the amplifier and its wavelength dependency reproduces the coarse shape of the spectrum. Then, the reflectivity parameters are varied to optimize the agreement between the Fourier transforms of the measured and theoretical spectra. The cavity lengths are then fitted to the original data. This sequence is repeated at least twice.

Measurements and fitting results

Measurements and fits have been realized on a series of extended cavity Fabry-Pérot lasers with a fixed total length. The chip was soldered on a temperature controlled copper mount (20°C). Light from a laser output waveguide was collected using a lensed fiber and led to an optical spectrum analyzer (ANDO AQ6315A). The spectrum intensities recorded were around -25dBm and a recording time of approximately 10s was used. Measurements have been performed on 9 devices with different SOA lengths. The fitting has been successful for 6 devices and at different currents. A comparison between an experimental and a simulated spectrum is plotted in figure 4.

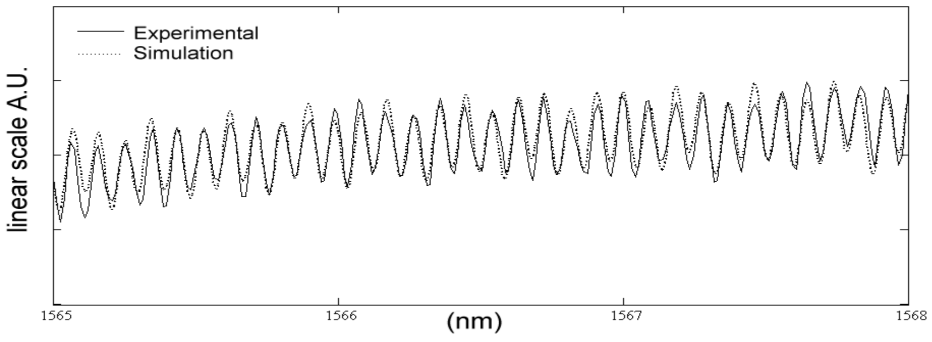

Fig. 4 Central part of a theoretical and experimental spectrum, Lsoa = 600µm.

The following table summarizes the results for the different devices:

LSOA (μm)	Length (μm)			Ref interface (x 10^{-4})			
	L1	L2	L3	R_{ia}	R_{ib}	R_{ic}	R_{id}
600	1305.05	599.945	1829.005	1.0	0.06	1.0	1.0
750	1256.26	700.1	1777.64	4.0	0.1	1.0	1.0
900	1157.025	899.945	1677.03	5.0	0.1	0.6	0.5
1000	1628.04	999.99	1105.97	1.0	0.1	7.5	3.0
1250	980.12	1249.895	1503.985	5.1	0.42	3.3	5.8
1500	855.97	1500	1378.03	1.0	0.32	0.47	2.7

The values for R_{ic} and R_{id} are very close for each device and it means that losses at the interface at this side of the chip are very low. In the other hands values of R_{ia} are an order of magnitude higher than R_{ib}. The losses at the interface at this side of the chip are higher. In average, a reflection of $2x10^{-4}$ has been measured. This average measured value of reflectivity and its spreading will be taken into account in the development of integrated mode-locked lasers.

Conclusion

A method and measurement results have been presented for the determination of the reflectivity of butt-joint active-passive interfaces in a series of extended cavity Fabry-Pérot lasers. The method is based on the analysis of sub-threshold laser spectra. An average value of 2.10^{-4} has been determined. The absolute value of the interface reflectivity is particularly important for the development of integrated mode-locked lasers.

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