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**BUTT-JOINT REFLECTIVITY AND LOSS IN InGaAsP/InP WAVEGUIDES**

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**SUMMARY**

We present a method and measurement results for the determination of the reflectivity of butt-joint active-passive interfaces in a series of extended cavity InP/InGaAsP Fabry-Pérot lasers with initial results of butt-joint losses on passive-passive interfaces.

**KEYWORD**

Active-Passive integration, integrated optics

**INTRODUCTION**

Low butt-joint loss and low butt-joint reflection values on active-passive interfaces are essential in Photonic Integrated Circuits (PIC). Reflections down to  $-50$  dB affect the operation of integrated lasers [1] 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) including an Arrayed Waveguide Grating (AWG) [2] have been realized which operate properly with maximum intra-cavity reflections of  $-30$  dB. However modelocked lasers [3] have a more stringent requirement on intra-cavity reflections. Furthermore, the noise at a modelocked laser output is dependent of the roundtrip cavity loss, consequently the lowest butt-joint loss is preferable for good performance. In this paper, we first present a method to measure the reflectivity of butt-joint active-passive interfaces and experimental results obtained in this way. Measurements of the reflectivity have been performed on a series of integrated extended cavity Fabry-Pérot lasers fabricated using active-passive material produced at JDS-Uniphase [4]. An average value for the reflectivity of the interfaces of  $-37$  dB has been determined. Then a method for measuring butt-joint loss is presented, together with initial results obtained on butt-joints realised in new material, fabricated at our Institute using selective area metal-organic vapor phase (MOVPE) regrowth with all metal-organic precursors.

**BUTT-JOINT REFLECTIVITY MEASUREMENT METHOD**

The butt-joints reflectivities have been measured in a series of integrated extended cavity Fabry-Pérot lasers. These consist 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 are caused by effective index differences and imperfections in geometry (see figure 1). These modify the longitudinal mode structure of the laser. 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 cavities 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 spectrum to the recorded data, values of the reflectivities have been extracted.

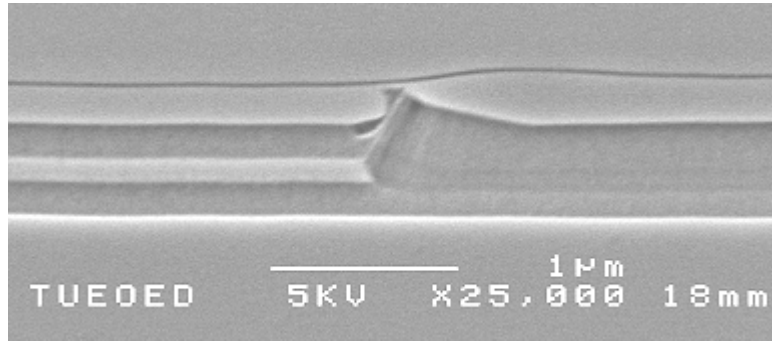


Figure 1 : SEM picture of an active passive butt-joint (011) plane.

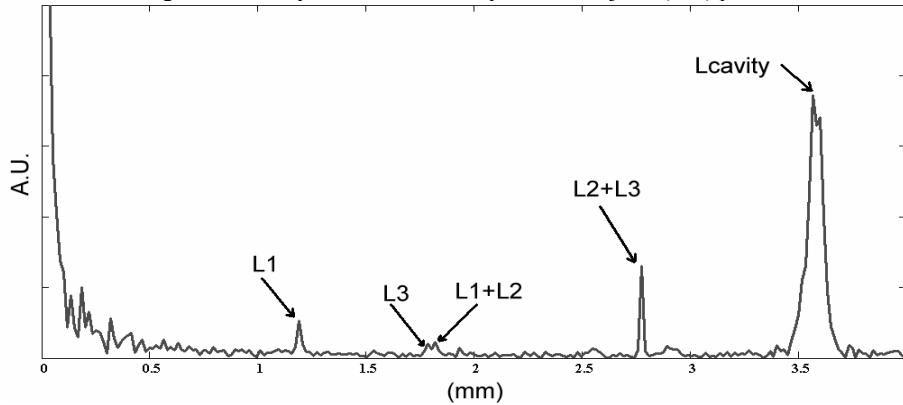


Figure 2. Fourier transform of an extended cavity laser spectrum,  $I=36\text{mA}$ ,  $L_{\text{soa}} = 600\mu\text{m}$

### MODELING OF THE SUB-THRESHOLD SPECTRUM

The sub-threshold spectrum is modelled 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 ( $R = 0.001$ ) 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 coefficients for the two directions at both interfaces between passive and active region. This improves the fit and allows us to neglect the losses at the interfaces. The intra-cavity field is calculated using the transmission matrix formalism.

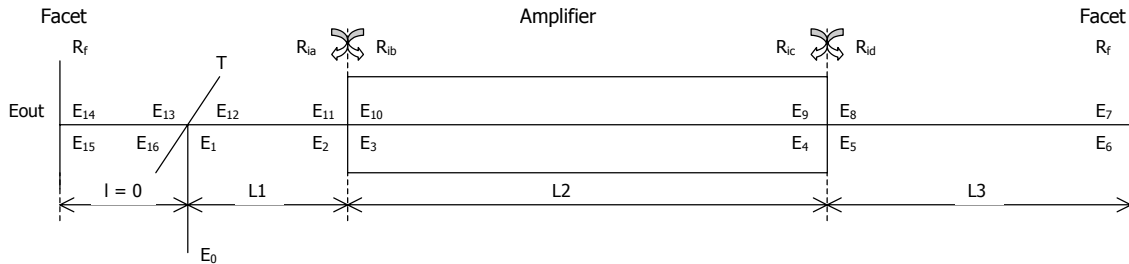


Figure 3: scheme of an ECL with definition of normalized fields and power reflectivity coefficients.

Dispersion in the different waveguides is included and assumed to be equal for the active and passive waveguides ( $N_1$ ). The difference between the group index of the active and passive waveguide has been measured separately. Our optical spectrum analyser showed a linear drift in wavelength, which is indirectly simulated by increasing the dispersion.

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

The theoretical spectrum is broadened to simulate the finite bandwidth of the spectrum analyzer and then fitted to the recorded data. The fitting process was 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.

### BUTT-JOINT REFLECTIVITIES MEASUREMENT 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 analyser (resolution 0.1 nm). The spectrum intensities recorded were around -25 dBm 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.

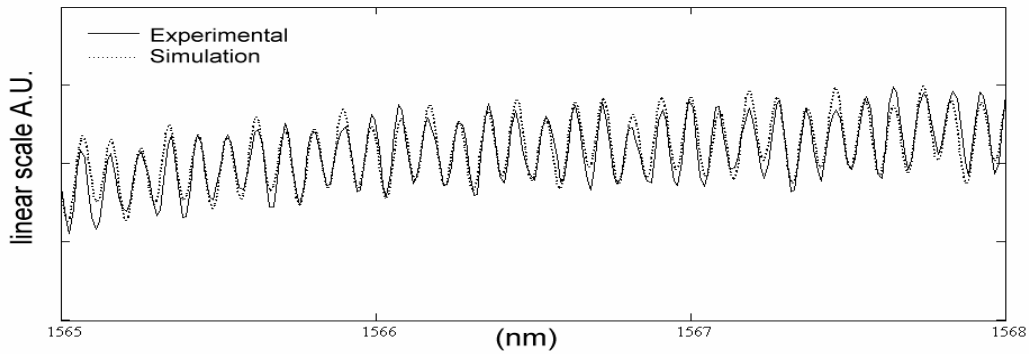


Fig. 4 Central part of a theoretical and experimental spectrum,  $L_{soa} = 600\mu\text{m}$ .

The following table summarizes the results for the different devices:

LSOA ( $\mu\text{m}$ )	Length ( $\mu\text{m}$ )			Ref interface ( $\times 10^{-4}$ )			
	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	750.1	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

For each device, values for  $R_{ic}$  and  $R_{id}$  are similar. Values for  $R_{ia}$  are an order of magnitude higher than  $R_{ib}$ . This stems from the fact that losses at the interfaces have been neglected and that these are different for each interface. According to our model including interface losses and equal reflection coefficients for the two directions at each interface, the interface at  $R_{ia,ib}$  has more losses than the interface at  $R_{ic,id}$ . Furthermore, the averaged value of reflection - 37 dB determined from measurements is not affected by the losses. This method will be used to characterize the butt-joints of devices fabricated with our new low-pressure MOVPE selective area regrowth process. We intend to improve the measurement method further by using an optical spectrum analyser with significantly higher resolution.

### BUTT-JOINT LOSS MEASUREMENT

In the development of our active-passive integration technology, the quality of the regrown material and the butt-joint loss is experimentally measured in so-called passive-passive structures. The passive layerstack is grown and selective areas are etched and regrown following the same process as if the initial layerstack was active. Interface losses are measured from waveguides crossing alternatively first-growth and regrown areas. These give a good indication of the quality of the process. Knowing accurately the losses from first growth waveguides and regrown waveguides, the butt-joint loss value per interface is extracted. All the waveguide losses are measured using the Fabry-Pérot technique [6]. Figure 5 shows the structures used for the measurements.



Figure 5 : Structures used from the butt-joint loss measurements.

Measurements have been performed on a chip fabricated using our new active-passive integration scheme. The shallow etched waveguides are 2  $\mu\text{m}$  wide. 20 waveguides of each type have been measured. The average optical losses for first-growth waveguides are 2.64 dB/cm with a variation of  $\pm 0.05$  dB. The average optical losses for regrown waveguides are 2.72 dB/cm with a variation of  $\pm 0.2$  dB. The increase in losses in these fully regrown waveguides is less than 0.1 dB. 22 waveguides with a total of 60 butt-joints have been measured. We have measured losses per interface between 0.1 and 0.25 dB with an average value of 0.19 dB losses per interface and an accuracy of  $\pm 0.02$  dB. These initial results show that a good quality of the butt-joints has been obtained.

### CONCLUSION

A method for the determination of the reflectivity of butt-joint active-passive interfaces in a series of extended cavity Fabry-Pérot lasers has been presented and experimentally demonstrated. The method is based on the analysis of sub-threshold laser spectra. An average value of  $-37$  dB has been determined for the reflectivity on the joints. This method will be used to characterize the butt-joints of devices fabricated with our new active-passive integration scheme in which we have now demonstrated 0.1-0.2 dB losses per interface. Low values of butt-joint interface reflectivity and loss are particularly important for integrated mode-locked lasers.

### REFERENCES

- 1) R. W. Tkach and A. R. Chraplyvy, "Regimes of feedback effects in 1.5  $\mu\text{m}$  distributed feedback lasers", *J. Lightwave Technology*, vol 4, pp. 1655-1661 (1986)
- 2) J. H. den Besten, R. G. Broeke, M. van Geemert, J. J. M. Binsma, F. Heinrichsdorff, T. van Dongen, E. A. J. M. Bente, X. J. M. Leijtens, and M. K. Smit, "Compact digitally tunable seven-channel ring laser" *PTL* 14, (2002) pp. 753-755
- 3) Y. Barbarin, E. A. J. M. Bente, M. J. R. Heck, D. Lenstra, J. H. den Besten, M. K. Smit and J. J. M. Binsma "Modelling and Experimental Results of a 26GHz Integrated Passively Modelocked Ring Laser." in Proc. IEEE/LEOS Symp. Benelux Chap. (2004)
- 4) J. J. M. Binsma, M. van Geemert, F. Heinrichsdorff, T. van Dongen, R. G. Broeke, and M. K. Smit, "MOVPE waveguide regrowth in InGaAsP/InP with extremely low butt joint loss," in Proc. IEEE/LEOS Symp. Benelux Chap. (2001) pp. 245-248
- 5) R. G. Broeke "A wavelength converter integrated with a discretely tunable laser for wavelength division multiplexing networks" Ph.D Thesis Delft Univ. of Tech. (2002) p.24
- 6) D. F. Clark and M. S. Iqbal, "Simple extension to the Fabry-Pérot technique for accurate measurement of losses in semiconductor waveguides," *Opt. Lett.*, vol. 15, no. 22, pp. 1291-1293, Nov. 1990.