MEASUREMENTS OF LOSS AND MIRROR REFLECTIVITY IN SEMICONDUCTOR OPTICAL WAVEGUIDES: A EUROPEAN INTERLABORATORY COMPARISON EXPERIMENT

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ABSTRACT

The results of round-robin measurements of waveguide loss and integrated mirror reflectivity in several European laboratories in the frame of the COST 240 project are presented. The Fabry-Perot cavity contrast method was used on semiconductor optical waveguides. The measured losses show a satisfactory agreement (within ±0.5 dB) between all the laboratories, but also point out some aspects which must be taken into account to get meaningful data.

1. - Introduction

Several aspects of the measurement procedure for integrated optical waveguides and components are at a far less evolved stage than for the optical fiber counterparts. The repeatability and reproducibility of measurements, the homogeneity and comparability of results from equivalent or similar methods or set-ups, even for basic parameters like waveguide loss, are just a few of these aspects. To address this problem, within the European Project COST 240 "Techniques for Modelling and Measuring Advanced Photonic Telecommunication Components" it was decided to organize the circulation of waveguide samples in a number of participating laboratories, to perform measurements and compare the results.

As a first test, it was agreed to measure the loss of waveguides fabricated on InGaAsP/InP chips, using the well-known method of Fabry-Perot resonances contrast in the cavity formed by the partially reflecting terminal facets [1]. The choice of this technique was prompted by its sensitivity, non destructiveness and availability (in a few modifications of the basic configuration) at several participating laboratories.

2. - Principle of the technique and experimental set-ups

In a Fabry-Perot resonator operating in a single transverse mode regime, the ratio K between its maximum and minimum transmittance when changing the resonance conditions appears in the following relationship [1]:

$$L\alpha = \ln R + \ln\left(\frac{\sqrt{K}+1}{\sqrt{K}-1}\right) \qquad (1)$$

where L is the geometrical length of the cavity (i.e. the waveguide in the present case), α the cavity attenuation and R the mirror (facet) reflectivity, assumed equal for both ends.

The basic experimental set-up to use this technique for waveguide measurements is shown in Fig. 1; the actual implementations differ in several details, the most significant one being the way of changing the resonance conditions to scan several periods of the transmission characteristics, and hence to determine K. Two techniques are currently in use: a) a slow heating or cooling of the sample, by which the length of the optical cavity is changed by the combined action of thermal expansion and thermooptic effect, while the wavelength of the narrow-linewidth source is kept fixed; b) small changes of wavelength of the source, while keeping constant the sample temperature and its optical length. AAR, DBP Telekom, EPFL and Thomson CSF used method a), while ETHZ, both TU Delft laboratories and CSELT used method b).

Other minor differences pertain to the source (gas or diode laser), the way of coupling light to the waveguide (lens or single-mode fiber) and the type of control of the input or output polarization state. All the implementations in the participating laboratories use either HeNe lasers operating at 1.532 μm or diode lasers operating in the 1.55 μm range.

3. - Sample structure

Semiconductor chips with stripe waveguides fabricated in the InGaAsP/InP material system were made available for this experiment; the high refractive index of these materials yields natural Fresnel reflectivities for the facets around 0.3, so that good contrast can be achieved without special sample preparation besides cleaving the I/O facets. A first sample with simple straight ridge guides, supplied by CSELT, was used for some initial essays; then a more complex chip, containing both straight guides and different types of integrated mirrors, supplied by ETHZ, was circulated among all the labs and extensively characterized. Its structure is shown in Fig. 2, and all data reported in this paper refer to this sample.

4. - Measurement results and discussion

Measurements of Fabry-Perot contrast were performed on selected waveguides and mirrors on the chip, separately for TE and TM polarizations. From the measured values of K, the total cavity loss was calculated, and the corresponding values are shown in Fig. 3 for the TE polarization. The data show a general agreement between the results of all laboratories, with some occasional discrepancies and more scattered data for particular guides; in two cases (Thomson-CSF and ETHZ data) the measurements were made after a new cleavage of one end (sample length reduced from 9 to 5.6 mm), so that the facets are not the same as for the other laboratories, and their quality may be different. Other differences can arise from cleaning of the sample in different solvents, which was performed in some laboratories to remove the mounting wax used to fix the chip on the holder after the measurements: residual contamination can alter both R (if the facet is affected) and α (if the guide surface is contaminated); a possible example of this effect is the sequence of results from AAR, CSELT and DBP for guides on one side of the chip. Some guides 6 μm wide exhibited multimode behavior, and in this case the contrast values K depended more or less sensitively on the input coupling conditions, thus increasing the uncertainty.

To get the corresponding values of attenuation α (expressed in dB/cm) for the waveguides, in addition to the measured length L, calculated values of modal reflectivity were used for R; these were computed by a Fourier analysis and Fresnel reflection method [2] applied to the actual waveguide structure, and range between 0.315 and 0.319 (TE) or 0.247 and 0.250 (TM) according to the guide width; no experimental value for R was available.

The attenuation values of course exhibit the same trend as the total cavity loss, and the average level is 1.1 ± 0.3 dB/cm for TE polarization; as a comparison, it should be noticed that for this chip length an uncertainty of ± 0.1 in the corresponding contrast (K=2.8) amounts to ± 0.16 dB/cm, and increases to ± 0.5 dB/cm when K=1.75. An uncertainty of ± 0.01 in the adopted value of R leads to a corresponding systematic error of ± 0.16 dB/cm in the attenuation.

The results for TM polarization are similar, except for a larger spread, due to lower reflectivity, smaller K values and higher loss ($\alpha = 2.4 \pm 0.6$ dB/cm).

The reflectivity of integrated mirrors was obtained by subtracting the average guide loss of the corresponding straight guides; mirror losses of 0.8 ± 0.2 dB and 1.0 ± 0.3 dB were obtained for TE and TM polarization respectively.

5. - Conclusions

An extensive series of optical loss measurements has been performed by several laboratories on semiconductor waveguides by similar set-ups based on the Fabry-Perot fringe contrast method. Agreement within about ±0.5 dB/cm has been found in the vast majority of cases for guide attenuation, and within ±0.2 dB for integrated corner mirros. It has been shown, on the other hand, that maintaining very carefully facet quality and cleanliness is extremely important, and that definitely single mode propagation is essential to achieve meaningful and reproducible results.

References

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[2] P.A. Besse, J.S. Gu, H. Melchior, "Reflectivity minimization of semiconductor laser amplifiers with coated and angled facets considering two-dimensional beam profiles", IEEE J.Quantum Electron., vol. QE-27, pp. 1830-1836, 1991.

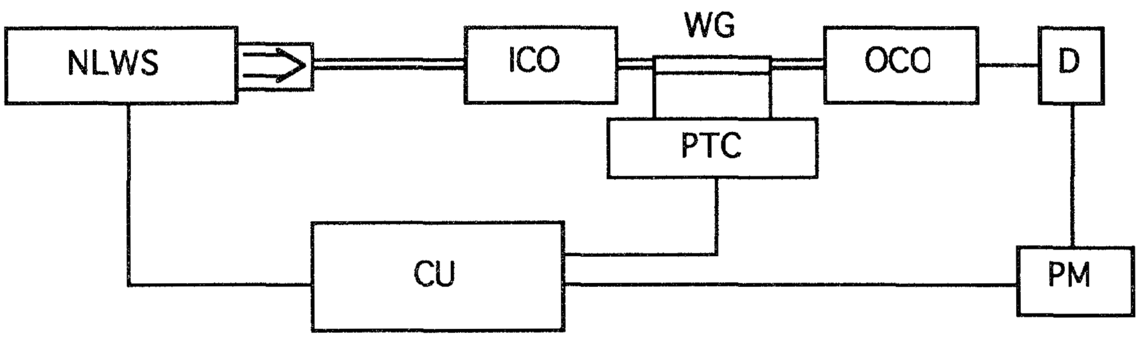

Fig. 1 - Schematic of a basic set-up for measurements of Fabry-Perot fringe contrast in optical waveguides. NLWS: narrow linewidth laser source with optical isolator; ICO: input coupling optics; WG: waveguide under test; PTC: sample position and temperature control; OCO: output coupling optics; D: detector; PM: power meter; CU: control and acquisition unit. Polarization control is present at least in one coupling optics unit.

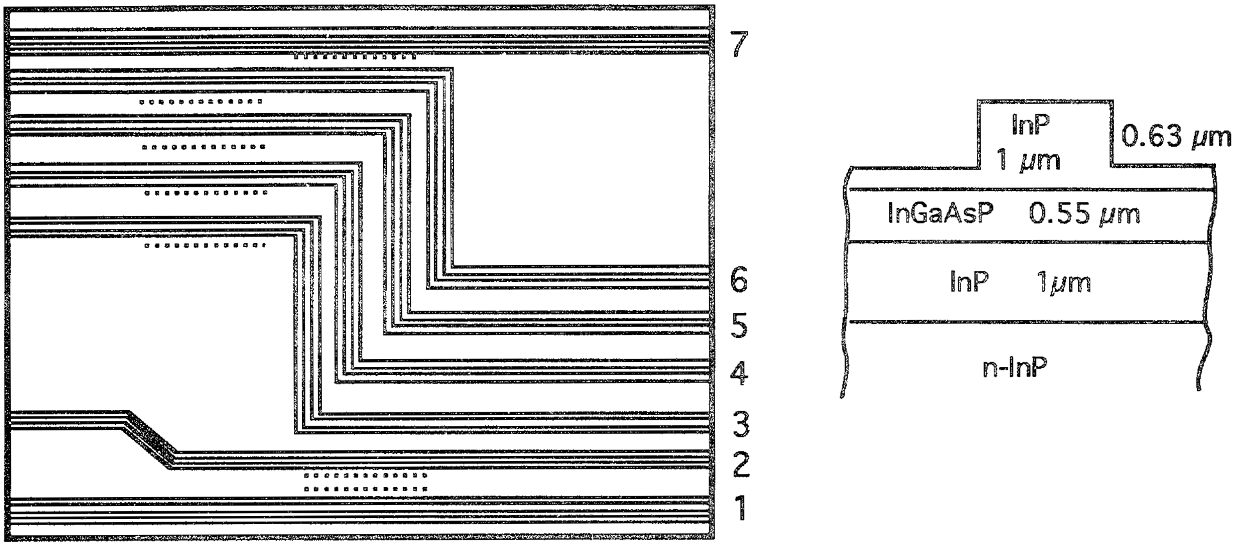

Fig. 2 - Schematic structure of the layout and waveguide cross-section of the ETHZ-supplied chip. Groups 1 and 7 contain sets of straight waveguides 3, 4, 5 and 6 µm wide; group 2 contains pairs of 45° deviating mirrors; groups 3 to 6 contain pairs of 90° deviating mirrors; mirror waveguides have the same widths as straight guides; total chip length 9 mm. The facets have no intentional coating.

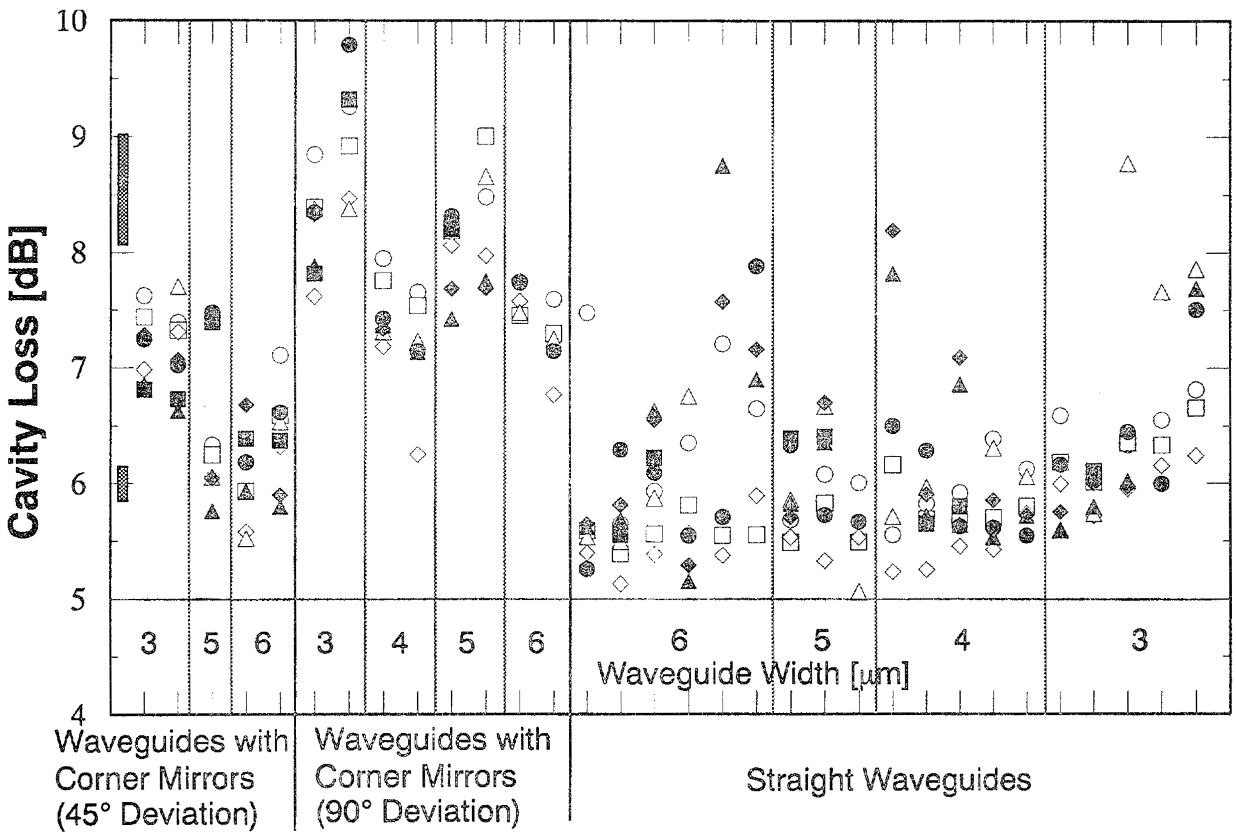

Fig. 3 - Distribution of the measured total cavity loss (propagation plus reflection loss at the facets) for TE polarization. ○ : TUD-EE; □ : TUD-AP; ◇ : AAR; Δ : CSELT; ● : DBP Telekom; ▩ : EPFL; ◆ : Thomson-CSF; ▲ : ETHZ (in order of measurement). The line at the 5.0 dB level corresponds to the calculated end facet reflection loss; average attenuation for waveguides is 1.1 ±0.3 dB/cm (see text). The bars at left show the uncertainty coming from a ΔK = ±0.1 at different total loss levels.