# Probing of localized reflections in photonic devices and circuits on InP using an upgraded high precision reflectometer

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## ABSTRACT

The high complexity of presently developed photonic integration technologies on InP necessitates a thorough knowledge on the prominence of reflections in guiding layers as they can profoundly influence the circuit performance. These can originate at spatially localized refractive index discontinuities in the guide and can have several potential sources ranging from the growth- or process-induced defects and component side-walls to such key elements for photonic integration as the butt-joints between active and passive components and the tapered regions for spot-size conversion. The work described in this paper precisely addresses this issue using an up-graded high precision reflectometer in two ways. First, by monitoring and precisely locating reflections in the guiding layer and second, by extracting relevant information on the device performance through a study of reflections and their spectral properties.

The high precision reflectometer employed here is basically a Michelson interferometer equipped with two different low-coherence light probes of central wavelength ~1.3 or ~1.55 m and a spectral half-width of about ~55 nm. One arm of the interferometer is coupled to the device under test through a lensed single mode fiber while the other to a movable reference mirror which scans the optical path to detect refractive index discontinuities less than $10^{-4}$ (dynamic range of ~80 dB) in the device. Additionally, the up-graded facilities to record the transmitted probe light and the edge-electroluminescence from the device under carrier injection, to be described here in detail, permit to investigate the optical and opto-electronic quality of the guide cavity and further help to locate precisely the unknown reflection. Indeed, a localized reflection in a guiding layer automatically induces a pair of resonant sub-cavities (one with respect to each facet) whose cavity lengths can be extracted by carrying out FFT (fast Fourier transform) analysis on the spectra recorded at a high resolution.

After briefly describing the basic operation principle of this instrument, the example of a growth-induced defect in a deep-ridge InGaAsP/InP waveguide (see **fig. 1**) is considered first to illustrate the methodology (experimental procedure and data analysis) to spatially localize reflections from transmitted spectral data. Later on, some relevant examples of key elements in photonic circuits are considered to demonstrate how reflection monitoring and the associated methodology can be efficiently employed to optimize the geometry of butt-joints for minimum reflections and also the design of bent guides [1] or MMI couplers [2]. For example, in the case of bent guides reflections have been monitored as a function of the radius of curvature ($R_C$), while in MMI couplers they are localized and further identified (spurious or back reflections) as a function of MMI length both in splitter and combiner modes (see **fig. 2**). Subsequently, as back reflections are highly undesirable, Gottesman et. al., have recently proposed a novel design for MMI s to suppress them in photonic circuits [3].

The other up-graded facility to record edge electro-luminescence spectrum from the test device (under carrier excitation), in contrast to simple transmission data, further gives access to the opto-electronic quality of the guiding layer and the carrier recombination properties of a center (for example, a defect) responsible for localized reflection in the cavity. This procedure in combination with reflection monitoring has been successfully employed to diagnose the quality of tapered regions in ~1.3 m F-P lasers grown butt-jointed with a passive section containing the taper for spot-size conversion. Finally, this basically non destructive technique which requires no special sample preparation (unlike conventional luminescence based methods) has also been efficiently employed to detect and localize degradation-induced defective regions in degraded laser cavities.

In summary, we show that the high precision reflectometer with its up-graded facilities and the analytical procedure as described here can be efficiently employed not only to monitor reflections but also to assist the design and further extract relevant information on the performance of individual devices in processed photonic circuits.

***References :***

*[1]. E.V.K. Rao et. al., Low-coherence reflectometry applied to InP-based photonic circuits, in ECIO 99, 9 th Eur. Conf. Integrated Optics, Torino, Italy, April 1999, pp, 377-380*

*[2]. Y. Gottesman et. al., Monitoring of multi-mode imaging devices using optical low-coherence reflectometer in reflection and transmission modes, Appl. Optics, Vol 39, no. 13, pp, 2140-2144, May 2000*

*[3]. Y. Gottesman et. al., A novel design proposal to minimize reflections in deep-ridge multimode interference couplers, to appear in IEEE Photon. Technol. Lett. Dec. 2000.*

# Supporting data for reviewing

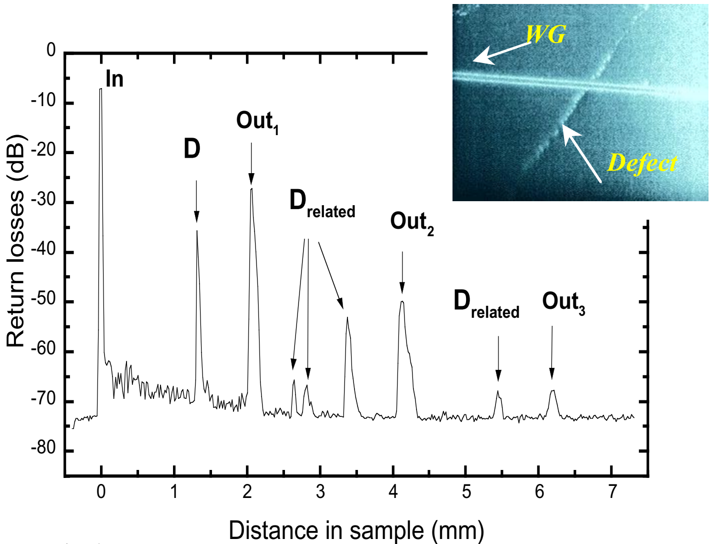


*Fig 1a*

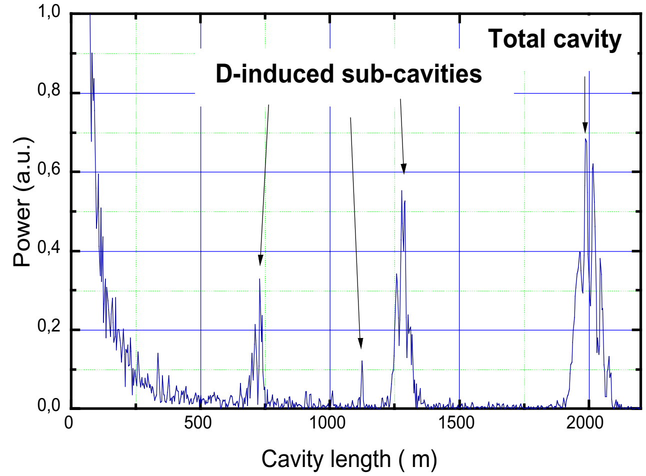


*Fig 1b*

***Figure 1°:*** **An example illustrating the detection and localization of a defect (D) in a deep-ridge InGaAsP-InP waveguide (WG). This defect is revealed in the layer underneath the guide during RIE processing (see inset micrograph). *Fig. 1a*°: The reflectogram depicting defect-induced reflections and also those at the in- and out-facets of the WG recorded in three round-trips oscillations. *Fig. 1b*°: Identification of defect induced sub-cavities subsequent to FFT treatment on the transmitted probe-light spectrum recorded in-situ using optical spectrum analyzer.**

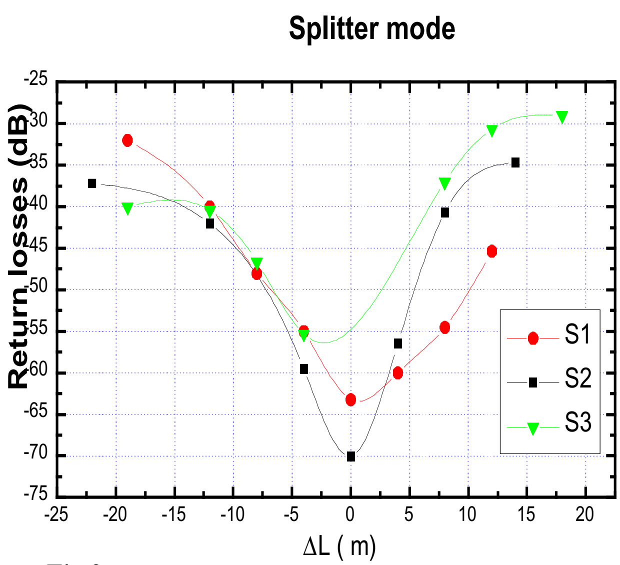


*Fig 2a*

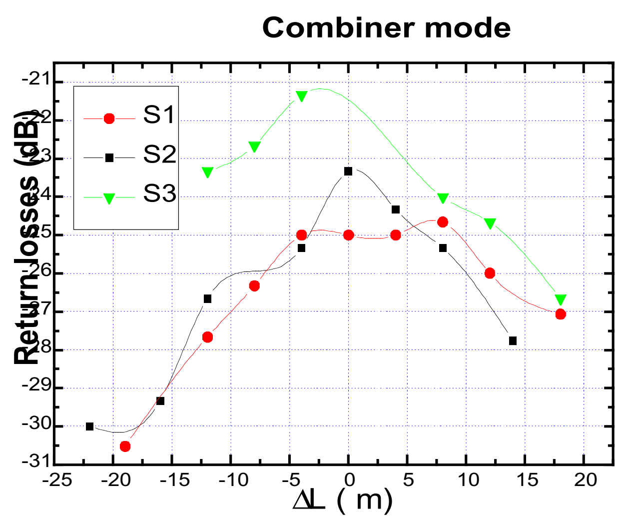


*Fig 2b*

***Figure 2*** **: An example illustrating the potential of reflectometer to assist the optimization of Multi Mode Imaging (MMI) couplers. The reflections are monitored in MMI couplers of three different widths (S1, S2, S3) in splitter (*fig. 2a* : spurious reflections) and combiner modes (*fig. 2b* : back reflections). Here, the abscissa ΔL represents the difference in length with respect to the optimal lengths. These results, in agreement with the self-imaging principle, confirm that back reflections are maximum when the spurious reflections are minimum in MMIs. These results precisely led to the proposal of a novel design to suppress back-reflections.**