Progress report on on-wafer testing of Photonic Integrated Circuits (PICs)

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The accurate characterization of photonic integrated circuits is time consuming and is influenced by the alignment tolerance. To overcome these problems we decided to characterize optical properties of the most important Basic Building Blocks (BBB) by means of electrical signals.

Introduction

Important progress has been made in developing a generic foundry approach [1]. With this approach a broad range of functionalities can be realized starting from a small set of Basic Building Blocks (BBBs). A BBB is a photonic component that implements a basic functionality like: optical amplification, modulation, power detection etc.
The foundry process is validated by measuring a few test cells containing the BBBs. If they perform according to specs the wafer is approved. To speed up the wafer validation we propose on-wafer probing of the BBBs by means of electrical signals. The use of electrical signals, to probe the integrated sources and detectors, eases the aligning requirements compared to the classical optical measurement. The most important BBBs selected for on-wafer characterization are: Straight Waveguides (SW), Phase Modulators (PM) and Semiconductor Optical Amplifiers (SOA).

Basic Building Block characterization

On-wafer characterization of the BBBs is applied to validate the Multi Project Wafer runs (MPW) [1]. Test structures presented in this paper were first introduced in [2].

- Straight Waveguides (SW)

Propagation loss is the main parameter that describes the SW performance. To measure it several test structures are proposed. Here we report on the Ring Resonator (RR) based test structure with a small footprint and promising in terms of accuracy as shown in Figure 1.

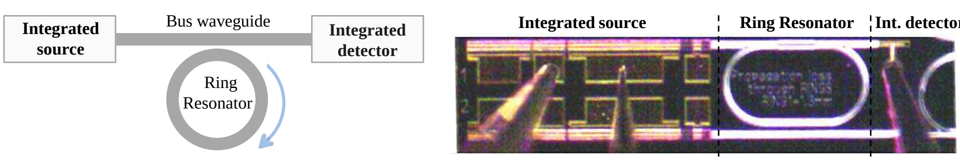

Figure 1 Schematic of the test structure for on-wafer characterization of propagation loss, composed of an integrated tunable Distributed Bragg Reflector (DBR) laser at the input, a ring resonator and an integrated full absorbing detector at the output (left) and a microscope objective picture of the fabricated device is shown (right).

The RR is very sensitive to waveguide loss therefore suitable for this purpose. As coupling element between the ring and the bus waveguide we have chosen the Multimode Interference (MMI) coupler for its tolerance to the fabrication process.
The power transmission at the output waveguide is obtained by a generalization of the RR equations in [3] that take into account the MMI coupling loss [4]:

$$|T|^2 = \alpha_{MMI}{}^2 \left[\frac{\tau^2 + t^2 - 2\tau t \cos\theta}{1 + \tau^2 t^2 - 2\tau t \cos\theta} \right]$$

Where t^2 is the power coupler coefficient which in the MMI we assume equal to ½, τ^2 is the total loss factor that includes the MMI imaging loss ($\alpha_{MMI}{}^2$) and the total ring propagation loss which includes also the MMI propagation loss (α^2), $\tau^2 = \alpha_{MMI}{}^2 \alpha^2$ as in [4] and θ is the round trip phase. The ratio between the maximum power transmission ($|T|^2{}_{\max}$) and the minimum power transmission ($|T|^2{}_{\min}$), obtained for $\cos\theta = 1$ and $\cos\theta = -1$ respectively, is called the Power Transmission Ratio (PTR)

$$PTR = \frac{|T|^2{}_{\max}}{|T|^2{}_{\min}} = \frac{(\tau - t)^2 (\tau t + 1)^2}{(\tau + t)^2 (\tau t - 1)^2}$$

The typical RR transmission measured at the integrated detector as a function of the tuning current is shown in Figure 2.

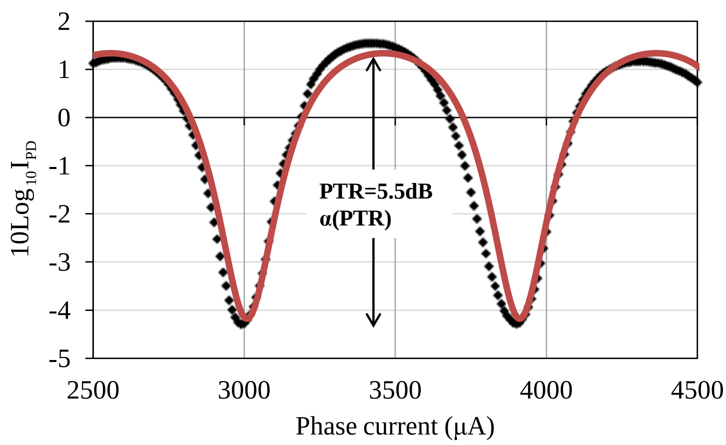

Figure 2 Measured (dotted black) and simulated (solid red) transmission of a 5.2mm long ring resonator. From the measured PTR the propagation loss is estimated. The phase current, applied at the phase section of the DBR laser, is used to fine tune its wavelength.

As MMI imaging loss the measured value of 0.7dB is used in the simulation. The propagation loss, estimated from the PTR of the transmission curve and the MMI imaging loss, is ~15.0dB/cm. We tested the structure on a waveguide with high losses and found from comparison between different structures an accuracy in the order of 10% of the propagation loss. Based on simulations we expect an absolute measurement accuracy of about 0.5dB/cm for low loss values.

-Phase Modulator (PM)

Phase modulation efficiency is the main parameter that describes the PM performance. To measure phase modulation on-wafer the test structure shown in Figure 3 has been tested.

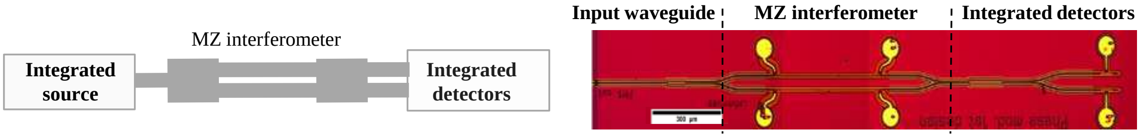

Figure 3 Schematic of the test structure for on-wafer characterization of phase modulation efficiency, composed of an integrated laser source at the input, a Mach-Zehnder interferometer and 2 integrated full absorbing detectors at the output (left) and a microscope objective picture of the fabricated device is shown (right).

The power splitter and combiner are a 1x2 and a 2x2 MMI coupler respectively. The device uses an external laser source. In the future run an integrated source will be present. The PM in the Mach-Zehnder (MZ) interferometer is 500µm long. The typical switching curves of a MZ interferometer when in one of the arms is injected current or applied a reverse bias are shown in the Figure 4 and agree well with measurement on non-integrated structures.

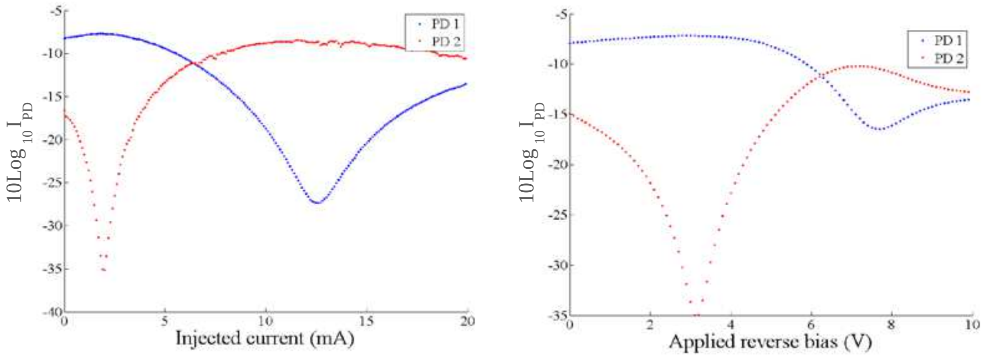

Figure 4 Mach-Zehnder interferometer switching curves when in one of the arms is applied a current (left) and a reverse bias (right). Due to the use of the 1x2MMI splitter at the input the switching curves maxima and minima do not start at 0 applied current or voltage.

***-Semiconductor Optical Amplifier (SOA)*:**

Modal gain is a major parameter that describes the SOA performance. To measure the SOA modal gain on-wafer the integrated test structure in Figure 5 is proposed.

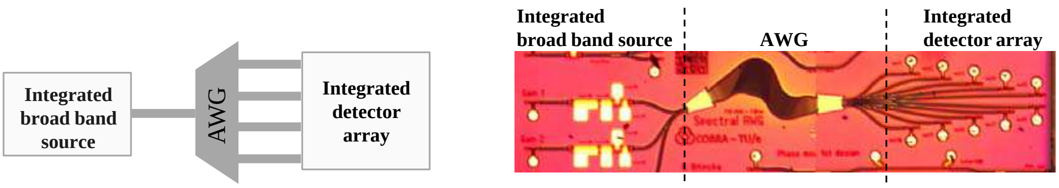

Figure 5 Schematic of the test structure for on-wafer characterization of SOA gain curves composed of a multisection SOA as a broad band source at the input, a large free spectral range arrayed waveguide grating and an array of integrated detectors at the output (left) and a microscope objective picture of the fabricated device is shown (right).

The integrated broad band source consists of SOAs of different length (50-50-100-200um). The large FSR AWG (120nm) is used to spectrally resolve the emission of the SOAs into the output PDs. The FSR is chosen large enough to cover most of the power emitted by the SOAs. By pumping a combination of these SOAs the Amplified Spontaneous Emission (ASE) spectra of 50-100-200-400um long SOA is measured, according to the Thomson measurement method [5].

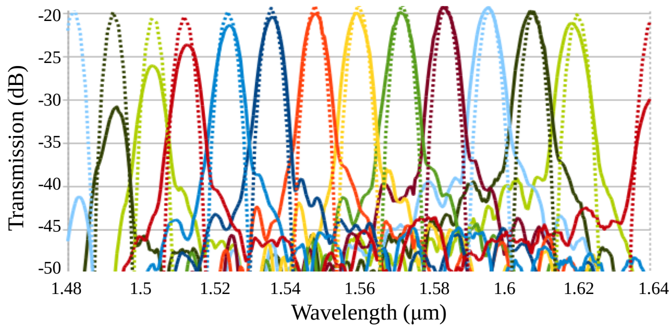

Figure 6 Simulated (dotted) vs. measured (solid) TE transmission spectra of the AWG used for on-wafer gain curves characterization. The output power is collected at the integrated detector array whereas at the input an external tunable source is used temporary.

The measured transmission of the large FSR AWG matches very well the simulated one. There is ongoing work to determine the SOA modal gain curves on-wafer.

Conclusions

In this paper an electrical on-wafer characterization approach is applied to characterize the fundamental BBBs as alternative to the classical optical method. It permits a faster and more accurate characterization of the BBBs thanks to the integration of light sources and detectors.

Acknowledgement

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