On-wafer electrical characterization of Photonic Integrated Circuits (PICs)

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We present the first fully electrical on-wafer characterization of the most important Basic Building Blocks in Photonic ICs, namely the semiconductor optical amplifier, the phase modulator and the waveguide. For each BBB we propose an innovative test structure that allows fast and accurate measurement with a small footprint. All the test structures comprise integrated sources and detectors, allowing characterization in the electrical domain by using electrical probes only avoiding thus the time consuming optical alignment. Validation in the electrical domain allows large scale automated testing, creating feedback between BBB performance and generic process optimization, crucial to successful PIC commercialization.

Introduction

In a generic foundry approach a broad range of functionalities, such as light amplification, modulation and detection, can be realized starting from a small set of Basic Building Blocks (BBBs) [1].
To show the power of the generic foundry approach in terms of cost reduction for PIC development Multi Project Wafer (MPW) runs are offered by different foundries [1]. The foundry process is validated by measuring a few generic test cells containing dedicated test structures for BBB characterization.
We propose on-wafer characterization in the electrical domain for the most important BBBs: Waveguides (WG), Phase Modulators (PM) and Semiconductor Optical Amplifiers (SOA). The use of electrical signals for on-wafer characterization speeds up the time needed for testing as well as reduces the aligning requirement present in classical optical characterization techniques. Test structures concepts present in this paper were first introduced in [2].

Propagation loss characterization

Propagation loss is the main parameter describing the WG performance. To measure it on-wafer, through electrical signals only, a dedicated test structure comprising an integrated tunable Distributed Brag Reflector (DBR) laser, an integrated Ring Resonator (RR), and an integrated Photo Detector (PD) is used, see Figure 1. The high sensitivity to loss of the RR cavity, as well as its compactness makes it the perfect choice. A 2x2 Multimode Interference (MMI) coupler couples light from the laser into the RR. The equations

describing the RR transmission that take into account the MMI excess loss, as well as the extinction ratio needed for calculating the WG propagation loss, is reported in [3].
MMI excess loss is detrimental to the waveguide propagation loss characterization. It adds to the WG propagation loss and is difficult to distinguish from waveguide loss [3].

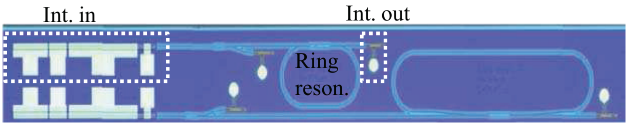


Figure 1 Microscope photo of the realized test structure for on-wafer characterization of propagation loss.

To decouple waveguide propagation loss from MMI excess loss, two test structures with different RR perimeters (different propagation loss), but the same MMI are proposed. The ring perimeters differ by 2 mm (1.5 and 3.5 mm), sufficient to distinguish propagation loss from MMI excess loss. This test structure allows determining the WG propagation loss with an excellent improvement in measurement accuracy [3].
To characterize propagation loss electrically the DBR laser is biased above threshold. Its wavelength is tuned by applying a varying current to the phase section. The output power is measured as photo current at the reverse biased PD. The transmission for the two RRs, measured at the respective PDs as a function of the tuning current, is shown in Figure 2.

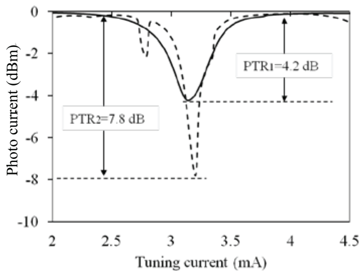


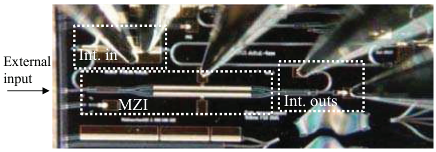
Figure 2 Electrically measured transmission for ring 1 (solid black) and for ring 2 (dashed black).

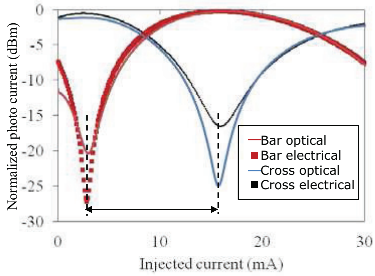
The propagation loss, measured with the test structure shown in Figure 1, is α=2.8±0.23 dB/cm. The variation in propagation loss is due to reproducibility limits of MMIs closely spaced on the wafer [3]. The propagation loss as well as the MMI excess loss variations were verified with extra test structures present in the test cell [3].

Phase efficiency characterization

Phase modulation efficiency is the main parameter that describes the phase modulator performance. To measure it on-wafer, through electrical signals only, a dedicated test structure comprising an integrated coupled cavity laser [4], a Mach-Zehnder Interferometer (MZI), and two integrated PDs are used, see Figure 3 (a). The MZI is composed of two 2x2 MMIs (the first as a splitter and the second as a combiner), and 1 mm long PMs. Optical fibers are not used for this all-electrical measurement, see Figure 3 (a).
To characterize phase efficiency electrically the integrated laser is biased above threshold.

Consequently at one of the PMs a varying current is applied. Similar curves are obtained applying a reverse voltage to the modulator.





(a) (b)

Figure 3 Microscope photo of the realized test structure during on-wafer phase efficiency characterization (a), and electrically measured (dotted) vs. optically measured (solid) phase efficiency (b).

The output power is measured as photo current at the reversely biased PDs, dotted curves in Figure 3 (b). To compare the electrical measurements with optical measurements a second experiment is performed where the same procedure is repeated by coupling an external laser in the external input of the test structure instead, the solid curves in Figure 3 (b). The phase change efficiency, measured both electrically and optically, is φ=12.8 mA.

Modal gain characterization

Net modal gain is an important parameter that describes the SOA performance. To measure it on-wafer, through electrical signals only, a dedicated test structure comprising an integrated multisection SOA in input, a large Free Spectral Range (FSR) Arrayed Waveguide Grating (AWG), and an array of integrated PDs in output is used, see Figure 4. To characterize modal gain we apply the Thomson method [5].

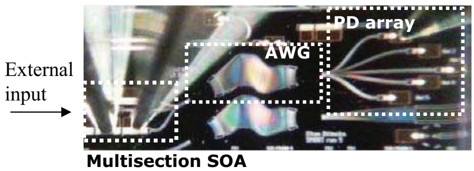
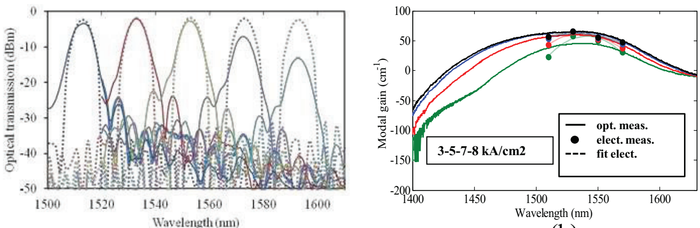


Figure 4 Microscope photo of the realized test structure for on-wafer modal gain characterization. Needles provide the electrical signals needed for the on-wafer characterization.

The integrated multisection SOA consists of electrically isolated SOAs of length (200-200 um). The large FSR AWG (160nm) has five channels centered at 1550 nm and channels spacing of 20 nm. It spectrally resolves the Amplified Spontaneous Emission (ASE) of the SOAs into the respective PD. The FSR is chosen to be large enough to capture most of the power emitted by the SOAs. To characterize the individual AWG passband response an external tunable source is coupled to the external input and the photocurrent is recorded from each PD. In Figure 5 (a) is shown the good match between the simulated AWG

transmission (using using OptoDesigner) and the measured AWG. The drop at channels 4 and 5 is due to reduced absorption in the PD at longer wavelengths.
We bias at different currents the first SOA (200 µm) and record at the PDs the ASE filtered by the AWG. We repeat the procedure by biasing with the same current density both SOAs. Modal gain for the 200-400 µm long SOA pair is calculated as in [5], see Figure 5 (b). Optically and electrically measured data agree well especially in the central AWG channels, Figure 5 (b).



(a) (b)

Figure 5 Simulated (dotted) vs. measured (solid) TE transmission spectra of the AWG in (a). Optically vs. electrically measured modal gain for different current densities in (b).

A maximum modal gain of 62 cm^{-1} is measured for the 200-400 µm long SOA pair for a current density of 7 kA/cm^2 at 1530 nm. Gain values are confirmed from optical measurement too, see Figure 6 (b).

Conclusions

We show electrical on-wafer characterization for characterizing the fundamental BBBs. Electrical domain characterization allows a faster characterization of the BBBs, therefore a quick validation of generic photonic integration technology.

Acknowledgement

The research leading to these results has received funding from the European Community's Seventh Framework Program FP7/2007-2013 under grant agreement ICT 257210 PARADIGM. Oclaro and Smart are acknowledged for fabricating the test structures.

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