Electrical on-wafer testing of Photonic Integrated Circuits (PICs)

E. Bitincka, X. Leijtens, J. J. G. M. van der Tol, E. Kleijn and M. K. Smit

COBRA Research Institute, Technische Universiteit Eindhoven

Characterization of Photonic ICs is time consuming because the optical ports can only be accessed after dicing of the wafer, and optical alignment tolerances for accurate measurement are very tight. A major improvement in measurement speed and accuracy can be achieved by testing the major properties on-wafer using only electrical contacts. Electrical testing of optical properties needs integration of calibrated light sources and detectors.
Here we describe an approach for electrical testing of the properties of the most important components in photonic ICs.

Introduction

During the last years 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 basic building block is a photonic component that implements a basic functionality like: optical amplification, modulation, power detection etc. Table **1** gives a list of the most important BBBs and the parameters that we would like to measure.

BBB	Parameter
Semiconductor Optical Amplifier (SOA)	modal gain (spectrum) (dB/cm)
Photo Detector (PD)	responsivity (A/W)
Straight Waveguide (SW)	propagation loss (dB/cm)
Isolation Section (IS)	resistivity (kΩ/μm)
Electro Optic Phase Modulator (EPM)	phase change (Rad/mm)

Table 1 List of the most important basic building blocks and the parameter to be characterized.

Here we describe a novel approach for electrical characterization of the most important Basic Building Blocks (BBBs).

Measurement Method

The electrical testing will be based on relative measurements rather than absolute ones because it is difficult to know exactly the absolute output power of sources and responsivity of detectors. The concept of relative measurement is shown in Figure 1(a). The transmission of the DUT is determined by comparing it to the transmission through a reference device, usually a section of straight waveguide. Normally this is done by coupling light in and out of the chip using lensed fibers or microscope objectives. Unreproducibility in the coupling efficiency degrades the measurement accuracy. By

integrating a source and a detector for testing, as indicated in Figure 1(b), we avoid this contribution to the measurement inaccuracy.
If the sources are assumed to be equal the power transmission coefficient of the device under test is found from $T=I_{DUT}/I_{REF}$, in which I_{DUT} and I_{REF} are the currents measured at the detectors.

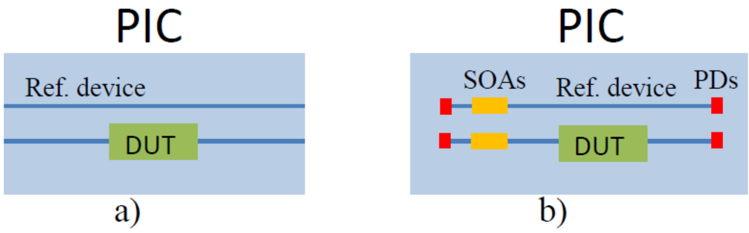

Figure 1 Schematic of the standard relative measurement approach in a) and the proposed relative measurement approach with integrated light source and integrated detector in b).

To use the relative measurement procedure we need to know the reproducibility limits with which sources and detectors can be processed or what we call to calibrate the system source-detector. To do this the circuit in Figure 2 will be used.

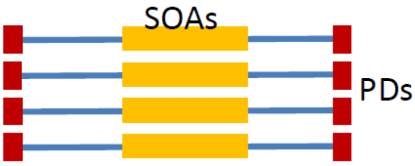

Figure 2 Source-detector calibration schematic

The system source-detector will be used extensively to characterize the other BBBs thus we need to know accurately the spread of its values. With the schematic in Figure 2 statistical data about the source-detector system will be obtained. The spread of these statistical data provides the resolution of our integrated measurements. With this circuit we cannot distinguish which part of the spread is ought to the reproducibility limits of the source and which to the detector but we actually don’t need to know it since the system is used as a whole. Another important thing to point out is the broad bandwidth of the SOA used as a source for the characterization. As a result of the broad bandwidth we will measure the weighted average of the DUT transmission over the source spectrum.

- *Photo Detector (PD)* To measure the PD responsivity an optical input coupling is needed. Usually integrated waveguide PDs have an internal quantum efficiency above 90% so even without optical coupling we will have a fair estimate of the optical power level at the detector. Another important parameter is the detector dark current. It is simply measured by detecting the current that flows in when no light is present. For measuring the spectral response again an output coupling is necessary.
- *Semiconductor Optical Amplifier (SOA)* To perform measurement of SOA spectral gain curves we use a multisection SOA with 200-200µm length, respectively SOA1 and SOA2 in Figure 3(a). By measuring the power detected at the left PD with and without powering SOA2 we find the gain of SOA1, averaged over the full bandwidth. We can spectrally resolve the gain curve by connecting it to an AWG (right part of the figure) and doing the same measurement for each AWG channel. By having the AWG channels at the

wavelengths of interest we can get a good impression of the SOA gain for those wavelengths.

The AWG with an FSR of 120nm will be used to perform the sampling of the SOA Amplified Spontaneous Emission (ASE) spectra and a set of PDs at the output arms of the AWG to detect the power in each channel (see Figure 3(a) and Figure 4). The AWG FSR is chosen the widest possible in order to cover the most of the ASE spectra of the SOA. From the interpolation of the power detected in each channel the ASE spectra can be reconstructed. Furthermore by biasing only one or both sections (see Figure 3(a)) an SOA with a total length of 200µm or 400µm can be obtained and by comparing the ASE spectra (at the same current densities) of two SOAs of length *L* and *2L* the gain spectrum from on-wafer measurements can be calculated [**2**]:

$$G = \frac{1}{L}\left[\ln\left(\frac{I_{2L}}{I_L} - 1\right)\right]$$

with *G* the modal gain, *L* the length of the SOA and *I* the intensity of the ASE spectra.

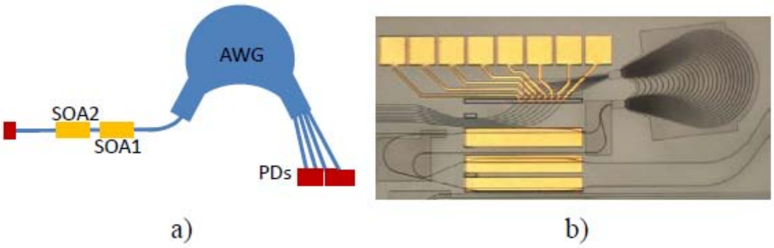

Figure 3 Schematic of integrated gain curve measurements in a) and an example of SOAs, AWG and PDs integration in the Cobra process in a tunable laser configuration in b).

In Figure 4 there is a schematic representation of the ASE sampling through the AWG channels. In a real circuit the AWG channels will be more and will cover most of the ASE spectra permitting a more accurate sampling.

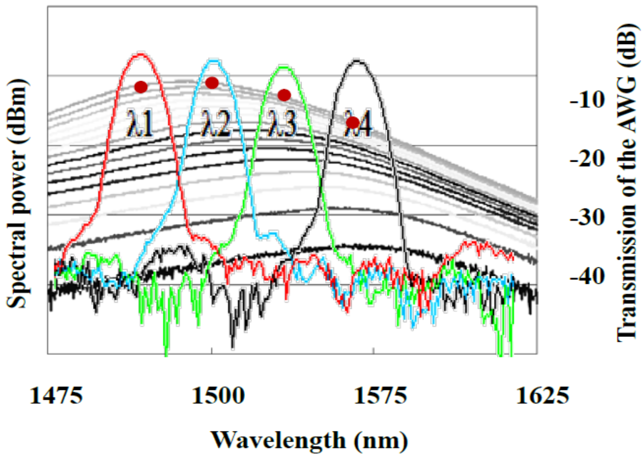

Figure 4 Sampling of the ASE spectra of an SOA through the channels of an AWG.

Straight Waveguides (SW) We propose to measure propagation losses of the PIC waveguide as depicted in Figure 5(a). It can be used for both shallow and deeply etched waveguides. The difference in power that the PDs will measure is due to the different SW lengths.

- *Isolation Section (IS)* is itself an electrical building block so the measurement is quite simple. A contact followed by the IS and at the end another contact. By applying a voltage and measuring the current that flows in the resistivity is obtained. Different IS lengths can be used to measure the “resistivity versus length” curve, see Figure 5(b).

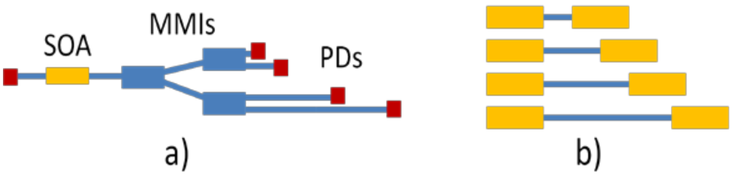

Figure 5 of: a) propagation loss characterization in SW and b) IS characterization

- *Electro-optic Phase Modulator (EPM)* will be characterized using PICs with different EPM arm lengths. The output power in the bar and cross outputs will be collected using integrated PDs. From the variation period the phase shift can be determined. The schematic in Figure 6 shows the concept.

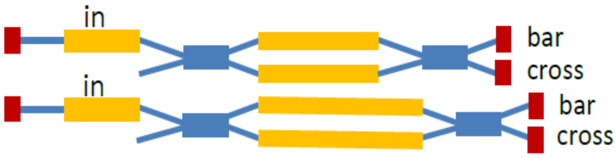

Figure 6 Schematic of the EPM characterization

Conclusions

An alternative approach for the testing and characterization of the most important building blocks for the photonic ICs is described This approach, which consists of on-wafer testing (prior to cleaving and coating), will permit a faster and more accurate characterization of the BBBs thanks to the integration of light sources and detectors. From relative measurements an absolute value of the BBBs parameters will be deducted.

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