Electrical Method for On-Wafer Modal Gain Characterization of Semiconductor Optical Amplifiers

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Abstract: We present a fast and innovative on-wafer measurement method for modal gain characterization of semiconductor optical amplifiers. It uses a compact integrated spectrometer with electrical control signals only, avoiding, thus the critical and time-consuming optical alignment.

1.Introduction

The generic foundry model[1] reduces the prototyping costs of Photonic Integrated Circuits (PIC) dramatically. One of the main Building Blocks (BB) within the generic foundry approach is the Semiconductor Optical Amplifier (SOA). It is the core element in every integrated laser source. Therefore, its accurate characterization in terms of modal gain is fundamental to the overall performance of the PIC. The main methods proposed for measuring modal gain are the Hakki-Paoli[2], the Thomson[3], and the fitting algorithm method[4]. The draw-back of the Hakki-Paoli method is the need to resolve with very high spectral resolution the longitudinal modes of a laser cavity which includes an SOA and the cleaved facets. For typical chip lengths of several mm this method is not practical since a high resolution spectrometer is needed. The fitting algorithm method[4] makes use of a non linear least square fitting algorithm over the Amplified Spontaneous Emission (ASE) of many SOAs and calculates the modal gain. The draw-back of this method lays in the large number of SOAs needed. The Thomson method in turn needs only two SOAs with length L and $2L$ to determine the modal gain.

Our approach is based on the Thomson method. Its novelty lies in the integration of the SOAs with an optical filter and an array of integrated detectors. The integration of the SOAs with the optical filter and a detector array allows for electrical on-wafer characterization without the need to couple optical signals out of the chip.

2. On-wafer characterization concept

To use the Thomson method a multi-section SOA, a large Free Spectral Range (FSR) Arrayed Waveguide Grating (AWG) and an array of photo detectors (PD) are integrated, see Fig. 1.

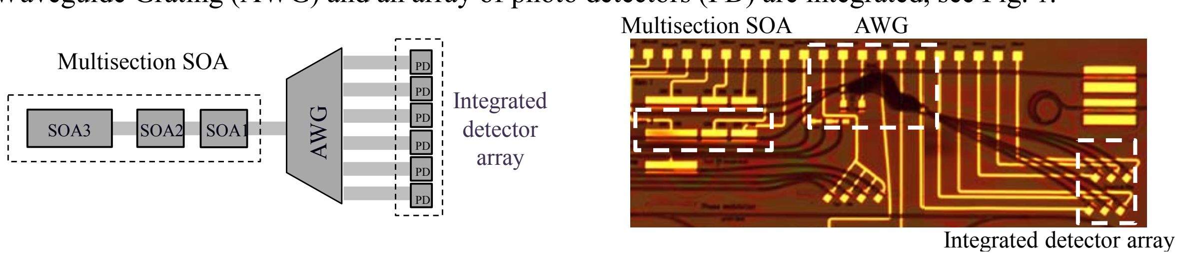

Fig. 1 Schematic of the integrated modal gain measurement (left) and a microscope photograph of the realized circuit (right).

The multi-section SOA consists of SOAs of different length (200-200-400µm). The large FSR AWG (120nm) spectrally resolves the ASE of the SOAs into the PD array. At each of the PDs connected to one of the outputs of the AWG we measure the spectral gain for the corresponding wavelength. The large FSR covers the most important part of the ASE spectra. By pumping different combinations of the three SOAs the following overall SOA length can be obtained: 200-400-800µm. The un-pumped SOAs are always reversely biased (-2V) to absorb incoming light and prevent unwanted feedback. When the feedback is absent the modal gain G and the ASE power are related by[3]:

$$P = \frac{P_{ASE}}{G}\left(e^{GL} - 1\right) \quad (1)$$

With P_{ASE} ASE power and L the SOA length. When comparing two SOAs with length L and $2L$ the analytical solution of (1) gives the net modal gain.

$$G = \frac{1}{L}\left[\ln\left(\frac{P_{ASE_{2L}}}{P_{ASE_{L}}} - 1\right)\right] \quad (2)$$

3. Experiments

The gain of the 400-800µm long SOA was measured by injecting the same current density (range 1-8kA/cm^2) in each of the two SOA configurations. In Fig. 2 (left) the measured AWG transmission (using an external optical input of the AWG and the detector array) and the simulated one are shown. The SOA ASE power for the 400-800µm long configuration was measured at the PD array, and in Fig. 2 (right) the corresponding gain curves, calculated with (2), are shown.

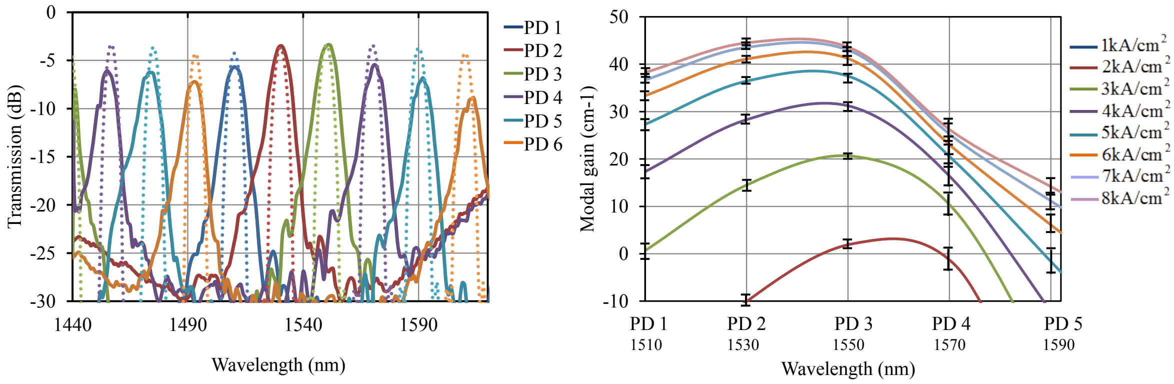

Figure 2 Measurement (cont.) vs. simulation (dashed) AWG transmission (left), and modal gain with error bars (right).

The 20nm measured AWG channel spacing matches very well the simulated one, whereas the measured channel bandwidth was larger than simulated most probably due to phase errors (confirmed by simulations). In Fig. 2 (right) the horizontal axes shows the designed wavelength of the corresponding AWG channel. The typical fabrication tolerance of the central AWG channel is a few nm which translates in a small error in gain estimation shown with the error bars in Fig. 2 (right). These error bars are highest in the outer channels and smaller at the highest gain region (flat gain curve at highest gain point). The typical blue shift of the modal gain at increased pumping current together with a modal gain peak of 45cm^{-1} is clearly observed. Gain saturation appears at ~7 kA/cm^2.

4. Conclusions

We presented for the first time an on-wafer gain measurement test structure using electrical signals only. Avoiding the optical output signals speeds-up the procedure. ASE power is measured in just a few points which is sufficient to calculate the modal gain curves. Characterized amplifiers show a typical modal gain of 45cm^{-1} which agrees well with values measured with other methods

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