Test structures for SOA gain and absorption measurement

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Semiconductor optical amplifiers are essential building blocks in photonic integration technology. Assessment of their properties is indicative of the quality of fabrication process and detailed knowledge is important for designing complex active circuits and devices. We investigate methods and test-structures for measuring gain and absorption of active materials that are suitable for integrated electrical on-wafer testing. We report measurement results for the Oclaro InP integration platform.

Introduction

In recent years progress was made in the development of an InP generic integration platform [1]. This platform provides the possibility to design complex circuits and manufacture them using a standard fabrication process. Designs of different users may be combined in so-called multi-project wafer runs (MPW). With such an approach designers can benefit from a well-developed semiconductor technology without having to go into the details of the production. The foundry is responsible to guarantee the performance of the basic building blocks (BBB) which are used by the designers. For the purpose of qualification of the production process, test cells containing specific test circuits are used. These circuits are designed to measure one or a few BBB parameters, such as waveguide loss for passive waveguides, phase modulation efficiency for phase modulators, gain for active material, etc. The main requirements to the test circuits and measurement methods are simplicity, speed and footprint on the cell. There is progress in development of electrical testing methods [2], making use of integrated light sources and detectors. They reduce the testing to measuring electrical performance of test circuits and deriving optical characteristics from the values obtained. Another methodology is to couple light into and/or out of test circuits and subsequently analyse it with external equipment. The latter method benefits from the functionality present in external equipment which is at the moment not available in integrated circuits. Using this method for on-wafer testing requires access to on-chip circuits through vertical couplers, which are currently being developed [3].
In the present work we concentrate on the development of test structures with optical outputs meant for measuring gain and absorption spectra of semiconductor optical amplifiers (SOA), which are of particular importance for building on-chip lasers and amplifiers.

Structures for gain measurements

Methods for measuring gain have been intensively studied. There is family of methods which derivers the gain spectrum from the modulation of amplified spontaneous emission spectrum by the Fabry–Pérot modes of an on-chip laser cavity [4, 5]. These methods

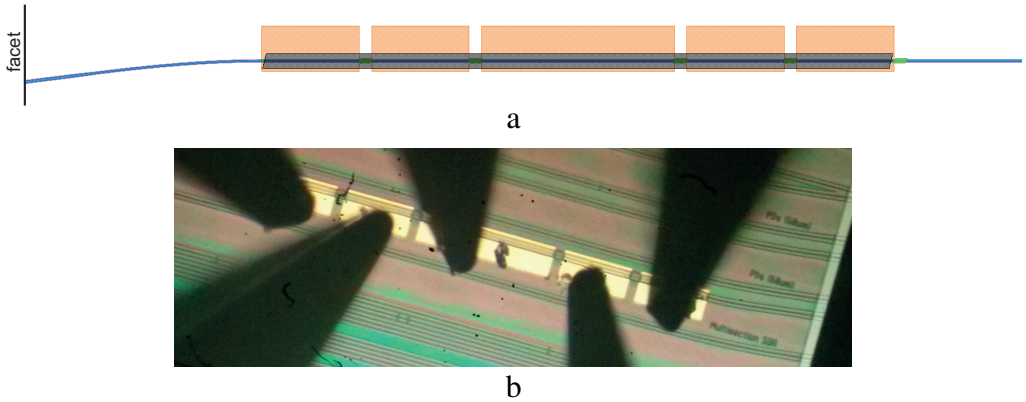
require a high spectrometer resolution and are applicable below threshold current density only. A method based on the measurement of the amplified spontaneous emission (ASE) spectrum as a function of the SOA length was proposed by Oster [6]. It makes use of the relation between output intensity I_{out} and the length SOA length L

$$I_{\text{out}}(\lambda) = \frac{I_{\text{sp}}(\lambda)}{G(\lambda)}(e^{G(\lambda)L} - 1), \tag{1}$$

where I_{sp} is the intensity of the spontaneous emission per unit length, and G is modal gain. The difficulty for this method is to ensure the same collection efficiency for all waveguides. As a modification of this method Thomson [7] proposed to use a multisectional SOA. The design of this type of test structure should guarantee absence of any reflections so that light passes through the amplifier only once. Several measurements are taken at the same current density.

ASE measurements using a multisectional SOA

In our measurements we used a multisection SOA test structure (fig. 1). The structure consists of several SOA sections of various length with separate electrical contacts. Sections are separated with short $L_{\text{isol}} \sim 30\,\mu\text{m}$ isolation sections. In order to prevent reflections from the facet, angled output waveguides which approach the facet at a 7° angle and/or an antireflection coating on the facet can be used. Active-passive butt-joints are angled for the same purpose.



a

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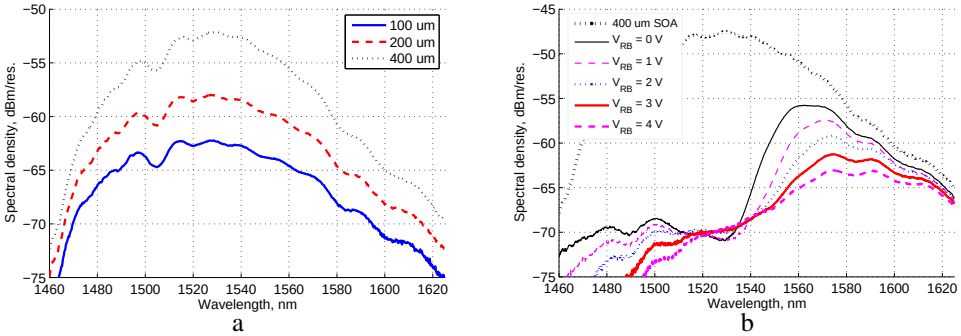
Figure 1: Example of a 5-section SOA test structure. (a) Mask design. Angled outputs are visible on the left side. (b) The fabricated chip (COBRA platform). The lengths of the sections are 200, 200, 400, 200, 200 µm.

Pumping and reverse biasing for spectra recording

The ASE spectra from SOAs of various length can be obtained by pumping different combinations of SOA sections with the same current density J_{pump}. Thus, by pumping first sections we obtain the spectrum for a SOA of length L_1, pumping first two sections gives the ASE for a SOA of length $L_1 + L_2$, etc. The resulting measured output spectra are shown in fig. 2a. The location of the peak for all three curves is at the same wavelength, which confirms that the current density for all devices is the same. In order to calculate SOA absorption spectrum (SOA is reverse biased), we apply reverse biases to the first

closest to the output SOA and continue pumping one or few following SOA sections. Spectra measured in this way are displayed on the fig. 2b.



a b

Figure 2: ASE from a multisection SOA on the Oclaro platform for gain and absorption measurements. (a) ASE from SOA of various length. Current density $J_{\text{pump}} = 3.2\,\text{kA/cm}^2$. (b) Emission spectra from 300 µm SOA after passing through a reverse-biased absorber. For comparison, the ASE spectrum of a 400 µm SOA (top curve) is shown.

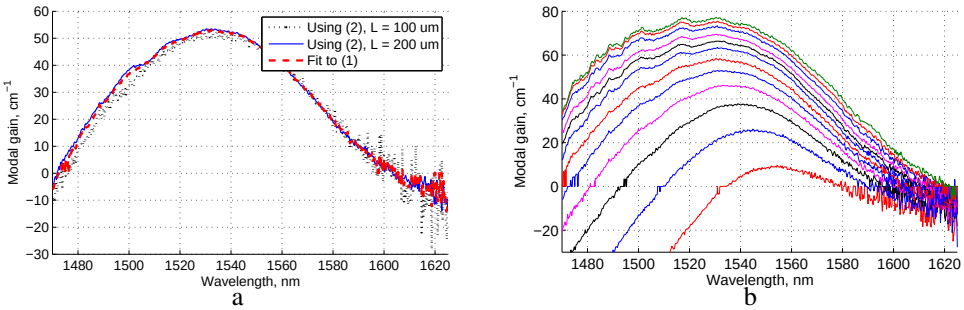
Gain calculation

A specific selection of the lengths of the SOA sections (i.e. $L_2 = 2L_1 \equiv 2L$, and $L_3 = 2L_2 \equiv 4L$) leads to straightforward way of calculating the gain using [7]:

$$G(\lambda) = \frac{1}{L}[\ln(\frac{I_L(\lambda)}{I_{2L}(\lambda)} - 1)], \tag{2}$$

where I_L and I_{2L} are the ASE intensities at particular wavelengths for SOAs of length L and $2L$, respectively. Therefore the measured values of the emission intensities I_L, I_{2L}, and I_{4L} at each wavelength are used to calculate modal gain in three different ways:

1. using (2) for a pair I_L, I_{2L};
2. using (2) for a pair I_{2L}, I_{4L};
3. using non-linear least square fit with (1) for all three intensities.



a b

Figure 3: Modal gain for the Oclaro platform. (a) Modal gain calculated with various methods. Current density $J_{\text{pump}} = 3.2\,\text{kA/cm}^2$. (b) Modal gain calculated by fit to (1). Current densities: $J_{\text{pump}} = 1.1; 1.6; 2.1; 2.6; 3.2; 3.7; 4.2; 4.7; 5.3; 6.3; 7.4; 8.4\,\text{kA/cm}^2$

The comparison of the results is shown in fig. 3a. The values from the three methods agree with each other. The advantage of the fitting method is that it provides means to recognize measurement faults such as the bias during the intensity measurements, which becomes clear in fitting quality. The results for the shortest pair, $L = 100\,\mu\text{m}$, are more sensitive to the intensity variations and noise, which are larger for the relatively weak emission from the short SOA.

The fitted modal gain spectra in the range of pump current densities is displayed in fig. 3b.

Absorption calculation

In order to calculate the absorption we assume it complies to the Beer-Lambert law

$$I_{\text{out}}(\lambda) = I_{\text{in}}(\lambda) e^{-\alpha(\lambda, V_{\text{RB}}) L_{\text{SOA}}}, \quad (3)$$

where $\alpha(\lambda, V_{\text{RB}})$ is the absorption coefficient which is dependent on the applied reverse voltage, and L_{SOA} is the length of reverse biased SOA. Measuring the output spectrum $I_{\text{out}}(\lambda)$ (fig. 2b) and calculating the incoming power $I_{\text{in}}(\lambda)$ from (1) with the previously obtained gain G and spontaneous emission spectrum I_{Sp}, we can evaluate the absorption (fig. 4).

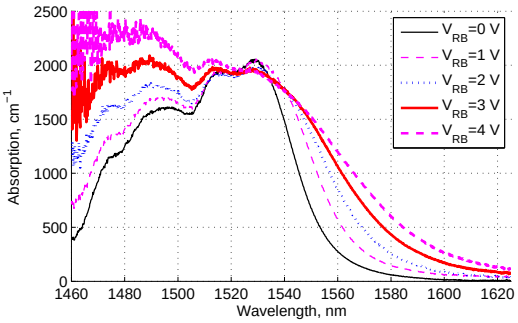


Figure 4: Calculated SOA absorption spectra for Oclaro platform for different reverse voltages. Current density is $J_{\text{pump}} = 2.6\,\text{kA/cm}^2$

Conclusions

We discussed various types of test structures for measurement of gain and absorption of SOAs. Experimental results on the Oclaro platform show that multisection SOAs can be successfully used for these measurements. Further quantitative analysis of the measurement accuracy is to be done.

Acknowledgement

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