Monolithically integrated SOA-MZI array in InP/InGaAsP, suited for flip-chip packaging

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An array of integrated all-optical SOA-Mach-Zehnder switches is demonstrated. The all-optical switches consist of MZIs with SOAs in the arms. For packaging a number of additional features are implemented: Spotsize converters are integrated to achieve a good overlap with cleaved fibers. For vertical alignment of the chips in the package, recesses are etched till a well defined level. For sub-micron horizontal alignment, cleave openings are lithographically defined and deeply wet-etched. First tests on chips packaged P-side-up, show large static extinction ratios (ER) and switching up to 40 Gb/s with an ER of more than 9 dB.

Introduction

Mach-Zehnder Interferometers (MZI) offer interesting properties for all-optical switching. Their multi-functional nature can be applied to achieve different all-optical functions: e.g. wavelength conversion, 2R regeneration, and logical functions such as a full-adder. The integration of arrays of generic switches will significantly reduce the cost per switch, and more important, the different MZIs in one package can be flexibly connected to be used for different applications.

This paper describes the design, fabrication, packaging and characterization of a monolithic integrated array of 4 MZI switches in one single InP/InGaAsP chip. For this a high yield is required.

Design

A single switch consists of an MZI with SOAs in the arms as shown in Fig. 1. 2×2 MMIs are used in the MZI to obtain a large bandwidth[1]. In both arms an additional coupler is placed to inject a pump signal into the arms. At all in- and outputs Spot Size converters (SSC) are present.

The SSC is designed to have a spotsize that matches a cleaved single mode fibre. The SSC is both vertically and laterally tapered (Fig. 1 right, [2]).

The SOAs in the arms consist of a waveguide with an active region of 8 strained InGaAs/InGaAs Quantum Wells inside a Q[1.25] waveguide layer, with a confinement factor of 0.19 for TE. The passive regions are butt-coupled to the actives using selective area LP-MOVPE.

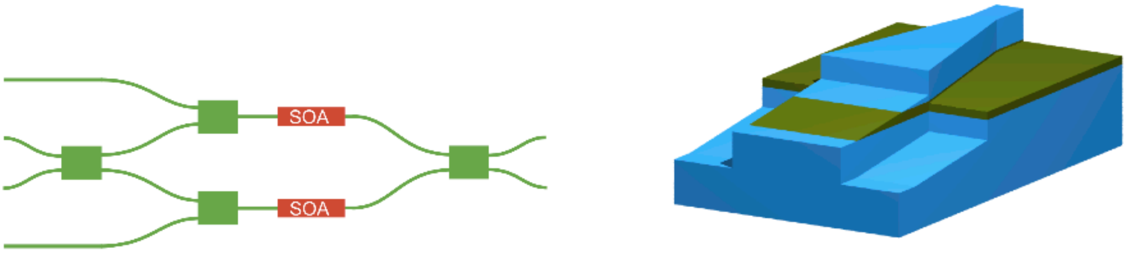

Figure 1: *Schematic overview of the SOA-MZI switch(left) and the SSC(right)*

The chips are designed for flip-chip mounting on a daughterboard. This daughterboard will be mounted on a motherboard in which fiber-assemblies are coupled to the in- and outputs of the switches similar to hybrid integration [3].

Fabrication and packaging

All waveguides are etched using a CH_4/H_2 RIE. For the flip-chip packaging 2 additional etches are needed to obtain a good vertical and horizontal alignment in the submount.
For the vertical alignment, oxide pillars are placed on the submount. On the InP chip a well-defined level is needed, the bottom of the waveguide layer is used for this. Recesses are etched into the chip using a selective wet etch.
To horizontally align the chip, the chips is pushed to stops on the submount. To ensure exact dimensions of the chip, as well as exact distance from the edge to the in- and outputs, precision cleave openings are defined lithographically at the same mask as the waveguides. The openings are deeply etched using a HCl/H_2O solution. After the chip is finished, the cleaving can be initiated at these precision openings.
The chip is kept in place by soldering the metal contacts onto thick gold solderbumps on the daughterboard, because of this, the contacts on the chip are just thin evaporated metal pads, as a good thermal and electrical contact is ensured by the solder. For a good adhesion of the metal contacts to the solder, the metal has to be planarized. Polyimide is used to passivate and planarize the contacts of the SOAs. Apart from these contacts, additional metal is present to enlarge the metal surface and thus enhance the adhesion of the chip. A photograph of the finished chip is shown in the left of Fig. 2.

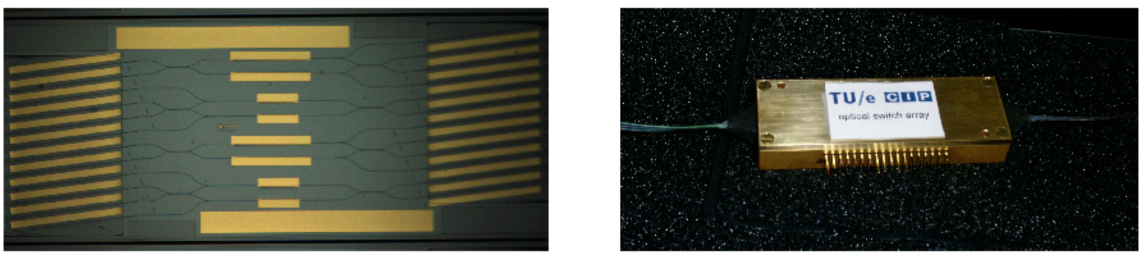

Figure 2: *Photograph of the integrated array of 4 MZI switches (left) and the packaged array (right)*

The finished chip is first mounted P-side up on a different submount. In this way the chip can be quickly packaged to assess the functioning, but an optimal performance is not possible in this case. In a flip-chip mount it is easy to get rid of the heat at the P-contact. By placing the chip P-side-up, the heat transfer is severely compromised. Furthermore the electrical contact is not good enough to obtain a good uniform injection into the SOAs. Nevertheless for the experiments shown in this article, the chip packaged in this way (Fig. 2) can be used.

Static characterization

First one of the 1250 nm long SOAs in the MZI is investigated. An LI curve and ASE spectra for different currents are measured (Fig. 3). From the spectra the wavelength at the ASE peak is obtained and plotted as function of current (Fig. 3).

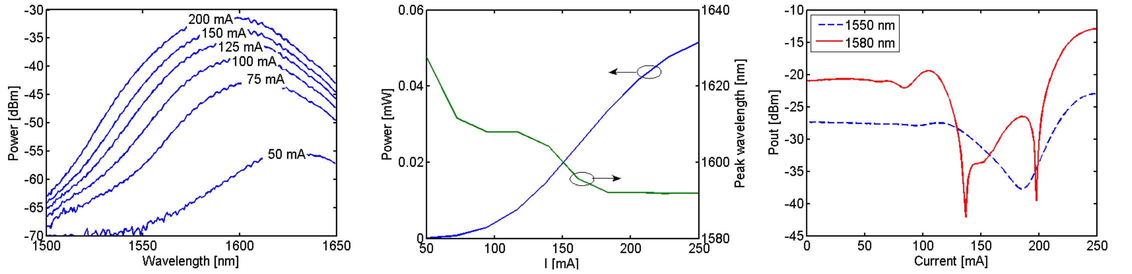

Figure 3: *ASE spectra (left), LI curve and peak wavelength as a function of current (middle), and static switching (right)*

From these graphs it can be seen that the peak wavelength shifts over approximately 40 nm because of bandfilling, but due to heating the peak cannot shift enough to obtain the peak around 1550 nm. The desired current density to completely employ the band-filling effect cannot be obtained as around 200 mA thermal roll-off starts to occur. This bad thermal behavior is most probably caused by the non-optimal mounting of the chip.
From the ASE spectra shown, it is anticipated that the device will not show proper cross-phase modulation around 1550 nm. Furthermore the gain will be low because of the low injection currents.
For testing the static switching, one SOA is biased at 200 mA, the current into the other SOA is swept. At the input, a Tunable Laser Source (TLS) is used, modulated at 1 kHz to detect the light using a lock-in amplifier. A polarization controller is used to set the polarization for maximum output power. The input power P_{probe} is set to 0 dBm.
The interference is investigated for input wavelengths of 1550 nm and 1580 nm (which is the maximum wavelength possible with the used equipment, and is closest to the gain-peak). The resulting switching is plotted in Fig. 3.
From this plot it is seen that a large extinction ratio ($\approx$ 25dB) is found for 1580 nm. For 1550 nm, the ER is limited to 14 dB. The shape of the curve for 1580 nm around 150 mA is probably caused by thermal effects. All switches are tested to be working statically.

Dynamic characterization

The dynamic performance of an MZI is investigated by using the switch as an all-optical wavelength converter. For this experiment a setup is used as shown in Fig. 4. The pump signal is obtained by modulating the short pulses ($\approx$ 5 ps) from a Mode Locked Laser (MLL) with a 10 Gb/s PRBS signal. A 40 Gb/s signal is obtained by multiplexing the 10 Gb/s signal. This signal has a wavelength of 1560 nm. The switch is operated in a push-pull configuration.
A TLS set to a wavelength of 1570 nm is used for the probe signal.

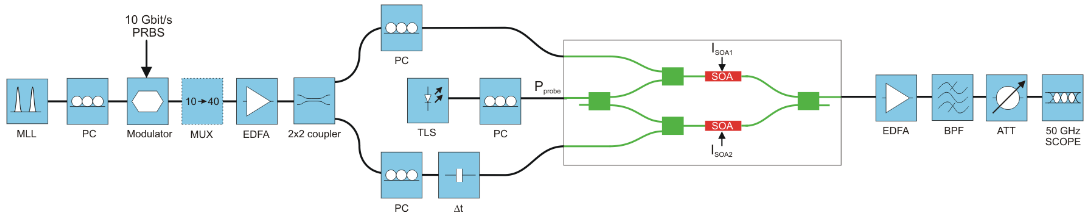

Figure 4: *Setup for testing dynamic switching of the MZI*

The resulting outputsignals for 10 Gb/s and 40 Gb/s switching are shown in Fig. 5. In the 10 Gb/s case a sequence of ones is shown. A pattern-effect is visible, but it is not very severe. An average output ER of more than 10 dB is obtained in this case.
In the 40 Gb/s case more noise is present, but still an ER of approximately 9 dB is found.

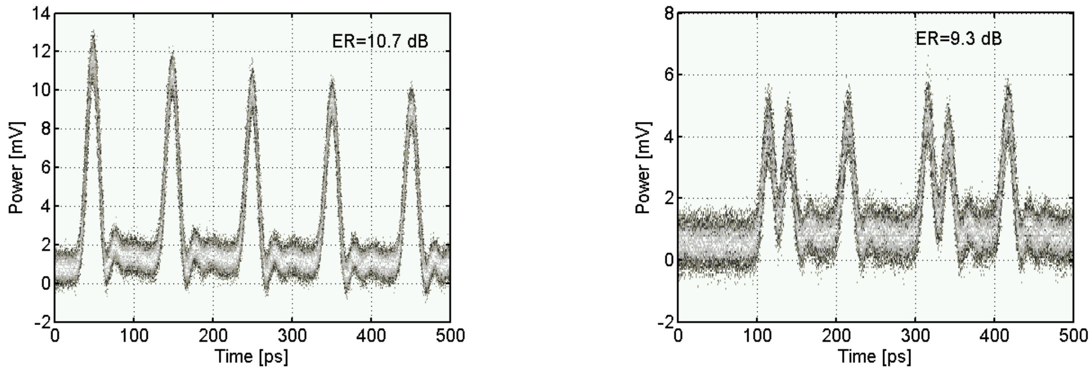

Figure 5: *output bitpattern at 10 Gb/s (left) and 40 Gb/s (right)*

Conclusions

MZI switches designed for flip-chip packaging are fabricated. Integration with SSCs, vertical and horizontal alignment features is shown. The chips are packaged P-side up to asses the function, but bad thermal behaviour is obtained. Bandfilling effect in Quantum wells is employed to achieve a blueshift of the gain peak. A maximal blueshift of 40 nm is observed, not large enough to have the peak around 1550 nm, but switching can be seen for longer wavelengths. For 1570 nm wavelength conversion at 40 Gb/s is demonstrated. All switches are working. This shows that complex integrated optical circuits can be realized with high yield.

References

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