SOI platform for high speed all optical wavelength conversion

K. Voigt[1], L. Zimmermann[1,2], G. Winzer[1], T. Mitze[1], K. Petermann[1],
J. Kreissl[3], E. Tangdiongga[4], K. Vyrsokinos[5], L. Stampoulidis[5]

[1] Technische Universität Berlin, HFT 4, Einsteinufer 25, 10587 Berlin, Germany, karsten.voigt@tu-berlin.de
[2] IHP, Innovations for High Performance, Im Technologiepark 25, 15236 Frankfurt (Oder), Germany
[3] Fraunhofer-Institut für Nachrichtentechnik, Heinrich-Hertz-Institut, Einsteinufer 37, 10587 Berlin, Germany
[4] COBRA Research Institute, Eindhoven University of Technology, NL-5612AZ, The Netherlands
[5] National Technical University of Athens, 9 Iroon Polytechniou Street, 15773 Zografou, Athens, Greece

Abstract— In this paper we present new design of an all-optical wavelength converter (AOWC) based on silicon-on-insulator platform. For that purpose we combine nonlinearities of semiconductor optical amplifiers (SOA) with high finesse Mach-Zehnder filters, available in SOI-technology.

0. Introduction

A review of recent research reveals that SOAs are a widely used tool in optical wavelength conversion, taking advantage of their nonlinearity [1, 2, 3]. There is a high integration potential of SOAs, they have high power efficiency, and, above all, the potential for ultrafast wavelength converters (> 100Gbit/s). The European project "BOOM" pursues the realization of Terabit router functionality utilizing ultrafast optical signal processing in SOAs. As part of the project, the project team works on the development of an integrated wavelength converter. The converter benefits from the combination of high speed SOAs and an underlying SOI-platform. The platform serves as a motherboard for SOA integration, and provides high quality passive optical filters. Here, the passive filter consists of two cascaded Mach-Zehnder delay interferometers (MZ-DI) with delays of 1 ps and 2 ps.

I. Principle Of Wavelength Conversion

When a fast optical pulse is applied, SOA devices show recovery times of the order of hundred picoseconds (see Fig.1). Nevertheless, high-speed wavelength converters up to 40 Gbit/s have been experimentally demonstrated [4].

In the present contribution high speed performance is achieved by using the chirped, wavelength converted light output of the SOA in combination with two MZ-DI.

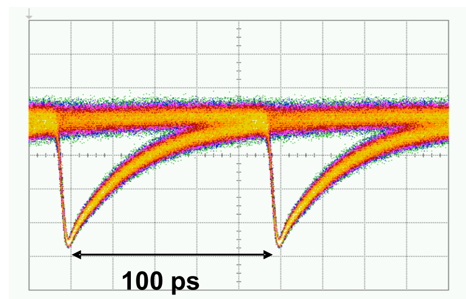

Fig.1 SOA Gain recovery curve

The working principle is as follows: An optical pulse injected into an SOA first modulates the gain. Furthermore, there is change in refractive index. This leads to chirp of the output signal – red- or blue-shifted, depending on the edge of incoming pulse. It has been shown that filtering of the red-chirped part of that output light can be used to obtain non-inverted wavelength conversion [5]. Similarly, the filtering of the blue-chirped part of output light can lead to an inverted wavelength conversion.

According to simulations, a well adjusted band pass (i.e. a well adjusted frequency transfer function at the output of the SOA) can decrease the recovery time from 90 ps to less than 3ps. In detail, various processes occur: Before saturation of the SOA, the red-chirped gain undergoes higher attenuation by the adjusted filter. This results in a reduced transmittance of incoming probe light. If the SOA starts to recover, the blue-shifted light (smaller wavelength) passes the filter, this time with higher transmission (Fig. 2). Therefore, gain saturation is balanced in case of the blue-shifted signal, so that we can achieve an increased signal level before the recovery cycle of the SOA is completed.

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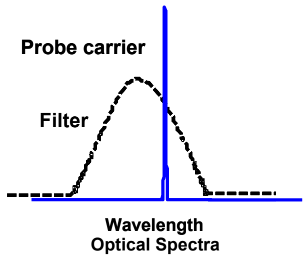

Fig.2 Blue-shifted light undergoes lower attenution by pass filter.

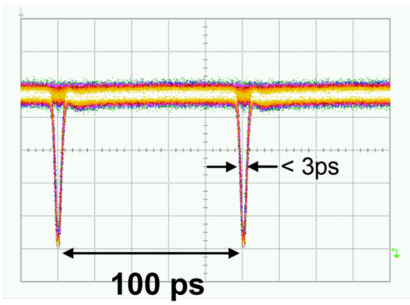

Fig.3 Probe light after passing SOA and pass filter.

As shown in figure 3, sum of the effects is a shortened pulse after passing the band pass, with approximately 3 ps full width half maximum (FWHM). Obviously the proposed system recovers much faster than the SOA gain itself. Furthermore, the experiment indicates very low energy level for operation of the system. The pump pulse energy corresponds to about 60 fJ. Note that the pulse at the output is inverted.

II. Design

The chirp filtering functionality of the proposed system can be provided by a Mach-Zehnder delay interferometer. In addition, a second MZ-DI serves as polarity inverter of the outcoming signal. It has been shown that high finesse can be achieved by cascaded interferometer systems, see e.g. [6, 7].
Figure 4 shows the complete filter configuration. The two interferometers have different filter response, i.e. free spectral range (FSR), equivalent to 1ps and 2ps time delay. The control of phase implies the extension with heater elements.

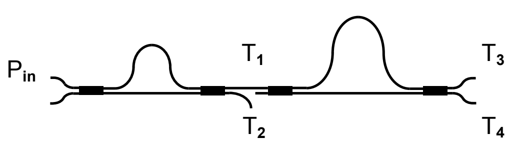

Fig.4 Filter configuration of proposed filter structure.

In our design we use 2x2 multi-mode interference (MMI) couplers with well known power and phase relations. For a single MZ-DI, the power transmission (T) at output as a function of frequency is:

$$T_1 = P_1/P_{in} \cdot \sin^2(\Delta\phi_1/2)$$

$$T_2 = P_1/P_{in} \cdot \cos^2(\Delta\phi_1/2)$$

The phase difference $\Delta\phi_1$ is defined with propagation constant β of the waveguides and the adjusted time delay in the interferometer given by a length difference ΔL_1. ($\Delta\phi_1 = \beta \cdot \Delta L_1$). For the complete device with cascaded delay interferometer we obtain transmission characteristic for output 3 and 4:

$$T_3 = P_3/P_{in} \cdot \sin^2(\Delta\phi_1/2) \cdot \sin^2(\Delta\phi_2/2)$$

$$T_4 = P_3/P_{in} \cdot \sin^2(\Delta\phi_1/2) \cdot \cos^2(\Delta\phi_2/2)$$

For case of half FSR (equal to half of the length difference) of the first MZ-DI in comparison to the second MZ-DI, we can substitute $\Delta\phi_1/2$ by $\Delta\phi_2/4$.
For better understanding of the complete interferometer structure we also split up the structure into two single devices with different FSR corresponding to delay of 1ps and 2ps. The designed chip area for a couple of single and combined structures was 10mm x 25mm.

III. Experimental Results

For fabrication of designed MZ-structures we used SOI rib waveguide technology. We used substrates with top silicon thickness of 4µm, which is very convenient in terms of packaging because it enables high coupling efficiency (~ 0.5 dB loss per facet) and reduced sensitivity to fiber misalignment. For rib definition we used standard contact lithography and reactive ion etching.
Fig. 5 shows measured filter curve for bar and cross port of structure with 2 ps time delay. Both outputs show for TE and TM polarization good homogeneity other C-band with extinction ratios up to 30 dB. The maximum loss of structure in reference to back-to-back (B2B) signal is 4.2 dB. The B2B-reference in that context respects all loss given by fiber-to-chip-coupling, additional connections and loss of the passive waveguide network. Fig. 6 shows the same measurement for single MZ-DI device with 1 ps.
Polarization dependent frequency shift (PDFS) is always an issue in planar waveguide technologies.

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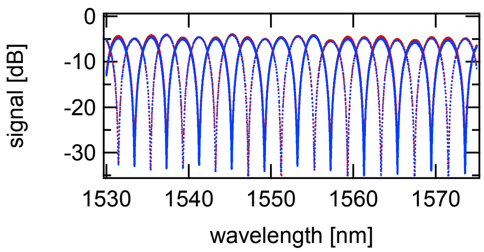

Fig.5 Filter characteristic of delay interferometer with 2ps time delay for TE (red line) and TM-mode (blue line). Solid line corresponds to bar port; dashed line to cross port.

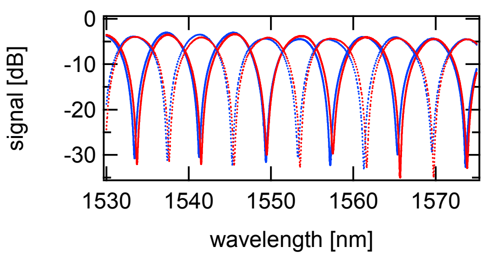

Fig.6 Filter curves of delay interferometer with 1ps time delay.

With a 2-cladding technology we could recently achieve relatively low PDFS, i.e. absolute birefringence, for the 2-ps MZ-DI. The amount of birefringence caused by rib waveguide geometry is in the range of $3{\cdot}10^{-4}$. With applied cladding, under conservation of performance, we could reduce absolute birefringence to $4{\cdot}10^{-5}$ (~ 2 GHz PDFS).

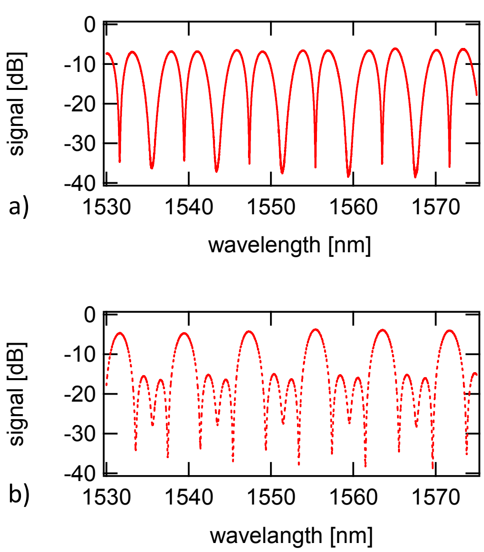

Fig.7 Filter characteristic of cascaded Mach-Zehnder delay interferometers with 1 and 2 ps time delay (TE-mode). Solid lines correspond to bar port (a); dashed line to cross port (b).

Results for cascaded devices are shown in Fig. 7. Shape of the filter characteristic for both outputs is consistent with calculated output signals. Extinction ratios are comparable to the results of single devices. The loss is slightly increased due to the doubling of involved interference couplers. As measured results show, cascaded SOI-MZ structure delivers required performance to act as proposed filter in connection with SOA. Verification experiments with discrete SOA and SOI-DIs are planned in the near future. Eventually, SOA and SOI-DIs will be integrated on a single chip. First integration tests of SOAs on SOI have been conducted. Fig. 8 shows a flip-chip soldered SOA on an SOI motherboard.

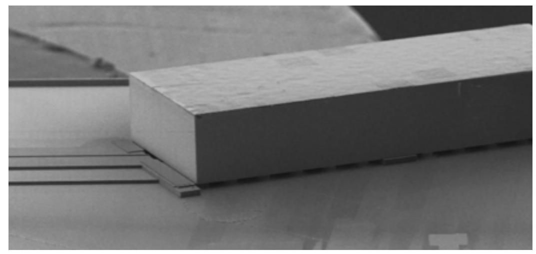

Fig.8 Flip-chip soldered semiconductor optical amplifier (SOA) on SOI motherboard.

IV. Summary

The concept for a new design of an all-optical wavelength converter (AOWC) based on silicon-on-insulator platform has been provided. Realized SOI-filters show expected filter transfer functionality with high extinction ratios (up to 30dB) and low insertion loss. First flip-chip tests have been conducted. High speed λ-conversion experiments with SOI chips and SOAs are underway.

V. Acknowledgements

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VI. References

1) M.L. Masanovic et al., "Widely tunable monolithically integrated all-optical wavelength converters in InP.", JLT, vol.23, pp. 1350-1362, 2005.

2.) Y.Miyazaki et al., "Polarization-Insensitive SOA-MZI Monolithic All-Optical Wavelength Converter for Full C-band 40Gbps-NRZ Operation.", in Proc. ECOC 2006, Th3.4.2.

3) G. Maxwell et al., "Very low coupling loss, hybrid integrated all-optical regenerator with passive assembly.", post-deadline paper PD3.5 ECOC 2002.

4) L. Stampoulidis et al, "Enabling Tb/s Photonoic Routing: "Development Of Advanced Hybrid Integrated Photonic Devices to Realize High-Speed, All-Optical Packet Switching.", IEEE Journal of Selected Topics in Quantum Electronics, vol.14, iss.3, pp. 849-860, May/June 2008.

5) H. Chayett, S. Ben Ezra, N. Shachar, S. Tzadok, S. Tsadka and J. Leuthold, "Regenerative all-optical wavelength converter based on semiconductor optical amplifier and sharp frequency respons.e", Proceedings OFC 2004, Ths2, USA, Feb 2004.

6) M. Kuznetsov: "Cascaded Coupler Mach-Zehnder Channel Dropping Filters for Wavelength-Division-Multiplexed Optical Systems.", JLT, vol. 12, nr.2, pp. 226-230, Feb. 1994.

7) S. Bidnyk et al.: "Silicon-on-Insultor-Based Planar circuit for Passive Optical Network Apllications.", PTL, vol.18, nr.22, pp. 2392-2394, Nov. 2006.

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