Numerical study of ultra-high speed wavelength conversion using a Gain-Clamped SOA in combination with optical filtering

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Abstract: Using numerical simulations, we demonstrate that wavelength conversion of 40 Gb/s and 160 Gb/s RZ signals is feasible using only a Gain-Clamped SOA (GCSOA) and optical filters. The signal is converted to the lasing wavelength of the GCSOA and no extra CW probe is thus required. The scheme is based on the optical filtering of the chirp of the lasing field induced by the input signal.

Keywords: wavelength conversion, optical filtering, GCSOA.

1. Introduction

All–optical wavelength converters are generally considered to be among the key building blocks of future high-capacity all-optical networks [1]. Several wavelength converters have therefore been presented in the past; e.g. non-linear fiber- or SOA-based interferometers, saturable absorbers and EA-modulators, …[2-4]. However, most of the solutions proposed so far are either very complex and require extensive control, or require large switching powers. Moreover, as there is trend to use bitrates of 40 Gb/s and bitrates as high as 160 Gb/s are considered for the future, many of the already proposed converters are too limited in speed.

Recently, an all-optical wavelength converter was proposed which is based on a single SOA in combination with optical filters. Wavelength conversion at 320 Gb/s was demonstrated with this set-up [5]. The simple structure in principle allows for monolithic integration and requires only small input signal levels.

Here we propose a slightly different configuration, in which the SOA is replaced by a gain-clamped SOA (GCSOA) and in which an external CW-probe is no longer necessary. In principle, the GCSOA can even be a tunable laser.

This paper is organized as follows. In the next section, we will give details of the λ-converter and explain the operation principles. In section 3, we give and discuss numerical simulation results showing conversion at 40 Gb/s and 160 Gb/s. Section 4 finally will give the conclusions of our work.

2. Scheme and operation principle of the λ-converter

The wavelength converter that we propose is schematically shown in Figure 1. A PRBS signal, consisting of short pulses is injected into a GC-SOA, which in our case is an AR-coated λ/4-shifted DFB laser diode. The output signal is then sent through 2 optical filters: one to reject the original signal wavelength and one to detect the chirp induced on the lasing wavelength of the GCSOA.

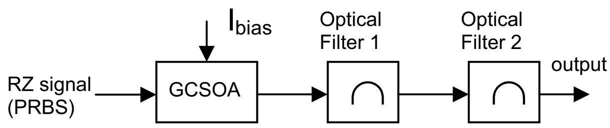

Figure 1 : Scheme of the all-optical wavelength converter

The operation principle is as follows. If the GCSOA is biased sufficiently strong and the peak power of the input signal pulses is not too high, then the GCSOA keeps lasing all the time. However, the ultra short input pulses all cause a sudden decrease of the carrier density and thus of the phase. As a result, the instantaneous frequency of the laser field exhibits large variations after each input pulse. Just as in the wavelength converter of [5] these large frequency variations are detected by an optical filter. Since also the input pulses themselves are amplified by the GCSOA, a first filter is used to suppress the amplified signal. The second optical filter is used to detect the frequency variations at the lasing wavelength. At the output, one then obtains a replica of the input pulse sequence, converted in wavelength to the lasing wavelength.

The simulations have been done using the commercial program VPITransmissionMaker from VPI. The GCSOA was a perfectly AR-coated λ/4-shifted DFB laser with length 1000 μm and κL=1 and with a bias current of 300 mA. The linewidth enhancement factor was chosen equal to 3, the confinement factor equal to 0.1 and the differential gain was 5 10^{-16} cm^2. Without optical injection, the device was lasing at 193.1 THz, with an output power given by 51 mW.

The input pulses were Gaussian pulses at an optical frequency of 195.1 THz of width 0.5-2 ps.

We used a Gaussian passband filter of 3rd order with center frequency of 193.1 THz and bandwidth 2.4 THz to reject the original signal. The frequency fluctuations of the laser field were filtered out using a Gaussian bandstop filter of order 3 with center frequency 193.055 THz and bandwidth 50 GHz. The same filters were used for 40 Gbps and 160 Gbps wavelength conversion, although one could optimise the filter for a given bitrate.

3. Numerical results and discussion

3.1 Results

Figure 2 shows the input signal at 40 Gbps, consisting of Gaussian pulses of 1 ps with peak power 30 mW. In this figure and in following figures, we only show the time window between 2 and 4 ns for reasons of clarity and such that the initial transient of the GCSOA is not included. Figure 3 shows the optical spectrum at the output. All frequencies are relative to the reference frequency of 194.1 THz.

The short pulses (shorter than the roundtrip time in the laser cavity) cause a sudden decrease of the carrier density in the laser cavity and thus a sudden decrease of the phase of the laser field. This in turn results in very short, relatively large frequency variations which can be seen in Figure 4. The magnitude of these frequency variations is a few tens of GHz. After optical filtering, these frequency fluctuations result in the wavelength converted signal shown in Figure 5.

It has to be noted that the signal in Figure 4 and 5 is slightly delayed (with about 150-200 ps) with respect to the input signal of Figure 2. This delay corresponds with the delay in the GCSOA, but also consists of delays added by the software tool. However, taking into account this delay, one can see that the wavelength converted signal is a replica of the input signal, with a power level of about 5 dB lower.

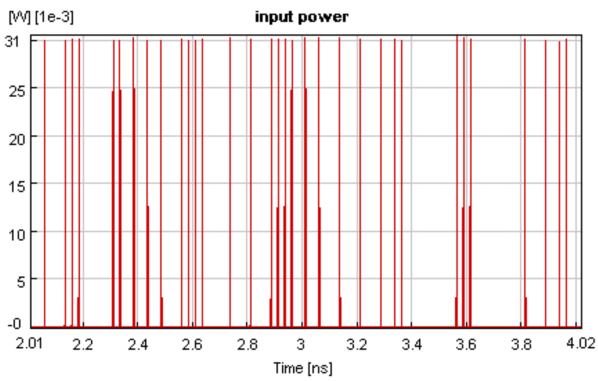

Figure 2 : Input signal of 40 Gb/s 1 ps pulses.

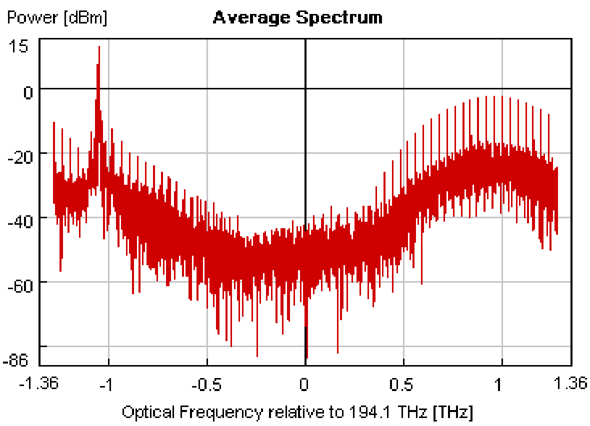

Figure 3 : Optical spectrum at the output of the GCSOA for an input signal of 40 Gb/s 1 ps pulses.

It must be remarked that the short pulses cause a sudden decrease of the carrier density to below the threshold carrier density. However, the carrier density never goes far below the threshold value and, due to the high current, it recovers so fast that the power of the lasing field never decreases very much and can keep acting as probe field.
We also want to point out that the very short frequency variations are somewhat contradictory to what one would expect based on the rate equations. From those rate equations, which are only valid on a time scale longer than the cavity roundtrip time, one would expect only a small frequency variation which is proportional with the small carrier density variation. However, on a time scale shorter than the roundtrip time, one obtains a sudden phase variation and thus a rather large frequency variation.

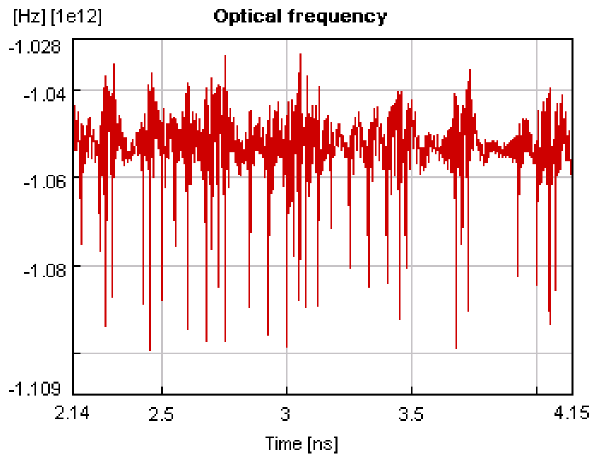

Figure 4 : Variations of the frequency of the laser field for an input signal of 40 Gb/s 1 ps pulses.

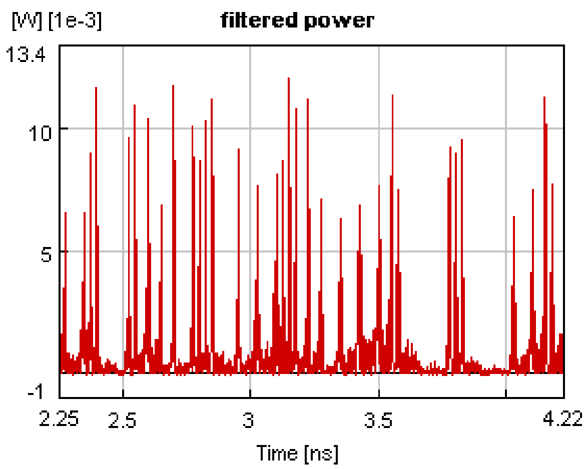

Figure 5 : Wavelength converted signal.

Using the same laser (at the same current) and the same optical filters we also succeeded in obtaining (numerically) wavelength conversion at 160 Gbps. For this bitrate however, the input optical pulses were shorter (width: 0.5 ps) and with a lower peak power of 10 mW. Figure 6 shows the input signal and Figure 7 the output signal. This time we only give a time window of 1 ns. for reasons of clarity.

One can see that there are significant patterning effects, both for 40 Gbps and 160 Gbps, which will normally result in a reduced eye-opening. These patterning effects are mainly due to the variation in laser power. It is currently being investigated whether these patterning effects can be reduced. Moreover, the output signals still have a large extinction ratio, which will allow error-less operation.

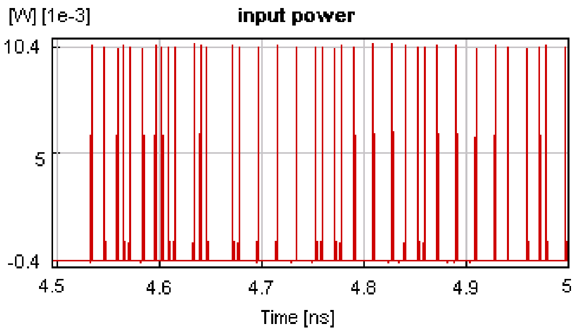

Figure 6 : Input signal for 160 Gb/s.

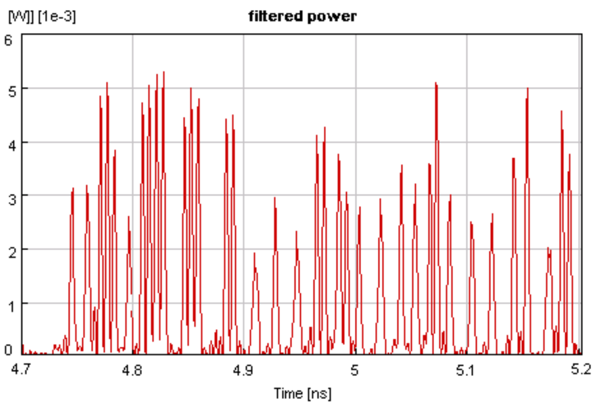

Figure 7 : Wavelength converted signal.

3.2. Discussion

In our simulations we have used a relatively long DFB-laser as GCSOA, with a relatively small threshold gain. Also a moderately low linewidth enhancement factor of 3 was used. In principle, it should be possible to optimise the GCSOA to get larger frequency variations, e.g. by aiming for a higher α-factor and/or a higher amplification in the laser cavity. The fact that a relatively long laser cavity can be used for this application implies that also several types of tunable or widely tunable laser diodes could be used as GCSOA.

Of importance is furthermore the total energy of the optical pulses. These pulses have to be sufficiently strong and short to cause the desired frequency variations. However, on the other hand their energy should be sufficiently small such that the laser field of the GCSOA doesn't switch off. In our simulations, the power of the laser field typically varied between 35 and 65 mW. It is also pointed out that the input pulses can be longer than those used above. We also could obtain wavelength conversion with 2 ps pulses for 40 Gb/s and 1 ps pulses for 160 Gb/s.

Finally, the gaussian filters of 3rd order that we used are rather realistic models of commercially available filters.

4. Conclusions

We have proposed a method for wavelength conversion of RZ signals at very high bitrates using a GCSOA in combination with optical filtering. Conversion at a bitrate as high as 160 Gbps has been demonstrated.
The method doesn't require an external CW probe beam and uses the laser field of the GCSOA as probe.
The GCSOA can in principle be any AR-coated DFB- or DBR-type laser and hence also a tunable laser could be used for conversion to a tunable wavelength.
The components that we have used in our similations have not been optimised towards high speeds and the method is thus rather robust.

5. Acknowledgment

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6. References

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7. Glossary

DBR: Distributed Bragg Reflector

DFB: Distributed Feedback

SOA: Semiconductor Optical Amplifier

GCSOA: Gain Clamped Semiconductor Optical Amplifier

PRBS: Pseudo Random Bit Sequence

CW: Continuous Wave

RZ: Return to Zero