Widely Tunable Wavelength Conversion 10 Gb/s Using a Modulated Grating Y-branch Laser Integrated with an Optical Amplifier

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Abstract: A simple integrated tunable wavelength converter is presented. 10 Gb/s XGM conversion of signals at wavelength 1530-1560 nm to 1531-1556 nm and transmission at 2.5 Gb/s over 25 km SSMF of the converted signals were achieved.

OCIS codes: (140.3600) Lasers, tunable, (230.1150) All-optical devices, (190.2620) Frequency conversion

1. Introduction

The all-optical wavelength converter is interesting as a key component for future all-optical WDM-based networks. Wavelength converters can be employed to increase the flexibility and reduce the blocking probability of the system or for all-optical switching. Key properties for a good wavelength converter are a high maximum speed, operation over a broad wavelength range and a high conversion efficiency.

Various techniques for all-optical wavelength conversion have been proposed in the literature, e.g. cross gain modulation and four wave mixing in semiconductor optical amplifiers (SOA's), cross phase modulation in active interferometers (e.g. Mach-Zehnder, Michelson), cross absorption modulation in e.g. saturable absorbers or electro-absorption modulators and several techniques making use of fiber non-linearities [1-8]. Cross gain modulation XGM in a SOA is attractive due to its simplicity and good efficiency over a broad wavelength range. The SOA can easily be integrated with a laser operating at the desired conversion wavelength that also acts as an optical source to saturate the SOA. There are several advantages using wavelength conversion in a SOA with an integrated laser. The component is compact and only one fiber needs to be aligned. Moreover, the optical saturation of the SOA can be kept constant since the optical coupling between the pump laser and the SOA is stable. With an integrated widely tunable laser diode, one obtains a monolithic device for high speed all-optical wavelength conversion within a large wavelength range. Recently, tunable wavelength conversion with an active interferometer integrated with a Sampled-Grating DBR tunable laser was demonstrated. Transmission at 2.5 Gb/s [1] and 40 Gb/s operation [2] utilizing cross phase modulation XPM were achieved. The rather complex component was about 5 mm long and utilized few integrated SOAs and phase shifter that were individually biased.

In this paper we demonstrate all-optical wavelength conversion using cross gain modulation XGM in a single and short SOA monolithically integrated with another type of widely tunable laser, a Modulated Grating Y-branch laser (MG-Y laser) [9,10]. This device is intended as a high power WDM transmitter but functions also as a tunable wavelength converter. We demonstrate 10 Gb/s operation over a large wavelength range (30 nm) for both the injected signal and the CW pump. We also demonstrate error-free transmission over 25 km of standard single mode fiber SMF-28 at 2.5 Gb/s.

2. Device and wavelength conversion setup

The component used for these experiments was designed and manufactured by Syntune AB. The chip consists of an MG-Y laser integrated with a 210µm long SOA. The necessary laser feedback is provided by an integrated front reflector (IFR); a short Bragg grating with high coupling coefficient. It gives 5% power reflectivity over a wide spectrum. The MGY-laser further consists of a 400µm gain section, a phase tuning section and a multimode interferometer (MMI) connected to two reflectors with Modulated Bragg Gratings via S-bends (Fig. 1). A wide tuning range is obtained by utilizing the additive Vernier effect by relative tuning of the two modulated gratings, each with a comb-like reflectivity spectrum. Static characteristics of similar MG-Y lasers were presented earlier in reference [9]. More than 10 mW output power into single mode fiber across a 40 nm tuning range in the C-band can be achieved with less than 1.2 dB power variation and more than 40 dB side mode suppression ratio (SMSR). The device is intended as a tunable high power WDM transmitter, for either external or direct modulation [10]. The SOA will in this scheme function as a booster amplifier. The front facet of the SOA-MG-Y laser is anti reflection (AR) coated to avoid perturbation of the lasing mode in the cavity.

The chip was mounted on a thermistor equipped AlN carrier and placed on a heat-sink. A Profile PRO8000 multichannel current source was used for individual current supply to the device sections and temperature control of the chip. The measurement setup is depicted in Fig. 1.

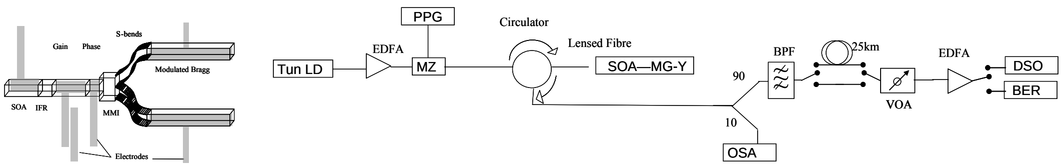

Fig. 1. A schematic view of the MG-Y laser (to the left), measurement setup for wavelength conversion experiment (to the right).

The optical signal to be wavelength converted was generated by a HP8168 tunable laser with an EDFA booster amplifier and a 10 Gb/s Mach-Zehnder modulator connected to an Advantest 3186 pulse pattern generator (PPG). The usable optical tuning range of the signal was 1530-1560 nm and the optical power was controlled by a variable optical attenuator after the modulator. The information carrying signal was coupled into the SOA-MG-Y via an optical circulator and a tapered fiber. The maximum modulated injection power level after the circulator was 11.4 dBm across the tuning range of the HP8168 laser. The output, containing both the partially reflected signal at original wavelength and the wavelength converted signal from the SOA-MG-Y was coupled through the same tapered fiber to the circulator; the outcoupling loss was around 8 dB. Assuming equal input coupling loss, the injected average power at the entrance of SOA was estimated to 3.5 dB. A small part of the total output was split-off via 10/90 coupler to an Agilent 86140B optical spectrum analyzer (OSA) for wavelength monitoring. The wavelength converted signal component was filtered out with a Santec OTF300 tunable optical band pass filter (BPF) to remove unwanted input signal wavelength. Then the signal was transmitted over a fiber link and fed to a low noise EDFA via variable optical attenuator VOA. The EDFA-amplifier was connected either to a Tektronix CSA8000 communication signal analyzer (DSO) for eye-diagram investigation, or to a 12.5 Gb/s detector followed by an Advantest 3286 BER analyzer (BER) for the transmission experiment. The EDFA limited the usable short wavelength range of the converted signal to 1530 nm. It should be noted that there was no optical filter between the optical amplifier and the detector; thus the spontaneous emission of the EDFA contributed somewhat both to the noise and the optical signal levels.

3. Experimental results

The currents provided to the gain section of the laser and the SOA were fixed during the test, with I_{SOA} ~ 70 mA, I_{GAIN} ~ 50 mA; only the tuning currents to each passive section were changed. The gain peak of the SOA at this current was around 1550 nm. The modulator was fed at 2.5 Gb/s and 10 Gb/s with a non-return-to-zero (NRZ) pseudo-random-bit-sequence (PRBS) with word length 2^{31}-1. The power of the converted signal on the exit of the SOA was in range of 4.5 dBm compared with estimated 3.5 dBm of the input to the device.

In the SOA-MG-Y the injected signal is amplified by the SOA and partially reflected by the integrated front reflector before it enters the laser. The wavelength conversion due to cross gain modulation (XGM) occurs hence twice in the SOA and additionally in the laser. On entrance into the SOA the injected beam is counter-propagating with the output beam whereas, after the reflection by the front reflector, it is co-propagating with the output beam. The increased interaction length improves the efficiency of the wavelength conversion, although the counter-propagating XGM exhibits significantly lower bandwidth compared to the co-propagating one [6]. The achieved conversion efficiency, defined as the ratio between the modulation index of the output signal to the modulation index of the input signal ranged from 20% to 73%. The conversion efficiency decreases when the separation of the pump- and probe-wavelengths increases and is higher for down-conversion than for up-conversion [7]. The conversion efficiency was found virtually independent of the polarization of the injected light. The extinction ratio and the conversion efficiency at a certain wavelength can be improved by optimizing the injected signal and the bias currents of the device. Further improvement can be achieved by filtering away the amplified spontaneous emission originating from the pre-amplifier EDFA before detection.

A 25 km transmission link experiment was performed at 2.5 Gb/s. A single mode optical fiber (SMF28) was inserted between the optical filter and the receiver unit that included an EDFA pre-amplifier. BER-measurements were performed for different input and output wavelengths within the usable tuning ranges 1530-1560 nm of the signal laser and 1531-1556 nm of the MG-Y laser. Example of BER curves are presented in Fig. 2a. No BER floor could be seen and the transmission power penalty was below 2 dB for all sets of input and output wavelengths. The measured conversion penalties were 4.5dB and 7dB at 2.5 Gb/s and 10 Gb/s operation speed, respectively. Figure 2b and 2c present the optical output spectra and eye diagrams for wavelength conversion at 10 Gb/s operation with NRZ PRBS (word length 2^{31}-1). The extinction ratio of the wavelength converted signal was around 2-3 dB compared to 5.5 dB for the injected signal from the modulator.

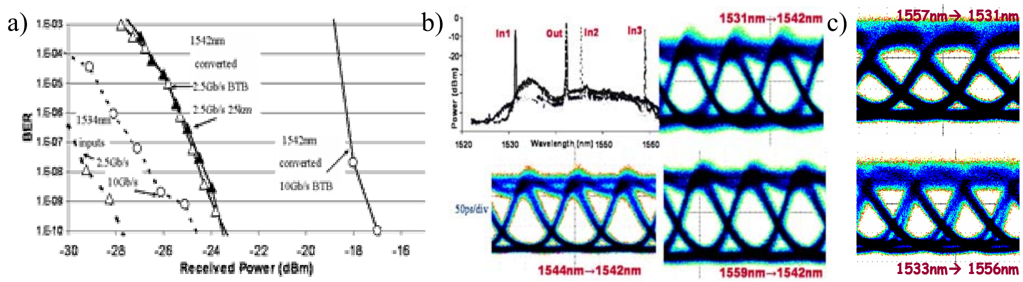

Fig.2. a) Typical BER curves of wavelength converted signals (solid lines) at 2.5 Gb/s back-to-back (open marks) and after 25 km (solid marks) transmission link and 10 Gb/s back-to-back. Curves correspond to conversion from 1534 nm to 1542 nm. The BER-curves of the injected signal for 2.5Gb/s and 10 Gb/s are presented by dashed lines with marks open triangles and open circles, respectively. b) Output spectra and eye diagrams of 10 Gb/s wavelength conversion of three different input wavelengths to 1542 nm output wavelength using integrated SOA-MG-Y device. c) Eye diagrams of 10 Gb/s up- and down-conversion of extremes wavelengths using integrated SOA-MG-Y device.

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4. Conclusions

All-optical wavelength conversion utilizing cross gain modulation XGM in a semiconductor optical amplifier (SOA) integrated with a widely tunable MG-Y laser was demonstrated. A 10 Gb/s signal with wavelength 1530-1560 nm was up or down converted to any wavelength within the range 1531-1556 nm with 20%-73% conversion efficiency. In addition error-free transmission at 2.5 Gb/s over 25 km of standard fiber was achieved. The 210 µm long SOA was continuously saturated (either only by CW light from the MG Y or combined with additional injection from the opposite direction) and exhibited high speed fully optical signal conversion of high power signals. The conversion was virtually independent on the polarization.

5. References

[1] M.L. Măsanović , V. Lal, J.A. Summers, J.S. Barton, E.J. Skogen, Lavanya, G. Rau, L.A. Coldren, and D.J. Blumenthal, "Widely Tunable Monolithically Integrated All-Optical Wavelength Converters in InP" IEEE JLT, Vol. 23, No. 3, March 2005 pp1350-1361

[2] V. Lal, M.L. Măsanović , J.A. Summers, L.A. Coldren, and Daniel J. Blumenthal, "Performance Optimization of an InP-Based Widely Tunable All-Optical Wavelength Converter Operating at 40Gb/s" IEEE PTL, Vol. 18, No. 4, February 2006 pp577-579

[3] A.E. Kelly, A.D. Ellis, D. Nesset, R Kashyap and D.G. Moodie "1OOGbit/s wavelength conversion using RNM in an MQW semiconductor optical amplifier" IEE Electronics Letters Vol. 34 No. 20, 1955-1956 (1998)

[4] C.C. Wang, R.S. Tucker "Tunable optical wavelength converters with reconfigurable functionality", IEEE Journal of Selected Topics in Quantum Electronics, Vol. 3 , No. 5, Oct. 1997 pp. 1181 – 1189

[5] M.-Y. Jeon, D.S. Lim, H.K. Lee, J.T. Ahn, D.I. Chang, K.H. Kim, "All-optical wavelength conversion scheme based on 20 Gb/s RZ data" CLEO 2000 San Francisco 2000, pp. 278-279

[6] J. Mørk, M. L. Nielsen and T.W. Berg "The Dynamics of Semiconductor Optical Amplifiers, Modeling and Applications" OSA Optics and Photonics News, June 2003, pp. 42-48

[7] INPHENIX application instruction "The Enhanced Functionalities of Semiconductor Optical Amplifiers and their Role in Advanced Optical Networking" September, 2004 http://www.inphenix.com/pdfdoc/Application_Notes_for_SOAs.pdf

[8] H.Yasaka, H. Sanjoh, H. Ishii, Y. Yoshikuni, K.Oe,"Finely Tunable Wavelength Conversion of High Bit-Rate Signals by Using a Superstructure-Grating Distributed Bragg Reflector Laser" IEEE JLT Vol 15, n 2, February, 1997, pp 334-341

[9] J.-O. Wesström, G. Sarlet, S. Hammerfeldt, L. Lundqvist, P. Szabo, P.-J. Rigole, "State-of-the-art performance of widely tunable modulated grating Y-branch lasers," OFC OSA, Washington, DC, 2004, TuE2.

[10] Marek Chaciński, Mats Isaksson, and Richard Schatz, "High-Speed Direct Modulation of Widely Tunable MG-Y Laser" IEEE PTL 17, 1157-1159 (2005)