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13. ABSTRACT *(Maximum 200 words)*

The objective of this program is to investigate multichannel, multiwavelength switching via four-wave mixing in semiconductor optical amplifiers. We have successfully demonstrated and modeled two channel switching within a single amplifier for the first time. Bit error rate and power penalty measurements are reported as well as techniques to increase channel capacity using Gain Clamping Techniquer.

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AFOSR FINAL TECHNICAL REPORT

Grant Number F49620-96-1-0168

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1. Objective:

The objective of this program was to investigate multichannel multiwavelength switching via four-wave mixing (FWM) in semiconductor optical amplifiers to independently control the switching of simultaneous wavelength channels.

2. Status of effort:

We have demonstrated and modeled simultaneous multichannel/multiwavelength conversion of two 2.5 Gbps data channels using two spectrally segmented FWM process within a single semiconductor optical amplifier (SOA). We have implemented several numerical simulation and analytical models for multiwave propagation in SOAs that account for wavelength dependent gain asymmetry, saturation power and small signal modulation. Our results show that multiple FWM process may be generated simultaneously with reasonable crosstalk performance for 10^{-9} BER using holding beams to strongly saturate the SOA. These results hold promise for highly functional multichannel switching within single nonlinear devices like SOAs.

3. Accomplishments/New Findings:

We have demonstrated that simultaneous, independently controlled wavelength conversion of two digital channels is possible using four-wave mixing in a single semiconductor optical amplifier. We have also identified the use of a holding beam to "clamp" the gain of the optical amplifier to reduce crosstalk due to cross-gain modulation. This result is significant in the field of wavelength conversion and switching using nonlinearities in SOAs as it demonstrates that information may be spectrally segmented and processed/switched independently in a single device. This result is one of the intended objectives for our original proposal and allows complex information processing and switching systems to be folded into highly functional devices. The FWM wavelength switching operation is independent of bit-rate and format and allows upgrade of data path without additional energy expenditures.

This result has potential application to Air Force mission in terms of high performance communications and computing technologies. The potential Air Force and civilian technology applications include switching fabrics for low temperature supercomputers, distributed switching systems for computing and telecommunications, and high performance information processing elements for ultra high throughput data reduction.

A dual-pump/dual-probe configuration was used to demonstrate independent switching, where each four-wave mixing process is located in a different portion of the amplifier optical gain spectrum. Bit error rates of better than 10^{-9} for two 1 Gbps channels were measured over a large range of input pump powers. The influence of the input pump powers on bit error rate for each channel is investigated. The experimental setup is shown in Figure 1. Each of the two FWM processes was driven by a single pump and single probe wavelength.

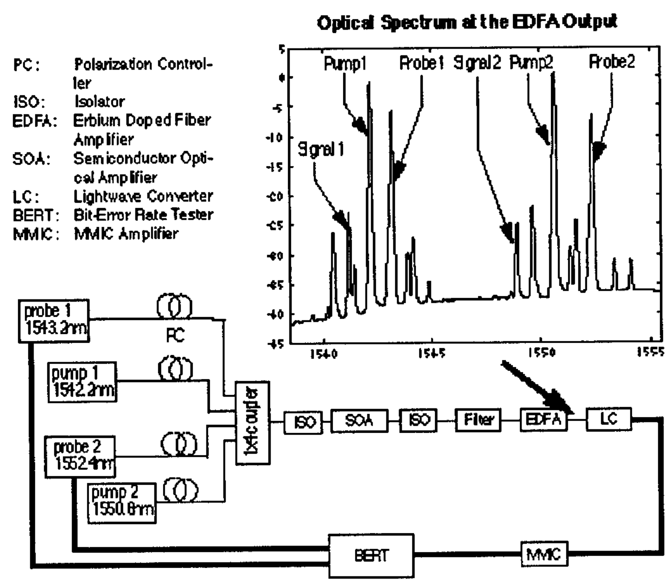


Figure 1. Experimental setup for 2 independent FWM spectrally segmented conversions.

We successfully recovered both wavelength converted PRBS at λ_{s1} and λ_{s2} with Q factors of 11.3 and 12.3 as shown in the eye diagrams in Figure 2. The eye diagrams are inverted and signal dependent noise at the high bit level (low voltage level) is a result of the signal-spontaneous beating at the EDFA output.

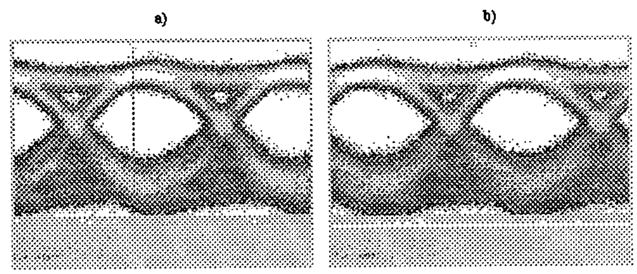


Figure 2. Successful recovery of independent FWM converted signals at 2.5 Gbps.

We measured the BER of the converted signals as a function of both input pump powers. The combined measured BER for simultaneous conversion of two independently controlled channels is shown in Figure 3. This figure shows contours of equal BER as a function of the pump powers for both channels. A BER contour of e.g. 10^{-9} means that the BER for both channels is less than 10^{-9}. From this figure it can be seen that to obtain a BER better than 10^{-9} for both channels, the input pump powers must be larger than P_{p1} = -7 dBm and P_{p2} = -6.5 dBm.

It can also be seen from Figure 3 that the four switching states using two pumps for control are indicated by the subfigures in the four corners. The related regions of the BER contour plots indicate that best performance is achieved when both pumps are on. This means that the predominate crosstalk mechanism is crossgain modulation that is suppressed when the amplifier is heavily saturated.

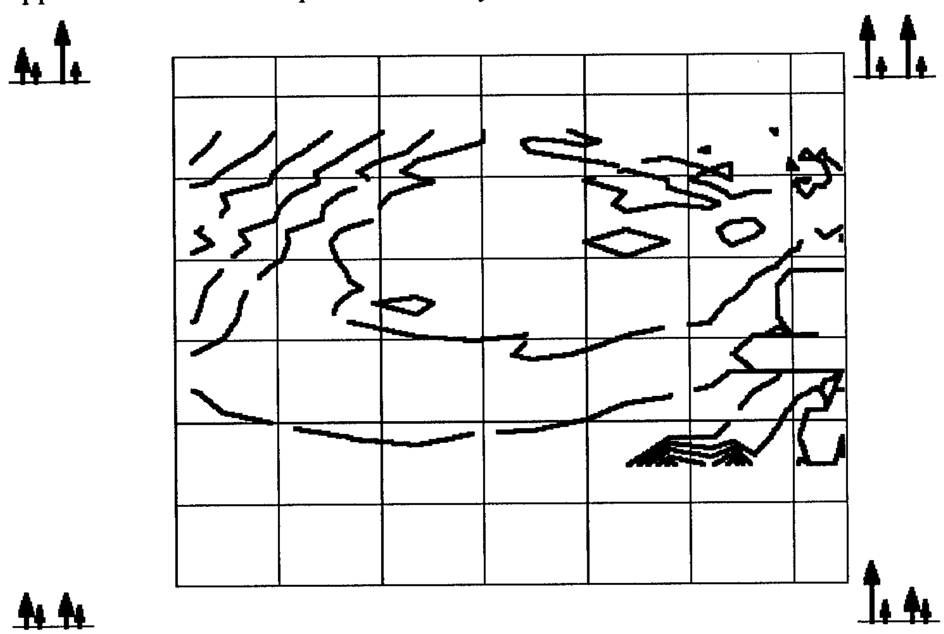


Figure 3. Worst case bit error rate (BER) contours for both wavelength converted channels as a function of pump powers for each FWM process.

We have also wavelength converted a single channel with a bit rate of 12.5 Gbps using FWM in SOAs as shown in the filtered received eye diagrams in Figure 4.

Multichannel conversion was also demonstrated for four 2.5 Gbps channels using a single pump and tunable optical filter at the output. The input and output eye diagrams for each channel are shown in Figure 5.

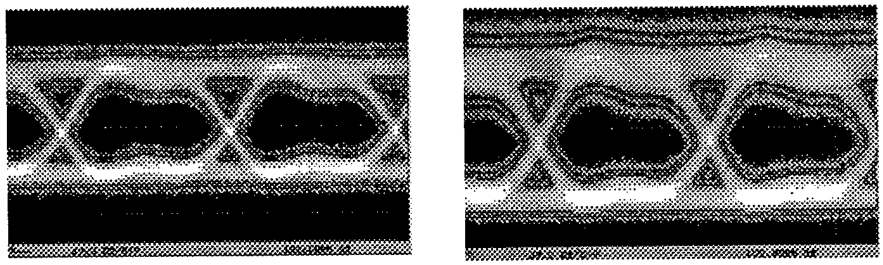


Figure 4. Single channel wavelength switching of a 12.5 Gbps channel. Left side is input, right side is FWM converted.

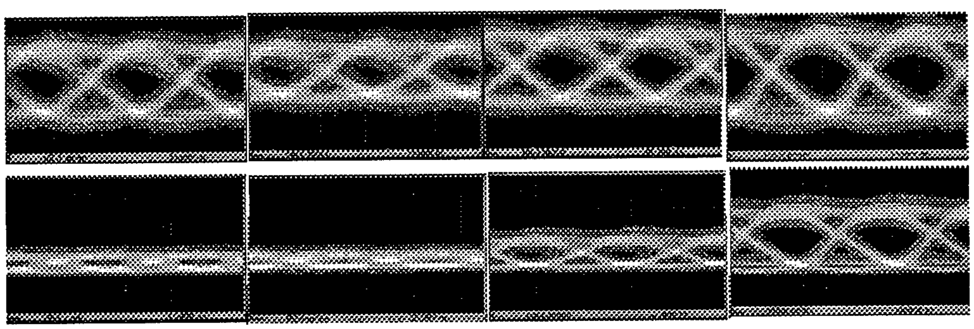
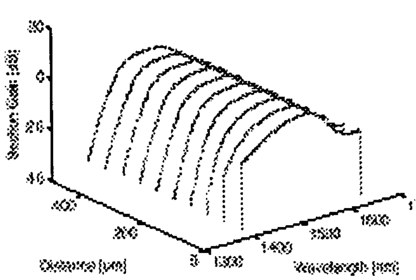


Figure 5. FWM conversion of four 2.5 Gbps channels with a single pump. Upper eye diagrams are inputs and lower eye diagrams are filtered outputs.

Numerical simulation models, based on discrete time/space coupled nonlinear equations, were developed to allow us to include wavelength and propagation distance gain and gain saturation effects. The wavelength dependent gain as a function of distance in the SOA is shown in Figure 6. The gain dependence of wavelength as a function of injection current is shown in Figure 7. These curves illustrate the effect of gain saturation and distributed amplification on gain flattening and gain peak shifting, parameters essential to understanding multichannel FWM process in SOAs.



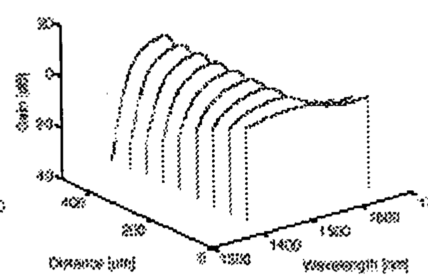


Figure 6. Wavelength dependent gain as a function of distance in the SOA.

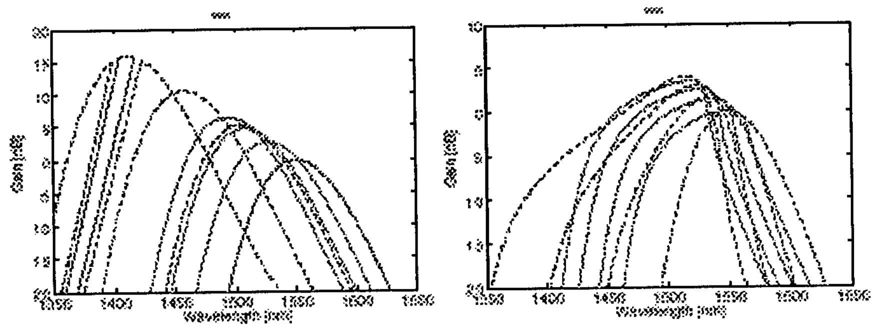


Figure 7. Wavelength dependence of gain as a function of injection current.

4. Personnel Supported:

- **Graduate Students:** Chris Scholz
- **Research Engineer:** Laurent Dubertrand
- **Postdoctoral Fellow:** Nitin Kothari
- **Faculty:** Daniel J. Blumenthal

5. Publications:

[1] C. J. Scholz, L. Dubertrand and D. J. Blumenthal. Two Independently Controlled Wavelength Conversions Using Four-Wave Mixing in a Single Semiconductor Optical Amplifier. Submitted for publication in *IEEE Photonics Technology Letters,* 1997.

[2] C. J. Scholz, L. Dubertrand and D. J. Blumenthal. Demonstration of two Simultaneous Independently Controlled Wavelength Conversions Using a Novel Dual-Pump/Dual-Probe Four Wave Mixing Configuration. To be presented at the *LEOS 10th Annual Meeting*, San Francisco, Nov., 10--13, 1997

[3] C. J. Scholz and D. J. Blumenthal. The Influence of Wavelength Dependent Distributed Gain on the Optical Bandwidth of Semiconductor Optical Amplifiers. To be presented at the *LEOS 10th Annual Meeting*, San Francisco, Nov., 10--13, 1997

[4] N. C. Kothari and D. J. Blumenthal, "Influence of gain saturation, gain asymmetry, and pump/probe depletion on wavelength conversion efficiency of FWM in semiconductor optical amplifiers," *IEEE Journal of Quantum Electronics*, Vol. 32, No. 10, pp. 1810-1816, Oct. 1996.

[5] D. J. Blumenthal and N. C. Kothari, "Semiconductor Optical Amplifiers," Chapter 61, The Communications Handbook, Eds. J. D. Gibson, CRC Press Inc., 1996.

6. Interactions/Transitions:

a.

Guest Editor	IEEE Journal of Lightwave Technology	1998
Program Committee	Optical Fiber Communications Conf.	1997, 1998, 1999
Program Committee	OSA Top. Mtng. on Photonics in Switching	1997
Program Committee	IEEE/LEOS WDM Component Technol.	1997

Invited Talk: D. J. Blumenthal, "Coherent Crosstalk in Photonic Switched Networks," Topical Meeting on Photonics in Switching, April 1-4, Stockholm, 1997.

Invited Talk: D. J. Blumenthal, "Physics and applications of semiconductor optical amplifiers," IEEE/LEOS Annual Meeting, Nov. 18-21, Boston, 1996.

b.

Naval Research Laboratory: Invited seminar on multiwavelength communications, switching, tunable lasers and microwave photonics. April 21, 1997. Joe Weller and Ron Esman.

7. New discoveries, inventions, or patent disclosures.

None

8. Honors/Awards:

Young Investigator Award	Office of Naval Research	1997
Associate Editor	IEEE Photonics Technology Letters	1997