Implementation of All-Optical Logic AND Gate using XGM based on Semiconductor Optical Amplifiers

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INTRODUCTION

All-Optical logic Gates

1) ***Based on Fiber***

Terahertz Optical Asymmetric Demultiplexer (TOAD)

Nonlinear Optical Loop Mirror (NOLM)

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- **High speed (100Gbps)**
- **Less compactness**
- **Less integration possibility**

2) ***Based on Semiconductor Optical Amplifiers (SOAs)***

1) *Four Wave Mixing*

2) *Cross Phase Modulation (XPM)*

3) ***Cross Gain Modulation (XGM)***

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- **Low speed**
- **More Compactness**
- **More Integration possibility**

Currently Known Logic Gates

Logic	Gate Implementation	Remarks
AND	Integrated SOA-based IWC [MZI]	20 Gbps [01]
	FWM in SOA	10 Gbps [95]
	Nonlinear Optical Loop Mirror in fiber (NOLM)	2.5 Gbps [98]
	Nonlinear transmission in EAM	10 Gbps [01]
	SOA based UNI	100 Gbps [98]
OR	SOA based UNI	10 Gbps [00]
	Monolithically integrated IWC [MI]	10 Gbps [96]
XOR	SOA fiber Sagnac gate	10 Gbps [99]
	Fiber-based UNI	40 Gbps [02]
	SOA-based UNI	20 Gbps [00]
	SOA-based cross-polarization modulation	5 Gbps [01]
	Integrated SOA-based IWC [MZI]	40 Gbps [03]
	Integrated SOA-based IWC [MI]	10 Gbps [01]
NAND		
NOR	SOA (XGM)	10 Gbps [02]
	Two-section SOA (0.5 +1.5mm)	5 Gbps [99]
NXOR	Integrated SOA-based IWC [MZI]	10 Gbps [01]

Why Logic Gates based on XGM?

- **Higher compactness compared to UNI and TOAD**
- **Simple and Stable compared to other optical logic gates**
- **Potentially independent on polarization and wavelength**
- **Potentially transparent**
- **Integration capable**
- **Low switching energy**

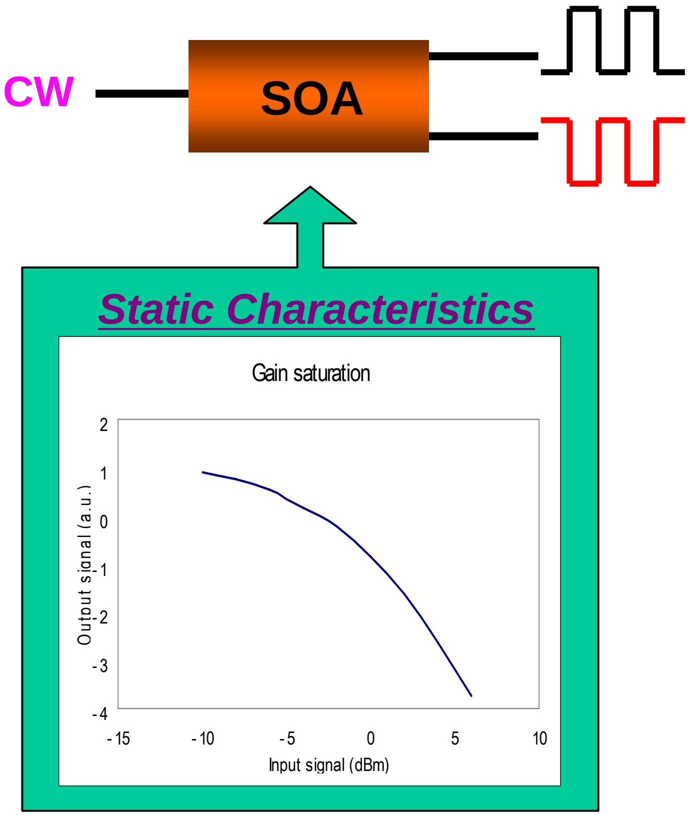
A Comparison of the performance among the XOR gates using various schemes

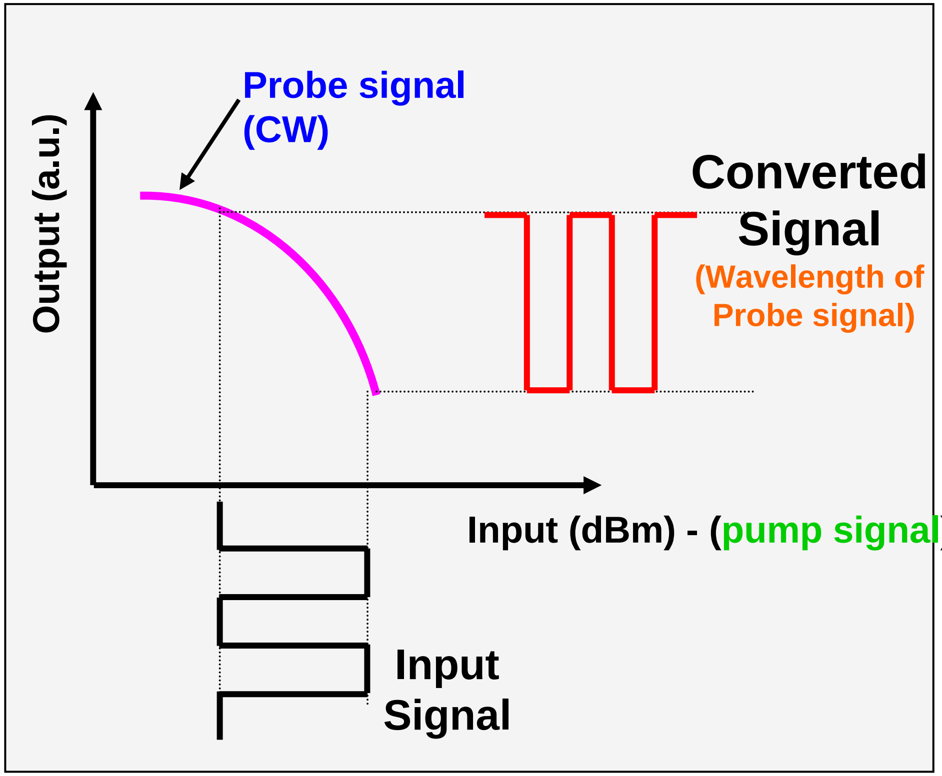
XOR Type	Performance	Contrast ratio at 10Gb/s	Repeated Operation speed	Energy	No. of SOA(s)	Bit-pattern Dependence	Polarization Sensitive	Integration Potential
XOR Based-on Kerr Effect in Fiber	NOLM-based XOR	10dB	100Gb/s	High	0	Very low	No	Weak
XOR Using Nonlinear Effects in SOA itself	XOR Using CPM in SOA	Poor	5/10/20Gb/s	Moderate	1	High	Very	Strong
	XOR Using FWM in SOA	20dB	2.5/10/20Gb/s	Low	1	Low	Yes	Strong
	XOR Using XGM in SOA	**11dB**	**5/10Gb/s**	**Moderate**	**1 or 2**	**Low**	**Not so**	**Strong**
XOR Based on SOA-Assisted Fiber Interferometer	TOAD-based XOR	11dB	10Gb/s	Moderate	1	Moderate	Yes	Weak
	UNI-based XOR		20/40Gb/s	Low	1	Low	Yes	Weak
XOR Based-on SOA-Assisted Integrated Interferometer	XOR Using XPM in SOA-MZI	13~15.5dB	10/20/40Gb/s	Low	2	Low if with Differential Scheme	Yes	Strong
	XOR Using XGM in SOA-MZI			Moderate	2	Low if with Differential Scheme	No	Strong

Min Zhang, Ling Wang, Peida Ye, "All optical XOR logic gates: technologies and experiment demonstrations, IEEE Communications Magazines, 43, 19-24(2005).

XGM Wavelength Conversion?

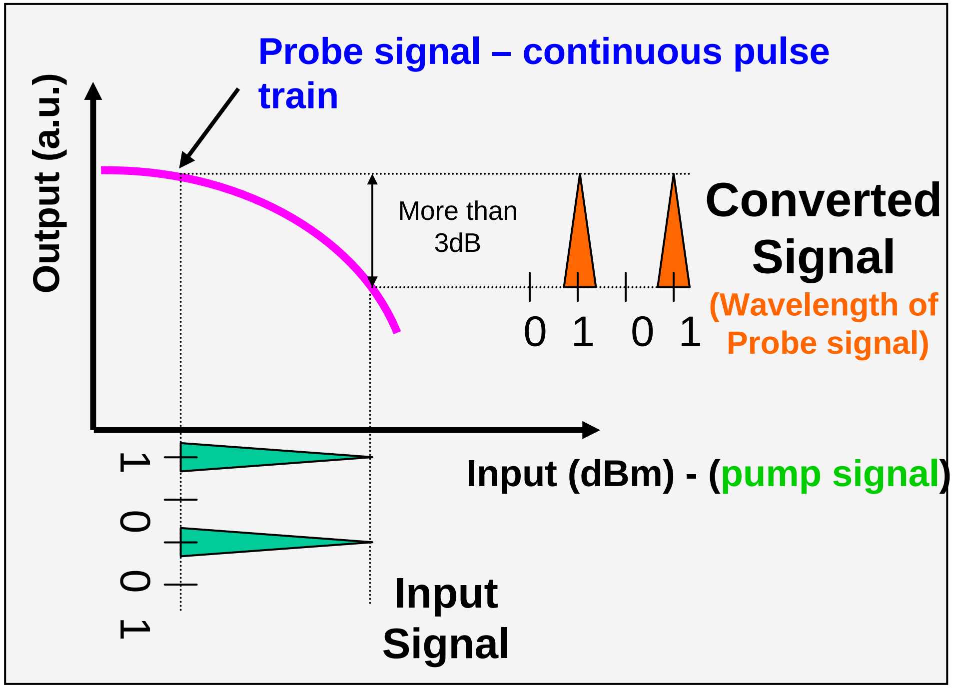
NRZ signal at Low Speed





XGM Wavelength Conversion

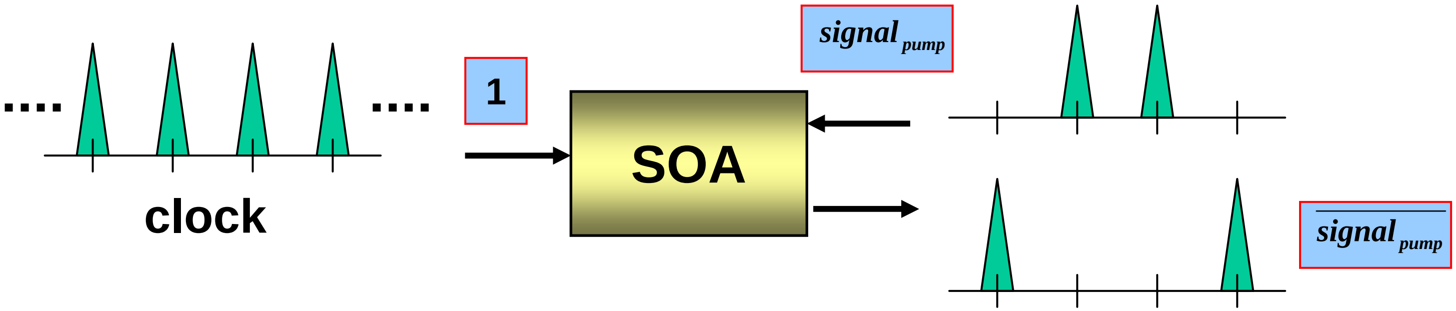
RZ signal at High Speed



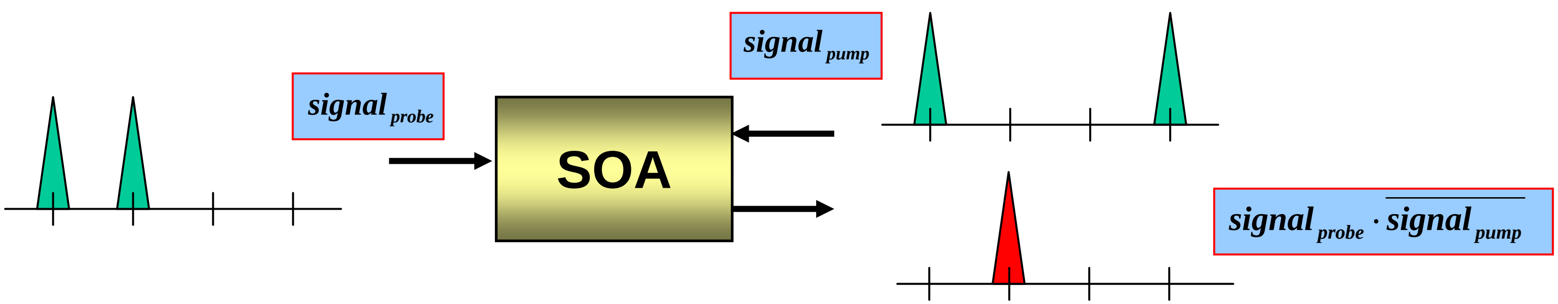
Cross gain modulation?

The carrier density changes in SOA a signal at one wavelength affect the gain of signal at another wavelength using carrier density change in SOA.

All-optical Logic Functions Using XGM

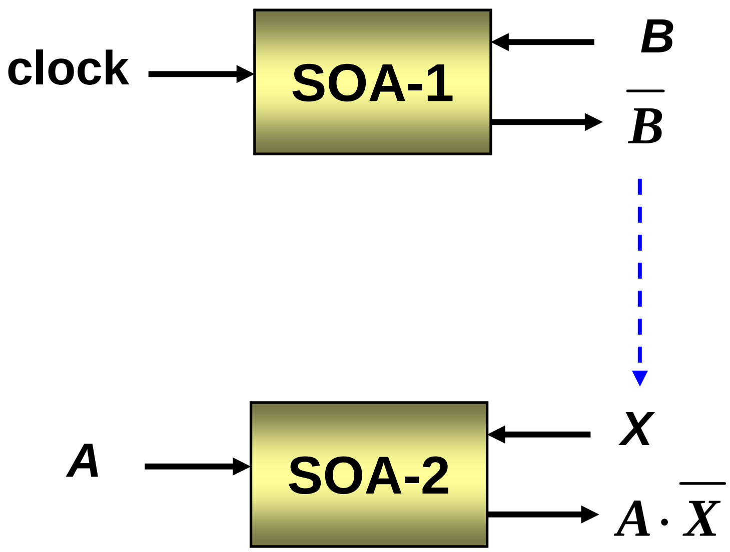


$$Boolean\ Function\ of\ SOA_{probe,pump} = 1 \cdot \overline{signal_{pump}} = \overline{signal_{pump}}$$



$$Boolean\ Function\ of\ SOA_{probe,pump} = signal_{probe} \cdot \overline{signal_{pump}}$$

Previous All-Optical AND Gate



$$\text{Output}_{SOA-1} = \text{Clock} \cdot \overline{B} = \overline{(B)}$$

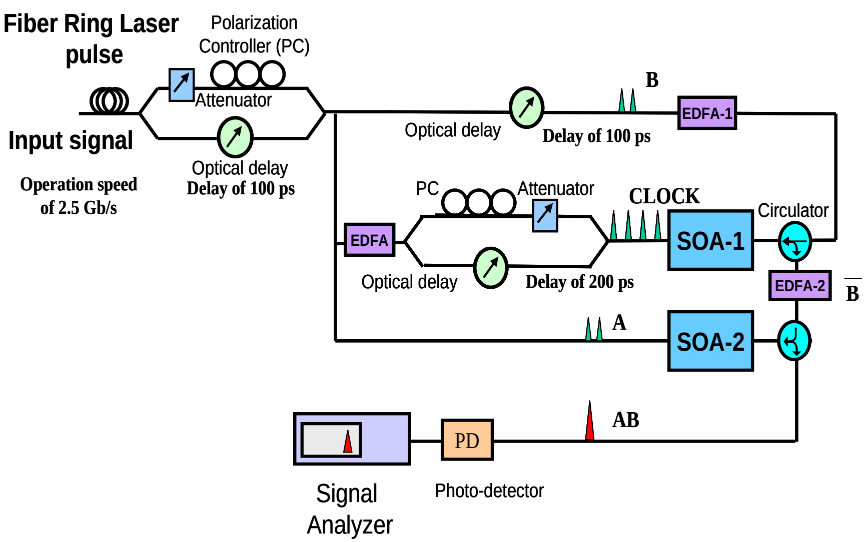
$$\text{Output}_{SOA-2} = A \cdot \overline{X} = A \cdot \overline{(\overline{B})} = A \cdot B$$

It requires 3 input signals!!!!!!

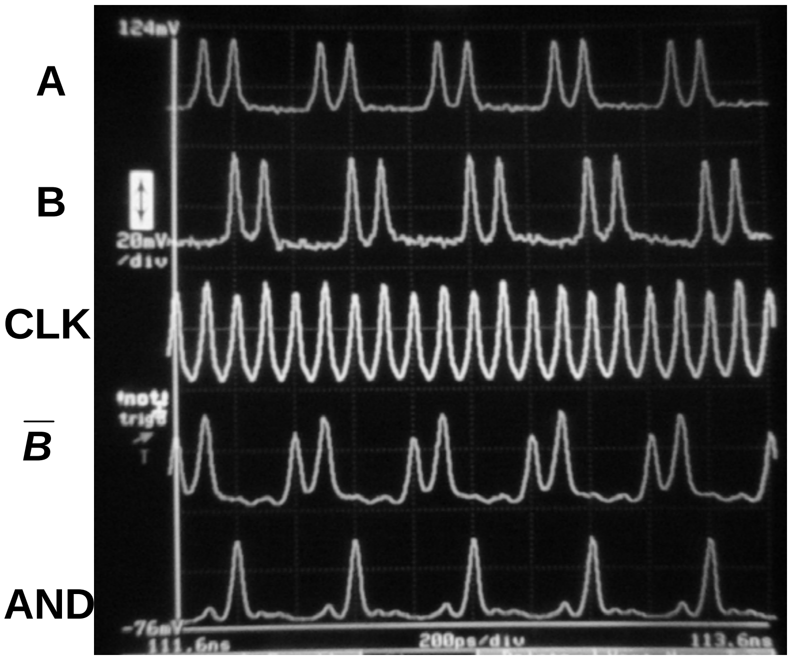
J. H. Kim et al., "All-Optical AND Gate Using Cross-Gain Modulation in Semiconductor Optical Amplifiers," Jpn. J. of Appl. Phys. 43, 608-610 (2004).

Previous Experimental Setup

Setup for All-Optical logic AND

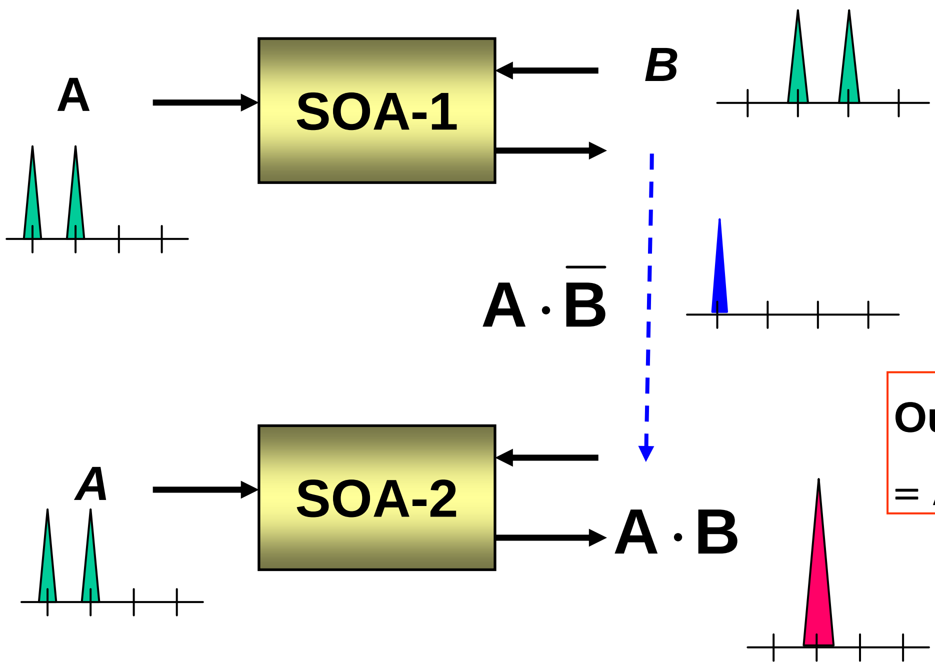


10Gbps All-Optical logic AND



J. H. Kim et al., "All-Optical AND Gate Using Cross-Gain Modulation in Semiconductor Optical Amplifiers," Jpn. J. of Appl. Phys. 43, 608-610 (2004).

New AND without Clock Signal

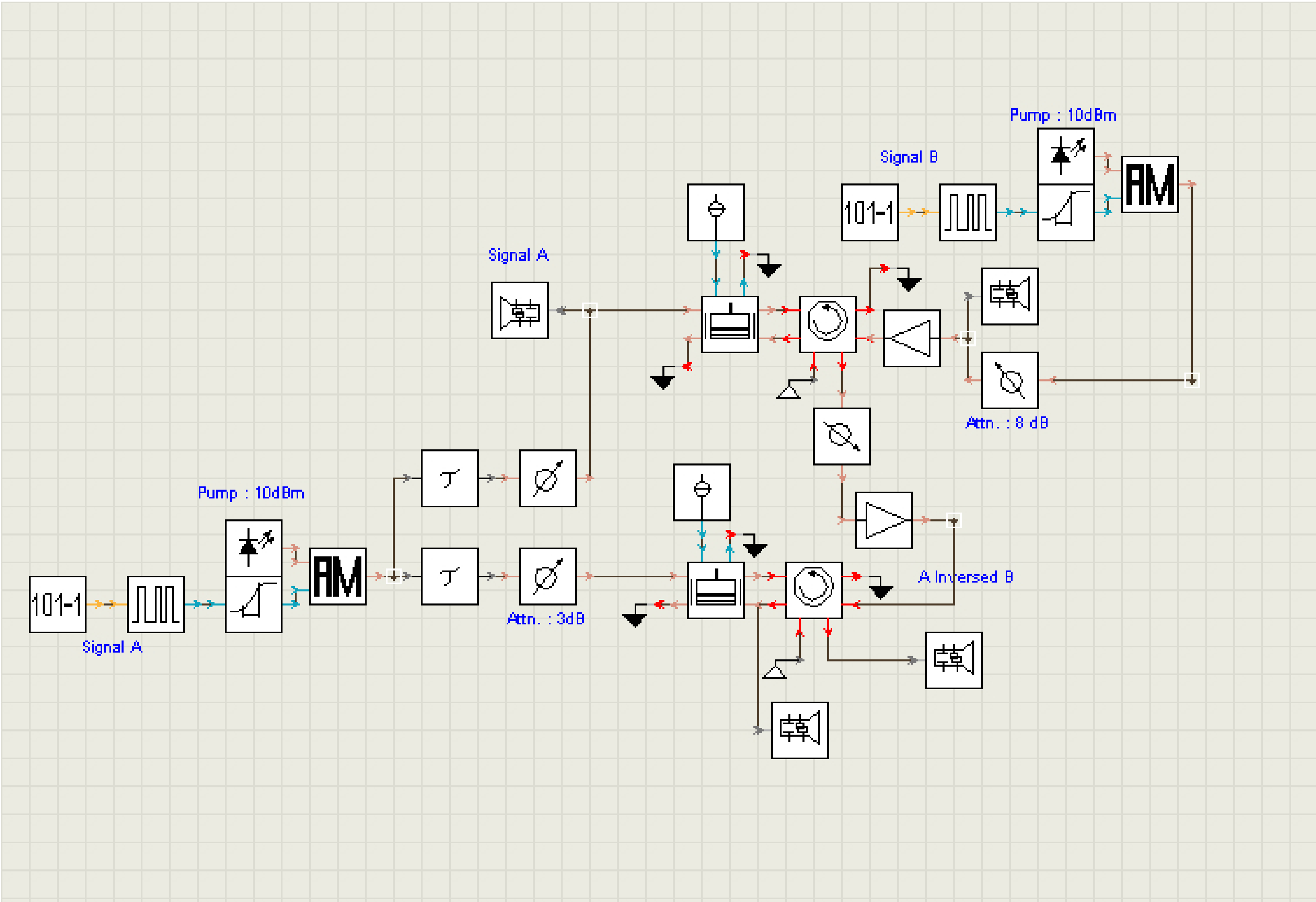


$$\text{Output}_{SOA-1} = A \cdot \overline{B}$$

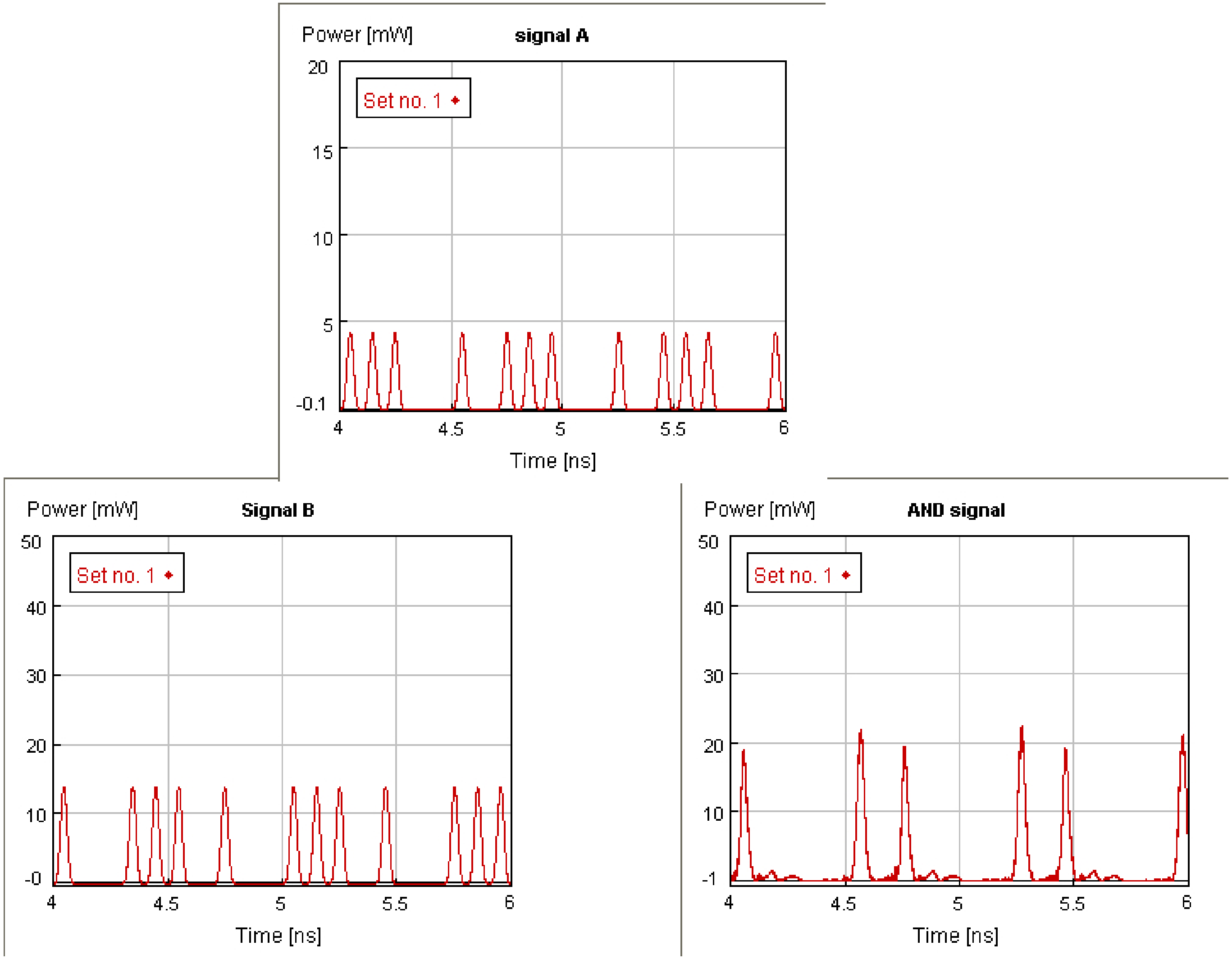
$$\text{Output}_{SOA-2} = A \cdot \overline{X} = A \cdot \overline{(A\overline{B})} = A \cdot (\overline{A} + B)$$
$$= A \cdot \overline{A} + A \cdot B = A \cdot B$$

It requires 2 Input signals !!!!!!

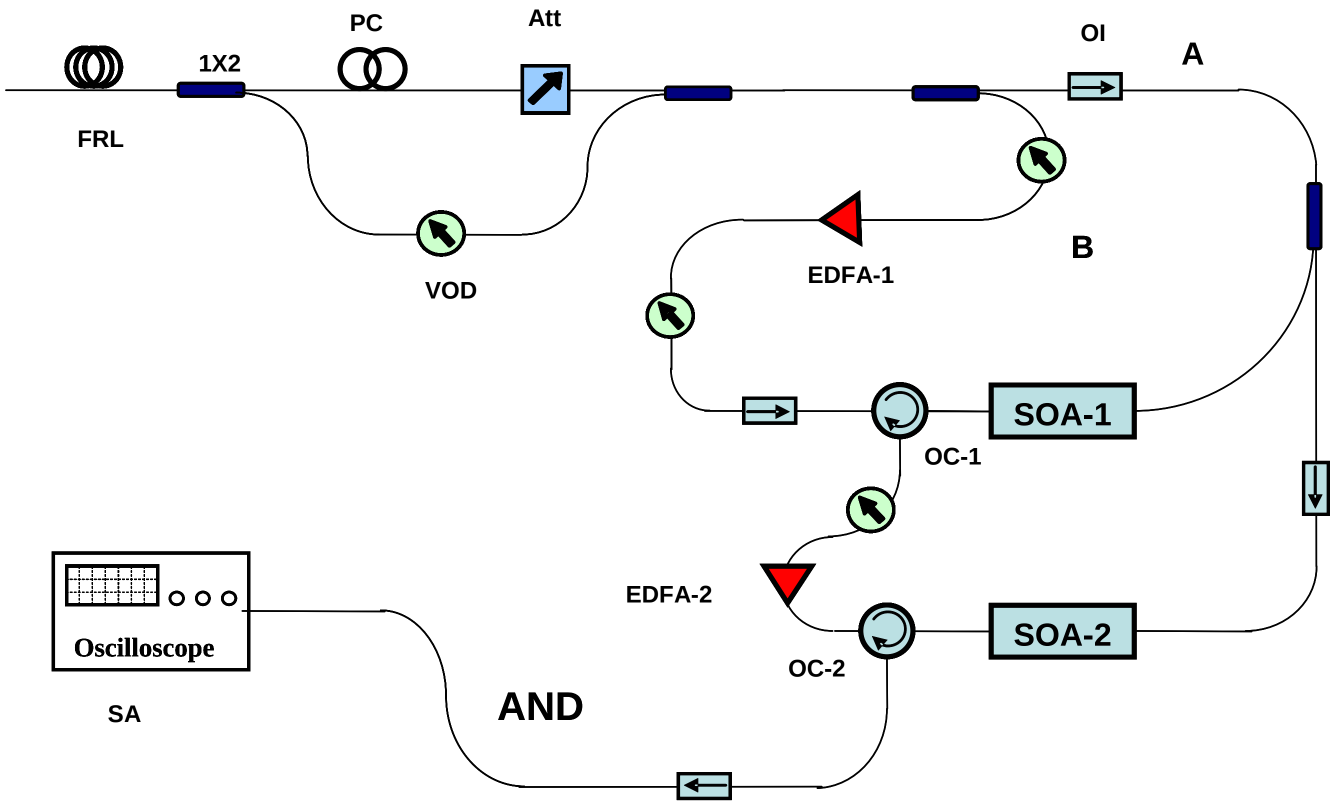
Setup for simulation results



Simulation results for implementing logic AND

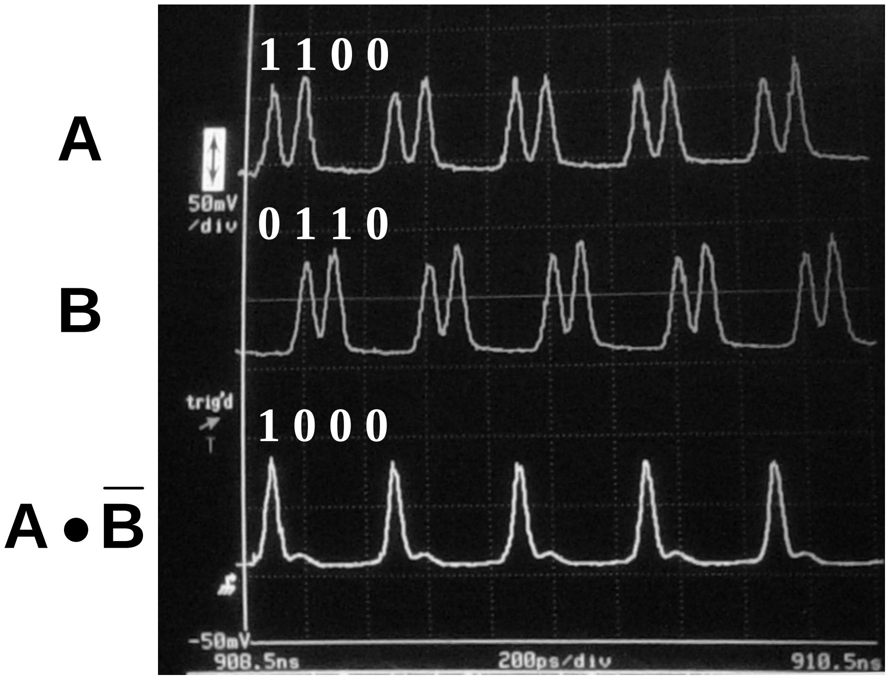


Experimental Setup for Logic AND

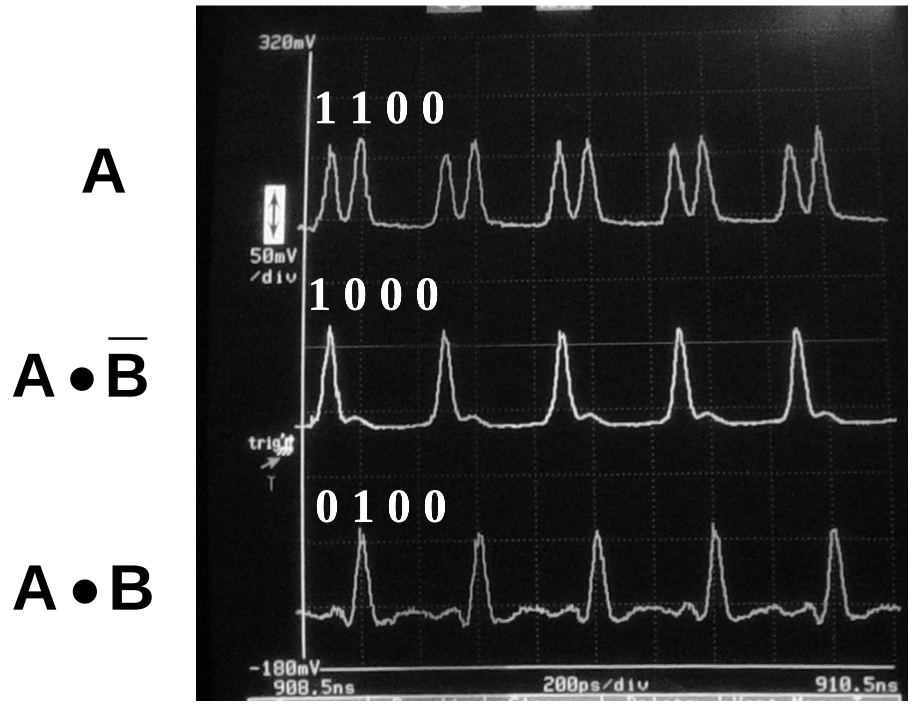


Experiment Results

Inputs and Output in SOA-1



Inputs and Output in SOA-2



Experimental Oscilloscope Traces of Input data pattern and Output data pattern in SOA-1 and SOA-2

Conclusions

1. All-Optical AND Gate using XGM in Semiconductor optical amplifiers is demonstrated at 10Gbps.

2. Further experimental works by using random input signals and BER measurement system will be performed.

3. XGM Logic gates with faster speed up to 100 Gbps will be performed.

(Ref: [1] A. D. Ellis, et al, Electron. Lett., Vol. 34, pp. 1958, 1998.)