Modelling of All-Optical Signal Processing Using SOI PICs with Amorphous Silicon

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A simulation model is presented which is used for the simulation of the 2R regeneration of non-return to zero (NRZ) signals and the format conversion from NRZ to binary phase shifting keying (DPSK) signal. The model is based on recent experimental investigations of the non-linear Kerr effect and self-phase modulation (SPM) in an amorphous silicon waveguide. The model also includes non-linear processes such as two-photon absorption (TPA) and free carrier absorption (FCA) of the silicon waveguide.

Introduction: During the last few years, all optical signal processing has been drawing more attention in higher bandwidth optical communication (40Gb/s and above), because signal regeneration, multiplexing/ demultiplexing, format conversion using high speed electro-optical conversions are extremely costly, bulky and also limited in data rate. All optical signal processing includes optical signal regeneration, wavelength conversion [1, 2], optical time division mux/demux, all optical flip-flops and optical logic. Silicon on isolator (SOI) photonic integrated circuits (PICs) have many advantages such as low loss, high power confinement and power density in the communication wavelength range, high non-linear effects and compatibility with CMOS fabrication technology. Amorphous silicon (a-Si) and hydrogenated amorphous silicon on a SOI, have many advantages over crystalline silicon (c-Si) such as high Kerr-effect, low non-linear absorption and small linear loss. Non-linear effects based on the Kerr effect such as Self-phase modulation (SPM) and Cross-phase modulation (XPM) are useful for all optical signal regeneration, multiplexing, conversion and signal processing.

NRZ 2R signal regeneration: The all optical 2R regeneration in an amorphous silicon (a-Si) interferometric Mach-Zehnder structure has been simulated for an intensity modulated non-return to zero (NRZ) signal. The performance of the output signal from the 2R regenerator, such as extinction ratio (ER), Optical Signal to Noise Ratio (OSNR) was studied for different input powers, bit rates and wavelengths. The scheme has been simulated with different 10 Gb/s NRZ pseudo-random binary data sequences (PRBS).

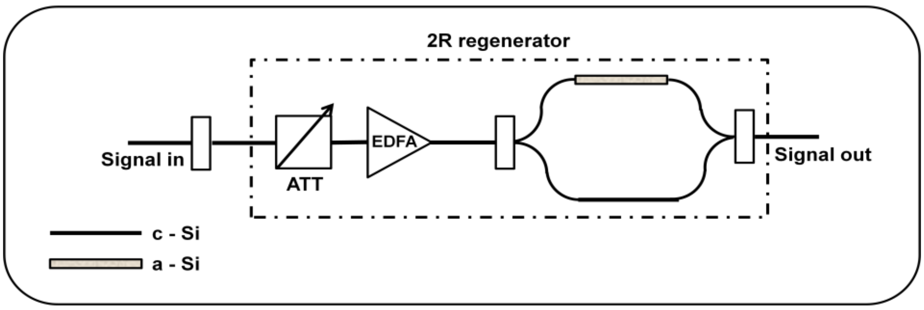

Fig.1. Block diagram of 2R regeneration of NRZ signal.

NRZ to BPSK generation: BPSK (or QPSK, DPSK, DPQPSK etc.) signals have many advantages over RZ or NRZ coded signals for transmission. In a BPSK signal the amplitude value remains constant during the transmission and only the phase value changes between the two phases 0 to 180 ^{0}. NRZ signal to Binary Phase Shifted Keying (BPSK) conversion could be done by a 2R regeneration of the NRZ signal and followed by Self-Phase Modulation (SPM) through an a-Si waveguide since the intensity dependence of the refractive index of an a-Si leads to SPM-induced non-linear phase shift.

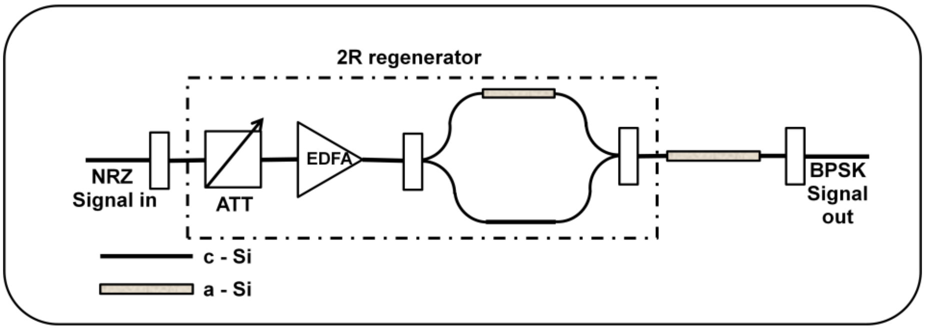

Fig.2. Block diagram of NRZ to BPSK signal generation.

In an approximation where the dispersion value is considered to be very small, the SPM induced maximum phase-shift [5] can be calculated as:
$\Phi_{NL,max} = \Upsilon P_0 L_{eff}$
where $\Phi_{NL,max}$ is the maximum phase shift,
Υ is the non-linear parameter of the a-Si waveguide,
P_0 is the peak power of the input signal,
L_{eff} is the effective length of the a-Si waveguide and is given as $L_{eff} = [1 - \exp(-\alpha L)]/ \alpha$, where L is the physical length of the waveguide and α is the linear absorption loss.
The EDFA gain is been adjusted in such a way to have a maximum phase shift of 180^0 or π as the maximum phase shift depends on the non-linear parameter, the input-peak power and the physical length and the linear absorption coefficient of a-Si.

The non-linear loss of the a-Si waveguide are two photon absorption (TPA) and free carrier absorption (FCA) [3,4]. The intensity I of light propagating in a waveguide with linear loss α and TPA coefficient β_2 will vary non-linearly with the distance z traveled along the waveguide according to

$$dI/dz = - \alpha I - \beta_2 I^2$$

From the above equation, the reciprocal transmission 1/T (input intensity/ output intensity) can be obtained as
$1/T = \exp(\alpha L) (L_{eff} / A_{eff}) \beta_2 P_i + \exp(\alpha L)$, where L_{eff} is the effective length and α is the linear loss.

Including the free carrier contribution, the free carrier density N_c is determined by the rate equation:

$$\frac{\partial N_c}{\partial t} = \frac{\pi\beta_2}{h\omega}\frac{|I(z,t)|^2}{A_{eff}^2} - \frac{N_c(z,t)}{\tau_c}$$

where τ_c is the carrier lifetime, A_{eff} is the effective cross sectional area and ω is the angular frequency of the carrier wave.
A propagation equation describing the temporal evolution of the intensity profile can be represented as:

$$\frac{\partial I(z,t)}{\partial z} = -\alpha I(z,t) - \beta_2 |I(z,t)|^2 - \sigma N_c(z,t) I(z,t)$$

where α is the linear loss and σ is the FCA coefficient.

Table of the parameter values used in the modeling:

The parameter of a-Si:

Length	**L**	**2.5**	**cm**
Active region area	σ_c	**0.2**	**µm²**
Group refractive index	n_g	**3.48**	
Attenuation	α	**3.6**	**dB/cm**
Reference frequency	**v**	193.1×10^{12}	**Hz**
Nonlinear Index	n_2	3.7842×10^{-17}	m^2/W

Result and discussion: The scheme has been simulated with different 10 Gb/s NRZ pseudo-random binary data sequences (PRBS). The carrier wavelength of the binary data used for the simulation is 1550 µm which is a widely used fiber communication laser wavelength.

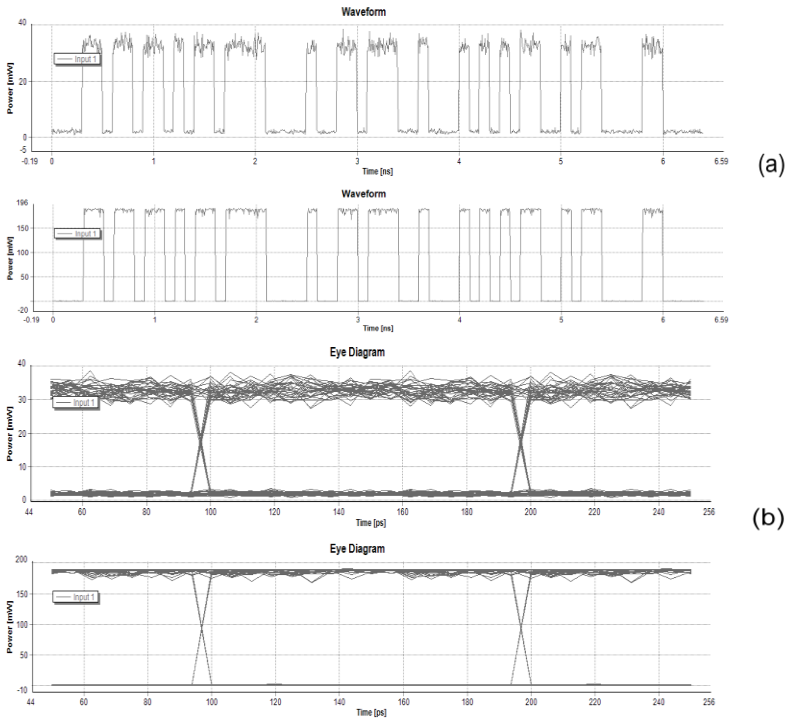

Fig.3. (a) Input and output of NRZ bit sequence,
(b) Input and output eye diagram of NRZ bit sequence.

From the simulated result the performance of the scheme is observed in signal trace diagrams and eye diagrams. The extinction ratio(ER) is found to be 15dB and also noise ratio improves in the output signal.

The simulated diagram is the output phase value of the generated BPSK signal. Ideally the phase value should lie exactly between 0 and 180 ^{0} which represent ‘0’ and ‘1’ of a digital signal. Due to noise from the input signal and also from the system itself, the low levels have much noise in the output though the high levels have much less noise.

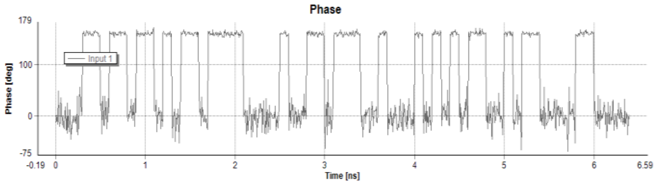

Fig.4. Output of BPSK signal.

The TPA coefficient is experimentally found from measuring the input and output power and by plotting reverse transmittance (1/T) versus the input power P_i of the NRZ signal.

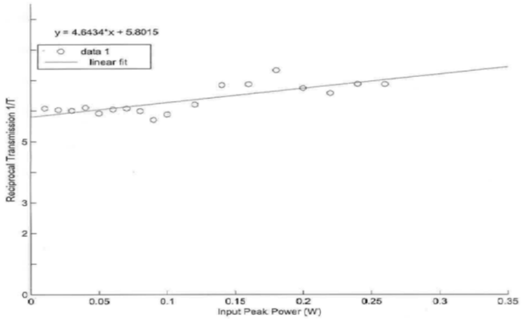

Fig.5. Reciprocal of transmittance (1/T) vs. Input peak (I_{peak}) power plot.

The graph shows the plot of Input peak power (I_{peak}) versus reciprocal transmittance (1/T) of a a-Si waveguide of length 0.92cm. A femtosecond laser of pulse width 350fs with repetition rate 20 MHz has been used. From the plot the measured β_2 value is found to be 0.52 cm GW^{-1}.

References:

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