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10 Gbps Externally Modulated XGM based Wavelength Conversion Using SOA
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Abstract

This paper proposes a method for All Optical Wavelength Conversion using semiconductor optical amplifier at 10Gbps. The system is demonstrated for Cross Gain Modulation (XGM) process of SOA, which is the simplest wavelength conversion technique that takes the advantage of non linear gain suppression mechanism in SOA. The system performances are analyzed using Q factor and Extinction Ratio of the eye diagram. The input pump power is varied from 2 dBm to 5 dBm; also the extinction ratio of Mach-Zehnder modulator is varied from 30 dBm to 60 dBm. Maximum Q Factor of 11.86 dB is obtained for a maximum output signal power 23.94 dBm. Minimum Q Factor obtained is 7.58 dB for a minimum output signal power 23.15 dBm. The extinction ratio falls from 18.56 dB to 16.63 dB as the input conditions are varied.

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1. Introduction

All multiplexed networks consist of a number of crossconnects to maintain proper routing of data from node to node. In a circuit-switched network, the blocking rate depends on the number of free paths. When there is no capacity available on any path, the requests are blocked. But in the optical domain, according to wavelength continuity constraint, to establish any lightpath, the same wavelength must be allocated on all the links in the path. Compared to a circuit-switched network, a wavelength-continuous network may suffer from higher blocking because the available wavelengths on the links might be different. To avoid the blocking problem, the data send on one wavelength along a link is converted into another wavelength at an intermediate node and then forwarded it along the next link. This technique is referred to as wavelength conversion and such wavelength-routed networks with this capability are known as wavelength-convertible networks. A wavelength-convertible network is

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functionally equivalent to a circuit-switched network, because it supports complete conversion of wavelength at all nodes, i.e., the lightpath requests are blocked only when there is no available capacity on the path. Hence, with the help of a wavelength converter a data stream at a specific wavelength is transferred to another one in order to be routed on a different wavelength path and release the original wavelength resource to another data stream [1, 2].

Wavelength conversion techniques exist in two methods – Optoelectronic wavelength conversion and All Optical wavelength conversion. In the first method, by using a photodetector the optical signal to be converted is first translated into the electronic domain. The electronic bit stream is stored in the buffer. The input of a tunable laser tuned to the desired wavelength of the output is driven by the electronic signal [3]. This method has been demonstrated for bit rates up to 10-Gb/s. But optoelectronic method is much more complex and consumes much more power compared to the other methods. In the second method, throughout the conversion process the optical signal is allowed to remain in the optical domain. There is no optical to electrical conversion involved, hence the name All-optical [4].

Semiconductor based all optical wavelength conversion devices are compact and easily compatible for integration and mass production using similar fabrication techniques to those used for silicon based integrated circuits. Comparing to techniques based on fiber, SOAs in the InP/InGaAsP material system are of the most interest because they can produce gain in the wavelength bands of modern fiber systems incorporating erbium doped fiber amplifiers [5]. Other major advantages of using SOA are its high gain, high saturation output power, wide gain bandwidth, high nonlinearity, low power consumption, short latency, and high stability [6].

To implement all optical wavelength converters several promising techniques relying on Cross- Gain Modulation (XGM), Cross- Phase Modulation (XPM), and Four Wave Mixing (FWM) in a single SOA, have been reported [7, 8, 9]. Among these, Cross Gain Modulation based all optical wavelength conversion is one of the simplest methods. XGM has the advantage of high conversion efficiency as well as insensitivity to polarization of input signals [4].

In this paper, the simulation of the SOA based XGM wavelength converter using external modulation is done. The simulation is carried out at 10Gbps. This paper is structured as follows. In section 2, the theoretical illustration of the process is described. In section 3, the system setup model and simulation results are described. In section 4, the main conclusions are discussed.

2. Theory

In a p-n heterojunction, the injection of electrons and holes from either sides of the junction builds up the carrier concentration in the active region. This establishes a non-equilibrium state in the active region and is called the population inversion. When the input signal photons passes through the excited area stimulated emission occurs. The incoming signal stimulates the radiative recombination of electrons and holes. As a result coherent amplification of signal power happens. Some recombinations occur spontaneously which is termed as Amplified spontaneous emission (ASE). Carrier density decreases as a result of increase in stimulated emission. Gain drops and shifts accordingly. Expression for saturation power is given below.

\[
P_{sat} = \ln(2)h\nu S / (\Gamma \tau \frac{dg}{dN})
\]

Where \(\Gamma\) is the cross sectional confinement factor of the propagating mode overlapping the active area, \(N\) is the carrier density depend on time \(t\), i.e. the electrical injection current, \(S\) is the active area cross section, \(\tau\) is the carrier lifetime that usually includes non radiative recombinations due to defects, impurities and other traps, radiative recombinations due to spontaneous emission and Auger processes, \(h\) is the Planck’s constant and \(\nu\) is the frequency [10, 11].

The principle behind using an SOA in the XGM mode is shown in Fig. 2.1 [12]. Due to gain saturation the intensity modulated input signal modulates the gain in the SOA. The gain variation modulates the continuous wave (CW) signal at the desired output wavelength (\(\lambda c\)) so that it carries the same information as the original input signal. Launching of the input signal and the CW signal in to the SOA can be done either co- or counter directionally into the SOA.

The XGM scheme generates a wavelength converted signal that is inverted with respect to the input signal. Even though the XGM scheme has the advantage of simpler configuration and penalty-free conversion, it has the disadvantage of extinction ratio degradation for an input signal converted to a signal of equal or longer wavelength.
and inversion of the converted bit stream [13,14].

![Fig. 2.1 Wavelength conversion based on XGM](image)

### 3. Simulation Setup and Results

A user defined sequence (0011) is modulated with probe signal of wavelength 1560 nm using a Mach-Zehnder Modulator (MZM). The key advantage of using an MZM is that the non-linear response of MZM results in an increase in signal extinction ratio after conversion, leading to 2R regeneration. 1550 nm signal is the pump signal. The pump beam power is varied from 2 dBm to 5 dBm. WDM multiplexer is used to combine pump and probe signals and is then fed to the semiconductor optical amplifier. SOA is pumped with an injection current of 0.5 Ampere. SOA provides amplification and wavelength conversion for the incoming optical signal. Emerging signal from the SOA is filtered using Gaussian optical filter and is detected using a APD photo detector. Different values of parameters set for the simulation is given in table 3.1.

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input sequence</td>
<td>0011</td>
</tr>
<tr>
<td>Input signal wavelength</td>
<td>1560 nm</td>
</tr>
<tr>
<td>Input signal power</td>
<td>2 dBm, 3 dBm, 4 dBm &amp; 5 dBm</td>
</tr>
<tr>
<td>CW wavelength</td>
<td>1550 nm</td>
</tr>
<tr>
<td>CW signal power</td>
<td>5 dBm</td>
</tr>
<tr>
<td>SOA injection current</td>
<td>0.5 A</td>
</tr>
<tr>
<td>Photo detector</td>
<td>APD</td>
</tr>
<tr>
<td>Photo detector Responsivity</td>
<td>1 A/W</td>
</tr>
<tr>
<td>Receiver Section Filter</td>
<td>Gaussian</td>
</tr>
<tr>
<td>Filter Centre frequency</td>
<td>1550 nm</td>
</tr>
<tr>
<td>Modulator Extinction Ratio</td>
<td>60 dB</td>
</tr>
</tbody>
</table>
From the principle of XGM it is found that it produces inverted output due to saturation gain modulation. The same is verified here and the obtained results are shown in Fig 3.2.a and 3.2.b. It is very clear that output bit stream is inverted with respect to the input bit stream. The signal is also amplified due to the gain provided by the SOA. The corresponding input and output spectrum is shown in Fig 3.3.a and 3.3.b. The input user defined sequence at 1560 nm is shifted to 1550 nm. The change in the shape of the output signal is due to the chirping effect.

The main characteristics of Wavelength converter is described in terms of extinction ratio and Q Factor. Fig 3.4 shows the variation of extinction with various input power levels. From the graph it is very clear that the extinction ratio, which is the ratio of on-stage power to the off-stage power, decreases with increasing pump power. The maximum extinction ratio obtained is 18.56 dB. As the input power is increased from 2 dBm to 5 dBm the extinction ratio falls to 16.63 dB.
Fig. 3.4 Relation showing the variation of Extinction Ratio to Input Pump Power

Fig. 3.5 shows the variation of Q Factor with various input power levels. From the graph it is very clear that Q factor increases with increasing input power. The maximum Q factor obtained is 11.86 dB. As the input power is increased from 2 dBm to 5 dBm, the output signal strength also increases and hence, the Q factor increases. The maximum output power obtained is 23.94 dBm.

Fig. 3.5 Relation showing the variation of Q Factor to Input Pump Power

Fig. 3.6 shows that output signal power and input power are in direct relation, as the input power increases output signal power also increases. Output signal power has its minimum value of 23.15 dBm when the input power is 2 dBm.

Fig. 3.6 Relation showing the variation of Output Signal Power to Input Power

Mach-Zehnder is used for providing external modulation. Simulation is done by keeping the CW laser power constant at 2 dBm and by varying the extinction ratio of the modulator. The results obtained are given in the graphs. Fig 3.7 shows that the extinction ratio has its minimum value of 16.6294 dB when the extinction ratio of the
modulator is 30 dB. When Mach-Zehnder’s extinction ratio is varied from 40 dB to 60 dB the extinction ratio of eye diagram shows only a small increment and it attains its maximum value of 16.6316 dB at 60 dB of extinction ratio of the modulator.

Fig. 3.7 Relation showing the variation of Extinction Ratio of eye diagram to Extinction Ratio of Mach-Zehnder Modulator

Fig 3.8 shows the variation of the Q Factor with extinction ratio of the modulator. The graph shows that as the extinction ratio of the optical modulator increases the Q Factor of the output also increases. Q Factor attains its maximum value of 11.8557 dB when the extinction ratio of the modulator is 60 dB. Fig. 3.9 shows that output signal power is in direct relation with extinction Ratio of Mach-Zehnder modulator, and it attains almost a constant value when the extinction ratio increases beyond 50 dB.

Fig 3.8 Relation showing the variation of Q Factor to Extinction Ratio of Mach-Zehnder Modulator

Fig 3.9 Relation showing the variation of Output Signal Power to Extinction Ratio of Mach-Zehnder Modulator
4. Conclusion

Wavelength conversion using SOA is one of the most intensively developing topics of telecommunication research. In this paper the simulation results are presented to determine the performance of SOA-XGM. We have observed that XGM based converter system has an inverted output and has a very low extinction ratio. But as the input power is increased the output power and also the Q factor increases. The maximum Q factor obtained is 11.86 dB for a maximum output signal power of 23.94 dBm. The highest extinction ratio obtained is 18.56 dB. Though extinction ratio of Mzm is also an important factor, it does not cause much variation in the output. We have observed that maximum Q factor of 11.8573 dB is obtained when the extinction ratio of the modulator is changed to 60 dB. The system provides the best output when the input power is set to 2 dBm and Mach Zehnder extinction ratio is 60 dB (generally >50 dB). The major advantage of this proposed system is that it works for low optical input levels of 2 dBm for pump beam and 5 dBm for probe beam.

References