Design and analysis of all optical switch architecture based on MZI switching elements and SOA, EDFA using band gap shifted switching scheme

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Abstract- In this paper, an all-optical switch based on semiconductor optical amplifiers (SOA) and Erbium Doped Fiber Amplifier (EDFA) monolithically integrated in a ‘Gain Shifted’ (GS) Mach- Zehnder interferometer (MZI) have been designed. The effect of variations of output power in respect of control signal wavelength, data signal power and control signal power are measured and plotted. The switch is designed with GS switching scheme to achieve high contrast ratio and the monolithic integration provides the required stability. Also the optical spectrum and time domain analysis of the proposed switch is done integrated with SOA and EDFA.

Index Terms - Optical switch, MZI, SOA, EDFA, Gain Shifted switching scheme, Spectrum analysis.

I. INTRODUCTION

In optical fiber communication, an optical switch used in optical fibers or integrated optical circuits (IOCs) to switched signals from one circuit to another selectively. Switching can be done by mechanical means, such as physically shifting an optical fiber to drive one or more alternative fibers, or by electro-optic effects, magneto-optic effects, or other methods. The type of switches needed for an optical path depends upon the requirement of switching speed like electro-optic or magneto-optic effects based switches used for fast switching applications. Different approaches have been proposed and used for optical switching. There are mainly two possible approaches that can be categorized as electro-optical switching and all-optical switching.

In the electro-optical switches, the electrical signal controls the switching function [1]. The applicability of these switches with recent technologies for ultrahigh-speed optical signal processing in future optical networks is restricted to less than 100 Gbit/s. The general principle of the all-optical switches relies on the control of light by light.

In a Mach-Zehnder Interferometer (MZI) a 3-db coupler splits the signal in to two beams, which then travel through two distinct arms of same and a second 3-db coupler is used to merge both and finally splits again. Switching action is achieved by varying the phase difference between the light beams [2]. The all-optical switch has been one of the most investigated components in OTDM communication networks. In high-speed OTDM systems, the all-optical switches are essential whenever the data rate exceeds the speed of electronics [3]. In this paper, we have used MZI all optical switch that is based on Semiconductor Optical Amplifier (SOA) and EDFA.

An optical amplifier amplifies an optical signal directly, without the need to first convert it to an electrical signal. An optical amplifier may be thought of as a laser without an optical cavity, or one in which feedback from the cavity is suppressed. Stimulated emission in the amplifier's gain medium causes amplification of incoming light. Semiconductor optical amplifiers (SOA) are amplifiers which use a semiconductor to provide the gain medium. [4]. Such amplifiers are often used in telecommunication systems in the form of fibre-pigtailed components, operating at signal wavelengths between 0.85µm and 1.6µm and generating gains of up to 30 dB. The semiconductor optical amplifier is of small size and electrically pumped. It can be potentially less expensive than the EDFA and can be integrated with semiconductor lasers, modulators, etc.
II. ALL-OPTICAL SWITCHING SCHEME

For all optical switching, the control of light by light is a basic need for an all optical switch as shown in Figure 1. To achieve this, an optical control signal is used which changes the optical properties of a nonlinear medium. The device then performs the switching of input data signal due to the changed transmission properties when it passes through the medium. As illustrated in Figure 1, an all-optical switch uses two inputs, data signal optical input and a second for the control signal. For different switching applications special requirements are needed. Demultiplexing, add/drop multiplexing, sampling are some of these special applications in the all-optical switching.

The following switching schemes can be considered depending upon operating wavelengths and the material band gap (or gain maximum) of the semiconductor optical amplifier within the symmetric MZI [4]:

i. Conventional switching scheme.
ii. ‘Gain transparent’ (GT) switching scheme.
iii. ‘Gain shifted’ (or ‘band gap shifted’) (GS) switching scheme.

The optical control and data signal are placed on the gain curve of SOA in the conventional all optical switching architecture. In this architecture the optical control signal saturates the SOAs and the simultaneous changes of gain, refractive index and phase are experienced by the data signal [5]. Whereas in gain transparent (GT) all optical switching, the data signal far off the gain curve of SOA experiencing the phase change, a negligible amplitude change, and no amplified spontaneous emission (ASE) at the data wavelength range. This is also give no gain changes for the transmitted data whereas enough phase change for all optical switching [5].

In this new all optical switching scheme “band gap shifted switching scheme” has been reviewed. Here the MZI with SOAs of gain curve centered at 1500nm have been monolithically integrated. The optical control signal wavelength is set at 1500nm, while the optical data signal is launched at 1550nm wavelength range [5]. The reduced noise, better linearity, low ASE, and less pattern effect were achieved using of this scheme, with the band gap shifted SOA by 50nm towards shorter wavelength compared to the wavelength of optical data signal compared to conventional scheme. Furthermore this scheme can also be useful for advanced application in all optical signals processing in the 1550nm wavelength range [6].

III. RESULTS AND DISCUSSION

We have designed MZI all optical switch with only SOA in its interferometric arms previously in which, we have found that when we use only SOA in its arms, then amount of amplification is less, the output...
power is varying with time and the polarization of output signal is also high. So we use EDFA in series with SOA as shown in fig 4. In this, we have to give control signal to actuate the injection current in SOA. We have three kinds of switching schemes as we have discussed so far: Conventional, Gain Transparent (GT) and Gain Switching (GS) which depends on the wavelength of control signal.

![Diagram of MZI all optical switches with SOA and EDFA in its arms](image)

**Fig.3. MZI all optical switches with SOA and EDFA in its arms (simulation courtesy Optiwave platform).**

We have varied the wavelength of control signal from 1300 nm to 1550 nm while the wavelength of data signal is constant at 1550 nm. The different parameters are set as:

i. Data signal power=1mW

ii. Control signal power=1mW

iii. Data signal wavelength=1550nm

iv. SOA1 current=0.15A

v. SOA2 current=0.1A

We found the corresponding values of output power at cross and bar port for different wavelengths of control signals as given in Table 1.
Table 1

Output power with control signal wavelength

<table>
<thead>
<tr>
<th>Wavelength of control signal (nm)</th>
<th>Output power at cross port (mW)</th>
<th>Output power at bar port (mW)</th>
<th>Extinction ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1300</td>
<td>13.28</td>
<td>8.1</td>
<td>1.63</td>
</tr>
<tr>
<td>1350</td>
<td>11.58</td>
<td>10.11</td>
<td>1.14</td>
</tr>
<tr>
<td>1400</td>
<td>22.9</td>
<td>17.1</td>
<td>1.33</td>
</tr>
<tr>
<td>1450</td>
<td>10.86</td>
<td>18.89</td>
<td>0.57</td>
</tr>
<tr>
<td>1480</td>
<td>15.65</td>
<td>6.2</td>
<td>2.54</td>
</tr>
<tr>
<td>1500</td>
<td>23.62</td>
<td>6.53</td>
<td>3.64</td>
</tr>
<tr>
<td>1510</td>
<td>23.83</td>
<td>6.5</td>
<td>3.64</td>
</tr>
<tr>
<td>1520</td>
<td>21.33</td>
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<td>1530</td>
<td>16.58</td>
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<td>11.58</td>
<td>19.32</td>
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<tr>
<td>1550</td>
<td>21.74</td>
<td>9.75</td>
<td>2.22</td>
</tr>
</tbody>
</table>

The values in Table 1 are plotted as shown in Fig. 5. It is clear from Fig. 5. That the extinction ratio is best for gain shifted switching scheme than other schemes. So we keep the wavelength of control signal at 1510nm.

We have also varied other parameters such as power of control signal, power of data signal, injection current of SOA-1 and SOA-2 and note the output power to get the optimum performance of the MZI switch. These results are shown in Fig. 6 to Fig. 9. From fig. 6, we can say that the output power at cross port and the extinction ratio is continuously decreased as we increase the input data signal power.

Fig. 4: Variation of output power with control signal wavelength.

Fig. 5: Variation of output power with data signal power.

Fig. 6: Variation of output power with control signal power.
So it can be easily deduced from fig. 6 that the output power and the extinction ratio have continuously increased as the input control signal power is increased.

Fig 7: Variation of output power with SOA-1 injection current.

Fig.8. indicates that the output power has continuously decreased with SOA1 current while the extinction ratio is maximum at injection current of 0.13A for SOA-1.

Fig. 8. Variation of output power with SOA-2 injection current

From this figure we can say that output power and extinction ratio is maximum at about a current value equal to 0.15A and 0.12A of SOA2. The analysis of our MZI switch by optical spectrum analyzer is shown in Fig.10.

Fig. 9. Optical spectrum analysis of GS-MZI switches with SOA and EDFA.

The analysis of our MZI switch by time domain analyzer is shown in Fig.11.

Fig.10. Time domain analysis of GS-MZI switch with SOA and EDFA.
We can see that the output power is almost constant with the time in this switch. Also when we measure the polarization, then we find about 46.7% and 47.4% polarization at cross and bar port respectively.

IV. CONCLUSION AND FURTHER WORKS

In this paper, theoretical and experimental studies on a monolithically integrated band gap MZI has been described as an all optical switch based on SOA and EDFA. Particularly design, switching dynamics and system performance of this switch were considered. From this paper, it can be concluded that symmetric MZI switch can be used towards ultrafast application, due to its superior specifications compared to other structures. The possibility to saturate the SOAs separately enables also an improved contrast ratio for the switched signal. The ‘gain shifted’ switching scheme investigated here was intended to find a compromise between the advantages and disadvantages of the ‘conventional’ and ‘gain transparent’ switching scheme. We have seen that the output power is almost constant with the time in this switch. Also the polarization effect is quite less than MZI switch using only SOA.

REFERENCES


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