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Optical Design of 4-channel TOSA/ROSA for CWDM Applications

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Abstract

In this paper, the optical design of 4-channel WDM Transmission Optical Subassemblies (TOSA)/Receiver Optical Subassemblies (ROSA) is reported. The TOSA and ROSA are being developed for uncooled modules for CWDM applications and are compatible with the SFP/SFF form factor TOSA and ROSA. The physical dimension of OSA together with the electronic circuitries is limited to \(10 \times 6 \times 5 \text{ mm}^3\). The designs of TOSA and ROSA are employed using four thin film filters (TFFs) to select the specific channel wavelength, four 500\(\mu\)m ball lenses, one 2.5 mm ball lens and a high reflection mirror using folded optical configuration. The optical elements are to be assembled on a SiOB, except the 2.5 mm ball lens. The simulation results are used to estimate the required optical components assembly accuracy. Based on the simulation results, the tolerance requirement for tilting the mirror and first thin film filter is approximately \(\pm 0.2^\circ\) for the longest optical path namely Channel 4.

Keywords: Optical design, optical subassemblies, TOSA/ROSA, silicon optical bench

1. Introduction

The demand for larger capacity transmission service is increasing every year. Due to the low cost requirements of access network coarse wavelength division multiplexing (CWDM) has become the alternative solutions for short distance network applications. This is because it allows the used of uncooled lasers, typically Distributed Feed-Back (DFB) laser. In this way, the design is much simpler and smaller then the DWDM. In addition, its cost is also much lower [1].

In this paper the design of 4-channel TOSA/ROSA for LX4 applications is presented. The physical dimension of the OSA is restricted to \(10 \times 6 \times 5 \text{ mm}^3\) including the electrical circuitries. These designs are later developed using Silicon Optical Bench (SiOB) technology. The SiOB technology provides the substrate which the optical components can be positioned precisely and bonded using commercially available systems and tools [2]-[3]. The concept of design is discussed in section 2, followed by the detailed simulation results in section 3. Lastly the conclusion based on the results in section 3 is given in section 4. The simulation results are used to estimate the required fabrication tolerances for passive device attachment.

2. Concept of Design TOSA/ROSA

The proposed design of TOSA and ROSA is schematically depicted in Figure 1. Their designs are implemented using four thin film filters (TFFs), four 500 \(\mu\)m ball lenses, one 2.5 mm ball lens and a high reflection mirror using folded optical configuration. TFFs are used to select a specific channel wavelength, while the ball lenses are employed to
collimate the transmitted optical signal or converge the received optical signal on the photo detector. All the optical elements excluding 2.5 mm ball lens are to be assembled on the SiOB. The size of the SiOB module for both TOSA and ROSA in this design is 4.2 x 3 mm².

The working principle of TOSA is as follow: the optical signal from the four laser diodes with difference wavelengths (λ₁, λ₂, λ₃, and λ₄) are collimated by four individual ball lenses of 500 µm diameter first. The collimated optical signals are then transmitted through four TFFs, where their pass band matched the respective laser diode wavelength, as depicted in Figure 1. All the TFFs have a dimension of 0.3x0.8x0.52 mm³, and an operating incidence angle of 10º. The mirror is designed to tilt at an angle of 10º in order to be parallel with respect to the TFFs. The mirror has a dimension of 1x1.9x0.5 mm³. It is used to reflect the optical signal toward the TFFs. As the wavelengths of the reflected optical signal from the mirror are outside the passband of the TFF, they are again reflected by the TFF with an angle equal to their incidence angle. Finally, all the optical signal are multiplexed, and are directed towards the 2.5 mm diameter ball lens, which is used to focus all the optical signals to the output fiber.

For ROSA configuration, the optical signals which consist of four wavelengths (λ₁, λ₂, λ₃, and λ₄) are coupled from the MMF as shown in Figure 1. Due to the large core diameter of the MMF of 62.5 µm, a 2.5 mm diameter ball lens is required to collimate the optical signals. The collimated optical signals are then directed towards the four TFFs and the mirror, which are designed to have an incidence angle of 10º with respect to the optical signal. Again the passband of the TFFs match the respective channel wavelengths. In this way, the optical signals are demultiplexed into four channels serially. The filtered optical signals of the TFFs are then focus to four similar photodiodes by 500 µm ball lenses. The basic operating principal of the optical multiplexer for the TOSA and demultiplexer for the ROSA are similar. Hence, they are shared the same design structure.
3. Simulation Results

In this section, the simulations are obtained to calculate the coupling efficiency ($\eta$) of TOSA and ROSA by using the commercial optical simulation software ASAP from Breault Research Organization [5]. The coupling efficiency ($\eta$) is determined using following equation:

$$\eta = \frac{\iint F_r(x, y)W^*(x, y)dx\,dy}{\iint F_r(x, y)F_r^*(x, y)dx\,dy \iint W(x, y)W^*(x, y)dx\,dy}$$

(1)

where $F_r(x, y)$ is the optical field of the input light, while $W(x, y)$ is the function describing the complex amplitude of the beam coupling into the detector. The * symbol denotes the complex conjugate of the function. The lay out of the basic components, such as ball lenses, TFFs and mirror is shown in Figure 2.

As it can be seen from Figure 2, the nominal distance between the edge of 2.5 mm ball lens and 500 µm ball lenses is about 5.715 mm. It means that the 2.5 mm ball lens is located outside the SiOB. The required 2.5 mm ball lens is not feasible to assemble in the SiOB due to the limited available Si wafer thickness and fabrication complexity. Therefore the 2.5 mm ball lens is to be integrated using ferrule with the SiOB. For miniaturization and better assembly tolerance, a smaller optical propagating distance is desired. The optical propagation distance of the demultiplexer and the multiplexer increases as the channel pitch increases. However, due to the SiOB fabrication limitation, there is a minimum channel pitch that can be obtained. With these two design factors, the pitch of the channel for both demultiplexer and multiplexer is set at 0.6225 mm, as shown in Figure 2.

As listed in Table 1, it shows all the relevant physical constants and nominal specification of the optical components which are being used for the optical simulations. The position of the fiber as well as the laser diode is very critical for determining the maximum coupling efficiency. Therefore to determine the position of the fiber as well as the laser diodes and the photo detectors, the EFL (Effective Focal Length) of a ball lens is used.

$$f_{\text{ball}} = \frac{n_r f_{\text{ball}}}{2(n - 1)}$$

(2)

where $f_{\text{ball}}$ is the effective focal length , $r$ is radius of the ball lens and $n$ is refractive index of the ball lens. A more mechanically useful quantity is often the back focal length, $f_{\text{back}}$ which is the distance from the lens surface to the point
of focus along the optical axis. When a ball lens is used to collimate the divergent output from a laser diode or the end of an optical fiber this should be the distance from the end of fiber to the edge of the ball lens. In case of the ball lens, the back focal length is:

\[ f_{\text{back}} = \frac{n \cdot r_{\text{ball}}}{2(n-1)} - r_{\text{ball}} = f_{\text{ball}} - r_{\text{ball}} \]  \hspace{1cm} (3)

The simulation was done to find out the coupling efficiency and the performance of TOSA and ROSA. To study the tolerance, the micro mirror and the first thin film filter (TFF1) are tilted and other optical components remain under ideal conditions or zero assembly error.

<table>
<thead>
<tr>
<th>Ball Lenses material</th>
<th>BK7 of refractive index = 1.503</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball lens nominal diameter</td>
<td>2.5 mm and 0.5 mm</td>
</tr>
<tr>
<td>Mirror material</td>
<td>BK7 of refractive index = 1.503</td>
</tr>
<tr>
<td>Mirror size</td>
<td>0.3x0.8x0.52 mm³</td>
</tr>
<tr>
<td>Thin Film Filter material</td>
<td>BK7 of refractive index = 1.503</td>
</tr>
<tr>
<td>Thin Film Filter size</td>
<td>1x1.9x0.5 mm³</td>
</tr>
<tr>
<td>Diameter of MMF</td>
<td>62.5 µm, NA = 0.131</td>
</tr>
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<table>
<thead>
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<th>Laser Diode</th>
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<tr>
<td>divergence angle along X</td>
<td>40°</td>
</tr>
<tr>
<td>divergence angle along Y</td>
<td>20°</td>
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<thead>
<tr>
<th>TOSA</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser diode to edge of the 500 µm ball lens nominal distance</td>
<td>123.5 µm</td>
</tr>
<tr>
<td>Nominal distance of MMFs from edge of 2.5 mm ball lens</td>
<td>0.6175 mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ROSA</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal distance of MMF from edge of 2.5 mm ball lens</td>
<td>0.6175 mm</td>
</tr>
<tr>
<td>Nominal distance of 120 µm photo detector to edge 500µm ball lens</td>
<td>123.5 µm</td>
</tr>
</tbody>
</table>

Table 1. The physical constants and nominal specifications being used in the simulation

For TOSA simulation, we study only the performance of the longest optical path namely Channel 4 with wavelength \(\lambda_4\), because this channel is expected to have the highest loss than the other channels. In this tolerance study, the simulation was done by tilting the angle of mirror about x and y-axis. The positions of other optical components are fixed and assumed zero assembly error. In addition, the transmission coefficient of the thin film filter is 81% and reflection coefficient of the mirror 98% are incorporated into the simulation result. The calculated coupling efficiencies as a function of tilted angles are depicted in Figure 3 and 4.

As shown in Figure 3, under ideal condition or zero assembly error, the highest coupling efficiency will be approximately 73% for Channel 4. Furthermore, after reach the maximum peak, the coupling efficiency will drop
because the optical signal will fall outside the fiber and not propagate along the optical z-axis. We also investigate that tilting mirror greater or lesser than 10\(^\circ\) about x-axis will cause the significantly decrease as displayed in Figure 4. It depicts that if the tilted angle is greater than 0.15\(^\circ\), the coupling efficiency will start to reduce. If the angle is further increasing, the reflected signal will not reach to the TFF1. This problem will also be occurred when the TFFs are tilted about x and y axis. Based on Figure 3 and 4, it can be concluded that the alignment tolerance for tilting the mirror is very tight; hence it is about ± 0.2\(^\circ\). Outside this value, the coupling efficiency starts to reduce severely.

![Figure 3](image1.png)

**Figure 3.** The calculated coupling efficiency of TOSA as a function of tilted angles of the mirror about y-axis

![Figure 4](image2.png)

**Figure 4.** The calculated coupling efficiency of TOSA as a function of 10\(^\circ\)± tilted angles of the mirror about x-axis
For the simulation of ROSA, the input multimode fiber is considered as a source. The core diameter of MMF is 62.5 µm, with numerical aperture of 0.131. Furthermore, the beam signals are collected by a 120 µm diameter photo detector after passing through the ball lenses. The simulation was done by tilting the first TFF and the micro mirror with respect to the zero assembly error (in ideal case). These two optical components are critical in order to determine the performance of the ROSA. We have noticed that the size of the output beam after propagating the 500 µm ball lens is smaller than the diameter of active area of the photo detector which is 120 µm. The simulation results of tilting angle of TFF1 are shown in Figure 5 and 6.

![Figure 5](image1.png)

**Figure 5.** The calculated coupling efficiency of ROSA as a function of tilted angles of TFF1 about y-axis

![Figure 6](image2.png)

**Figure 6.** The calculated coupling efficiency of ROSA as a function of 10°± tilted angles of TFF1 about x-axis
The results which are given in Figure 5 and 6 shows that Channel 4 has the highest loss with respect to the TFF1 angle variation. The effect of TFF1 angle variation on Channel 1 is not critical. This is because after passing through the TFF1 the optical signal is just slightly offset due to small angle variation (± 1°). However the 500 µm ball lens still can focus the signal to the detector. Additionally the beam size which passes through the filter is still smaller than the width of the filter. Under ideal condition, the coupling efficiency of Channel 1, 2, 3 and 4 is 80.6%, 78%, 75% and 72% respectively. Figure 5 and 6 display that if the tilt is greater than 0.2°, the coupling efficiency will decreased gradually.

Figure 7. The calculated coupling efficiency of ROSA as a function of 10°± tilted angles of mirror about x-axis

Figure 8. The calculated coupling efficiency of ROSA as a function of tilted angles of the mirror about y-axis
We also investigate the effect of the tilting mirror on the four channels. The results are depicted in Figure 7 and 8. As shown in Figure 7 and 8, the coupling efficiency of Channel 1 remains constant, and Channel 4 has the lowest coupling efficiency. The coupling efficiency in Channel 2 is slightly constant, because the photo detector still can capture the optical signal from the tilting mirror. However, the tilted angle is greater than 0.75° the effect of tilting mirror in Channel 2 will be significant. Because ROSA does not require the optical isolator to prevent the back reflections, the spacing between 2.5 mm diameter ball lens and the edge of the mirror can be reduced. This will make the optical propagation distance becomes shorter and the coupling efficiency is expected to improve.

4. Conclusions

The design of 4-channel TOSA/ROSA for CWDM applications is presented in this paper. Based on the simulation results, Channel 4 suffers the highest loss, this is because it has longest optical path and depends on the alignment of the mirror and other TFFs. However ROSA does not require an optical isolator, the spacing between the 2.5 mm diameter ball lens and SiOB can be reduced resulting in higher coupling efficiency as the optical propagation distance is reduced. The results showed that the alignment of micro mirror and TFFs requires very tight tolerance (±0.2°) with the purpose of Channel 4.

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References


