Chapter 7

Analysis of TM-Pass Reflection Mode Polarizer

7.1 Introduction

In this chapter, periodic corrugations are introduced and combined with the high-index metal-clad waveguide to obtain a TM-pass reflection mode polarizer. The modal spectral response of this polarizer will be analyzed using the Method of Lines with seven-point formulation. The PML layer is used as an absorbing boundary condition. The TM-pass reflection mode polarizer structure itself is wavelength selective ($1.55\mu m$) as the resonance condition is satisfied only in a certain wavelength range. So for wavelength above or below the design wavelength, all modes will have higher loss.

7.2 Proposed Reflection Mode Polarizer

In the proposed reflection mode polarizer, periodic corrugations were first introduced in the waveguide core as shown in figure 7.1.

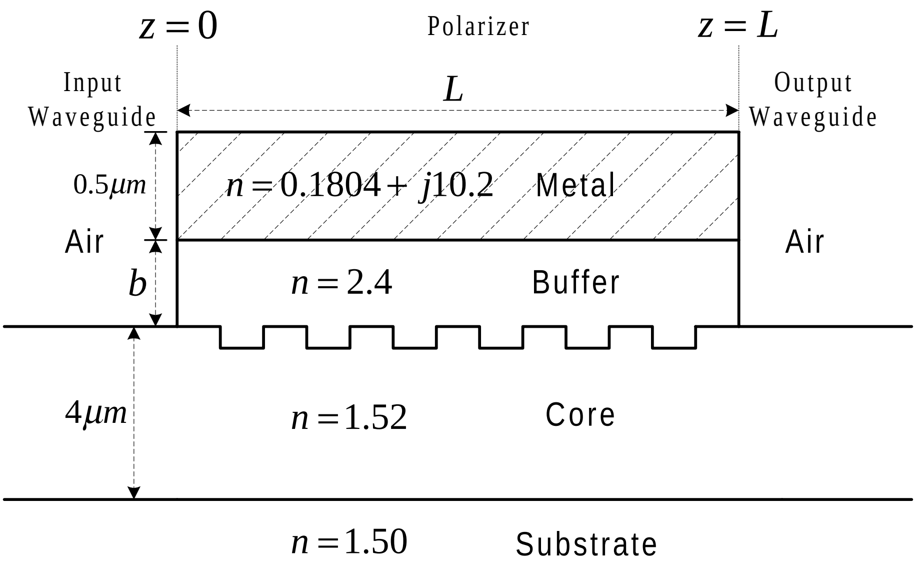

Figure 7.1: Proposed Reflection Mode Polarizer

The TE/TM modal spectral response of the proposed polarizer is analyzed for different high-index buffer thicknesses, different grating depths and different number of grating periods. Typical results are shown in figures 7.2 and 7.3. It can be concluded that this structure has a poor TE/TM discrimination and does not discriminate against the TE polarized waves, which is our aim. The poor performance of this structure is due to the fact that the presence of the TE_0 and TE_1 modes in the polarizer causes interference that leads to the high TE_0 modal reflectivity.

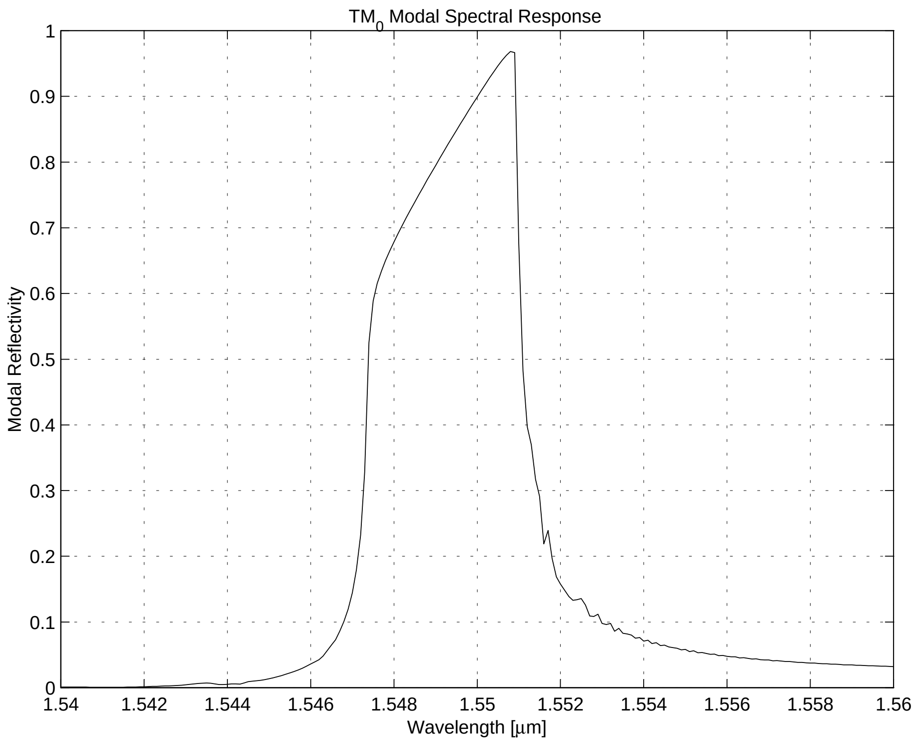

Figure 7.2: TM_0 Mode Spectral Response of the Proposed Reflection Mode Polarizer

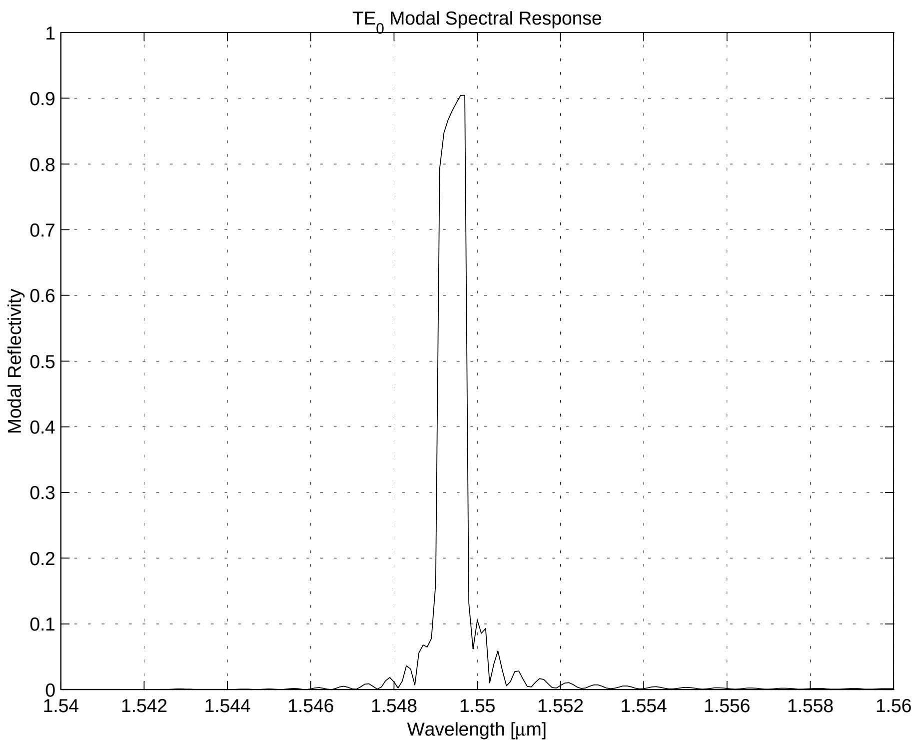

Figure 7.3: TE_0 Mode Spectral Response of the Proposed Reflection Mode Polarizer

7.3 TM-Pass Reflection Mode Polarizer

We then modified the above structure by putting the grating in series with the high-index metal-clad waveguide, rather that being within it. The structure of the modified TM-pass reflection mode polarizer is shown in figure 7.4. This device behaves as a wavelength selective filter due to multiple reflections from each discontinuity of the grating and their interaction with each other to cause resonance in the propagation direction. In this section, the modal spectral response of the reflection mode polarizer will be analyzed using the Method of Lines for different high-index buffer layer thicknesses (b), different groove depths, different number of grating periods, different polarizer lengths (L) and different spacings (L_s) between the high-index metal-clad waveguide and the grating.

Our main focus will be to cause the TM_0 mode to have high reflectivity with negligible TE reflection. It is found that the TM-pass reflection mode polarizer has very high loss for the TE_0 mode (see figure 7.5) and very low loss for TM_0 mode, (see figure 7.6). The peak TM_0 modal reflectivity is 0.92 with a very narrow bandwidth of 0.1 nm and the peak TE_0 modal reflectivity is very low that is 5.45e-4 which gives clear TE_0/TM_0 discrimination in favor of the TM_0 mode. In addition, there is a shift in the TE_0 Bragg wavelength (resonance wavelength) to the higher wavelength due to the higher value of the effective index of the TE_0 mode in the corrugated part. An approximate relation between the Bragg wavelength (λ_B), the grating period ($2d$) and the effective index (n_{eff}) is given approximately by $\lambda_B = 2d\ n_{eff}$ [86].

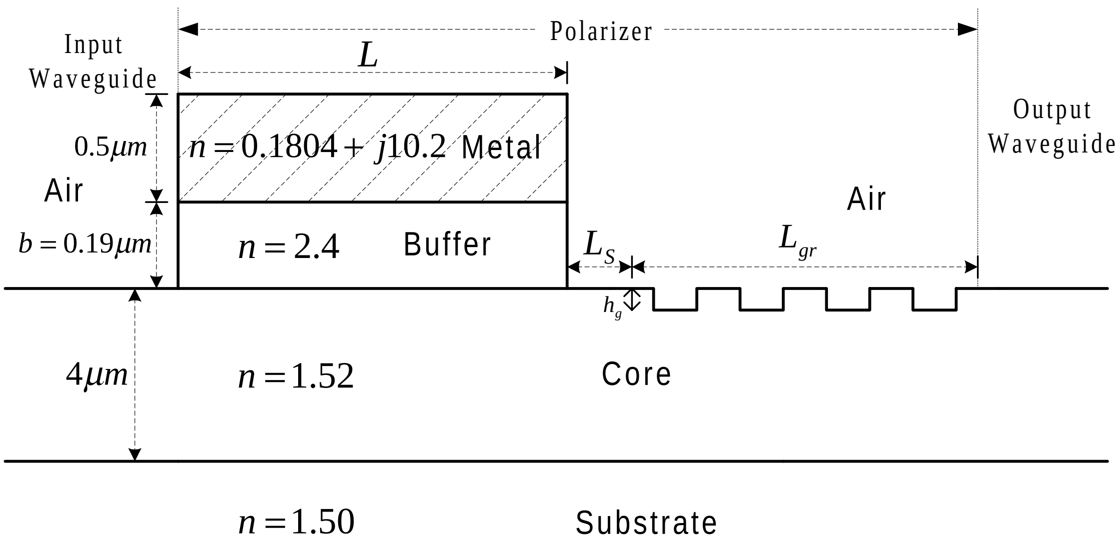

Figure 7.4: TM-Pass Reflection Mode Polarizer

The TM-pass reflection mode polarizer spectral width can be change by varying the grating depth. The polarizer spectral width can be lowered by reducing the grating depth while increasing the number of grating periods to achieve a higher peak reflectivity. If the grating is made deeper, its spectral width increases.

7.4 Effect of Polarizer Length and Buffer Thickness

The effect of the polarizer length and the high-index buffer layer thickness has been discussed in chapter 5. It is clear that there is one or more optimum polarizer

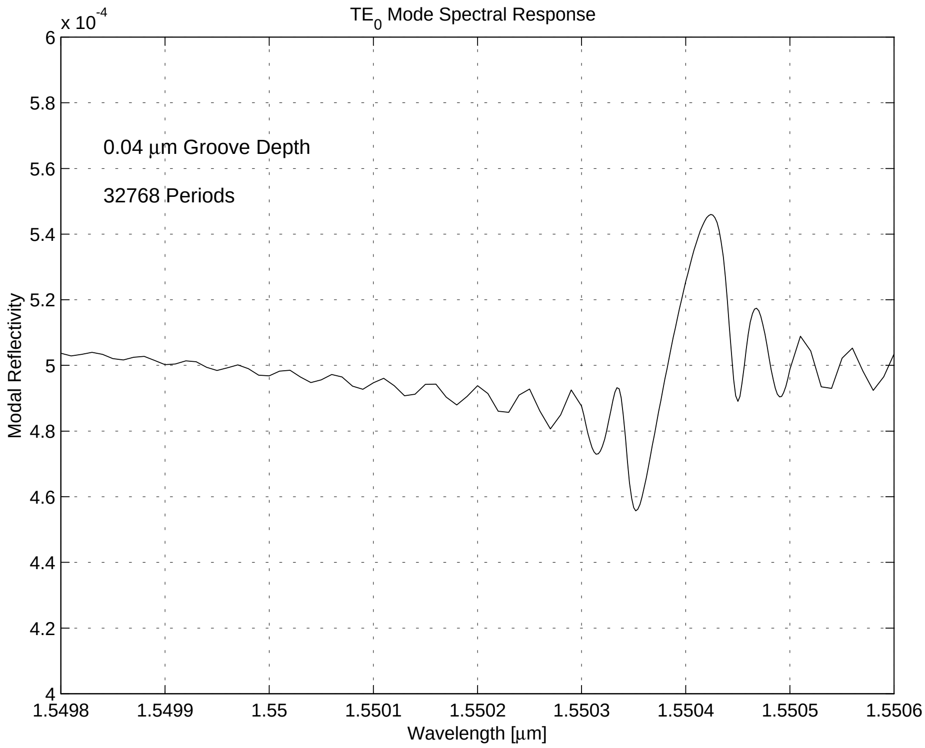

Figure 7.5: TE_0 Modal Refletivity

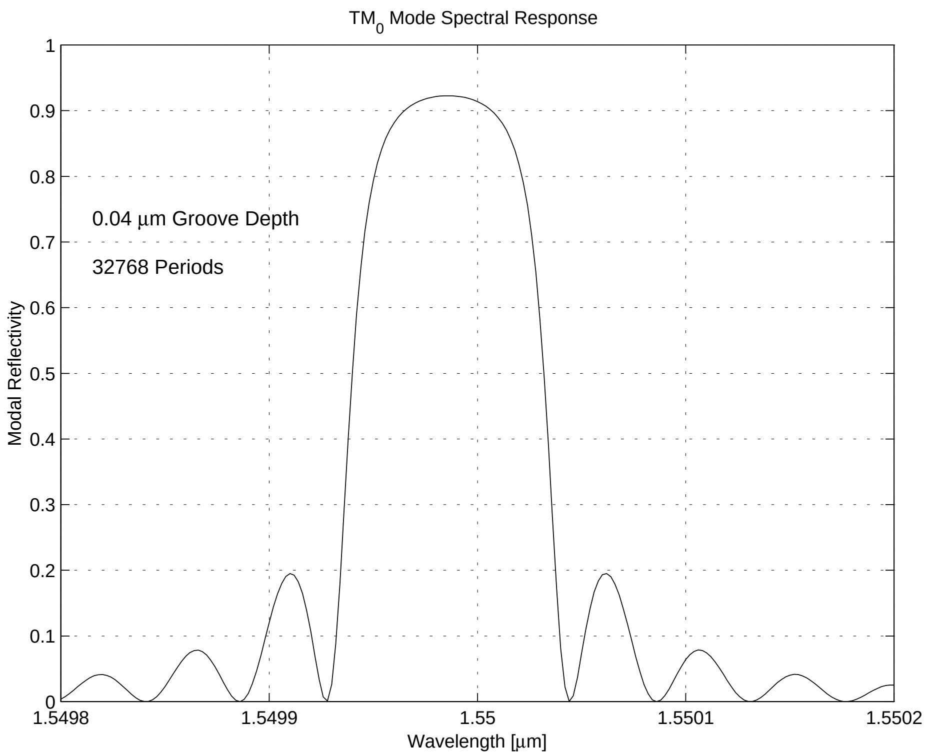

Figure 7.6: TM_0 Modal Reflectivity

lengths for each buffer layer thickness, where maximum TM_0 modal reflectivity and polarizer extinction ratio can be obtained. Here the buffer layer thicknesses and optimum polarizer lengths along with TM_0 and TE_0 peak modal reflectivities and TM-pass reflection mode polarizer extinction ratio are shown in table 7.1 while other polarizer parameters keep constant.

Buffer Thickness b (μm)	Optimum Polarizer Length L (mm)	Peak TM_0 Modal Reflectivity	Peak TE_0 Modal Reflectivity	Polarizer Extinction Ratio PER (dB)
0.185	1.97	0.822724	1.68277e-04	36.892
0.186	1.95	0.823363	6.26503e-05	41.187
0.187	1.93	0.823963	1.55571e-05	47.240
0.188	1.58	0.846295	1.46352e-05	47.621
0.189	0.91	0.891392	1.18196e-04	38.775
0.190	0.47	0.921921	5.45458e-04	32.279
0.191	0.15	0.945210	2.66215e-03	25.503
0.192	0.05	0.951437	2.72451e-03	25.431
0.193	0.05	0.950120	3.30968e-03	24.580

Table 7.1: Optimum Polarizer Lengths (L) for Different High-Index Buffer Layer Thicknesses (b) (Grating Depth=0.04μm, Periods=32768)

From table 7.1, it is evident that short polarizers give high TM_0 modal reflectivity and long polarizers give sufficiently high polarizer extinction ratio. With buffer layer thickness of 0.190 μm and polarizer length of 0.47 mm, we have 92 percent TM_0 modal reflectivity with 32 dB extinction ratio. This buffer layer thickness and polarizer length will be used for reflection mode polarizer analysis throughout the rest of this chapter.

7.5 Effect of the Polarizer Grating Separation (L_S)

The polarizer grating separation (L_S) is the distance between the metal-clad section and the corrugated part as shown in figure 7.4. We have found through numerical calculation that the L_S has a negligible effect on the overall device performance. Thus, we will fix L_S to $\lambda_B/4$ (approximately $0.1281\mu m$) throughout this work, and will not investigate the effect of L_S further.

7.6 Effect of Groove Depth

The variation of the TM_0 and TE_0 peak modal spectral reflectivity, reflection mode polarizer extinction ratio and spectral width (based on half power or 3-dB width) as a function of groove depths are presented in table 7.2. It is evident from table 7.2 that the spectral width increases with groove depth and the TM_0 modal reflectivity and polarizer extinction ratio reach maximum values for certain groove depths. If the grating depth is increased substantially, the TM_0 modal reflectivity decreases and TE_0 modal reflectivity increases, which results in lowering the value of extinction ratio.

In figure 7.7, the TM_0 modal spectral reflectivity and transmissivity of the TM-pass reflection mode polarizer with 1% groove depth is presented. The reflectivity spectrum has a small spectral width of about 0.1 nm, low side lobes level (about 7 dB) and a minimum modal transmissivity of about -14 dB. For the 2.5% groove

Groove Depth (μm)	Peak TM_0 Modal Reflectivity	Peak TE_0 Modal Reflectivity	Polarizer Extinction Ratio PER (dB)	Spectral Width (nm)
0.01	0.422948	3.42957e-04	30.910	0.040
0.02	0.612464	4.18016e-04	31.659	0.063
0.04	0.921921	5.45458e-04	32.279	0.100
0.06	0.952652	6.84628e-04	31.435	0.110
0.08	0.957105	8.41667e-04	30.558	0.130
0.10	0.958034	1.01873e-03	29.733	0.170
0.20	0.957450	2.21174e-03	26.364	0.290
0.40	0.952833	5.55657e-03	22.342	0.610
0.60	0.943497	8.87202e-03	20.267	0.890
0.80	0.928877	1.28800e-02	18.580	1.260

Table 7.2: Effect of Groove Depth (b=0.19 μm, Periods=32768 and L=0.47 mm)

depth case shown in figure 7.8, the spectral width increases to 0.15 nm and the transmissivity decreases to -36 dB. When the groove depth is increased to 5% (see figure 7.9), the spectral width of the polarizer is approximately doubled and the side lobes become higher and more closely packed. The minimum modal transmissivity is further reduced to a very low value of about -75 dB.

If the groove depth is increased further to 10%, the spectral width is again approximately doubled (see figure 7.10). The side lobes become higher and more closely packed. The minimum modal transmissivity curve is also plotted, and is seen to resemble a deep notch filter in the stop band of -165 dB.

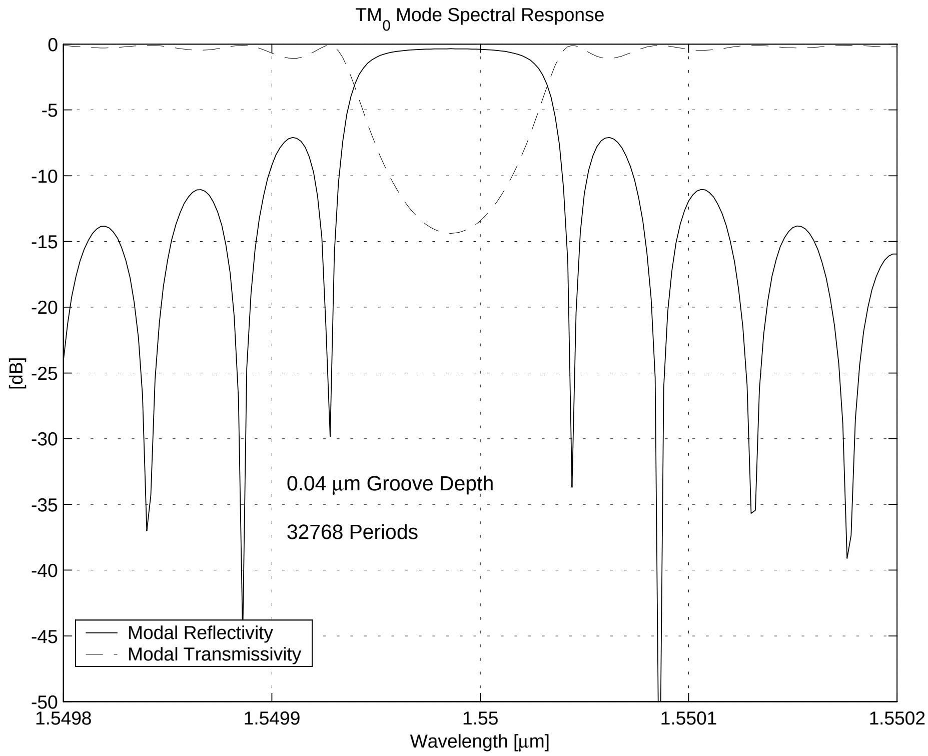

Figure 7.7: TM_0 Mode Response, 1% Groove Depth, 32768 Periods

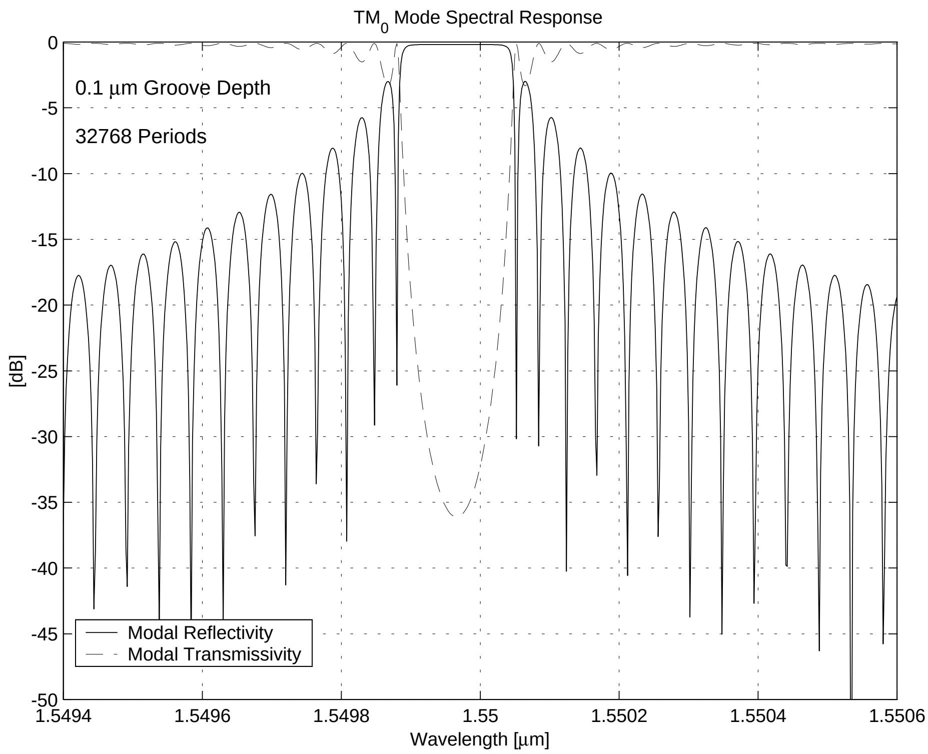

Figure 7.8: TM_0 Mode Response, 2.5% Groove Depth, 32768 Periods

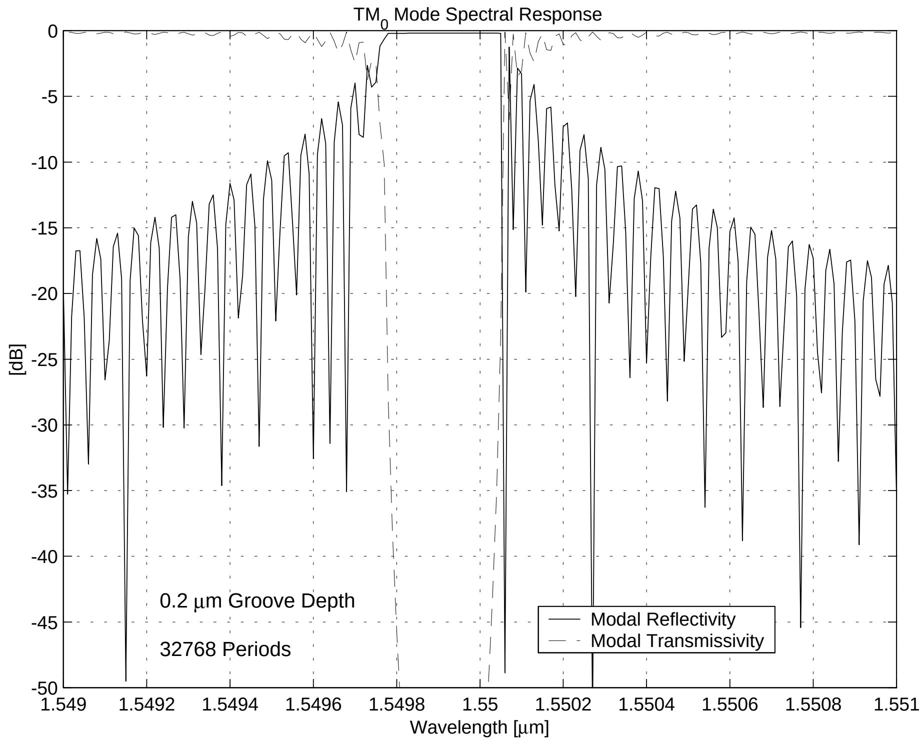

Figure 7.9: TM_0 Mode Response, 5% Groove Depth, 32768 Periods

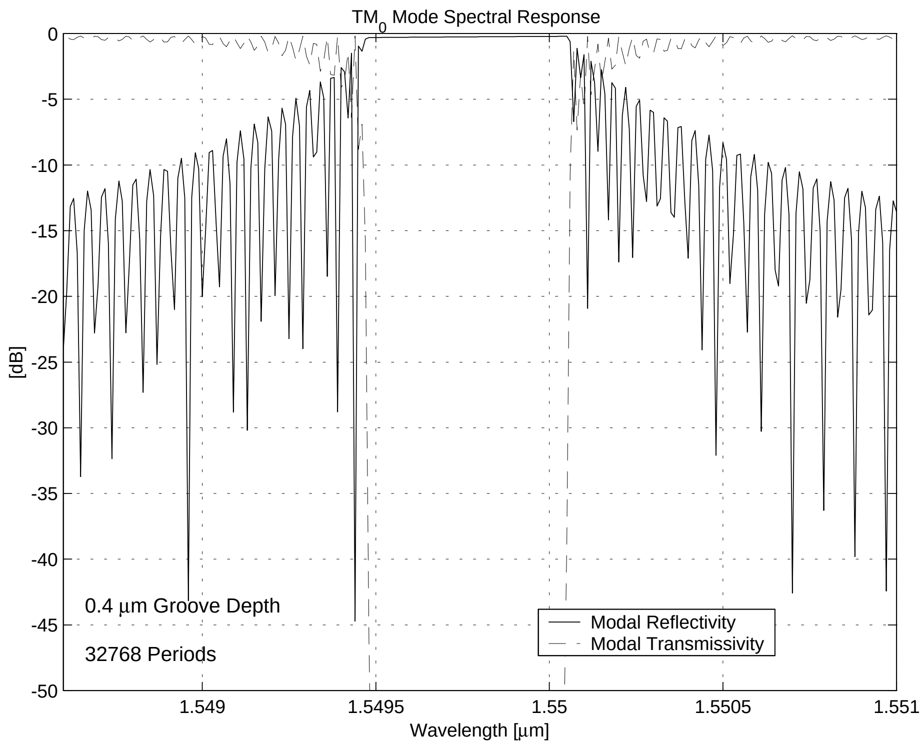

Figure 7.10: TM_0 Mode Response, 10% Groove Depth, 32768 Periods

7.7 Effect of the Number of Grating Periods

In this section, the modal spectral response of the TM-pass reflection mode polarizer is presented for different number of grating periods. It is evident from table 7.3 that for small number of grating periods the TM_0 modal reflectivity is low and spectral width is relatively high. Beyond a certain number of grating periods, adding extra periods does not affect the modal spectral reflectivity or spectral width.

Grating Period	Peak TM_0 Modal Reflectivity	Peak TE_0 Modal Reflectivity	Polarizer Extinction Ratio PER (dB)	Spectral Width (nm)
8192	0.652491	1.00545e-03	28.122	0.250
16384	0.938613	1.01134e-03	29.676	0.190
32768	0.958034	1.01873e-03	29.733	0.170
65536	0.977572	1.01220e-03	29.849	0.170
131072	0.977572	1.01220e-03	29.849	0.150
262144	0.977572	1.01220e-03	29.849	0.150

Table 7.3: Effect of Grating Periods (b=0.19 μm, Groove Depth=0.1 μm and L=0.47 mm)

In figure 7.11, the modal spectral reflectivity and transmissivity of the TM-pass reflection mode polarizer with 8192 periods is shown. The spectral reflectivity has width of 0.25 nm and a peak reflectivity of -2 dB and a minimum transmissivity of -5 dB. Thus, the TM-pass reflection mode polarizer having low number of grating periods has high reflection loss and transmission loss. If the number of grating periods is increased to 16384 and 32768 (see figures 7.12 and 7.8 respectively), the performance of the polarizer in terms of modal reflectivity and transmissivity improves and the side lobes become higher and more closely packed while the spectral width nearly remains the same.

If the number of grating periods is further increased to 65536, the peak reflectivity remains the same and main lobe becomes flatter with higher and closely packed side lobes as shown in figure 7.13. The modal transmissivity plot has a deep notch in the stop band.

7.8 Discussion

The modal spectral response of the TM-pass reflection mode polarizer (see figure 7.4) is very similar to that of the conventional waveguide grating. As the number of grating periods is increased, the peak reflectivity also increases as there are more discontinuities to reflect the incident field backwards. The side lobes become densely packed and the main lobe becomes flatter. The side lobe level increases and the spectral width decreases slightly.

For shallow gratings, the response is symmetrical about the peak reflectivity wavelength. The main lobe has very narrow spectral width and the side lobes level is much lower. As the groove depth is increased, the response becomes asymmetric. The main lobe becomes broader and the side lobe level is increased.

The reflection mode polarizer is composed of two sections, the metal-clad section and the grating section. The total length of the reflection mode polarizer depends on the length of metal-clad and grating sections. The short polarizer

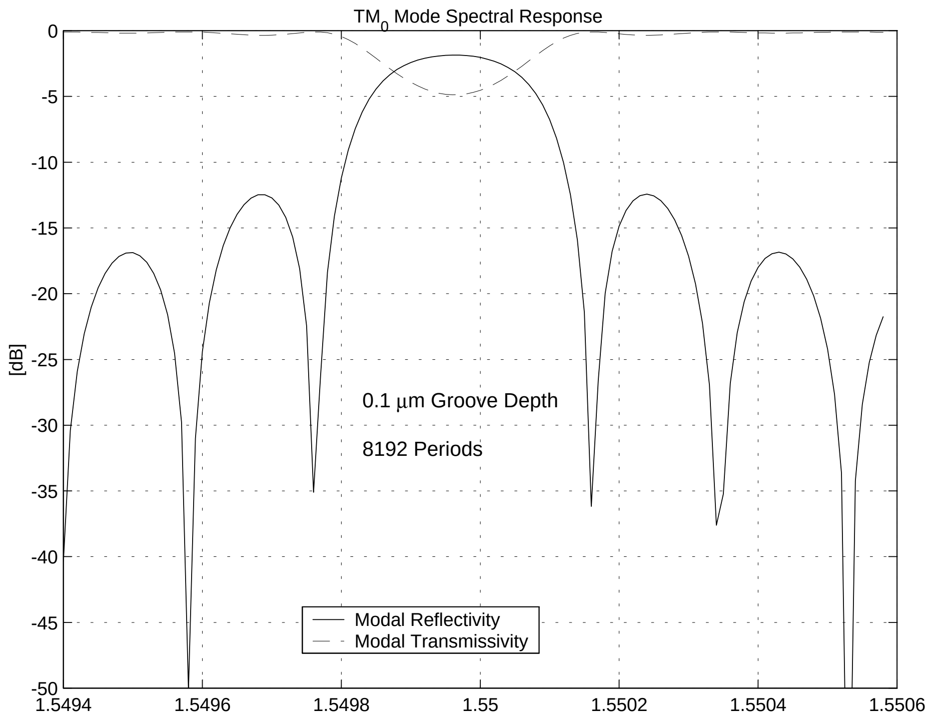

Figure 7.11: TM_0 Mode Response, 2.5% Groove Depth, 8192 Periods

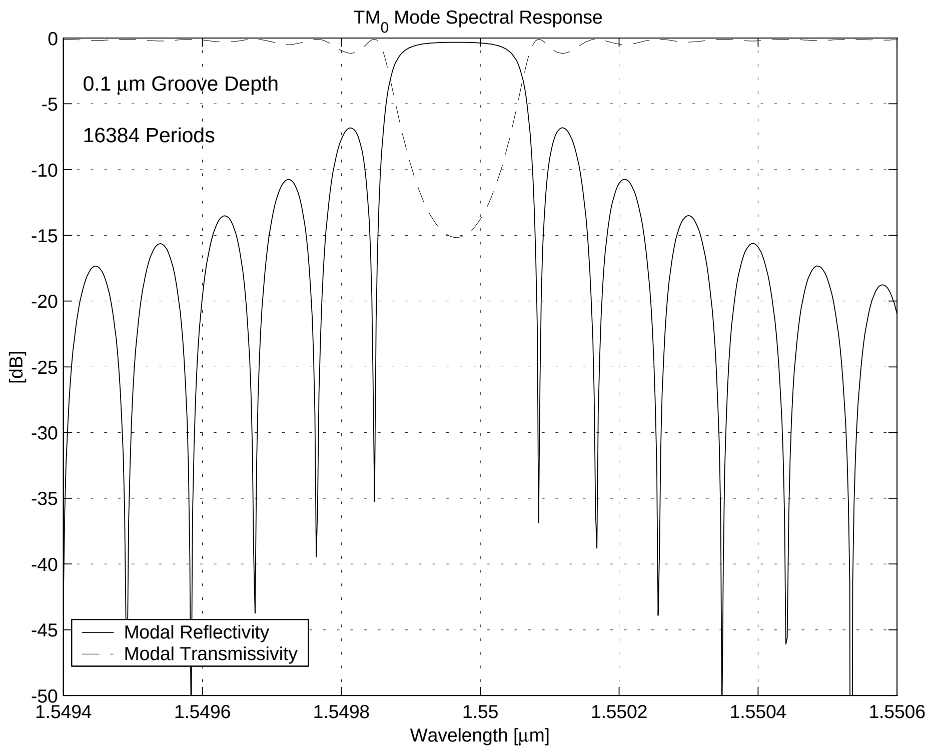

Figure 7.12: TM_0 Mode Response, 2.5% Groove Depth, 16384 Periods

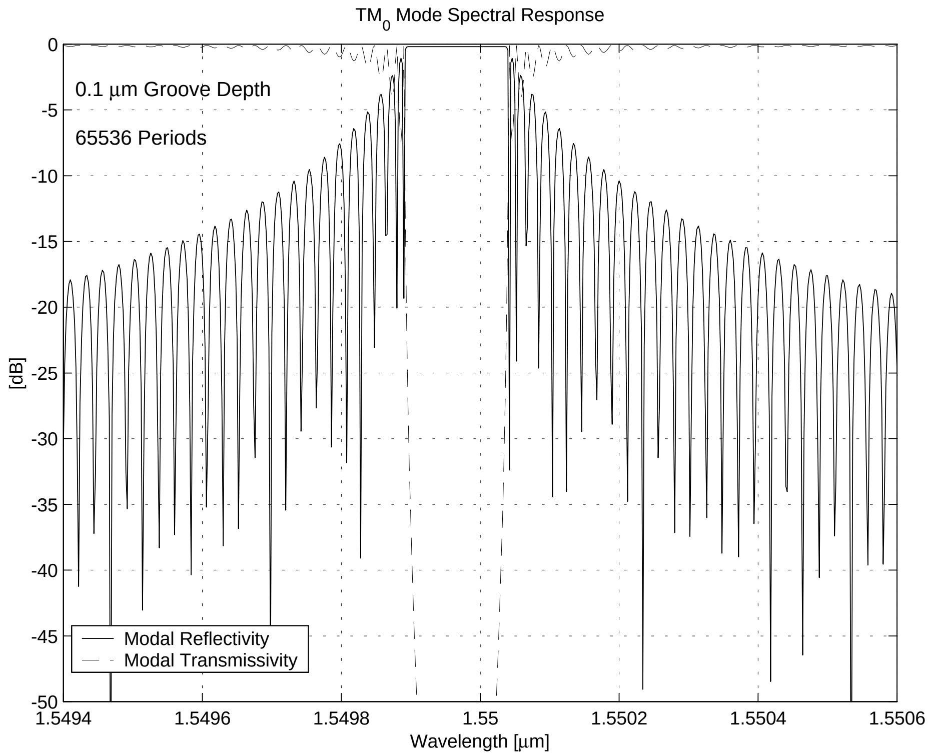

Figure 7.13: TM_0 Mode Response, 2.5% Groove Depth, 65536 Periods

with PER of 19.4 dB has the parameters; buffer layer thickness=0.192μm, grating depth=0.20μm, grating periods=8192, L_{gr}=4.2 mm, L=0.05 mm, peak TM_0 modal reflectivity=0.9525 and peak TE_0 modal reflectivity=0.011. The total length of this short polarizer is 4.25 mm. In order to obtain a polarizer with high extinction ratio the length of the polarizer is increased. The polarizer having the large length of 18.37mm has extinction ratio of 47.6 dB with parameters; buffer layer thickness=0.188μm, grating depth=0.04μm, grating periods=32768, L_{gr}=16.79 mm, L=1.58 mm, peak TM_0 modal reflectivity=0.8463 and peak TE_0 modal reflectivity=1.46e-5. Thus, the length of the polarizer can be chosen according to the particular application and requirement.