

Article

Polarization-Splitting Grating Coupler on Lithium Niobate Thin Film

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Abstract: In this study, one-dimensional grating coupler on single-crystal lithium niobate thin film (lithium niobate on insulator, LNOI) that also served as a polarization splitter was designed. The coupler could separate both orthogonal polarization states into two opposite directions while coupled light from a standard single-mode fiber to a waveguide on LNOI at the same time. Using segmented and apodized designing, the peak coupling efficiencies (CEs) around telecommunication wavelength 1550 nm for fundamental TE and TM modes of -2.82 dB and -2.83 dB, respectively, were achieved. The CEs could be optimized to -1.97 dB and -1.8 dB when a metal layer was added below the silicon dioxide layer.

Keywords: polarization splitter; grating coupler; lithium niobate; LNOI



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1. Introduction

The grating coupler (GC) is an important optical device to couple light from fibers to micro/nano integrated waveguides. Different from end-face couplers, GCs that do not require facet polishing and can be freely placed on the waveguides bring size freedom and fabrication flexibility in coupling [1,2]. Waveguide GCs have been widely designed and studied on some useful platforms, such as silicon on insulator (SOI) [3], silicon nitride (Si_3N_4) [4], indium phosphide (InP) [5], and single crystal lithium niobate thin film (lithium niobate on insulator, LNOI) [6]. Among them, LNOI is considered as the most promising platform due to its excellent nonlinear and electro-optical properties, as well as the wide transparency window in visible and infrared regions [7]. More attractive devices on LNOI have been designed and fabricated, such as the high-speed electro-optic modulator [8–10], high performance RF filter [11], acousto-optic modulator [12], and entangled quantum source [13,14]. The demand of GCs to couple light in or out of the platform increases with the growing research on LNOI.

Coupling efficiency (CE), bandwidth, and polarization independence are the key performance indices (KPIs) of GCs. Studies are generally concerned with improving the CE by adding top layer, loading bottom reflector, chirping period, apodizing filling factor, or forming some effective structures [15–20]. However, most of the GCs based on the Bragg diffracted effect are polarization dependent, as coupling of the transversal electric (TE) mode requires a lower grating period than transversal magnetic (TM) polarization. The polarization dependence of GC limits the potential application in optical fiber communication networks, especially in which both orthogonal polarization states need to be transmitted and operated (such as the optical receiver). Polarization-splitting GC which can couple and split the orthogonal modes at the same time is a potential solution to this problem.

Polarization-splitting GCs such as two-dimensional polarization independence grating coupler and one-dimensional polarization-splitting GCs (which are easier to be fabricated) have been designed and studied on SOI [21–24]. In contrast, there are few reports concerned

The polarization-splitting grating is essentially a diffracted Bragg grating. It satisfies the Bragg condition:

$$\beta_1 + m\mathbf{K}_\Lambda = \beta_2 \quad (1)$$

where m is the diffraction order, $\mathbf{K}_\Lambda$ is the grating vector, and β_1 and β_2 are the wave vectors of the input light and waveguide mode. In y direction, the values $\beta_1 = \frac{2\pi}{\lambda_0} N_{\text{cladding}} \sin\theta$, $\beta_2 = \frac{2\pi}{\lambda_0} N_{\text{eff}}$, and $K_\Lambda = 2\pi/\Lambda$. λ_0 is the free-space wavelength ($\lambda_0 = 1550$ nm), Λ is the period of the grating, N_{cladding} is the refractive index of the top layer on LN ($N_{\text{cladding}} = 1$), θ is the fiber tilted angle with respect to the normal direction of waveguide surface. N_{eff} denotes the effective index of waveguide mode, and is different for waveguide TE_0 mode and TM_0 mode, meaning that grating couplers are generally polarization-dependent. The polarization dependence can be employed in splitting the different polarization modes. As schematically shown in Figure 1b, the grating diffracted the fiber mode to the waveguide TE_0 mode in the forward direction with $m = 1$ but diffracted the fiber mode to the waveguide TM_0 mode in the backward direction with $m = -1$. This difference introduced an offset of $\frac{4\pi}{\lambda_0} \sin\theta$ for the two modes according to Equation (1), so a grating coupler which can split the TE_0 polarization mode and TM_0 mode in opposite directions was worked out with the initial fiber angle $\theta_0 = \arcsin \frac{N_{\text{TE}} - N_{\text{TM}}}{2}$ and $\Lambda_0 = \frac{2\lambda_0}{N_{\text{TE}} + N_{\text{TM}}}$. N_{TE} and N_{TM} denote the refractive indices of waveguide TE_0 and TM_0 modes.

Lumerical mode solutions were employed to find the fundamental TE_0 and TM_0 modes by solving Maxwell's equations on a cross-section mesh, and the finite different algorithm was used for meshing the structure. Maxwell's equations were then formulated into a matrix eigenvalue problem, so the effective indices N_{TE} and N_{TM} and the mode profile of the two polarization modes could be gained after solving. Finite-difference time-domain simulation method (FDTD) was employed in the grating coupler's design, simulation, and optimization. To save simulation time, two-dimensional FDTD was applied instead of three-dimensional FDTD, as the typical waveguide width (~ 12 μm) is much bigger than its height (0.5 μm) [2]. Perfectly matched layer (PML) boundary conditions were applied to absorb the electromagnetic energy incident to the boundary to avoid interference with the fields inside. FDTD solutions generated a rectangular, Cartesian-style mesh. A lower mesh accuracy of 2 with 10 mesh points per wavelength was employed in the initial optimization for quick optimization, and a higher mesh accuracy of 4 with 18 mesh points per wavelength was employed for the convergency test. Monitors were placed in all sides of the grating, so the upward optical power, the downward optical power, the forward optical power, and the backward optical power could be detected and analyzed. By exploiting the Fourier transforms, normalized transmission and CE were gained.

In simulation, the ordinary and extraordinary refractive indices of LN were set to be 2.2112 and 2.138, and the refractive index of silicon dioxide was set to be 1.46 [29,30]. Firstly, a uniform grating coupler for coupling both TE_0 and TM_0 polarization modes was designed and optimized to gain optimal parameters such as period, filling factor, and fiber position. Secondly, the optimal uniform GC was segmented into three parts of which the period and filling factor were modulated to achieve better CEs. Lastly, the fabrication tolerance of parameters was systematically simulated and analyzed.

3. Results and Discussion

The initial optimizations were performed in uniform grating coupler with the calculated θ of 6° and period of 823 nm for both waveguide TE_0 and TM_0 modes by Bragg condition, respectively. Parameters such as Λ , etch depth (d), filling factor (the ratio of the air groove width to the period, FF), θ , and fiber position (y_0 and z_0) were all variables, and were optimized and studied to achieve a good CE and polarization splitting. The relative position of fiber and grating was crucial to the coupling because it played an important role in the diffracted power distribution and mode-matching situation. For the sake of simplicity, z_0 was fixed at 10.1 μm . The CEs of TE_0 and TM_0 modes with different fiber horizontal position at wavelength 1550 nm were shown in Figure 2. Different numbers of

grating period N were employed in the optimization. CEs of waveguide TE_0 mode and TM_0 were demonstrated in dashed and solid curves, respectively.

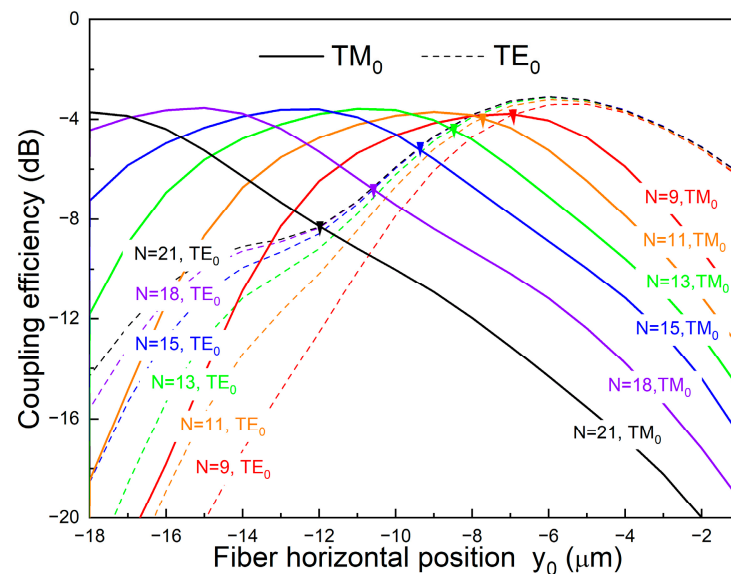


Figure 2. Coupling efficiency at wavelength 1550 nm with different horizontal placement of fiber when $\Lambda = 920$ nm, $FF = 0.4$, $\theta = 6^\circ$, and $d = 300$ nm. The solid lines denoted the TM_0 mode, the dashed lines denoted the TE_0 mode, and N denoted the number of grating periods.

From Figure 2, the maximum CE of TE_0 and TM_0 modes increased slightly with the increase of N , and the maximum CEs are -3 dB and -4 dB when $\Lambda = 920$ nm, $d = 300$ nm, $N = 21$, but a different y_0 , respectively. The y_0 corresponding to the peak CE was defined as y_{0m} . The bigger the N , the bigger the y_{0m} difference of the two modes. For TE mode, the y_{0m} varies little (around -6.5 μm (± 1 μm)), but for TM_0 mode, the y_{0m} varied widely (from -18 μm to -6.8 μm). This might be because that the horizontal position of the first air groove for TM_0 mode was greatly dependent on the N . The optimal y_{0m} tended to keep close to their own first air groove of TE_0 mode (Port A) and TM_0 mode (Port B), respectively. So, N and y_{0m} should be properly adjusted to keep an identical grating configuration for both TE_0 and TM_0 modes at the expense of CE. As shown in Figure 2, the best CE for both TE_0 and TM_0 mode was about -4.2 dB when $y_{0m} = -6.8$ μm and $N = 9$ (red arrow). The CE decreased with the increase of N , dropping to -8.3 dB when $N = 21$ (black arrow) and $y_{0m} = -11.8$ μm . When considering improving the CE and lowering the backward transmission, the next optimizations were performed at a compromise of $N = 13$ with a CE of -4.82 dB for the two modes.

By diffracting, a uniform grating coupler might yield an exponentially decaying power field distribution along the y direction, so there existed a certain mode mismatch between the input mode field and the waveguide modes field. The CE could be further improved by chirping the period and apodizing the filling factor to form a better mode matching with the waveguide mode. Regarding the basics of uniform grating, the grating region was segmented into three parts named L_1 , L_2 , and L_3 regions (Figure 1a). L_1 region, which contained five grating teeth and air grooves numbered 1–5, were chirped and apodized for the mode-matching of waveguide TE_0 mode. L_2 region, which contained a uniform configuration which had four uniform grating teeth and air grooves numbered 6–9, was designed to guarantee coupling strength. L_3 region, which contained four grating teeth and five air grooves numbered 10–14, were apodized for the mode-matching of waveguide TM_0 modes. The dimensions of each grating period and groove width is shown in Table 1.

Table 1. Dimensions of each grating period and groove width.

Grating Number	Period (nm)	Groove Width (nm)
1	825	41.25
2	844	101.28
3	863	163.97
4	882	229.32
5	901	297.33
6	920	368
7	920	368
8	920	368
9	920	368
10	920	303.6
11	920	239.2
12	920	174.8
13	920	110.4
14	/	46

As shown in Table 1, the Λ and groove width in L_1 and L_3 part were varied. In L_1 , the parameters of period and filling factor gradually increased from 1–5 for TE_0 . Also, the variation of filling factor (δFF) and variation of period ($\delta \Lambda$) were 0.07 and 19 nm, respectively. In L_3 , the filling factor was gradually decreased from 10–14, and δFF was 0.07. The gradually increased or decreased groove width in L_1 and L_3 regions modified the exponentially decayed power distribution to a Gaussian-like field distribution. The CE for both TE_0 and TM_0 modes could be improved due to the improved mode field matching between the grating diffraction field distribution and waveguide modes field distribution. The details of the chirped and apodized GC could be seen in our primary work [31]. In addition, the asymmetric configuration of L_1 and L_3 was to reduce the opposite transmission. The peak CEs for TE_0 and TM_0 modes with wavelength are shown in Figure 3.

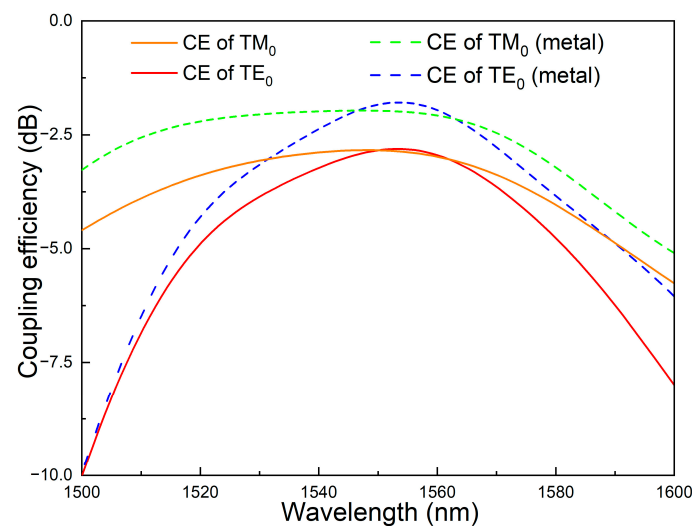


Figure 3. Coupling efficiency with wavelength of segmented and apodized grating coupler. The solid and dashed lines denote the CEs of grating coupler with and without a gold bottom reflector, respectively.

It could be seen that CEs of TE_0 and TM_0 modes were improved to -2.83 dB and -2.82 dB with 3-dB-bandwidths of 73 nm and 100 nm at wavelength 1550 nm, respectively. An increase of about 2 dB in CE was gained when the segmented and apodized grating configuration was applied. The polarization-splitting ratio was defined as the CE of TE_0

polarization over the CE of TM_0 polarization. The difference of CEs for the two modes was small, indicating that the polarization-splitting GC had a good polarization independence and a good polarization-splitting ratio of 1:1. Along with that, if the gratings numbered 1 and 14 were deleted on consideration of the fabrication process, a decrease of only 0.02 dB was introduced in the CE.

Grating parameters such as the thickness of LN film (h), Λ , FF, and d played important roles in the CE and splitting ability. Their fabrication tolerances were important to the performance of coupler. CEs at different parameters' deviations for TE_0 and TM_0 modes were shown in Figure 4. The CEs of TE_0 mode and TM_0 mode were demonstrated in dashed and solid curves, respectively. The optimal CE at wavelength 1550 nm was marked by an orange dot.

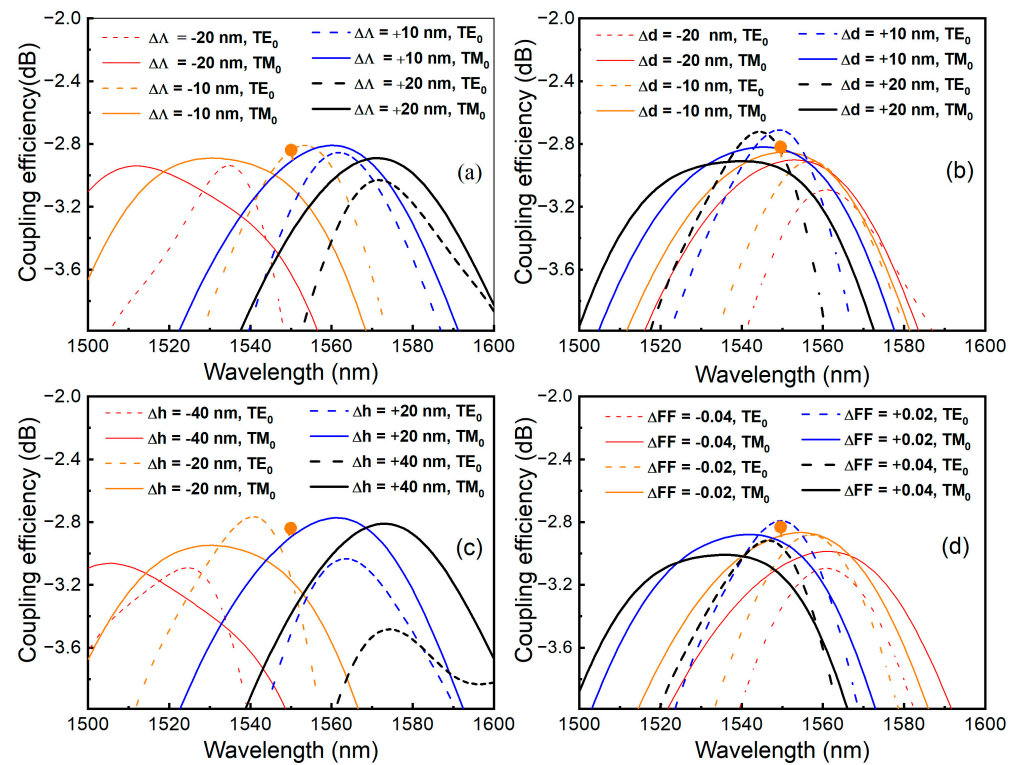


Figure 4. Coupling efficiency for different deviations of (a) period Λ from 920 nm, (b) etch depth d from 300 nm, (c) thickness of LN film h from 500 nm, and (d) filling factor FF from 0.4.

In Figure 4a, grating period varied around the optimal value of 920 nm with ± 20 nm when other parameters were kept at their optimal values. The red, orange, blue, and black lines denoted the CEs when the periods were 900 nm (-20 nm), 910 nm (-10 nm), 930 nm ($+10$ nm), and 940 nm ($+20$ nm). A deviation of period made the peak wavelength move, with the greater the deviation of period, the greater the peak wavelength shift. The shift made the intersection point of the two CE curves (TE_0 and TM_0) at the same period move down or move out of the range 1500 nm to 1600 nm. Deviations of -10 nm and -20 nm introduced decreases of about 0.2 dB and 0.28 dB in CEs, respectively. Deviations of $+10$ nm and $+20$ nm made the intersection point move out of the 1500 nm to 1600 nm range. Therefore, it was difficult to keep the polarization-splitting ratio at 1:1 with a good CE. In addition, at a wavelength of 1550 nm, the CEs for TE_0 and TM_0 modes were -4.4 dB/ -3.62 dB, -2.84 dB/ -3.06 dB, -3.21 dB/ -2.89 dB, and -3.34 dB/ -4.32 dB when the periods were set to 900 nm, 910 nm, 930 nm, and 940 nm and the polarization-splitting ratios were 1:1.19, 1:0.95, 1:1.08, and 1:0.8, respectively. The greater the deviation from 1:1, the worse the polarization independence at wavelength 1550 nm of the coupler. It could be seen that deviations of ± 20 nm introduced a maximum extra loss of about 1.6 dB

and 1.5 dB for TE_0 and TM_0 modes at wavelength 1550 nm. The above results suggested that the polarization-splitting GC was sensitive to the parameter of grating period which determined the coupling strength. One can vary this parameter to change the CE and polarization-splitting ratio. The deviation of period should be tightly controlled to achieve a good polarization-splitting ratio and CE.

In Figure 4b, the etch depth varied around the optimal value of 300 nm with ± 20 nm when other parameters were kept at their optimal values. The red, orange, blue, and black lines denote the CEs when the etch depths d were 280 nm (-20 nm), 290 nm (-10 nm), 310 nm ($+10$ nm), and 320 nm ($+20$ nm), respectively. A deviation of d made the peak wavelength move, a positive deviation resulted in a blue-shift, and a negative deviation resulted in a red-shift for both modes. The greater the deviation of d , the greater the peak wavelength shift. Although parts of the peak CEs increased (the black and blue curves for TE_0 mode), the shift also made the intersection point of the two CE curves (TE_0 and TM_0) at the same etch depth move down. Deviations of ± 10 nm and ± 20 nm resulted in a decrease of CE at intersection points less than 0.1 dB and 0.8 dB, respectively. At a wavelength of 1550 nm, the CEs for TE_0 and TM_0 modes were -3.42 dB/ -2.9 dB, -3.02 dB/ -2.86 dB, -2.72 dB/ -2.83 dB, and -2.82 dB/ -2.96 dB when the h was 280 nm, 290 nm, 310 nm, and 320 nm, meaning that the polarization-splitting ratios were 1:1.23, 1:1.04, 1:0.98, and 1:1.03, respectively. Deviations of ± 20 nm only introduced a maximum extra loss about 0.37 dB and 0.13 dB for TE_0 and TM_0 modes at wavelength 1550 nm. The above results suggested that the polarization-splitting GC had a good fabrication tolerance of etching depth. A deviation of ± 20 nm was acceptable.

In Figure 4c, the h varied around the optimal value of 500 nm with ± 40 nm when other parameters were kept at their optimal values. The red, orange, blue, and black lines denote the CEs when the h was 460 nm (-40 nm), 480 nm (-20 nm), 520 nm ($+20$ nm), and 540 nm ($+40$ nm), respectively. A deviation of h made the peak wavelength move, a positive deviation resulted in a red-shift, and a negative deviation resulted in a blue-shift for the two modes. The greater the deviation of h , the greater the peak wavelength shift. The shift made the intersection point of the two CE curves (TE_0 and TM_0) at the same h move down or move out of the range 1500 nm to 1600 nm. Deviations of -40 nm and -20 nm resulted in a decrease of CE at intersection point about 0.34 dB and 0.15 dB, respectively. In addition, at a wavelength of 1550 nm, the CEs for TE_0 and TM_0 modes were -6 dB/ -4.2 dB, -3.16 dB/ -3.17 dB, -3.59 dB/ -2.92 dB, and -5.1 dB/ -3.42 dB when the h was 460 nm, 480 nm, 520 nm, and 540 nm, so the polarization-splitting ratio were 1:1.52, 1:1.002, 1:1.17, and 1:1.47, respectively. Deviations of ± 20 nm introduced a maximum extra loss of about 0.76 dB and 0.34 dB for TE_0 and TM_0 modes at wavelength 1550 nm, respectively. Deviations of ± 40 nm introduced a maximum extra loss of about 3.2 dB and 2.3 dB for TE_0 and TM_0 modes at wavelength 1550 nm. The polarization-splitting GC was sensitive to the parameter h which could change the refractive indexes of the waveguide mode. To keep a good CE and polarization-splitting ratio, the deviation of h should be controlled in ± 20 nm.

In Figure 4d, the filling factor varied around the optimal value of 0.4 with ± 0.04 when other parameters were kept at their optimal values. The red, orange, blue, and black lines denote the CEs when the FF was 0.36 (-0.04), 0.38 (-0.02), 0.42 ($+0.02$), and 0.44 ($+0.04$). A deviation of the FF makes the peak wavelength move. A positive deviation results in a blue-shift, and a negative deviation results in a red-shift for both modes. The greater the deviation of FF, the greater the peak wavelength shift. Although parts of the peak CEs were increased (the blue curve for TE_0 mode), the shift also made the intersection point of the two CE curves (TE_0 and TM_0) at the same FF move down. Deviations of ± 0.02 resulted in a decrease of CE at interaction point less than 0.07 dB and 0.7 dB, respectively. It indicated that a CE of -2.91 dB for the two modes with a polarization-splitting ratio of 1:1 was obtained when the deviation was controlled in ± 0.02 . At wavelength 1550 nm, the CEs for TE_0 and TM_0 modes were -3.36 dB/ -3.1 dB, -3.02 dB/ -2.9 dB, -2.91 dB/ -2.8 dB, and -2.97 dB/ -3.14 dB when the FF was 0.36, 0.38, 0.42, and 0.44, so the polarization-splitting

ratios were 1:1.06, 1:1.03, 1:1.03, and 1:0.96, respectively. Since a narrow FF range near 0.4 was investigated, the polarization-splitting GC showed less-insensitivity to the FF which played an important role in the field distribution. A deviation of ± 0.04 was acceptable.

For the segmented, chirped, and apodized GC, $\delta\Lambda$ and δFF were especially important for the coupling and splitting performance. Figure 5a,b gave the CEs at different $\delta\Lambda$ and δFF for TE_0 and TM_0 modes. The CEs of TE_0 mode and TM_0 mode were demonstrated in dashed and solid curves. The optimal CE at wavelength 1550 nm was marked by an orange dot.

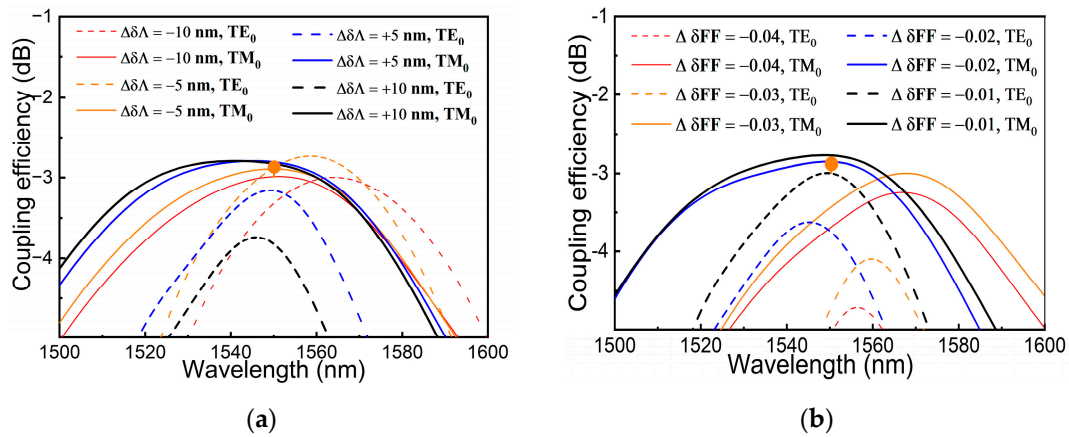


Figure 5. Coupling efficiency for different (a) variation of period $\delta\Lambda$ and (b) variation of filling factor δFF .

In Figure 5a, the red, orange, blue, and black lines denoted the CEs when $\delta\Lambda$ were 9 nm (−10 nm), 14 nm (−5 nm), 24 (+5 nm), and 29 (+10 nm). Deviations of $\delta\Lambda$ made the peak wavelength move. The greater the deviation of $\delta\Lambda$, the greater the peak wavelength shift. The shift made the intersection point of the two CE curves (TE_0 and TM_0) at the same period move down when $\delta\Lambda$ were 9 nm and 14 nm, while out of the range from 1500 nm to 1600 nm when $\delta\Lambda$ were 24 nm and 29 nm. The decreased CE at the intersection points were −3.05 dB and −2.9 dB when $\delta\Lambda$ were 9 nm and 14 nm. This resulted in an extra loss of 0.2 dB and 0.17 dB in CE for the two modes from the optimal value of −2.83 dB, respectively. There was no intersection when $\delta\Lambda$ were at 24 nm and 29 nm, as a splitting ratio of 1:1 would never be achieved in that case. At wavelength 1550 nm, the CEs for TE_0 and TM_0 modes were −3.61 dB/−3.05 dB, −2.83 dB/−2.83 dB, −3.44 dB/−2.79 dB, and −3.82 dB/−2.8 dB when $\delta\Lambda$ were 9 nm, 14 nm, 24 nm, and 29 nm. The polarization-splitting ratios were 1:1.14, 1:1, 1:1.16, and 1:1.26, respectively. Deviations of ± 10 nm introduced a maximum extra loss of about 1 dB and 0.2 dB for TE_0 and TM_0 modes at wavelength 1550 nm. The worse splitting ratio was obtained when a positive deviation of $\delta\Lambda$ which resulted in smaller periods and groove widths in L_1 and L_3 region and could not modify the exponentially decaying distribution of field very well in a limited number of periods was applied.

In Figure 5b, the red, orange, blue, and black lines denoted the CEs when δFF were 0.03 (−0.04), 0.04 (−0.03), 0.05 (−0.02), and 0.06 (−0.01), respectively. A deviation of δFF made the peak wavelength move. A positive deviation resulted in a blue-shift, and a negative deviation resulted in a red-shift for both modes. The greater the deviation of δFF , the greater the peak wavelength shift. The shift made the intersection points of the two CE curves all move out of the wavelength range from 1500 nm to 1600 nm. It indicated that a splitting ratio of 1:1 would never be obtained when δFF was deviated from 0.07. At wavelength 1550 nm, the CEs for TE_0 and TM_0 modes were −3.61 dB/−3.05 dB, −2.83 dB/−2.83 dB, −3.44 dB/−2.79 dB, and −3.82 dB/−2.8 dB when $\delta\Lambda$ were 9 nm, 14 nm, 24 nm, and 29 nm, and the polarization-splitting ratio were 1:1.14, 1:1, 1:1.16, and 1:1.26, respectively. The polarization-splitting GC was highly sensitive to the parameter of δFF which was crucial to

the modified field distribution. The parameter δFF should be under precise control since a small deviation of δFF could destroy the mode field matching condition.

The impact of a deviation of the optimal fiber angle of 6° on the CE and polarization-splitting ability was also studied. CE at different fiber angles was shown in Figure 6. The red and black lines denoted the TE_0 and TM_0 modes, respectively. For TE_0 mode, the deviation of fiber angle made the peak wavelength move, a positive deviation resulted in a blue-shift, and a negative deviation resulted in a red-shift. The shift was exactly the opposite for TM_0 mode. A positive deviation resulted in a red-shift, and a negative deviation resulted in a blue-shift. The opposite shift of the two modes made polarization-splitting with a high CE much more difficult. For the two modes, the greater the deviation of fiber angle, the greater the peak wavelength shift. Take $\theta = 9^\circ$ for example—the peak wavelength shifts to 1529 nm and 1576 nm for TE_0 and TM_0 modes, respectively. The deviation of 3° introduced a shift of 47 nm in peak wavelength. Deviation of fiber angle also resulted in change of peak CE. Except for $\theta = 5^\circ$, the peak CEs all decreased with the deviation, and the bigger deviation of fiber angle, the bigger decrease of peak CE. As shown in Figure 4, the CE at intersection wavelength for both TE_0 and TM_0 mode had a decrease of about 1 dB when the angle deviation equaled to $\pm 3^\circ$, respectively. The fiber angle played an important role in polarization splitting and CE, and the deviation should be controlled in $\pm 3^\circ$ to achieve a good polarization splitting and CE.

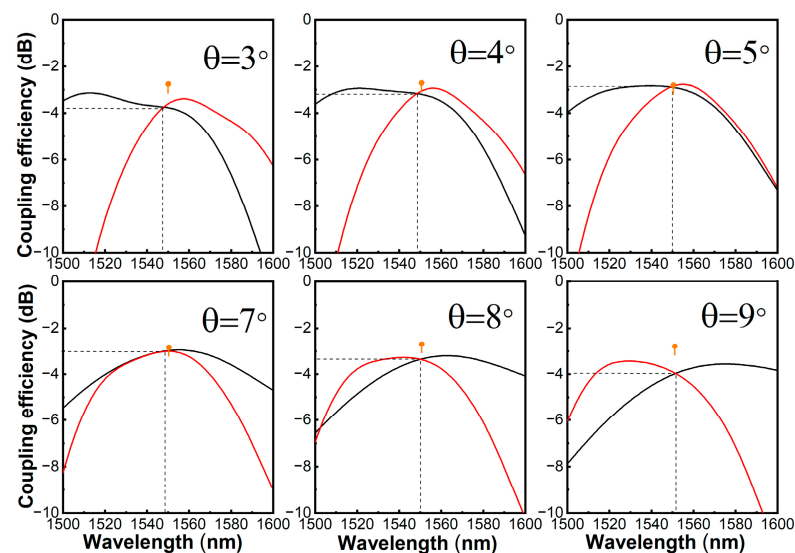


Figure 6. Coupling efficiency of TE_0 mode (red lines) and TM_0 mode (black lines) at different fiber angles. Orange arrows denote the same optimal CE at wavelength 1550 nm when fiber angle is fixed at 6° .

The polarization-splitting grating coupler can also be used as polarization beam combiner in the output coupling. Figure 7 gave the E_x -field profile when used as an output coupler. Waveguide TE_0 and TM_0 modes were excited at port A and port B simultaneously, and were both diffracted by the grating and then combined with the upper fiber. The total transmission was -2.72 dB, which contained 45% TE_0 and 55% TM_0 polarization. The ratio of TE_0 and TM_0 polarization was about 1:1.22, which is a decrease from the polarization-splitting ratio of 1:1. This might be attributed to the interaction of the two beams in the output coupling which did not happen in the input coupling. At the input coupling, TE_0 and TM_0 polarization lights were employed separately, but were excited simultaneously at the output coupling.

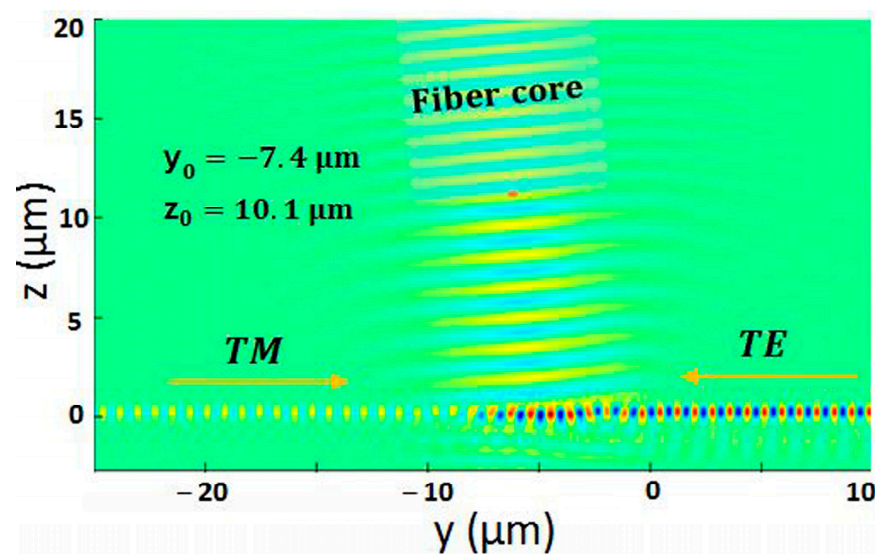


Figure 7. E_x field profile when grating coupler used as a polarization beam combiner at wavelength 1550 nm.

4. Conclusions

In conclusion, this study designed and optimized a multifunctional grating coupler with polarization-splitting ability for coupling between waveguide on LNOI and single-mode fibers. Using segmented and apodized grating structure, peak coupling efficiencies of -2.82 dB and -2.83 dB at a wavelength of 1550 nm with a 3-dB-bandwidth of 73 nm and 100 nm for fundamental TE and TM polarization mode were achieved. The fabrication tolerance of parameters such as grating period, etch depth, thickness of lithium niobate thin film, filling factor, variation of period, variation of filling factor, and fiber angle were studied. Results showed that the deviations from optimal values all resulted in peak wavelength shift, decrease of CE at intersection point (polarization-splitting ratio was kept at 1:1), and decrease of polarization independence at wavelength 1550 nm. In addition, the polarization-splitting GC had good fabrication tolerance of etch depth and filling factor in a variation range of ± 20 nm and ± 0.04 , respectively. The coupler was highly sensitive to the period, the thickness of lithium niobate thin film, the variation of filling factor, and the fiber angle, respectively. One could adjust the splitting ratio by varying them. The coupler can also be used as a polarization beam combiner, and was meaningful to the polarization diversity system.

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Conflicts of Interest: The authors declare no conflicts of interest.

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