Optics & Laser Technology 44 (2012) 1992–1994

Contents lists available at SciVerse ScienceDirect

Optics & Laser Technology

journal homepage: www.elsevier.com/locate/optlastec

Research Note

Tunable polarization-independent Šolc-type wavelength filter based on periodically poled lithium niobate

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ARTICLE INFO

Article history:
Received 20 September 2011
Received in revised form
5 December 2011
Accepted 28 December 2011
Available online 20 February 2012

Keywords:
Šolc-type filter
Quasi-phase-matched nonlinear crystal
Polarization-independent

ABSTRACT

We demonstrated a compact structure to implement the tunable Šolc-type wavelength filter based on periodically poled lithium niobate device. The theoretical analysis and experimental results show that the wavelength filter exhibits polarization independent. By comparing the polarization-independent and single-pass Šolc-type filters, same wavelength spectrum response was observed, while the improvement on the transmission power was obviously achieved and the polarization dependent loss was eliminated efficiently using polarization diversity and multiplexing.

1. Introduction

The Šolc-type filters are well known as polarization interference ones constructed by a stack of identical birefringent plates. They have the folded azimuth angles between crossed polarizers or the fanned azimuth angles between parallel polarizers [1]. Quasi-phase-matched (QPM) nonlinear crystal, such as periodically poled lithium niobate (PPLN), has been widely studied in the field of nonlinear optical interactions because of its effective frequency conversion. Šolc-type filters based on bulk or waveguide-type PPLN are also investigated because the successive reversal domains can work as the half-wave plates based on the electric-optic effect [2–4]. By applying a uniformed electric field along the transverse axis of PPLN, the optical axis of domains is alternately rotated with $\pm\theta$ [5]. Due to the misalignment of LN wafer, there is always fabrication error in crystal orientation. The narrowband (<1 nm) Šolc-type filters can be realized in QPM crystals without applying external electrical field [6,7]. The central wavelength of this kind of filters can be tuned using UV exposure or changing crystal temperature. However, as a disadvantage of traditional Šolc-type wavelength filter [3–7], polarization dependence is not favorable for practical applications. In order to address polarization dependent loss (PDL), we demonstrated a compact polarization-independent scheme using polarization diversity and multiplexing. The counter-propagating beams with orthogonal polarization state are passing through the same Šolc-type filter. As being insensitive to the input polarization state, this scheme can minimize polarization mode dispersion (PMD) and more robust to environmental changes [7].

The scheme, as shown in Fig. 1, separates the polarization state into the counter-propagating optical paths using a polarizing-beam splitter (PBS). Two orthogonal polarization directions are parallel to the front polarizer and the end polarizer, respectively. The decomposed lights with orthogonal linearly polarization propagate the single-pass PPLN Šolc filter and recover together with same optical path in the PBS, where it acts as a beam combiner. The fibers used in (counter-) clockwise (CW) optical path are polarization maintained.

We theoretically analyze the transmission characteristics of polarization-independent filter described above using Jones Matrix method [8]. The optical transmission along CW direction can be described as

$$T_{cw} = \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix} M_{cw} \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix} \tag{1}$$

where M_{cw} represent the coordinate Jones Matrix of PPLN [9], which is

$$M = \begin{pmatrix} \frac{A\sin m\Gamma - \sin(m-1)\Gamma}{\sin\Gamma} & B\frac{\sin m\Gamma}{\sin\Gamma} \\ C\frac{\sin m\Gamma}{\sin\Gamma} & \frac{D\sin m\Gamma - \sin(m-1)\Gamma}{\sin\Gamma} \end{pmatrix} \tag{2}$$

$$\Gamma = \arccos[\tfrac{1}{2}(A+D)] = \arccos[\sin^2 2\theta + \cos^2 2\theta\cos\delta] \tag{3}$$

where m is the total number of PPLN grating period, Λ is the grating period, $\delta = \pi(n_e - n_o)\Lambda/\lambda$ is the detune parameter, n_o and n_e are the indices of the ordinary and extraordinary waves, respectively. Then we obtained the transmission in CCW (counter-CW)

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doi:10.1016/j.optlastec.2011.12.046

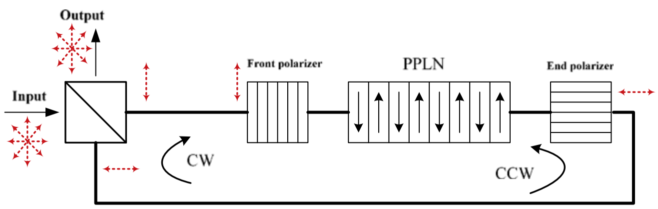

Fig. 1. Principle of polarization-independent PPLN based Šolc filter.

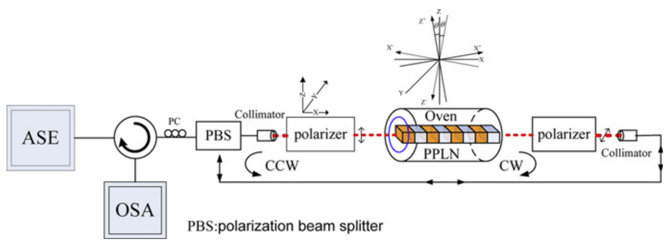

Fig. 2. Experimental setup of polarization-independent Šolc-type filter.

direction as

$$T_{cw} = \begin{pmatrix} 0 & 0 \\ C_{cw}\frac{\sin m\Gamma}{\sin\Gamma} & 0 \end{pmatrix}; \quad T_{ccw} = \begin{pmatrix} 0 & B_{ccw}\frac{\sin m\Gamma}{\sin\Gamma} \\ 0 & 0 \end{pmatrix} \tag{4}$$

We notice $C_{cw}=B_{ccw}$ under the relation of $\theta_{cw}=-\theta_{ccw}$, where θ_{cw} (θ_{ccw}) is the azimuth angle θ of optical axis of domains relative to z-axis [2] under the CW and CCW path, respectively, as shown in Fig. 2. Then the transmission intensity I_{out} can be expressed as

$$I_{out} = B^2\frac{\sin^2 m\Gamma}{\sin^2\Gamma}[|a|^2+|b|^2] \tag{5}$$

where a, b represent the input field amplitude components of the orthogonal linearly polarization state. It shows that the output intensity is a wavelength dependent function and is independent of the input polarization state and intensity.

2. Experiment

The experimental schematic of polarization-independent Šolc-type filter is shown in Fig. 2. The Z-cut PPLN crystal is fabricated using the electric-poling technique at room temperature. The PPLN dimensions are 50 mm (length), 3 mm (width) and 1 mm (thickness), and the grating period is 20.4 μm. We use the YOKOGAWA optical test kit in our experiment, which includes a C+L broadband ASE source with an output wavelength range from approximately 1520 nm to 1610 nm and an optical spectrum analyzer (OSA) to detect the output light. Crystal temperature is precisely adjusted by a temperature control oven. The PBS separates the input ASE light with orthogonal polarization states in the polarization-maintaining fibers. The output lights from two arms are collimated using two collimators with 100-mm working distance. The planes of polarization state are polarized with the front and the end polarizer, respectively. Thus two orthogonal polarized lights can travel through the polarizers and PPLN crystal in the counter-propagating directions. The polarization-state outputs from Šolc-type filtering based on PPLN crystal have the same optical path and the same transmission spectrum. Therefore the polarization-independent Šolc-type wavelength filter is constructed, while the typical Šolc-type filter based on PPLN crystal is considered to be single-pass, as one of the optical path in the ring structure. The polarization direction of the front polarizer is along the Y-axis, and that of the end polarizer is vertical to the front one. In order to minimize the coupling loss between the polarizers and the end collimators, we insert an optical power meter between the polarizers and PPLN crystal, and then rotate the collimators until the received optical power reaches the maximum, which means that the polarization direction of the output light had already been parallel to the front or end polarizer.

3. Results and discussion

As shown in Fig. 3 the central wavelength of the measured normalized transmission was 1586.4 nm when the crystal temperature is 40.2 °C, which is in fair agreement with the theoretical results both in the central wavelength and the full width at half maximum (FWHM), 0.55 nm. By increasing the temperature of PPLN crystal, the central wavelength was shifted towards the shorter wavelength and the transmission spectrum showed a good stabilization. We also observed that the relationship between the central wavelength and the temperature was almost linear, approximately −0.665 nm/°C, which is equal to the theory result obtained from Sellmeier equation [10].

We compared the transmission spectrum of the polarization-independent Šolc-type filter to the traditional single-pass one as shown in Fig. 4(a) when the temperature is 40.2 °C and 45 °C, respectively. They had similar wavelength spectrum response while the improvement on the transmission power was obviously achieved in the polarization-independent Šolc-type wavelength filter. The amount of transmission power increment was about 34% under the same input light power. Fig. 4(b) showed the improved tendency under the other temperatures.

Considering the PDL is at least 3 dB in the single-pass Šolc-type filter, in theory, the transmission power will be increased at most 50% because the lights of both polarization states are fully utilized in the compact structure proposed here. But the experimental results were not as high as our prediction due to the optical losses of the additional components. After the same counter-propagating distance, the output lights at the identical selected wavelength in two different polarization states are circulated clockwise (or counter-clockwise) and combined in the PBS. The PBS and circulator which are inserted in the ring structure have caused additional optical loss than that of single-pass Šolc-type filter. The insert loss of PBS and circulator are 0.35 dB and 0.55 dB, respectively. Considering the light travel through these components twice, the total additional optical loss is estimated about 1.8 dB.

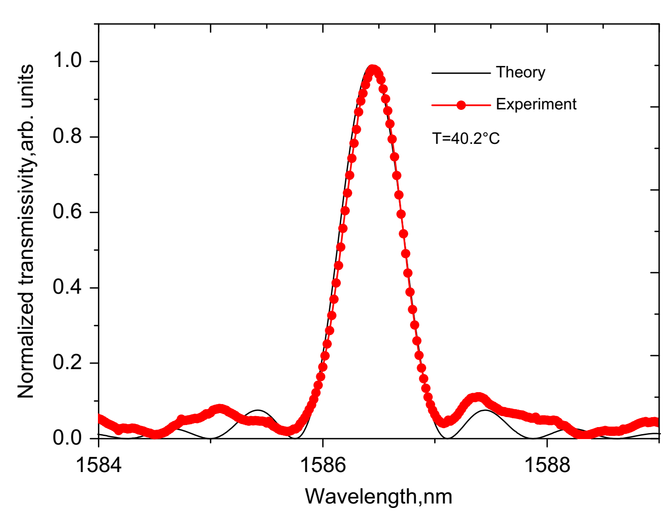

Fig. 3. Transmission spectrum of polarization-independent filter when the temperature is 40.2 °C.

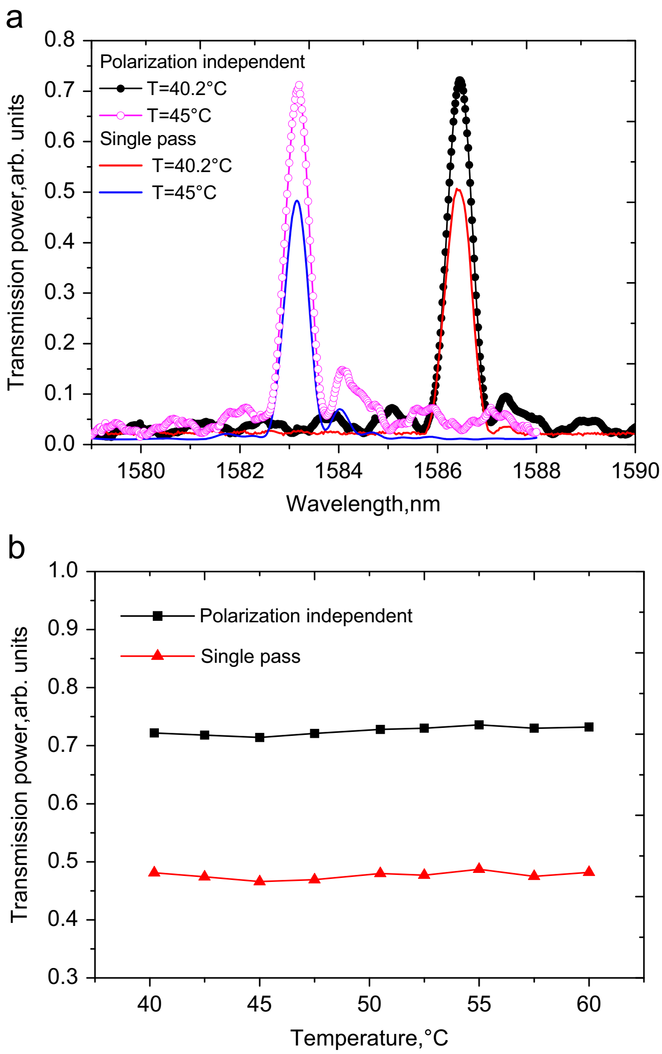

Fig. 4. (a) Transmission spectrum and (b) peak power between the polarization-independent and single-pass structures.

4. Conclusion

We have demonstrated a tunable polarization-independent Šolc-type filter based on PPLN crystal using a compact ring structure. The spectrum transmission is nearly improved 34% and the PDL is eliminated effectively. The polarization-independent configuration can be easily implemented in waveguide-type PPLN filter or used in the integration of wavelength converter based on PPLN waveguide [11]. The proposed scheme shows a promising application in the all-optical information process system.

Acknowledgments

This work is supported in part by the National Natural Science Foundation of China (60978004, 60937003, 61132004), Shanghai Municipal Education Commission (10YZ14) and Shuguang Program (10SG38), Shanghai Science and Technology Development Funds (11XD1402600), SSTCP (11511502501-2) and Leading Academic Discipline Project (S30108).

References

[1] Evans John W. Solc birefringent filter. Journal of the Optical Society of America 1958;48:142–5.
[2] Chen Xianfeng, Shi Jianhong, Chen Yuping, Zhu Yiming, Xia Yuxing, Chen Yingli. Electro-optic Solc-type wavelength filter in periodically poled lithium niobate. Optics Letters 2003;28:2115–7.
[3] Lee YL, Yu NE, Kee C-S, Ko D-K, Noh Y-C, Yu B-A, et al. Waveguide-type wavelength-tunable Solc filter in a periodically poled Ti: $LiNbO_3$ waveguide. IEEE Photonics Technology Letters 2007;19:1505–7.
[4] Liu Kun, Shi Jianhong, Chen Xianfeng. Linear polarization-state generator with high precision in periodically poled lithium niobate. Applied Physics Letters 2009;94:101106.
[5] Wang Jinghe, Shi Jianhong, zhou Zhuoer, Chen Xianfeng. Tunable multi-wavelength filter in periodically poled $LiNbO_3$ by a local-temperature-control technique. Optics Express 2007;15:1561–6.
[6] Lee Yeung Lak, Noh Young-Chul, Kee Chul-Sik, Yu Nan Ei, Shin Woojin, Jung Changsoo, et al. Bandwidth control of a Ti:PPLN Šolc filter by a temperature-gradient-control technique. Optics Express 2008;16:13699–706.
[7] Xue Shicheng, van Eijkelenborg Martijn A, Barton Geoff W, Hambley Philip. Wide-range tunable wavelength filter in periodically poled lithium niobate. Journal of Optical Communication 2003;228:139–43.
[8] Jones RC. New calculus for the treatment of optical systems. Journal of the Optical Society of America 1941;31:500–3.
[9] Yariv, Yeh P. Optical waves in crystal: propagation and control of laser radiation. New York: John Wiley & Sons; 1984.
[10] Jundt Dieter H. Temperature-dependent Sellmeier equation for the index of refraction, n_e, in congruent lithium niobate. Optics Letters 1997;22:1553–5.
[11] Zeng Xianglong, Chen Xianfeng, Chen Yuping, Xia Yuxing, Chen Yingli. Observation of all optical wavelength conversion based on cascaded effect in periodically poled lithium niobate waveguide. Optics and Laser Technology 2003;35:187–90.