Analysis on Output Polarization Characteristics of Fiber Comb Filters based on Polarization-Diversity Loop Structure

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Keywords: Comb Filter, Solc-Type Filter, Lyot-Type Filter, Polarization-Diversity Loop, Polarization-Maintaining Fiber.

Abstract: The output states of polarization (SOP's) were investigated within the bandwidth of a filter channel (0.8 nm) for a variety of optical fiber comb filters based on polarization-diversity loop structure including a zeroth-order comb filter, first-order Lyot-type and Solc-type comb filters, and a second-order Solc-type comb filter. The output SOP's (SOP_{out}'s) of the filters were calculated at a flat-top band operation mode of each filter for four different input SOP's (SOP_{in}'s) except for the zeroth-order filter. It was found that the SOP_{out} of each filter had unique dependence on wavelength. Specifically, the SOP_{out}'s of first-order and second-order comb filters vary periodically with spectral periods of a channel bandwidth (0.8 nm) and its half (0.4 nm), respectively. If an output linear polarizer is located at the output port of each filter, the specific portion of transmission spectra can be passed or rejected, and the rejected band can be continuously tuned in a limited wavelength range by controlling the SOP_{in}. Moreover, the SOP_{in} can be figured out by analyzing the location of the spectral dip at the output transmission spectra obtained above by using the output polarizer.

1 INTRODUCTION

A polarization-diversity loop structure (PDLS), which can form a Sagnac interferometer loop using a polarization beam splitter (PBS), has been used to eliminate the dependence of input polarization in nonlinear optical switching applications (Morioka et al., 1993). Fiber comb filters based on the PDLS are capable of wavelength switching of multiwavelength filter channels, which is difficult to be realized in a conventional fiber comb filter that uses an optical fiber coupler (Fang and Claus, 1995). Solc-type birefringence combination have been incorporated to implement high-order transmission spectra including flat-top or narrow band spectra in first-order and second-order fiber comb filters based on the PDLS (Lee et al., 2005). Recently, a first-order Lyot-type fiber comb filter based on the PDLS was demonstrated, and its output state of polarization (SOP) was investigated (Jo et al., 2015). But the output SOP's (SOP_{out}'s) of the Solc-type filters already reported have not been analyzed yet. Among those PDLS-based comb filters, a zeroth-order comb filter has a comb-like transmission spectrum whose transmittance is expressed as only a sinusoidal function (Lee et al., 2003), and both first-order and second-order Solc-type filters have flat-top and narrow band transmission spectra (Lee et al., 2008). Moreover, the first-order Lyot-type comb filter has flat-top and lossy flat-top band transmission spectra (Jo et al., 2015).

Here, the SOP_{out}'s of these filters such as a zeroth-order comb filter, first-order Lyot-type and Solc-type ones, and a second-order Solc-type one are analyzed within the bandwidth of a filter channel (0.8 nm). The SOP_{out}'s of the filters were calculated at a flat-top band operation mode of each filter for four different input SOP's (SOP_{in}'s) except for the zeroth-order filter. It was found that the SOP_{out} of each filter had unique dependence on wavelength. Specifically, the SOP_{out}'s of first-order and second-order comb filters vary periodically with spectral periods of a channel bandwidth (0.8 nm) and its half (0.4 nm), respectively. If an output linear polarizer is located at the output port of each filter, the specific portion of transmission spectra can be passed or rejected, and the rejected

Jo, S., Park, K., Choi, S., Lee, S., Jeong, J., Kim, J. and Lee, Y.
Analysis on Output Polarization Characteristics of Fiber Comb Filters based on Polarization-Diversity Loop Structure.
DOI: 10.5220/0005635400470050
In *Proceedings of the 4th International Conference on Photonics, Optics and Laser Technology (PHOTOPTICS 2016)*, pages 49-52
ISBN: 978-989-758-174-8

band can be continuously tuned in a limited wavelength range by controlling the SOP_{in}. Moreover, the SOP_{in} can be figured out by analyzing the location of the spectral dip at the output transmission spectra obtained above by using the output polarizer.

2 OUTPUT POLARIZATION ANALYSIS

2.1 Filter Structures for SOP_{out} Analysis

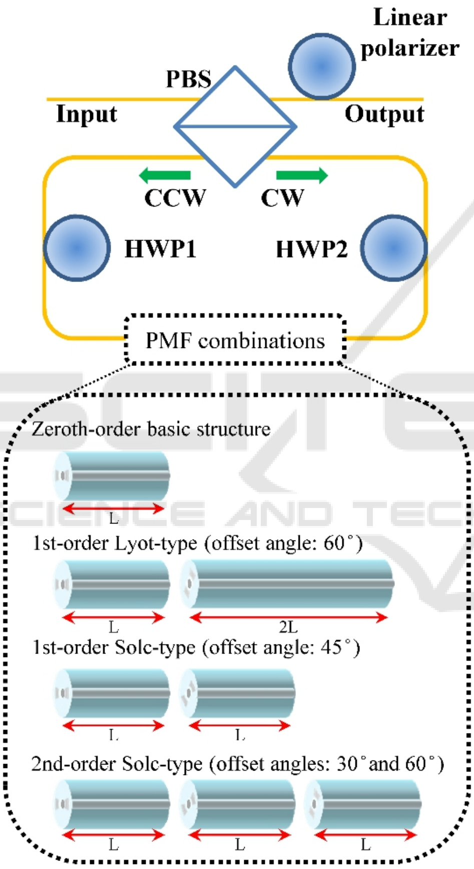

Figure 1: Schematic diagram for SOP_{out} analysis of optical fiber comb filters based on PDLS.

The schematic diagram for the SOP_{out} analysis of PDLS-based fiber filters is illustrated in figure 1. Polarization-maintaining fiber (PMF) combinations in the figure represent the composition of PMF segments used for each filter. The PMF segments in the Lyot- and Solc-type filters used in the SOP_{out} analysis were arranged by using the birefringence combination styles of Lyot and Solc filters, respectively. Input light coming out of the PBS decomposes into two polarization components such as linear horizontal polarization (LHP) and linear vertical polarization (LVP) ones. The LHP and LVP components circulate through the Sagnac loop of the PDLS in clockwise (CW) and counterclockwise (CCW) directions, respectively. Then, the first-order Lyot-type filter has two PMF segments spliced with a 60° offset between their principal axes (Jia, et al., 2002). The lengths of the two PMF segments are L and 2L. In the case of the first-order and second-order Solc-type filters, all PMF segments used in them have an identical length L, and they are concatenated with a 45° offset (first-order) and a 30° offset (second-order) between the principal axes of two adjacent PMF segments, respectively.

2.2 Wavelength Dependence of SOP_{out}

Owing to the wavelength dependence of the SOP_{out}, new transmission spectra can be obtained if we locate a polarizer at the output port of each filter. In order to achieve this, the orientation angle of the polarizer was fixed at 45° with respect to the horizontal axis of the PBS. For four different specific SOP_{in}'s such as 45° linear polarization (LP), 135° LP, right circular polarization (RCP), and left circular polarization (LCP), the transmission spectra of each filter were calculated in the flat-top band mode except for the zeroth-order comb filter, as shown in figure 2. The zeroth-order filter, as shown in figure 2(a), results in only constant losses for the four SOP_{in}'s without spectral shape changes. The first-order Lyot-type and Solc-type filters have totally different spectra with respect to the SOP_{in}, as shown in figures 2(b) and 2(c), respectively. Their transmission spectra have one channel or two channels within the channel bandwidth (0.8 nm) when they have no or one rejection band, respectively. As can be seen from figure 2(d), two or three channels of the second-order Solc-type filter are created within 0.8 nm, which results from one or two rejection bands, respectively. The rejection band results from the existence of 135° LP in the SOP_{out} because the polarizer is oriented at 45°. In particular, the wavelength of the rejection band that separates the channel can be adjusted according to the SOP_{in}.

As mentioned above, in the zeroth-order filter, only a transmission loss varies without spectral shape changes as the SOP_{in} changes. In the first-order Lyot-type filter, the transmission spectrum does not have a rejection band at an SOP_{in} of 135° LP but possesses one rejection band at other SOP_{in}'s. When the SOP_{in} varies from 135° LP to RCP via LCP and 45° LP, rotating in a CCW direction around the axis of LHP

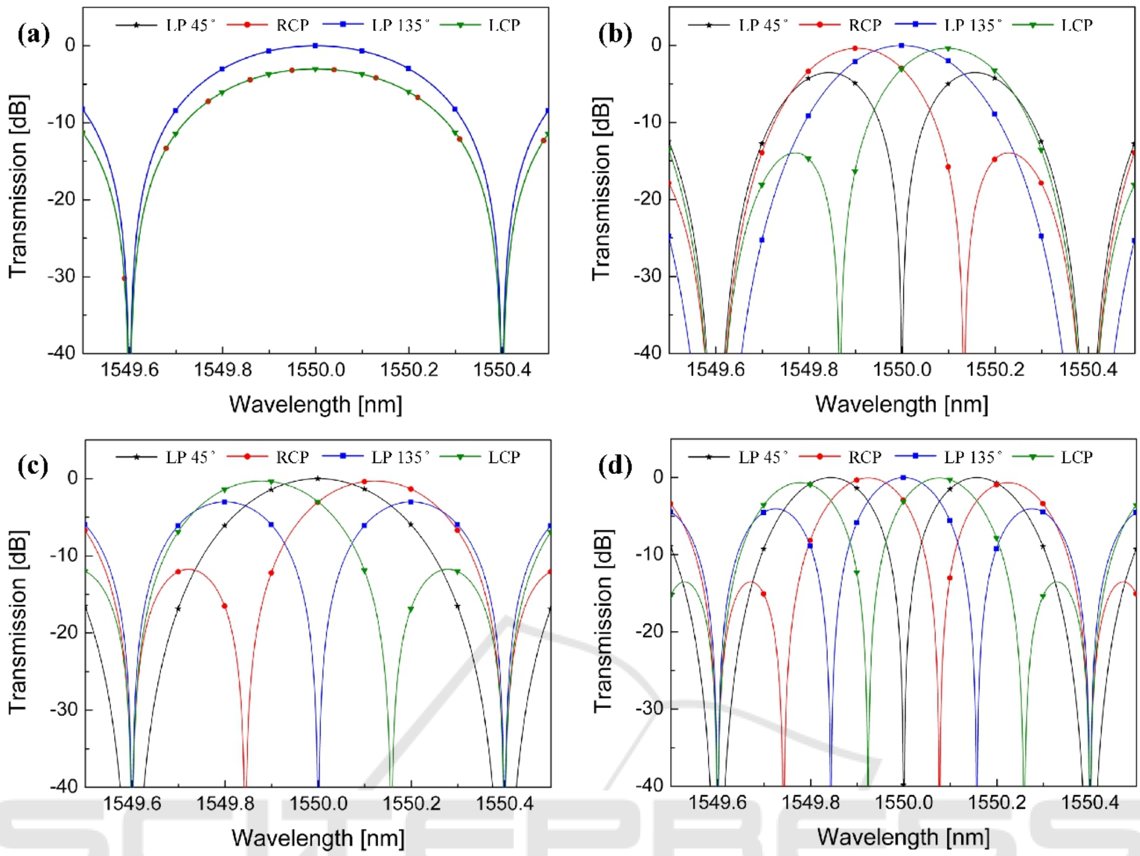

Figure 2: Calculated transmission spectra with respect to four different SOP_{in}'s in (a) zeroth-order comb filter, (b) first-order Lyot-type filter, (c) first-order Solc-type filter, and (d) second-order Solc-type filter.

on the Poincare sphere, this rejection band moves from the shorter wavelength dip to the pass band center of one channel, showing redshift, as shown in figure 2(b). Similarly, in the first-order Solc-type filter, the rejection band in its transmission spectrum also shows redshift while the SOP_{in} varies from 135° LP to RCP via LCP and 45° LP, as shown in figure 2(c). But the initial spectral location of the rejection band is the pass band center, which is different from the case of the first-order Lyot-type filter. Finally, in the second-order Solc-type filter, two rejection bands appear except for at the SOP_{in} of 45° LP and exhibit redshift while SOP_{in} changes from 135° LP to RCP via LCP and 45° LP, as shown in figure 2(d). It is confirmed from figure 2 that the specific portion of transmission spectra can be passed or rejected by controlling the SOP_{in} if a linear polarizer is located at the output port of each filter, except for the zeroth-order filter. Moreover, it is found that modulated spectra can be continuously tuned in a limited spectral range in high-order filters.

Figure 3 shows the spectral variations of the SOP_{out}'s of four filters, theoretically obtained at the analysis points (λ_n) equally spaced in wavelength, with respect to two specific SOP_{in}'s such as 45° LP and RCP in the flat-top band mode except for the zeroth-order filter. Filled and empty geometries indicate SOP's that lie on northern and southern hemispheres of the Poincare sphere, respectively. Except for the zeroth-order filter, the SOP_{out} represents vibrations of ellipses of the same orientation (45° or –45°) whose eccentricity varies from 0 on the equator to ±1 at the north and south poles of the Poincare sphere, respectively. The SOP_{in} dependence of the transmission spectrum of each filter, shown in figure 2, can be explained from figure 3. For example, if the SOP_{out} is 45° LP or 135° LP, the output of the polarizer shown in figure 1, which has an orientation angle of 45° with respect to the horizontal axis of the PBS, exhibits no insertion loss (IL) or complete rejection, respectively.

The SOP_{out} of the zeroth-order filter is wavelength-independent and located on the opposite side of the SOP_{in} on the Poincare sphere, i.e., orthogonal to the SOP_{in}. On the contrary, the SOP_{out}'s of three remaining comb filters are wavelength-dependent and vary periodically with spectral periods of a channel spacing (0.8 nm) or its half. The spectral period of the SOP_{out} evolution is the filter channel spacing in the first-order filter and its half in the second-order filter. In each filter, it is found that the SOP_{out} at the same analysis point is different according to the SOP_{in}, which results in the SOP_{in} dependence of the output spectrum of each filter in figure 2. In other words, it is possible to figure out the SOP_{in} of each filter except for the zeroth-order filter by analysing output spectra obtained in the experimental setup shown in figure 1.

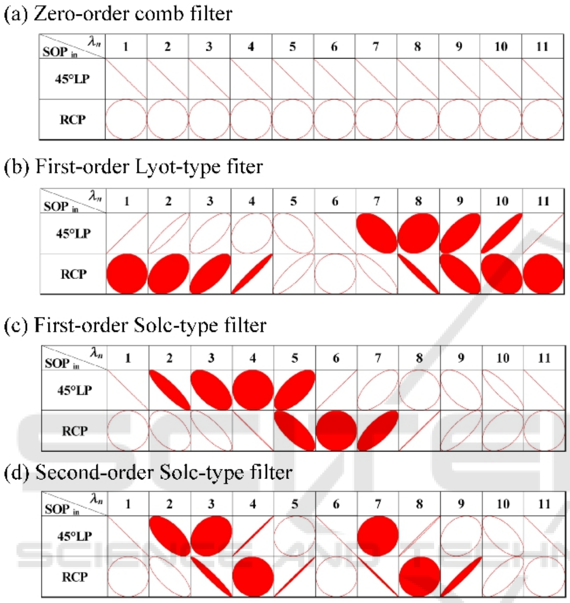

Figure 3: Calculated spectral variations of SOP_{out}'s of four filters with respect to two specific SOP_{in}'s such as 45° LP and RCP.

3 CONCLUSIONS

In this paper, the SOP_{out}'s of PDLS-based comb filters such as a zeroth-order comb filter, first-order Lyot-type and Solc-type ones, and a second-order Solc-type one were investigated within one channel bandwidth (0.8 nm). It was found that the SOP_{out} of the zeroth-order filter was wavelength-independent and orthogonal to the SOP_{in}. On the contrary, the SOP_{out}'s of three remaining comb filters are wavelength-dependent and vary periodically with spectral periods of the channel spacing (0.8 nm) or its half. Owing to this wavelength dependence of the SOP_{out}'s of the filters, one or two rejection bands appear in the output spectrum if a linear polarizer is located at their output port. When the SOP_{in} varies from 135° LP to RCP via LCP and 45° LP except for the zeroth-order comb filter, rotating in a CCW direction around the axis of LHP on the Poincare sphere, this rejection band exhibits redshift. In particular, the rejection band was possible to be continuously tuned in a limited wavelength range in the high-order filters by controlling the SOP_{in}.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. 2013R1A2A2A01068390). This research was also supported by a grant from Marine Biotechnology Program (20150220) funded by the Ministry of Oceans and Fisheries, Korea.

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