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Photonic Filters Using Optical Retarders Based on Birefringent Optical Media

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Abstract

Photonic filters can be used for filtering the spectrum of wide-band optical sources such as light emitting diodes (LED) or multimode laser diodes (MMLD). In this work the use of birefringent optical media such as polarization maintaining fiber (PMF) or birefringent optical waveguides on Lithium Niobate ($LiNbO_3$) crystal, perform as optical filters. The birefringent optical media, used as optical retarders, modify the optical spectrum by "channelizing" them. These devices act as photonic filters, thus modifying an optical spectrum. As reported in this paper, integrated optics photonic filters are easily implemented by birefringent optical waveguides on $LiNbO_3$ electrooptic crystals. The practical filtering of LED and MMLD spectra is demonstrated in this work. The photonic filters can be used for implementing microwave filters or optoelectronic multiplexing for radio or radio over fiber schemes.

Keywords: photonic filters, optical delays, broadband optical sources, birefringent optical media.

1 Introduction

Very simple photonic filtering can be achieved by optical retarders, which modify the optical spectrum of semiconductor LED's and MMLD. The LED optical emission can be filtered for generating a multimode spectrum; a multimode laser spectrum can be filtered for eliminating emitted modes. An optical retarder can be easily implemented by birefringent optical media such as PMF or optical waveguides on $LiNbO_3$. The optical retarder introduces an optical delay (OD) or its equivalent optical path-difference (OPD) when 45° polarized light enters the media and is projected in two propagating orthogonal modes, transversal electric (TE) and transversal magnetic (TM), respectively. The two optical modes travel at different velocities thus introducing an OPD, which depends on the optical birefringence and the length of the optical path. The optical delay modifies the optical spectrum by "channeling" it. Such an effect has been described in detail when studying coherence multiplexing of light [1]. The channeling effect can be matched to the optical spectrum of a multi-longitudinal laser diode and its optical modes can be selectively filtered as reported in this paper. A photonic filter based on a birefringent optical waveguide on a lithium niobate ($LiNbO_3$) crystal is described in this paper. The proposed photonic filter is a kind of Solc optical filter and can be considered as an elementary block of such a configuration [2, 3].

Photonic filters, as the one described in this paper, are being proposed either for implementing microwave filters or for transmitting modulated microwave sub-carriers in the field of high speed telecommunications on radio over fiber schemes [4-7].

2 Optical Retarders as Photonic Filters

Optical delays can be introduced by optical retarders when using birefringent optical media. Optical delays are easily generated by $LiNbO_3$ electro-optic waveguides, and can be measured as a fringe pattern when the waveguide is placed between crossed polarizers (polarization interferometer). The optical waveguides generate static optical path-differences, OPD's. An optical retarder can be implemented using Z-cut Y-propagating $LiNbO_3$ birefringent optical waveguides, which introduce optical delays when 45° polarized light is projected in orthogonal propagating modes TE and TM. Such modes travel in the waveguide at different velocities, as determined by the group refractive index ($n_o - n_e$), where n_o and n_e are the ordinary and extraordinary refractive index, respectively. A $LiNbO_3$ optical waveguide acting as an optical retarder is depicted in Figure 1. The optical waveguide is an indifussed Ti strip that makes 8 μm wide and 8 μm depth and performs as single mode guide at an optical wavelength of 1550 nm.

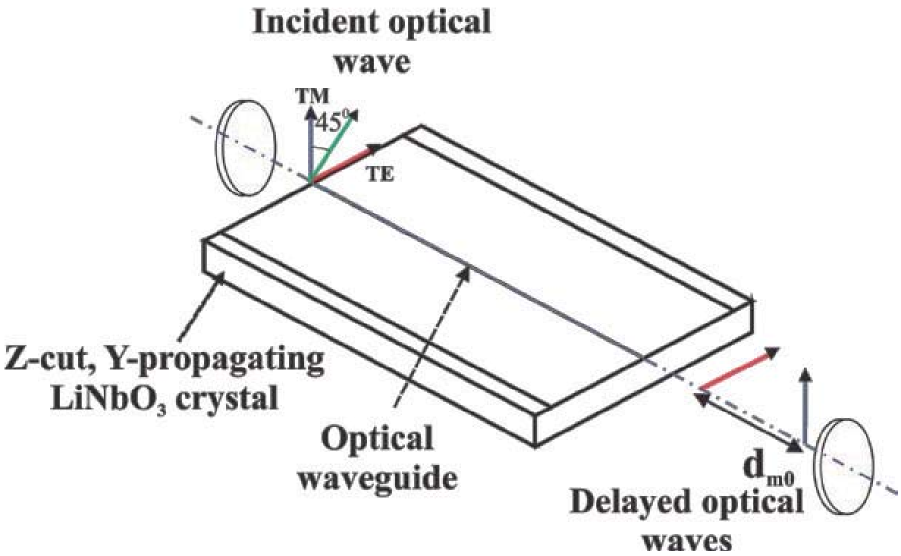


Figure 1. *An optical waveguide on a LiNbO3 substrate working as optical retarder.*

The optical delay between the orthogonal waves TE and TM is given as

$$\tau_0 = \frac{(n_o - n_e)L}{v} \tag{1}$$

L is optical waveguide length and v is the light propagation velocity in the waveguide and $(n_o - n_e) \approx 0.083$ is the crystal birefringence. The optical path - difference is given as

$$d_{mo} = \tau_0 v = (n_o - n_e) L \tag{2}$$

To determine the values of OPD's that can conveniently filter an optical spectrum $P(\lambda)$, the filtering function is given as [5]

$$S(\lambda) = \frac{1}{2} P(\lambda) \left[1 + \cos(\frac{1}{\lambda} 2\pi d_{mo}) \right] \tag{3}$$

Where d_{mo} is the introduced OPD and λ is the optical wavelength.

From expression 3, the filtering process of a LED spectrum is illustrated by Figure 2.

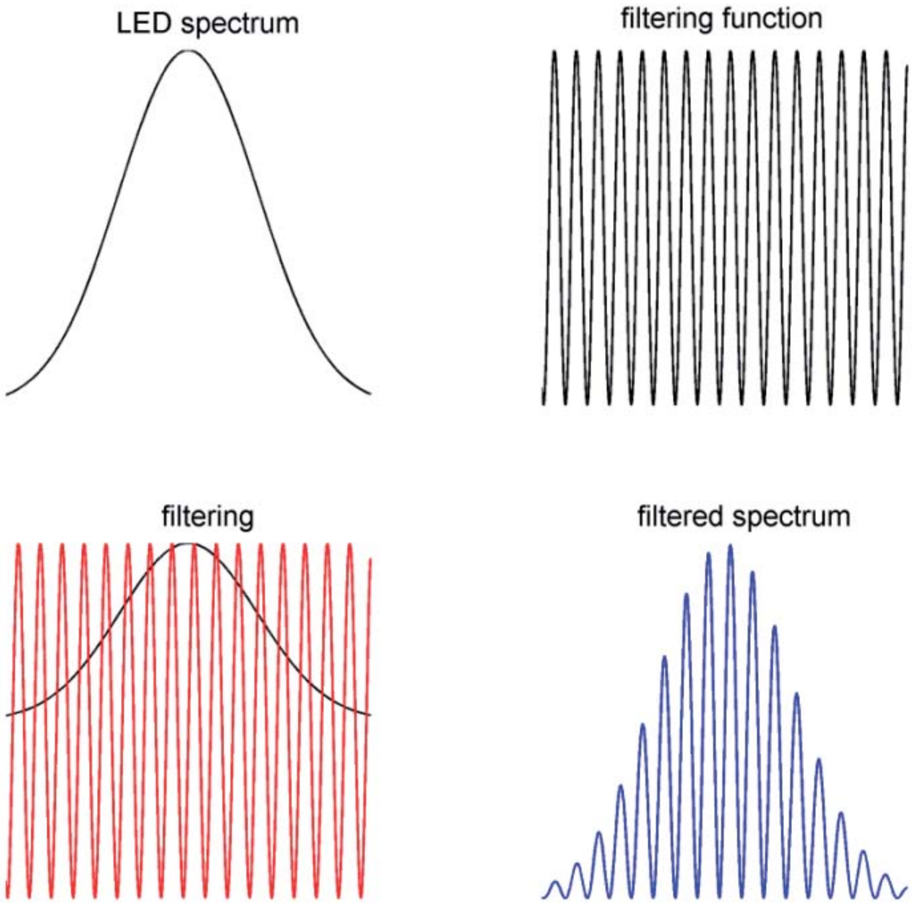


Figure 2. *Photonic filtering of a LED continuous optical spectrum.*

Figure 3 represents the photonic filtering a multimode laser spectrum, as given by eq. 3. An optical regular filtering can be obtained when an optical delay or its equivalent optical path difference is matched to the optical spectrum. By selectively cancelling alternate optical modes, a modified spectrum showing a new free spectral range results.

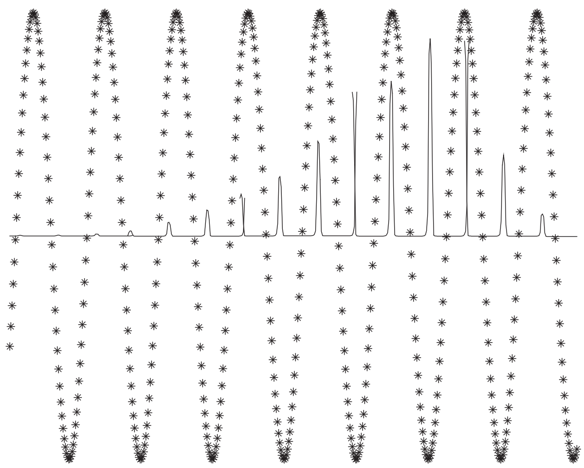


Figure 3. *Channeling of the optical spectrum of a multimode laser. The free spectral range is increased by eliminating alternate longitudinal modes.*

3 Experimental Optical Filtering of a Multi-Longitudinal Mode Laser

A photonic filter based on a $LiNbO_3$ optical retarder is shown by Figure 4. In this set-up, the polarization interferometer introduces an OPD that can be matched to the optical spectrum of a multimode laser, in order to eliminate alternate modes as to increase the free spectral range.

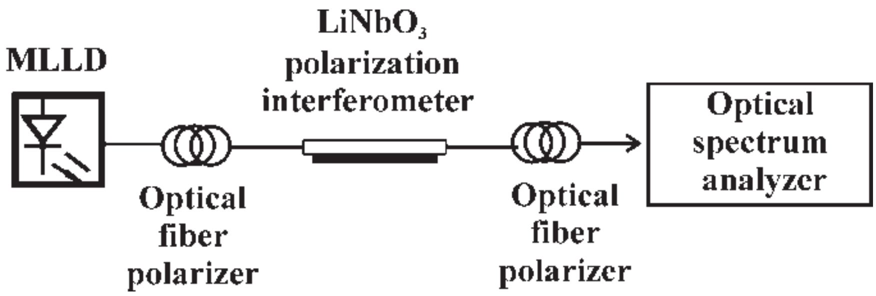
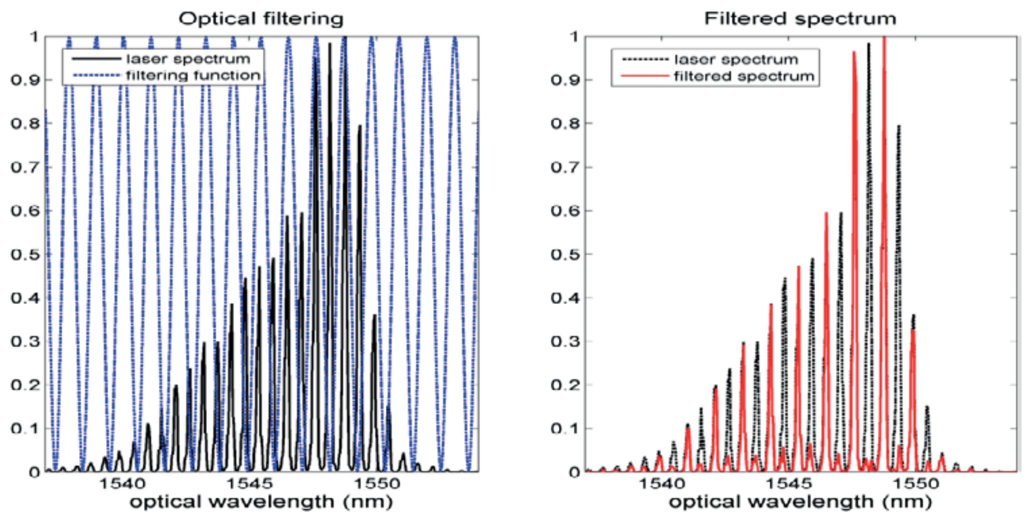


Figure 4. *A photonic filter based on a $LiNbO_3$ optical retarder.*

The optical spectrum of a multi - longitudinal laser was measured showing a spectral width $\Delta\lambda = 12nm$, between 1539 nm and 1551 nm; a free spectral range $\partial\lambda = 0.5nm$ and a FWHM mode $d\lambda = 0.2nm$. The measured spectrum is depicted in Figure 5(a).

From eq. 3, an optical regular filtering can be obtained by canceling alternate optical modes. Calculations at different values of OPD for filtering the multi-longitudinal laser were conducted. An $LiNbO_3$ optical waveguide of 26.5 mm was used for implementing a photonic filter, which introduced an OPD's of 2.2 mm, in agreement to eq. 2. The optical waveguide allows a periodic filtering of alternate optical modes, as depicted in Figure 5(b). The modified optical spectrum shows a free spectral range of 1nm.



(a) (b)

Figure 5. *a) The multimode unfiltered optical spectrum; b) the filtered optical spectrum.*

4 Conclusion

In this work, we have described the optical filtering of a multi-longitudinal mode optical source by the introduction of optical delays from $LiNbO_3$ birefringent optical waveguides. Such devices, acting as selective photonic filters can be used for modifying the free spectral range of a multimode laser. The optical delays must be matched to the spectrum characteristics in order to achieve a specific filtering effect. The selective photonic filtering has been experimentally demonstrated when using an OPD of 2.2 mm. The introduced OPD has allowed periodic filtering of the laser spectrum by eliminating alternate longitudinal modes and in this way increasing the free spectral range of the multimode laser. Multimode lasers are essential elements of microwave photonic filters, whose electrical response depends on the free spectral range of the laser. As this last parameter can be changed by a $LiNbO_3$ photonic filter, the frequency response of microwave photonic filters can also be easily modified.

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References

[1] Gutiérrez-Martínez, C., Sánchez-Rinza, B., Rodríguez-Asomoza, J., y Pedraza-Contreras, J. (2000). Automated Measurement of Optical Coherence Lengths and Optical Delays for Applications in Coherence-modulated Optical Transmissions. *IEEE Transactions on Instrumentation and Measurement*, *49*(1), 32-36.

[2] Evans, J. W. (1958). Solc birefringent filter. *Journal of the Optical Society of America*, *48*(3), 142-145.

[3] Shabatay, G., Eidinger, E., Zalevsky, Z., Mendlovic, D., y Marom, D. (2002). Tunable birefringent filters – optimal iterative design. *Optics Express*, *10*(26), 1534-1541.

[4] Lue, J., Chi, H., Zhang, X., y Shen, L. (2006). Noise reduction using photonic microwave filter for radio over fiber system. *Microwave and Optical Technology Letters*, *48*(2), 305-307.

[5] Gouraud, H., di Bin, P., Billonet, L., Jarry, B., Lecroizier, E., Barge, M., y Bougrenet, J-L. (2006). Reconfigurable and tunable microwave-photonics banda-pass slicing filter using a dynamic gain equalizer. *Microwave and Optical Technology Letters*, *48*(3), 562-567.

[6] Gutierrez-Martinez, C., Mollier, P., Porte, H., Carcano-Rivera, L., y Goedgebuer, J. P. (2003). Multichannel long-distance optical fiber transmission using dispersion-induced microwave transmission windows. *Microwave and Optical Technology Letters*, *36*(3), 202-206.

[7] Gutierrez-Martinez, C., Santos-Aguilar, J., Santiago-Bernal, M., Morales-Diaz, A., Torres Fórtiz, J. A., y Meza-Pérez, J. (2012). Reconfiguring the frequency response of dispersive-channel radio over fiber systems by using fiber photonic filters: application to transmission of multiplexed microwave subcarriers. *Microwave and Optical Technology Letters*, *54*(8), 1869 - 1874.

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