All-optical wavelength tuning in Šolc filter based on Ti:PPLN waveguide


All-optical wavelength tuning in a waveguide-type Šolc filter based on a Ti:PPLN waveguide has been demonstrated for the first time by ultraviolet illumination. The measured wavelength tuning rate as a function of the UV intensity was about $-26.42 \text{ nm/} \text{W cm}^{-2}$.

Introduction: Although the Šolc filter was proposed more than 50 years ago [1], difficulties with the fabrication technology in making a large number of birefringent plates stack has prevented the appearance of a practical narrowband Šolc filter. Recently, the advance in electric-field poling technology [2] in LiNbO3 allowed a new type of narrowband Šolc filter based on periodically poled LiNbO3 (PPLN). After the first PPLN Šolc filter was demonstrated [3], several researchers have reported on the wavelength tuning [4, 5] and transmission control properties [6]. The wavelength tuning methods can be classified into the temperature control [4] and light illumination method [5]. Both tuning methods give an almost linear wavelength tuning curve as a function of the control parameters such as temperature and light intensity. In the case of the temperature control method, some results have already been achieved in bulk PPLNs [4, 6] and Ti:PPLN waveguides [7, 8]. However, up to now, the light illumination method was only adopted in a bulk PPLN Šolc filter [5]. There has been no research into the dependence of wavelength-type PPLN Šolc filter characteristics on light illumination. In this Letter, all-optical wavelength tuning in a waveguide-type Šolc filter based on a Ti:PPLN waveguide by ultraviolet (UV) illumination is demonstrated for the first time.

Experiments: The experimental setup to perform the all-optical wavelength tuning in the Šolc filter based on a Ti:PPLN waveguide is shown in Fig. 1. An optical signal from the wavelength swept fibre laser (WSFL) [8] with an average power of 10 mW was polarised in TE-polarisation by a fibre u-bench polarisation controller and butt coupled into the Ti:PPLN waveguide through a single mode fibre. The output signal from the Ti:PPLN waveguide was filtered by an analyser (OSA). A UV source (Moritex Co.) with a centre wavelength of 310 nm was irradiated onto the Z-face of Ti:PPLN, while measuring the spectrum. The physical length of the Ti:PPLN waveguide was about 78 mm and the periodicity of the quasi-phase-matching (QPM) grating was 16.6 μm. Detailed information about the Ti:PPLN waveguide and the WSLF are listed in Tables 1 and 2, respectively.

The centre wavelength of the Ti:PPLN Šolc filter is defined as

$$\lambda_0 = (n_o - n_e) \cdot \Lambda / (2m + 1) \quad (1)$$

where $n_o$ and $n_e$ are the refractive indices of the ordinary and extraordinary waves, respectively, $\Lambda$ is the periodicity of QPM-grating, and $m$ is the order of the bandpass wavelength (in our case $m = 0$). When unpolarised UV light irradiates onto the Z-face of Ti:PPLN, the centre wavelength of the Ti:PPLN Šolc filter shifts according to the variation of the refractive index difference between $n_o$ and $n_e$. This refractive index change results from the electric field generated by the photovoltaic effect (PVE) along the z-axis [9]. The variation of the refractive index difference between $n_o$ and $n_e$ can be described as follows [10]:

$$\delta n = (n_o - n_e) - (n_o^3 \gamma_3 - n_e^3 \gamma_3) \frac{E_{pve}}{2} \quad (2)$$

where $\gamma_3$ and $\gamma_3$ are nonlinear coefficients and $E_{pve}$ is given by

$$E_{pve} = -\alpha \kappa_3 \gamma_3 / \sigma \quad (3)$$

where $\alpha$ and $\kappa_3$ represent the absorption coefficient and photovoltaic constant of Ti:PPLN, respectively, $\gamma$ is the light intensity, and $\sigma$ is the conductivity of Ti:PPLN.

The measured transmission spectrum of the Ti:PPLN waveguide is shown in Fig. 2. The scatter and the solid line indicate the experimental data measured at room temperature (23°C) and the theoretical curve [8, 11], respectively. The measured 3 dB bandwidth of the filter was about 0.21 nm (theoretical value: 0.22 nm) which is narrow enough to be used as a tunable wavelength filter in an optical communication system. Also, the filter shows the signal-to-noise ratio of $\sim 13$ dB over the tuning range (1260 ~ 1340 nm). Fig. 3 shows the centre wavelength of the filter as a function of the UV illumination intensity. As the intensity increases, the centre wavelength of the filter shifts to a shorter wavelength, because the second term of (2) increases as a function of the intensity of UV. The measured wavelength tuning rate of the filter was about $-26.42 \text{ nm/} \text{W cm}^{-2}$ which shows more slant than that of a bulk PPLN Šolc filter ($\sim 19.23 \text{ nm/} \text{W cm}^{-2}$) [5]. The right axis of Fig. 3 indicates the amount of change in the refractive index difference ($\delta n$) between $n_o$ and $n_e$ as a function of UV intensity. These results indicate that a Ti:PPLN Šolc filter gives a wider wavelength tuning range than that of a bulk PPLN Šolc filter.

**Table 1: Specifications of Ti:PPLN waveguide**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical size (mm) (length × width × thickness)</td>
<td>78 × 10 × 0.5</td>
</tr>
<tr>
<td>Propagation loss: TM-mode (at 1280 nm) TE-mode</td>
<td>$\sim 0.11 \text{ db/cm} \text{ &lt; 0.1 dB/cm}$</td>
</tr>
<tr>
<td>Mode size (FWHM) filtered signal: TM, at 1280 nm</td>
<td>6.64 μm × 5.15 μm</td>
</tr>
<tr>
<td>SHG efficiency (3 dB bandwidth)</td>
<td>$\sim 544 % / \text{W} (\sim 0.2 \text{ nm})$</td>
</tr>
</tbody>
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**Table 2: Specifications of WSFL**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output power (average)</td>
<td>10 mW</td>
</tr>
<tr>
<td>Wavelength swept frequency</td>
<td>15 kHz</td>
</tr>
<tr>
<td>Wavelength tuning range</td>
<td>1260 ~ 1340 nm</td>
</tr>
</tbody>
</table>

Fig. 1 Experimental setup for all-optical wavelength tuning in Ti:PPLN Šolc filter by UV illumination

PC: fibre u-bench polarisation controller

Analyser: bulk-type linear polariser

Fig. 2 Measured transmission spectrum of Ti:PPLN Šolc filter at room temperature (23°C)

**Fig. 3 Centre wavelength of Ti:PPLN Šolc filter against UV illumination intensity**
Conclusions: For the first time to the best of our knowledge, all-optical wavelength tuning in a waveguide-type Šolc filter based on a Ti:PPLN waveguide has been demonstrated by changing the light intensity. The origin of the wavelength shift by UV illumination is the change of the refractive index difference between \( n_o \) and \( n_e \), which is induced by the PVE. The 3 dB bandwidth and the wavelength tuning rate as a function of the UV illumination intensity were measured to be 0.21 nm and \(-26.42 \text{ nm/W/cm}^2\), respectively. The 3 dB bandwidth of the filter is narrow enough to be used as a tunable filter for all-optical wavelength routing. Also, the wavelength tuning rate of the waveguide-type filter is larger than that of the bulk filter. We believe that the all-optical wavelength tunable Šolc filter based on Ti:PPLN waveguides will be one of the key components for all-optical communication systems.

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References