LASERS

IR LOW DISPERSION SOLITON WAVEGUIDES WRITTEN WITH LOW POWER LASERS

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Abstract. We show that soliton waveguides written in the volume of lithium niobate crystals with low power continuous wave lasers in green – blue spectral domain have low dispersion in guiding ultrashort (femtosecond) pulses of infrared light. We analyze different components of dispersion and their contribution to the total dispersion of these soliton waveguides. Our experimental results obtained in guiding near infrared ultrashort pulses confirm the theoretical predictions.

Key words: soliton waveguides, lithium niobate, ultrashort pulses, dispersion.

1. INTRODUCTION

Optical waveguides are fundamental building blocks for integrated optical micro-circuits, in which the information carriers are photons. Digitized information is sent through them as light pulses, therefore a very important characteristic of an optical waveguide, which determine its capacity for carrying information, is the dispersion. Optical spatiotemporal solitons are from a theoretical point of view the ideal way to transmit information [1].

In our work with soliton waveguides, we have chosen Lithium Niobate (LiNbO₃ or LN) crystals, which are widely used for optical communications, due to their high transparency in the near infrared wavelength range.

Screening photorefractive – photovoltaic bright spatial solitons induced in the volume of LN were demonstrated and characterized in the last years [2–7]. The light induced refractive index distribution written in the LN crystal acts as a waveguide for the laser beam that generated it, as well as for light beams at other wavelengths. The recorded waveguide has a lifetime of the order of the dielectric relaxation time of LN, which can be in the range of months-years, if the crystal is not illuminated with light in its sensitivity range (blue-green). Also, the
waveguides can be permanently fixed by using different techniques [7]. Several studies of the guiding properties of soliton waveguides (SWGs) recorded in LN, using continuous wave and pulsed lasers, have been done in the last years [4–6, 8]. These studies revealed that the SWGs, which can be written in the volume of the LN crystal, have an optimum graded refractive index profile that matches the fundamental laser mode. SWGs can be stored for long time without fixing or can be erased by illuminating the crystal with light in its sensitivity spectral range. Dispersion is an important parameter in the use of waveguides for guiding ultrashort light pulses. It defines the light pulse broadening in the guided propagation. The total dispersion affecting the propagation of ultrashort pulses is the result of three additive components: chromatic dispersion, modal dispersion, polarization dispersion.

In this paper, we analyze the dispersion properties of the SWGs written in LN crystals, taking into consideration different components of dispersion and their contributions to the total dispersion introduced by SWGs. The dispersion measured in our experiments on guiding near infrared ultrashort pulses through SWGs written in LN is remarkable small and in agreement with the results of the theoretical analysis.

2. CHROMATIC DISPERSION IN SOLITON WAVEGUIDES WRITTEN IN LITHIUM NIOBATE

Chromatic dispersion produces a pulse spreading due to the dependence of the refractive index of the SWG on wavelength. It has two components: material dispersion and waveguide dispersion.

2.1. MATERIAL DISPERSION

Material dispersion is an intrinsic property of the material in which SWGs are recorded. This dispersion component is always present and it is due to the finite spectral width of the pulse, $\Delta \lambda_0$, which introduces a group velocity mismatch between different spectral components. The dependence of the refractive index of the material on light wavelength is described by the Sellmeyer equation.

A simple form of Sellmeyer equation for LN is [9]:

$$n^2 = A + \frac{B}{\lambda^2 - C} - D \cdot \lambda^2,$$  

(1)

where the wavelength $\lambda$ is expressed in $\mu$m and the Sellmeyer coefficients have the values: $A = 4.9048$, $B = 0.11768$ $\mu$m$^2$, $C = 0.04750$ $\mu$m$^2$, $D = 0.027169$ $\mu$m$^{-2}$ for the ordinary polarization of the light incident on the crystal and $A = 4.5820$, $B = 0.099169$ $\mu$m$^2$, $C = 0.04443$ $\mu$m$^2$, $D = 0.021950$ $\mu$m$^{-2}$ for the extraordinary polarization of the light incident on the crystal, respectively.
Some more refined and generalized Sellmeyer equations for LN have been derived, including the dependence of the refractive index not only on wavelength but also on composition of the LN crystal (stoichiometric, congruent, with different percentages of Li₂O) and on temperature [10, 11]. In Fig. 1 the dependences of the extraordinary \( n_e \) and ordinary \( n_o \) refractive indices of LN are shown, for the wavelength range 0.38 \( \mu m \) – 2 \( \mu m \), calculated with the Eq. 1 for \( (n_{e1}, n_{o1}) \), and by using the Sellmeyer equations from [10] for \( (n_{e2}, n_{o2}) \), from [11] for \( (n_{e3}) \), and from [12] for \( (n_{e4}, n_{o4}) \), respectively. In the Sellmeyer equations from Refs. [10] and [11], the temperature was considered 20º C and the Lithium content 48.41%. 

\[
\text{Fig. 1 – The dependence of the LN refractive index on the wavelength, calculated using the Eq. 1 (} n_{e1}, n_{o1})\text{, and using the Sellmeyer equations from Ref. 2 (} n_{e2}, n_{o2})\text{, Ref. 3 (} n_{e3})\text{, and Ref. 4 (} n_{e4}, n_{o4})\text{, respectively.} \\
\]

\( n_e \) is the LN extraordinary refractive index and \( n_o \) is the LN ordinary refractive index, respectively.

The broadening of a light pulse (also called material dispersion) in propagation through a dispersive medium is given by [13]:

\[
\Delta \tau = \frac{d \tau}{d \lambda_0} \cdot \Delta \lambda_0 = -L \cdot \frac{\lambda_0}{c} \cdot \frac{d^2 n}{d \lambda_0^2} \cdot \Delta \lambda_0 = L \cdot D_m \cdot \Delta \lambda_0, \tag{2}
\]

where \( D_m \) is the dispersion coefficient:

\[
D_m = -\frac{\lambda_0}{c} \cdot \frac{d^2 n}{d \lambda_0^2}. \tag{3}
\]

In these relations, \( L \) is the length of propagation through dispersive medium, \( \lambda_0 \) is the central wavelength of the pulse spectrum, \( \Delta \lambda_0 \) is the pulse bandwidth, \( c \) is the
speed of light in vacuum and \( n \) is the wavelength dependent refractive index. \( D_{\text{ms}} \), expressed in units of fs/(cm-nm) gives the broadening (in fs) experienced by a pulse with spectral bandwidth of 1 nm, propagating through 1 cm of the dispersive material. From Eq. (2) results that the broadening of a pulse passing through a dispersive medium is proportional to the length of the medium, \( L \), its dispersion properties, \( D_{\text{ms}} \), and the spectral width of the pulse, \( \Delta \lambda_0 \).

The wavelength dependence of the LN dispersion coefficient for extraordinary (\( D_e \)) and ordinary (\( D_0 \)) polarizations, in the visible and infrared wavelength ranges, are shown in Fig. 2. The wavelength dependences of the refractive index shown in Fig. 1 have been used to calculate the dispersion coefficients, \( D_e \) and \( D_0 \).

![Graph showing dispersion coefficient vs. wavelength](image)

**Fig. 2** – The dependence of dispersion coefficient of LN on wavelength (0.38-2 µm), corresponding to the refractive index dependence showed in Fig.1. \( D_{e1} \), \( D_{e2} \) and \( D_{e3} \) correspond to refractive index dependences given by \( n_{e1} \), \( n_{e2} \) and \( n_{e3} \), respectively, while \( D_{03} \) and \( D_{03} \) correspond to the refractive index variation given by \( n_{d4} \) and \( n_{d4} \) in Fig.1.
In Table 1 we calculated the values of the material dispersion of LN for several wavelengths of interest in photonics, in the visible and near IR wavelength ranges.

Table 1
Material dispersion of LN for several wavelengths of interest in photonics, generated by usual laser sources. Dispersion coefficients $D_{\omega}$, with indices 1, 2, 3, given in fs/cm-nm correspond to the dependences shown in Fig. 2

<table>
<thead>
<tr>
<th>$\lambda$[nm]</th>
<th>$D_{\omega 1}$</th>
<th>$D_{\omega 2}$</th>
<th>$D_{\omega 3}$</th>
<th>$D_{0 1}$</th>
<th>$D_{0 2}$</th>
<th>$D_{0 3}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>388</td>
<td>-212</td>
<td>-228</td>
<td>-212</td>
<td>-262</td>
<td>-275</td>
<td>-263</td>
</tr>
<tr>
<td>405</td>
<td>-170</td>
<td>-180</td>
<td>-170</td>
<td>-208</td>
<td>-216</td>
<td>-209</td>
</tr>
<tr>
<td>514.5</td>
<td>-57.1</td>
<td>-57.2</td>
<td>-57.5</td>
<td>-68.1</td>
<td>-67.9</td>
<td>-68.5</td>
</tr>
<tr>
<td>532</td>
<td>-49.8</td>
<td>-49.7</td>
<td>-50.2</td>
<td>-59.1</td>
<td>-58.9</td>
<td>-60</td>
</tr>
<tr>
<td>776</td>
<td>-12</td>
<td>-11.5</td>
<td>-12.6</td>
<td>-14</td>
<td>-13.5</td>
<td>-14.7</td>
</tr>
<tr>
<td>800</td>
<td>-10.8</td>
<td>-10.3</td>
<td>-11.4</td>
<td>-12.6</td>
<td>-12.1</td>
<td>-13.3</td>
</tr>
<tr>
<td>1030</td>
<td>-4.4</td>
<td>-4.1</td>
<td>-5.1</td>
<td>-5.1</td>
<td>-4.8</td>
<td>-6</td>
</tr>
<tr>
<td>1300</td>
<td>-1.8</td>
<td>-1.5</td>
<td>-2.7</td>
<td>-2.1</td>
<td>-1.8</td>
<td>-3.2</td>
</tr>
<tr>
<td>1550</td>
<td>-0.9</td>
<td>-0.6</td>
<td>-2</td>
<td>-1.1</td>
<td>-0.8</td>
<td>-2.3</td>
</tr>
<tr>
<td>2000</td>
<td>+0.1</td>
<td>+0.4</td>
<td>-1.3</td>
<td>+0.2</td>
<td>+0.5</td>
<td>-1.5</td>
</tr>
</tbody>
</table>

From Fig. 2 and Table 1 it is possible to see the strong decrease of the absolute value of the dispersion coefficient when the wavelength increases from visible to near infrared. For the wavelengths used in telecom, 1300 nm and, especially at 1 550 nm, the LN dispersion coefficient is $\sim$ 2 orders of magnitude lower than for visible wavelengths. This is an important advantage of SWGs written in LN in guiding near infrared ultrashort pulses. Other important advantage of LN in this spectral range is the very small absorption (the absorption coefficient of LN at $\lambda = 1\, \text{064 nm}$ is $\alpha < 0.0015 \, \text{cm}^{-1}$) [14].

In order to calculate the pulse duration of an ultrashort pulse propagating through a LN crystal, we shall assume a Gaussian shape of the pulse:

$$A_G(t) = A_{G0} \exp\left[-\left(t/\tau_G\right)^2\right],$$

where $\tau_G$ is related to the full width at half-maximum (FWHM) of the Gaussian intensity profile of the pulse, $\tau_P$ by [15]:

$$\tau_G = \tau_P / \sqrt{2 \ln 2} = \tau_P / 1.177.$$  

The temporal (pulse duration) and spectral (bandwidth) characteristics of the pulse are linked to each other through Fourier transforms. The minimum value of the pulse-bandwidth product for a Gaussian pulse is [15]:
in which $c_0 = 0.441$. This minimum value corresponds to bandwidth limited (Fourier limited) pulses, without frequency modulation (unchirped), the shortest possible pulses corresponding to a spectral width. Depending on the pulse chirp, the time-bandwidth product can reach higher values.

For a Gaussian beam with linear chirp, described by the chirp parameter $a$, the electric field is [15]:

$$A_g(t) = A_{g0} \exp\left[-(1 + ia)(t/\tau_g)^2\right]$$

and the pulse-bandwidth product is given by [15]:

$$\tau_p \cdot \Delta \nu_p = (2 \ln 2 / \pi) \sqrt{1 + a^2}.$$ (8)

In the case of a chirped Gaussian pulses, the pulse duration – bandwidth product is $\sqrt{1 + a^2}$ times larger than that corresponding to Fourier limited pulses. For an unchirped pulse, the change of the pulse duration in the propagation through a dispersive medium with length $z$ is described by [15]:

$$\tau_g(z) = \tau_{g0} \sqrt{1 + (z/L_d)}.$$ (9)

in which the characteristic dispersive length $L_d$ is given by:

$$L_d = \tau_{g0}^2 / 2 \left[k^2 \partial^2 / \partial \omega^2\right].$$ (10)

The pulse duration, $\tau_p$, at the exit from the dispersive medium can be calculated considering Eq. (9) and Eq. (5).

Using the dispersion coefficient $D_m$ given by Eq. (3), the characteristic dispersive length can be written as:

$$L_d = \tau_{g0}^2 / \left[\lambda^2 \left|D_m\right| (\pi \cdot c)\right].$$ (11)

For a linearly chirped pulse with the chirp parameter $a$, the change in the pulse duration after passing a distance $z$ through a dispersive medium is described by [15]:

$$\tau_g(z) = \sqrt{(4 / x) \left[x^2 + y^2(z)\right]},$$ (12)

where

$$x = \tau_{g0}^2 / \left[4 \left(1 + a^2\right)\right], \quad y = a \tau_{g0}^2 / 4 \left(1 + a^2\right) - \left(\lambda^2 \cdot D_m \cdot z / 2 \pi c\right) / 2.$$ (13)
The material dispersion is very low when using near IR wavelengths in telecom spectral ranges. If we consider unchirped 100 fs pulses at 1 550 nm wavelength, with the corresponding bandwidth of the transform limited pulse of ~ 35 nm, the dispersion introduced by a 1 cm long LN crystal broadens the pulse to ~100.4 fs.

2.2. WAVEGUIDE DISPERSION

The second component of the chromatic dispersion, the waveguide dispersion, depends on the variation of the guided mode profile with the wavelength. In order to estimate the contribution of waveguide dispersion to the total dispersion in SWGs induced in LN, we shall use the simple model of step index transversal profile of the refractive index. An important waveguide parameter is the numerical aperture (NA) which gives the maximum acceptance angle for a coupling beam. NA is given by the relation [13]:

$$NA = \sqrt{n_1^2 - n_2^2} = \sin \theta_a,$$

where $n_1$ is the refractive index of the core, $n_2$ is the refractive index of the cladding and $\theta_a$ is the acceptance angle.

For waveguides induced in LN, we consider as $n_1$ the value of the refractive index corresponding to the centre of SWG, where the light induced refractive index change is the largest, and as $n_2$ the refractive index of LN in the region surrounding SWG, unperturbed by light; $n_2 = n_0$.

For SWGs induced in LN the maximum change of the refractive index due to the electro-optic effect is given by [16]:

$$\Delta n = -(1/2) r_{\text{eff}} n^3 E,$$

in which $r_{\text{eff}}$ is the effective electro-optic coefficient, corresponding to the polarization of the incident light beam, $n$ is the refractive index and $E$ is the electric field on the crystal given by the external applied field and the photovoltaic field. For extraordinary polarization, $r_{\text{eff}} = r_{33} \approx 32 \text{ pm/V}$, while for ordinary polarization, $r_{\text{eff}} = r_{13} \approx 10 \text{ pm/V}$ [9, 14, 17].

Considering an overestimated value for $E \sim 40 \text{ kV/cm}$, we estimated the maximum refractive index change in the centre of SWGs written in LN, which is shown in Fig. 3 versus light wavelength.

Due to the wavelength dependence of the LN refractive index, the numerical aperture $NA$ and acceptance angle $\theta_a$ are wavelength dependent, also. Their dependence on wavelength are shown in Fig. 4 a,b, respectively.
Fig. 3 – The wavelength dependence of the maximum change of the refractive index in SWGs written in LN, for extraordinary and ordinary polarizations, respectively.

Fig. 4 – The dependence on wavelength of \( N_A \) (a), of the corresponding acceptance angle \( \theta_a \) (b), for SWGs in LN with maximum change of refractive index from Fig. 3, for extraordinary and ordinary polarizations, respectively.
Waveguide dispersion is a consequence of the dependence of the mode’s propagation constant $\beta$ on the ratio $a/\lambda$ ($a$ – the waveguide core radius, $\lambda$ - the wavelength of the guided light, in air).

The waveguide dispersion for a step index waveguide can be calculated with an approximate formula [13]:

$$D_{n_g}[\text{fs/cm/nm}] \approx -100 \frac{n_2 \Delta}{3\lambda_0} \left( V \frac{d^2(bV)}{dV^2} \right), \quad (16)$$

in which the central wavelength $\lambda_0$ is given in $\mu$m, $n_2$ is the cladding index, $\Delta = (n_1^2 - n_2^2)/2n_2^2 = NA^2/2n_2^2$. $V$ is the normalized frequency also called the waveguide $V$ parameter given by $V = k_0 a \cdot NA$ and $b = (\beta^2/k_0^2 - n_2^2)/NA^2$ is the normalized propagation constant, where $k_0 = 2\pi/\lambda_0$ is the wave number. The second derivative of $(bV)$ is expressed by the approximate formula [13]:

$$V \frac{d^2(bV)}{dV^2} \approx 0.08 + 0.549(2.834 - V^2). \quad (17)$$

The waveguide dispersion is shown in Fig. 5, considering some typical properties for SWGs written in LN. It can be seen from this figure that waveguide dispersion is negligible small when comparing with material dispersion calculated above.

![Fig. 5 – Waveguide dispersion for a step index waveguide in LN with refractive index contrast of $10^{-4}$.](image)

For the maximum refractive index contrast of $6 \cdot 10^{-4}$, achievable in SWGs written in LN, the waveguide dispersion is lower than 0.03 fs/cm/nm. From the above estimations it is possible to consider as negligible the waveguide dispersion in SWGs written in LN in comparison with the material dispersion of LN.
3. MODAL DISPERSION IN SOLITON WAVEGUIDES WRITTEN IN LITHIUM NIOBATE

Modal dispersion can be important in multimode waveguides but it is not present in single-mode waveguides.

In order to estimate the contribution of this component of dispersion in SWGs induced in LN, we shall use the results predicted by existent models for some wide-spread transversal profiles of the refractive index: step index, parabolic, hyperbolic secant, in which we takes into account the change of the refractive index produced in LN crystal by the process of SWG writing.

It is shown that the modal dispersion of a waveguide with a parabolic index profile is reduced by a factor $\Delta/2$ compared to that of step index waveguide with the same numerical aperture and radius [13]. For $\Delta=2\cdot10^{-4}$, this means a reduction of $10^4$ times of the modal dispersion in a waveguide with parabolic index profile compared to that of a step index profile waveguide with the same $\Delta$, induced in LN. On the other hand, the broadening of a pulse propagating through a waveguide can be reduced by decreasing the numerical aperture $NA$, for both types of index profiles, step index and graded index [18]. But the reduction of $NA$ diminishes the acceptance angle of the waveguide also, reducing the coupling efficiency to the waveguide.

For a waveguide with a refractive index profile given by $n^2(x) = n_0^2 \sec h^2(bx)$ where $b$ is a constant, it is shown that the modal dispersion is zero [13], the amount of time to propagate through a length $z$ of the waveguide being the same for all guided rays emerging from a point. This profile is of a particular interest for spatial solitons whose transversal intensity distribution is described by a squared hyperbolic secant.

The modal analysis of a waveguide strongly depends on the waveguide profile. For a step index waveguide, guided modes should fulfil the condition, $n_c^2 < \beta^2/k_0 < n_i^2$, where $\beta$ is the propagation constant. Using the $V$ parameter the single-mode condition is given by $0 < V < 2.4048$. In a first approximation, we extend this condition to SWGs in LN, considering a refractive index difference between core and cladding of $10^{-4}$, a typical value of the refractive index change achievable for SWGs written in LN. The wavelength dependence of the $V$ parameter, in the range of 0.4-1.6 $\mu$m, is shown in Fig. 6, for different waveguide diameters and considering extraordinary polarization of the guided beam.

In this first approximation of a step-index waveguide, it can be seen that multimode propagation can be obtained only when guiding short wavelengths (blue - green) and only when the waveguide diameter has a value higher than 15 $\mu$m.
The diameter of SWGs induced in LN is usually in the range 8–25 µm. For these SWG cross sections, the propagation is in the single-mode regime when guiding beams in near IR spectral region. Consequently, the modal dispersion is zero for these single-mode SWGs. On the other hand, if the single-mode condition of propagation is not fully fulfilled, the achievable change of the refractive index in SWGs written in LN ensures a negligible modal dispersion, even for cases when the transversal refractive index profiles are different from the theoretical one.

4. POLARIZATION DISPERSION IN SOLITON WAVEGUIDES WRITTEN IN LITHIUM NIOBATE

The polarization dispersion appears due to the fact that a guided mode can be composed of two distinct polarization modes, with the electric field components orthogonal to each other.

For an arbitrary polarization of the light pulse, the orthogonal components, parallel to the c-axis of the crystal and orthogonal to this, in which the initial polarization state is decomposed, will propagate with different velocities corresponding to extraordinary and ordinary refractive indices, respectively. Thus, due to the natural birefringence of the LN crystal, the polarization state and the duration of the pulse traveling through SWG are changing in propagation.

This type of dispersion can appear even in isotropic single mode waveguides if the cross section of the waveguide is elliptic, when launching light with an arbitrary polarization with respect to the major and minor axes of the elliptic waveguide, and also in circular waveguides which are bended or stressed [19].

A linearly polarized pulse, with extraordinary or ordinary polarization, shall not change its polarization state in the propagation through a single mode SWG induced in LN, the guide maintaining the polarization state of the pulse. This is the
case for both circular and elliptic shapes of single mode SWGs. Therefore, when guiding extraordinary polarized or ordinary polarized beams of light, as is the case for most experiments, the pulse broadening due to this type of dispersion is negligible.

The evaluation of chromatic and modal contributions to the total dispersion in SWGs written in LN shows that the material dispersion plays the major role in broadening of ultrashort pulses propagating through these waveguides, for usual lengths, refractive index contrasts, refractive index profile and transversal sizes of SWGs.

5. EXPERIMENTAL RESULTS

We have experimentally analyzed dispersion in LN and in SWGs written in LN. We have made pulse duration measurements using the autocorrelation technique. Experimental setup is shown in Fig. 7.

We wrote several SWGs to compare pulse dispersion of a SWG with material dispersion of LN. SWGs were recorded using a beam with $\lambda = 388$ nm, $\approx 10$ µm FWHM beam diameter, $\sim 2.8$ µW optical power and $\sim 42$ kV/cm external static electrical field applied along the c-axis direction. The setup for SWG writing is similar to that used in [2]. SWG1 to SWG4 were recorded using e-pol, while SWG5 to SWG7 were recorded with a polarization rotated by 50° in respect with e-pol and slightly lower optical power $\sim 1.9$ µW. The writing time was $\sim 2$ minutes for SWG1-SWG4 and $\sim 4.5$ minutes for SWG5-SWG7.
Guided propagation through SWG was done by focusing extraordinary polarized light pulses on the input face of the LN crystal and translating the crystal in the transversal plane while observing a magnified image of the output face of the crystal. In Fig. 8, the input beam profile and the output beam profile when propagating through different SWGs is shown.

Material dispersion was measured in a LN crystal of 4.83 mm length on the propagation direction. The pulse width was measured before and after passing through the LN crystal using an e-pol beam at $\lambda = 776$ nm. Considering a Gaussian shape of the pulse, the measured pulse width was 144 fs in free space and 171 fs after passing through the LN crystal. The theoretical calculation shows that an unchirped pulse with a pulse width of 144 fs at FWHM should be broadened to ~ 148 fs after passing through the LN crystal. This means that in our case, the significant pulse broadening is given by a chirp component (Eq. 12). For a measured bandwidth of ~7.2 nm, the parameter $a$ that characterizes the pulse chirp (Eq. 9), has a value of ~ 0.6. The new estimated theoretical value, considering this chirp parameter, is ~170 fs which is very close to the measured result.
Autocorrelation measurements were made also for comparing the pulse dispersion in the LN crystal in free propagation with pulse dispersion when propagating through SWGs. The measured pulse duration in guided propagation is close to the pulse duration measured in free propagation, the difference between them being much lower than the resolution of our autocorrelator (15 fs). These measurements have shown that the waveguide dispersion introduced by SWG is very low, negligible in comparison with material dispersion. Even if the transversal profile of written SWG was slightly different, as can be seen from mode profile in Fig. 8, there was no significant difference in pulse broadening when propagating infrared light through these SWGs. We can conclude that waveguide dispersion introduced by SWGs written in LN is very small and negligible in contrast with material dispersion of LN, for wavelengths in near infrared. As it was shown by the theoretical analysis, this was expected because of the very low difference in refractive index change of SWG compared to that of LN.

6. CONCLUSIONS

We have analyzed the pulse dispersion in soliton waveguides induced in lithium niobate crystals. The contribution of different dispersion components to the total dispersion was considered. We have shown that the contributions of waveguide dispersion and modal dispersion for these soliton waveguides are negligible in comparison with material dispersion for near-IR radiation. This is due to the low refractive index contrast, transversal refractive index profile and waveguide diameter. When guiding extraordinary or ordinary polarized light through these waveguides, the polarization mode dispersion is also negligible. Consequently, the total dispersion in soliton waveguides written in lithium niobate is mainly due to the material dispersion. We have shown that material dispersion for infrared light is strongly decreased in comparison with the same parameter for visible light, making lithium niobate an important candidate for photonic applications in telecom. Dispersion measurements were done in lithium niobate crystal and soliton waveguides recorded with blue-violet light. The results of the theoretical analysis are in agreement with experimental results obtained in guiding ultrashort light pulses through soliton waveguides.

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