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Optical delay in photorefractive SBN:61 and SBN:61:Ce via two-wave mixing : A theoretical study

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ABSTRACT

The slowing down of light in photorefractive SBN:61 and SBN:61:CeO2 as a function of input pulse width via two wave mixing is presented theoretically. Optical delay has been found to vary from 0.106 s to 4.411 s in SBN: 61 and from 0.212 s to 6.852 s in SBN:61:CeO2 on varying the pulse width from 0.25 s to 7 s respectively. Cerium doping resulted in enhancement of optical delay at low pulse width. At higher pulse width optical delay was stabilized.

1. Introduction

Optical delay of light in photorefractive (PR) crystals is a promising field [1–5]. It has enormous application in the field of non-linear optics and information processing [6–10]. Optical delay is generated in PR crystals by pump-probe coupling via two-wave mixing technique [11–13]. This technique provides wide range of tunability of optical delay by tuning various input parameters during two-wave mixing viz. laser power, pulse width, polarization and beam crossing angle. Thus it is a suitable candidate for all optical tunable delay line [14,15]. Moreover, the experimental set-up required is simple and can be operated at low laser power [16].

Optical delay of light has been experimentally demonstrated as well as theoretically estimated in various PR crystals viz. BTO, LN, BSO, SBN etc [17–21]. SBN is one of the most promising PR crystals for generation of optical delay of light due to its superior nonlinear properties as compared to other crystals [22]. The single crystals of SBN are characterized by extremely large photorefractive properties, dielectric properties, electro-optic coefficients and high non linear optical properties [23]. This material is used in applications such as pyroelectric detectors holographic data storage systems, phase conjugation, generation of photorefractive solitons, quasi-phase-matched second harmonic generation, and electro-optic modulation [24]. Further the non-linear optical properties of SBN crystals are very sensitive to the Sr / Ba ratio [25]. Increasing the Sr content reduces the interval between room and Curie temperatures, thus inducing a drastic enhancement of the dielectric permittivity, pyro electric coefficient and non-linear optic properties [26]. The properties of SBN are known to be substantially dependent on the index $x = N_{Sr}/N_{Sr+Ba}$ (N is number of atoms) [27]. SBN:61 (SBN with x = 0.61) is Known as a congruently melting composition [28].

SBN:61:Ce is doped SBN crystal with high photorefractive sensitivity, which is four orders of magnitude more than un-doped SBN [29]. Cerium doping of SBN:61 increases the rate of response and reduces the dark conductivity, although this

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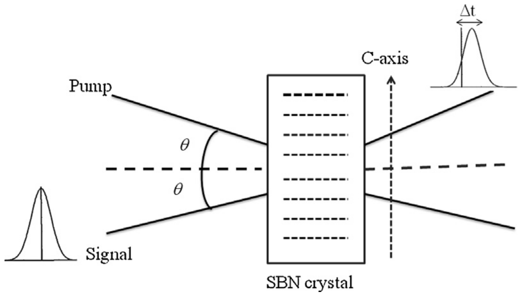

Fig. 1. Schematic diagram of two- wave mixing in SBN photorefractive crystal.

crystal's overall response is relatively slow compared to SBN: 61 due to increase of its dielectric constant [30]. Cerium doping enhances the two-wave mixing gain and charge density by order of magnitude [31–35].

In the present manuscript optical delay of light has been simulated in SBN:61 and SBN:61:Ce. The optical delay and corresponding group velocity has been estimated as a function of input pulse width.

2. Theory of pulse propagation in SBN crystal via two-wave mixing

In two-wave mixing a strong C. W. pump beam and a weak pulsed signal beam is launched onto the SBN crystal as shown in Fig. 1.

The continuous pump and weak pulse beam is launched with some beam crossing angle 2Θ. Pump and signal beam interfere inside the crystal to form volume grating. These beams will couple inside the SBN crystal via Bragg diffraction from the index grating. The energy of continuous wave pump beam will be transferred to the pulse signal. The transmitted signal beam will be amplified and delayed.

Let us consider a Gaussian signal pulse launched onto the PR crystal with the form given by Eq. (1),

$$S(0,t) = S_0 exp\left[\frac{-t^2}{T^2}\right] \tag{1}$$

$S_\omega(0)$ is the Fourier transform of the input amplitude S(0,t) and T is the input pulse width.

$$S_\omega(0) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} S(0,t)\exp(-i\omega t)\,dt$$

Substituting the input Gaussian beam,

$$\begin{aligned} &= \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} S_0 exp\left[\frac{-t^2}{T^2}\right]\exp(-i\omega t)\,dt \\ &= \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} \mathrm{S}_0\exp\left\{-\left(\frac{t^2}{T^2}+i\omega t\right)\right\}dt \end{aligned} \tag{2}$$

Now applying the Completion of a square in the exponential part of the above Eq. (2)
Therefore,

$$\left(\frac{t^2}{T^2}+i\omega t\right) = \frac{t^2}{T^2}+2i\frac{\omega}{2}\frac{t}{T}T+\left(i\frac{\omega}{2}T\right)^2-\left(\frac{i\omega T}{2}\right)^2$$

$$= \left(\frac{t}{T}+\frac{i\omega T}{2}\right)^2-\left(\frac{i\omega T}{2}\right)^2$$

After simplification we get as below
Then,

$$\begin{aligned} S_\omega(0) &= S_0\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} exp\left\{-\left(\frac{t}{T}+\frac{i\omega T}{2}\right)^2+\left(\frac{i\omega T}{2}\right)^2\right\}dt \\ &= S_0\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty}\exp\left\{-\left(\frac{\mathrm{t}}{\mathrm{T}}+\frac{\mathrm{i}\omega\mathrm{T}}{2}\right)^2\right\}exp\left(-\frac{\omega^2T^2}{4}\right)dt \\ &= S_0\frac{1}{\sqrt{2\pi}}exp\left(-\frac{\omega^2T^2}{4}\right)\int_{-\infty}^{\infty} exp\left\{-\left(\frac{t}{T}+\frac{i\omega T}{2}\right)^2\right\}dt \end{aligned} \tag{3}$$