Slow and fast light in photorefractive SBN:60 using the contra-directional mixing geometry

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Abstract: We investigate reduced and increased group velocity in photorefractive SBN:60 crystals using co- and contra-directional non-degenerated two-wave mixing configurations. A tunable delay is achieved by frequency shifting the pump beams.

In general, slow-light devices use a narrow-band loss or gain to produce a steep slope in the dispersion. Recently, slow-light in different photorefractive materials including $BaTiO_3$ was used for the deceleration of light pulses [1, 2]. Employing nearly-degenerated two-wave mixing, group-velocities down to 0.025 cm/s were obtained.

To realize slow-light in a photorefractive material, a strong nonlocal nonlinearity with a phase-shift between the interference of the writing beams and the refractive index modulation is needed. Self-diffraction of a strong cw pump wave and a signal pulse with a Gaussian temporal shape yields signal amplification and a large dispersion depending on their frequency difference.

Up to now, all experiments have been conducted in transmission geometry, but slow light operating in the reflection geometry has only been proposed [1]. The reflection geometry has several advantages: with decreasing grating spacing Λ, the space-charge field grows, and with sufficient trap densities the highest coupling-coefficient can be reached when the grating period equals the Debye screening length. Additionally, scattering in the direction of the pulse originating from self-diffraction is expected to be much lower. We theoretically and experimentally analyze the slow-down performance of SBN:60 that has not been investigated yet, to the best of our knowledge.

In case of an undepleted pump approximation, the phase-shift per unit length K of an output signal can be written as [3]:

$$K(\Delta\omega) = \frac{\Gamma_0 \lambda}{4\pi}\left[\frac{\Delta\omega\tau}{1+\Delta\omega^2\tau^2}\right]$$

Where Γ_0, λ, $\Delta\omega$ and τ are the coupling constant, laser wavelength, frequency difference between the beams and response time, respectively. Following the procedure in [4], the resulting group velocity is:

$$v_g(\Delta\omega) = \frac{c}{n + c \cdot dK/d\omega_s} \approx \frac{2\left[1+\Delta\omega^2\tau^2\right]^2}{\Gamma_0\tau\left[1-\Delta\omega^2\tau^2\right]}$$

For a non-shifted signal beam, one simply has the relation $v_g(0) = 2/(\Gamma_0\tau)$ with a delay-time $T_d \approx d/v_g(0)$.

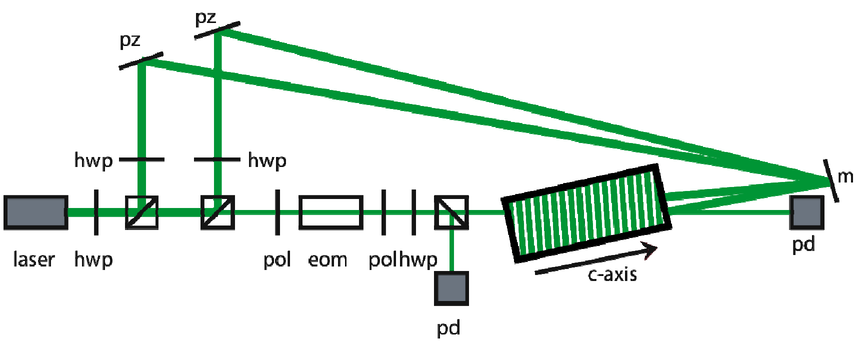

Figure 1: Experimental configuration for contra-directional two-beam coupling. .pd: photodiode; pz: piezo mirror; hwp: half wavelength plate; pol: polarizer; eom: electro-optic modulator; m: mirror

The typical setup for reflection geometry is shown in figure 1, where the pump and the signal beam enter the SBN:60 crystal from opposite sites, and an index modulation with a small grating period of Λ = 0.1 μm is formed. Pulses with a temporal Gaussian shape are generated using an electro-optic modulator. After passing through the crystal the signal is compared with a reference pulse to determine delay/advance and dispersion/compression. For non-degenerated wave-mixing, the frequency shift of the pump beams is obtained by two piezo mirrors operated with a sawtooth voltage.

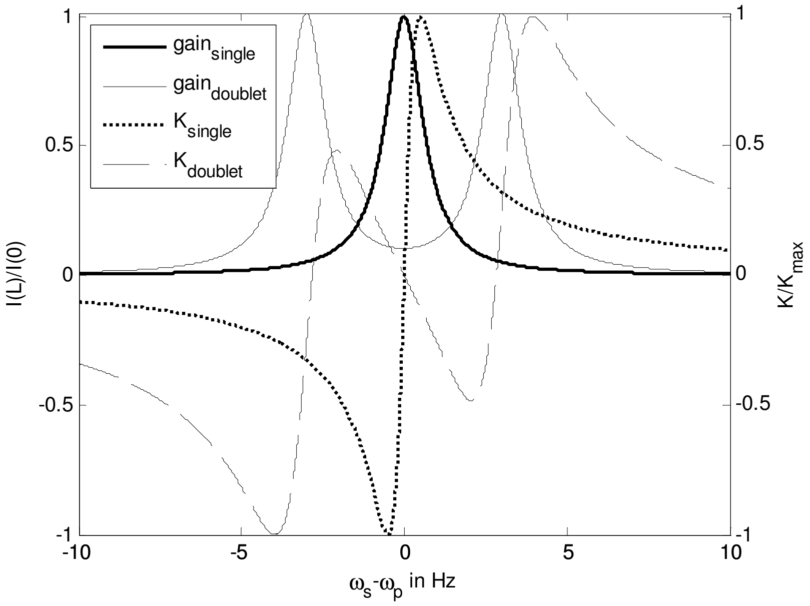

Figure 2: Calculated normalized phase change per unit length (dashed) and gain coefficient (solid) for a single non-shifted and two shifted pump beams as a function of the frequency difference between ω_s and ω_p. In a diffusion-only case the dispersion changes from normal to anomalous.

For observation of fast light, we create a gain doublet by mixing the weak signal with two symmetrically shifted pump beams [5]. To minimize signal distortion, the frequency gap has to be larger than the spectral width of the signal itself. Then anomalous dispersion in-between the doublet for the non-shifted signal (fig.2) can be observed.

In our contribution we investigate numerically and experimentally the slow and fast light characteristics in high-gain photorefractive SBN:60 and $BaTiO_3$. We compare the dispersive properties of samples in co- and contra- directional, non-degenerated two-wave-mixing setups with regard to the group velocity, dispersion, input pulse length and different dopant concentration.

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