Slowdown of nanosecond light pulses without distortion

Nacera Bouldja,[1,2] Alexander Grabar,[3] Marc Sciamanna,[1,2] Delphine Wolfersberger,[1,2]

[1]1Chair in Photonics, CentraleSupélec, LMOPS, F-57070 Metz, France
[2]Université Lorraine, CentraleSupélec, LMOPS, F-57070 Metz, France
[3]Institute of Solid-State Physics and Chemistry, Uzhhorod National University, Pidhirna 46,88000 Uzhhorod, Ukraine

The slowdown of the light is focused on the study of the physical processes that can reduce the group velocity of a light pulse as it propagates in non-linear media. This phenomenon has been observed in several physical systems, including optical fibers[1] and photorefractive (PR) media[2]. The ability to slowdown light pulses is a fascinating phenomenon with important applications, such as optical information processing and optimization of telecommunications infrastructures. For that, the slow light phenomenon must have a large bandwidth to respond quickly to the short light pulses that will carry the data. However, in the PR crystal, only light pulses of the order of milliseconds or seconds have been slowed down, and because of the high dispersion, they are broadened at the output of the PR crystals[2, 3], leading to loss of the information.

Recently, we have demonstrated that the two-wave mixing (TWM) effect in the pulsed regime can slowdown nanosecond light pulses in a PR SPS crystal[4]. This is possible only if the laser intensity is high enough to reduce the crystal response time to the value of the input pulse duration. The experimental setup of TWM is performed with a Sb-doped SPS crystal whose dimensions are 8.x8x8.1 mm^3 along the x, y, and $z-$axis. The beam laser is split into two arms corresponding to the pump and signal pulses with the same duration ($t_0 = t_p$). The two light pulses interfere in the PR sample and create a refractive index grating as it is shown in Fig. 1(a).

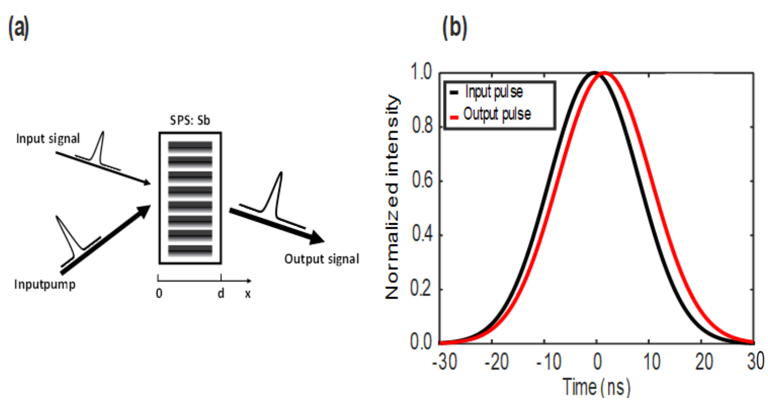

Figure 1: a) Geometric scheme of the two-wave mixing in the pulsed regime in a PR SPS: Sb crystal with thickness $d = 0.8$ cm and response time of $\tau = 32$. b): Experimental result of the temporal envelopes of the normalized input (black line) and output (red line) pulses as a function of the time, time delay $\Delta\tau = 2$ ns for a light pulse with a width $t_0 = 20$ ns and a coupling strength $\Gamma d = 5$.

By analyzing the intensity profiles of the signal pulse at the input and the output of the PR crystal, we note that the output pulse is amplified and its maximum is shifted in time compared to the input one. As we reported in[4], this configuration can achieve a maximum PR gain of the order $\Gamma = 7$

cm^{-1} and decrease the response time of the PR crystal to a value of $\tau = 32$ ns. In this case, we have successfully slowed down pulses with durations t_0 which vary between 10 to 100 ns with time delays of 1 to 25 ns. On the other hand, we note that TWM with a pulsed laser allows decelerating nanosecond light pulses and limits their distortion at the output of the crystal. As is shown in Fig. 1(b), for a coupling strength of $\Gamma d = 5$ and a response time of $\tau = 32$, a pulse of 20 ns can be delayed by 2 ns without distortion[4].

To understand why the pulse propagates in the crystal without broadening in the case of the TWM in the pulsed regime, a theoretical study has been performed. This consists in the analysis of the influence of the pump pulse duration on the slow light performances using the Eq. (14) of [5]. Fig. 2 shows the temporal envelopes of the normalized output pulses as a function of the normalized time (t/τ). The result is plotted for $\Gamma d = 5$, $t_0/\tau = 0.6$ ($t_0 = 20$ ns and $\tau = 32$ ns) and three values of the pump width (($t_p/\tau = 0.4,\ 0.6,\ 2$). As is shown in Fig. 2, we note that the normalized time delay $\Delta\tau/\tau$ and the output pulse duration t_1/τ depend on the value of t_p/τ. Indeed for large values of the pump duration ($t_p/\tau \leq t_0/\tau$), no widening is calculated but the delay is smaller. However, if we increase the pump width, both the time delay and the widening become important.

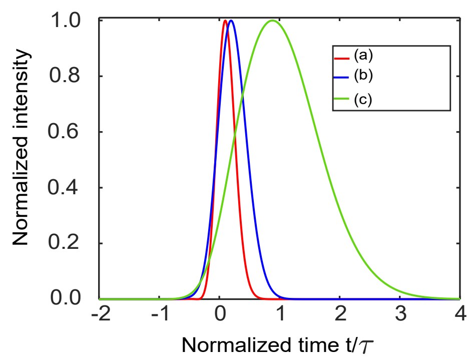

Figure 2: Temporal envelopes of the normalized output pulses as a function of the normalized time, with $\Gamma d = 5$, $t_0/\tau = 0.6$. a): $t_p/\tau = 0.4$, $\Delta\tau/\tau = 0.1$ ns and normalized output pulse duration $t_1/\tau = 0.3$. b) $t_p/\tau = 0.6$, $\Delta\tau/\tau = 0.2$ ns and normalized output pulse duration $t_1/\tau = 0.5$. c) $t_p/\tau = 2$, $\Delta\tau/\tau = 0.9$ ns and normalized output pulse duration $t_1/\tau = 1.7$, the result is obtained using the Eq. (14) of [5].

In conclusion, we have demonstrated that the SPS crystal can slow down nanosecond light pulses using a TWM method in the pulsed regime. Also, the theoretical studies show that the signal pulse can propagate in the PR crystal without distortion if its width is equal to or larger than the pump pulse duration. Finlay, our results show that, besides the PR gain, the pump pulse duration is another key parameter that can control the slow light performances.

References

[1] Baba, T. Slow light in photonic crystals. Nature photonics 2, 465 (2008).

[2] N.Bouldja, A.Grabar, M.Sciamanna, D. Wolfersberger,Phys. Rev. Research 2, 032022. (2020).

[3] N. Bouldja, M. Sciamanna, and D. Wolfersberger, Opt. Lett. 44, 1496-1499 (2019)

[4] N. Bouldja, M. Tsyhyka, A. Grabar, M. Sciamanna, and D. Wolfersberger, Phys. Rev. A 105, L021501 (2022).

[5] Sturman, et al. J. Exp. Theor. Phys. 106, 668 (2008).