Liquid Crystal Light Valves for Slow Light and applications

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Abstract. The large dispersive properties of wave mixing in liquid crystal light-valves allow obtaining fast and slow light with tunable group velocities. A slow light interferometer is shown by using this interaction.

1. Introduction

Slow and fast light have recently received a large interest, both from the fundamental point of view and for applications in, communications, high sensitivity interferometers, precision metrology and optical sensing [1]. Different methods to realize slow and fast light are currently employed. Among them, the processes of nonlinear wave mixing offer the advantage of large and tunable dispersion properties, which can be used to obtain controllable group velocities in small-sized experiments. These properties have recently been exploited in photorefractive crystals [2] and in optical fibers through stimulated Brillouin scattering [3]. Here, we show that by performing two-wave mixing experiments in a liquid crystal light valve (LCLV), we are able to obtain fast and slow light down to group velocities as slow as a few tenths of mm/s. In the LCLV the two-wave mixing occurs in the Raman-Nath regime of diffraction, leading to multiple-order output beams, each characterized by a different group delay [4].

2. Two-wave mixing in the liquid crystal light valve

The liquid crystal light-valve combines a thin liquid crystal (LC) layer (thickness 10 µm) with a monocristalline Bi12SiO20 (BSO) photoconductive crystal (1 mm thickness, 20x30 mm2 transverse size). The other wall is a glass window as shown on fig 1. Transparent electrodes allow the application of an external voltage across the liquid crystal layer.

The photoconductive and electro optic properties of the LCLV are separately optimized. While the excellent sensitivity comes from the photoconductive properties of the BSO, the large electro-optic effect is due to the birefringence of the liquid crystals. The BSO is transparent in the visible range and, thus, the LCLV works in transmission. This property allows performing wave-mixing experiments, in which two or more beams interact inside the LC layer and gives rise to nonlinear phenomena such as optical amplification and phase conjugation.
Two-wave mixing in the LCLV occurs following the schematic representation of Fig.1. A pump beam $E_p$ and signal beam $E_s$ are sent to the BSO side of the LCLV with parallel polarizations along axis of the LC molecules to create an interference pattern. The beam coupling occurs in the Raman-Nath regime of diffraction and several diffracted beams are observed at the output of the LCLV. The intensity of the pump beam is much higher than that of the signal. For this condition, part of the pump is transferred to the diffracted orders: the output signal on the $m=0$ order results amplified, with a gain $G>1$ and there is a phase transfer on the signal as a function of the pump-signal frequency detuning leading to slow light interaction.

3. Slow and fast light in the LCLV: tuning the group velocity
To obtain slow and fast light the 2WM is performed by sending on the LCLV a light pulse together with the pump beam. The pulse width is larger than the LC response time, which is around 120 ms and its center frequency can be changed by a few Hz by using a piezo mirror. By exploiting the large phase dispersion we can obtain both fast and slow light, with the output pulse either anticipated or delayed. In Fig.2a) and b) are shown two representative data, displaying a fast pulse taken at the $m=0$ output and a slow-light output at the $m=-2$ diffraction orders. The dispersion curves can be theoretically calculated from the model of the two wave mixing in the LCLV [4].

4. Interferometry with the LCLV as a slow light medium
The spectral sensitivity, or resolution, can be enhanced by a factor equal to the group index $n_g$ of the slow light medium [5]. At the same time with LCLV, the optical amplification prevents losses and provides a gain that is tunable with the applied voltage, so that the slow light interferometer can be adjusted to work in optimal conditions. As example, we have realized a Mach-Zehnder interferometer, where a LCLV in inserted in one of the arms. We use the $m=0$ order, so that the signal is present even when the LCLV is not operating and we can make a direct comparison between the sensitivity with and without the slow light effect.
5. Conclusions
In conclusion, we have shown that by performing two-wave mixing experiments in LCLV, and by using the dispersive properties associated to the two-beam coupling process, we can obtain fast and slow light phenomena with very large and tunable group delay. The corresponding group index due to slow light has also been exploited to enhance the sensitivity of interferometric detection systems.

References
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