

Pattern formation and direct measurement of the spatial resolution in a photorefractive liquid crystal light valve

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Abstract

In a photorefractive liquid crystal light valve, acting as a Kerr-like nonlinear optical medium, we show the appearance of optical patterns induced by a single mirror feedback. The spatial wavelength of the patterns scales with the distance between the mirror and the valve and the contrast of the patterns decreases for decreasing this distance. We use these properties to setup a new optical scheme for the measurement of the spatial resolution of the nonlinear device.

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1. Introduction

A photorefractive liquid crystal light valve (PLCLV) can be considered as a nonlinear optical component, which exhibits very attractive capabilities for laser beam manipulation or spatial control of an incident wavefront. Motivated by the possibility of using such devices in optical pattern formation, we have set up a single mirror feedback experiment, where a PLCLV acts as a Kerr-like nonlinear medium [1]. Another type of nonlinear behavior of the valve is the first demonstration in [2] of coherent image amplification through two wave mixing and dynamic holography. Also the PLCLV is a very useful device for laser beam shaping and wavefront correction [3]. In other terms, it is viewed as a nonlinear component with an hybrid structure combining a piece of photoconductive crystal sandwiched to a liquid crystal layer. The excellent photo-

sensitivity arises from the photoconductor crystal while a large electro-optic effect at low applied voltage is due to the large birefringence of the liquid crystals. Therefore, in a liquid crystal light valve both photoconductive and electro-optic properties can be separately optimised. Note that in a conventional photorefractive crystal these two properties at the origin of the nonlinear effect are present in the same volume of the crystal.

All these applications require a precise knowledge of the spatial frequency response of the optically addressed spatial phase modulator in order to quantify its performance for the processing and manipulation of laser wavefronts carrying spatial informations. The presented device works in transmission, hence allows much more simplified schemes with respect to classical types of liquid crystal light valves that work in reflections [4]. Here, we show that, when inserted in the optical feedback loop, the PLCLV gives rise to optical pattern formation. The characteristic size of the patterns scales with the free propagation length in the feedback loop. When this distance decreases, the pattern wavelength decreases and eventually approaches the diffusion

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length of the nonlinear medium, hence the contrast of the patterns is strongly diminished. We use these properties to perform a direct measurement of the spatial frequency response of the nonlinear device.

Several other methods have been used to quantify the spatial resolution of a light valve, in particular: incoherent image projection of a binary chart and measurement of image contrast for each spatial frequency of the pattern [5]; holographic recording and probing the diffraction with an auxiliary laser beam. In comparison with these methods requiring more sophisticated optical set up the experiment based on nonlinear pattern formation in a transmission type light valve is easy to implement. The laser is only passing through the device with a retromirror, and it permits to access to the nonlinear parameters and to the spatial resolution of the device. The method is very general and it can be extended to other nonlinear optical media.

2. Experimental setup

The PLCLV is realized by using a $\text{B}_{12}\text{SiO}_{20}$ (BSO) photo-refractive crystal as a photoconductor [6], cut in the form of a thin slice, 1 mm thickness, 20×30 mm lateral sizes. On one side the BSO is coated with an indium-tin-oxide (ITO) transparent electrode. The other wall is a glass window (BK7) coated with ITO. Both the BSO surface and the ITO of the glass window are treated with polyvinyl-alcohol (PVA) for planar alignment. Teflon spacers of $14 \mu\text{m}$ are inserted between the two walls and the cell is sealed with UV photo-polymerizing glue. The assembled cell is filled with the nematic liquid crystal E48, which has a positive dielectric anisotropy, $\Delta\epsilon = 15.1$ at 1.0 kHz, and optical birefringence $\Delta n = n_e - n_o = 0.2306$, the extraordinary and the ordinary index being, respectively, $n_e = 1.7536$ and $n_o = 1.5230$ at $\lambda = 589.3$ nm and $T = 20^\circ\text{C}$. The final quality of the planar alignment is tested under the optical microscope. A schematic drawing of the finished PLCLV is shown in Fig. 1a.

The BSO crystal is well-known for his photorefractive response [6]. Here, we make use of his large photoconductivity in the visible range, from $\lambda = 400$ to $\lambda = 550$ nm [2]. An AC voltage V_0 is applied across the device through the ITO electrodes. Under the application of an electric field, liquid crystals tend to realign in such a way to become parallel to the direction of the applied field [7]. When the light intensity on the BSO increases, its impedance decreases due to the photoconductivity and hence, the voltage drop across the liquid crystal layer increases, inducing liquid crystal reorientation. As a consequence, a light beam passing through the liquid crystal layer will experience a refractive index change and, thus, a phase change ϕ , which is a function of the light intensity on the BSO.

The response of the PLCLV is measured by inserting the component between two crossed polarizers, with the liquid crystal director making an angle of 45° with the polarizer axis. A diode pumped solid state laser DPSS, $\lambda = 532$ nm, incident on the BSO side acts as the pump beam, whereas

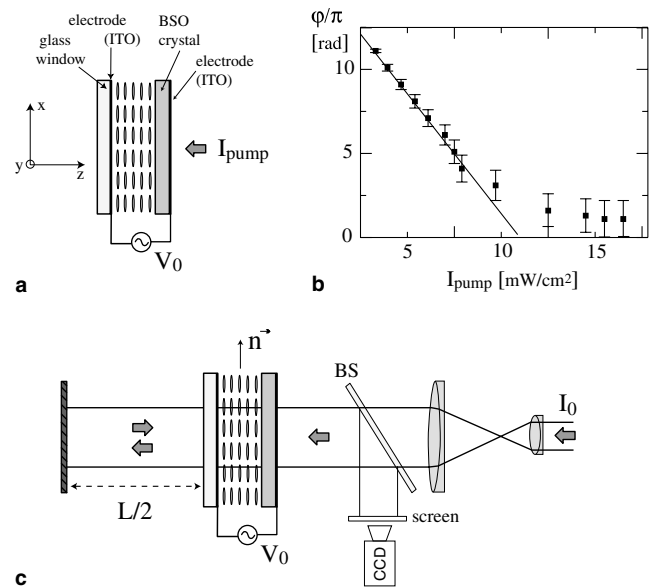


Fig. 1. (a) Schematic representation of the PLCLV and (b) its typical response for an applied voltage $V_0 = 20$ V, frequency $f = 2$ kHz. (c) The single mirror feedback setup for pattern formation: $L/2$ is half the free propagation length.

a low power He–Ne laser beam, $\lambda = 632.8$ nm is used to probe the liquid crystal reorientation. A typical response is displayed in Fig. 1b, where the phase change ϕ experienced by the probe beam is plotted as a function of the light intensity incoming on the photoconductor. The saturation of the response is attained when the liquid crystals are aligned along the direction of the applied field, which correspond to zero birefringence. The full range of phase variation is $\phi = k\Delta n d \simeq 11\pi$, which corresponds to the maximum birefringence $\Delta n = n_e - n_o \simeq 0.2$, realized for the initial planar alignment of the liquid crystals.

In Fig. 1c it is shown the experimental setup for the optical feedback. The DPSS laser beam is enlarged and collimated, so that the beam diameter on the PLCLV is 30 mm. The beam is sent onto the BSO side of the PLCLV, pass through the liquid crystal layer and then is reflected back by a mirror. When the light pass for the second times trough the photorefractive crystal, it induces a local electric field modulation that is proportional to the feedback light intensity and phase shift. Because of its optical activity, the BSO crystal induces on the input beam a polarization rotation $\psi \simeq 44^\circ/\text{mm}$ [6]. To compensate this effect, a half-wave plate is inserted before the entrance face of the BSO and the input beam polarization is rotated of an angle $-\psi$, so that it becomes parallel to the liquid crystal director $\vec{n}$ after its passage through the BSO. Under this condition, when the liquid crystal reorientation takes places only a phase shift occurs in the pump beam without any change in the intensity.

3. Spontaneous pattern formation

According to the response of the PLCLV, for low pump intensity the device can be considered as a Kerr-like nonlin-

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