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Real time phase modulation measurements in liquid crystals

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ABSTRACT

We propose real time phase measurements in liquid crystals cells using Young's interferometer constructed with a new principle with possibility to control the distance between two point sources. The optical interference optical pattern is detected by a bicell photo-detector in a back Fourier focal plane. A phase modulation controlled by a monopixel liquid crystals' cell placed in a reference arm of interferometer is observed as a dynamic shift of the fringes' pattern in spatial domain. Concept of signals' demodulation in the Fourier focal plane will be described using a new approach to the demodulation signals. In this work we evaluate the demodulation condition of our setup and we present measurements of a dynamic phase response for nematic liquid crystals and antiferroelectric liquid crystals cells.

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1. Introduction

For many applications in a bio analysis, there is a need to use a non-contact method such as interferometry, because of the object damage risk. Interferometry techniques such as laser Doppler perfusion imaging [1], electronic speckle pattern interferometer [2], scanning electronic speckle pattern interferometry [3] are successfully used for a number of medical diagnostics, including diseases of the blood and organ transplants. In this case the real time analysis of fringe patterns could limit the examination of the object under study. In the literature several works analyze the changes in the fringe pattern comparing images obtained from a CCD camera. In this case a usual process of phase extraction needs to be additionally calculated [4]. Therefore, these methods are slow and cannot accurately measure fast changes in the object under study. Phase measurements in time domain may overcome this problem and give the possibility to analyze dynamic changes of the analyzed specimen in real time. When the two wave's signals arrive at the detector plan with a different relative phase delay, results that the fringes are spatially moved through a detector or camera positioned at the Fourier plan. If the phase difference is varying very fast with time, the acquisition must be done with a high precision in time domain. In this case we are confronted with a technology problem because camera based interferometry has a limited capturing rate and long processing time for fringe pattern. On the other hand, detector-based interferometry techniques have enough sampling rate along the time axis, but only one measurement point in spatial domain can be performed [5]. Since the phase shifts take place in space instead of time, the problem can be solved if we develop a technology taking advantage of a spatial domain control of fringe pattern. Two photo detectors placed in Fourier plane can be considered as a useful alternative when a dynamic phase is being investigated; In this case, all the data needed to calculate a phase shifting are acquired at the same time. In the present work, we adopt the basic concept Young's double slits experiments to measure the dynamic phase response, considering the possibility to optimize stable modulation conditions. This technique has been used for measuring a real-time phase modulation in nematic and antiferroelectric liquid crystals.

2. Experimental setup

The optical setup we have used to produce a double-slit Young's interferometer with a possibility to control the distance between the two point sources consists of light source coming from the laser He–Ne (632.8 nm) and passing through the polarizer Pol_1, the light was spatially filtered and collimated using lens (L_1). Then, the light was divided into two parts by a beam splitter (BS_1). One of the beams is reflected by a mirror (M_1) to act as a reference beam. The other is reflected by a second mirror (M_2) to act as a probe beam. In order to convert a large diameter collimated beam to a small diameter collimated beam, we insert a telescope formed by two positive lenses' combination in the path of reference and probe beams. Finally, the diameters of the two beams were adjusted to

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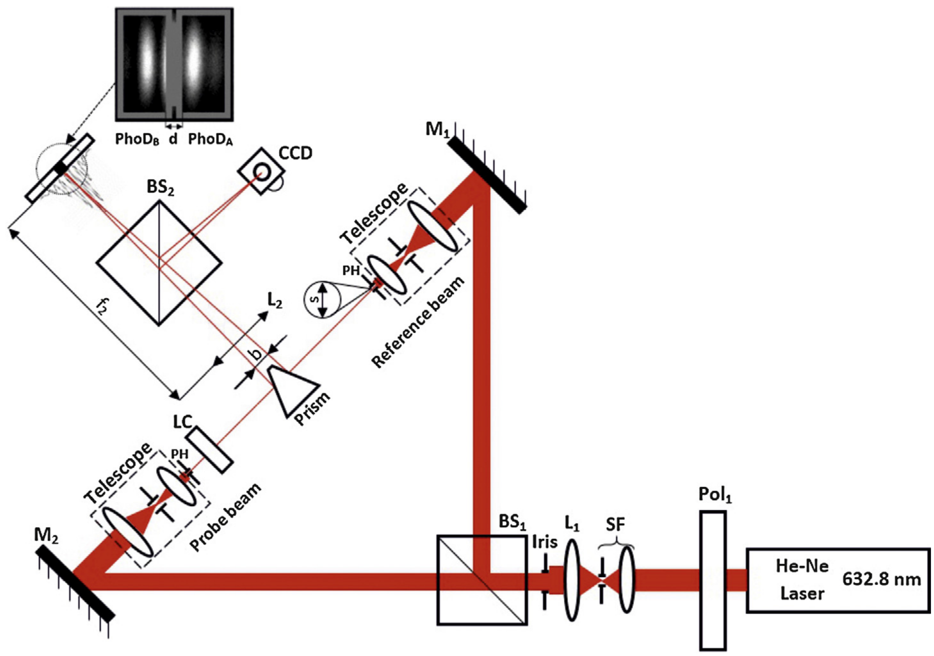

Fig. 1. Sketch of the optical setup we have used to produce a double-slit Young's interferometer with a varying distance between the source beams. Light source: HeNe laser $\lambda = 633$ nm; Pol$_1$: linear polarizers; BS$_1$ and BS$_2$ beam splitters; M$_1$ and M$_2$: mirrors; PH: pinhole; LC: liquid crystal cell; L$_1$, L$_2$: lenses.

the size (s of 400). This tiny collimated beam spot size has been established, when circular pinhole (PH) with a diameter of 400 μm is inserted in the path of beams. As a result the output beams of a diameter of 400 μm with a homogeneous distribution of amplitude and phase is obtained. This parameter determines the distribution envelope of the interference pattern. A gold coated right angle prism mirror has been used to bend light coming out from pinholes by 90 degrees. Therefore, the reflected rays from both sides of the prism become parallel to each other separated by the distance b (Fig. 1). The two beams are combined by Fourier Lens (L$_2$) and the interference pattern is observed at the focal plane of lens L$_2$, where two photo-detectors $PhoD_A$ and $PhoD_B$ separated from each other by the distance gap d (Fig. 1) are located. In order to conduct an appropriate fringe pattern, it is necessary to make both beams focus at the same point. Accordingly second BS$_2$ has been used to monitor a focused image of each point source in a CCD camera and to allow the fringe pattern to be viewed.

We have used photo detectors with an active area of 2.5 mm × 2.5 mm, segmented into two cells with a 48 μm gap. In Fourier plane, the size of airy disc containing fringe pattern is determined by the source size s of interfering beams, the wavelength λ *and* the focal length f. These parameters have been chosen to fix the Airy disc to approximately 500 μm diameter size. The advantage of this arrangement setup consists of spatial domain control of the fringe pattern which the period of spatial modulation of intensity distribution can be controlled varying the distance between two point sources' beams by moving the prism position. In this case, the spatial distribution of intensity will be recorded simultaneously in two photo detectors.

During the measurement the LC cell under study was placed in a probe beam inside a hot-stage maintaining a constant temperature of 35 °C.

2.1. Adjustment conditions for an optical phase demodulation

Phase demodulation performance is strongly determined by geometrical parameters of the above setup such as a distance between two point sources and distance between two photo-detectors (see Fig. 1).

The electric signals coming out from $PhoD_A$ and $PhoD_B$ are collected in a data acquisition card (DAC) controlled by Lab VIEW software. Those signals are added (*Sum*) and subtracted (*Diff*) to each other:

$$\begin{aligned} Sum &= I_A + I_B \\ Diff &= I_A - I_B \end{aligned} \tag{1}$$

Information about a phase shift in the observed fringe pattern can be described by using *Sum* and *Diff* characteristics described in reference [6]:

$$\begin{aligned} Sum &= 2a_1 + 2a_2 \cos\Delta\varphi \\ Diff &= 2a_3 \sin\Delta\varphi \end{aligned} \tag{2}$$

where a_1, a_2 and a_3 depend on the wavelength λ, the focal length f, the distance between the two point sources b and the beam size s. Those parameters can be given as integral of interference pattern over receiving area of photo-detectors, such as:

$$\begin{aligned} a_1 &= C \int_{d/2}^{\infty} \int_{-\infty}^{\infty} A^2(\rho)\, dy_f\, dx_f \\ a_2 &= C \int_{d/2}^{\infty} \int_{-\infty}^{\infty} A^2(\rho) \cos\left(\frac{4\pi b x_f}{\lambda f}\right) dy_f\, dx_f \\ a_3 &= C \int_{d/2}^{\infty} \int_{-\infty}^{\infty} A^2(\rho) \sin\left(\frac{4\pi b x_f}{\lambda f}\right) dy_f\, dx_f \end{aligned} \tag{3}$$

where $A(\rho)$ is the spatial distribution of amplitude on the Fourier plane. For the uniform input beam this distribution is expressed as:

$$A(\rho) = \left(\frac{2J_1(\pi\rho s)}{\pi\rho s}\right) \tag{4}$$

where J_1 is the Bessel function of the first-order and ρ represents the radius in the spatial frequency domain [7].

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