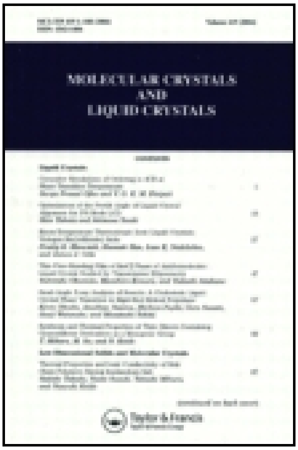

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Phase Shifting Twyman-Green Interferometer Utilizing Nematic and Cholesteric Liquid Crystal Cells

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PHASE SHIFTING TWYMAN-GREEN INTERFEROMETER UTILIZING NEMATIC AND CHOLESTERIC LIQUID CRYSTAL CELLS

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Abstract We show a phase shifting Twyman-Green interferometer utilizing a nematic liquid crystal (NLC) cell and a cholesteric liquid crystal (CLC) cell. NLC cell is used as a phase shifter (PS) and CLC cell is used as an intensity stabilizer. The NLC PS is designed to induce a phase shift of 2π rad for He-Ne laser beam (λ=632.8 nm) with the applied voltage of about 10 V, and a CLC cell which is designed to exhibit its selective reflection peak at 632.8 nm, is used to remove the fluctuation of the intensity of the interferogram. The interferometer system is evaluated by testing a concave mirror surface and the result is discussed.

INTRODUCTION

Liquid crystals have widely been used in optical systems owing to the ability to synthesize them with tailor-made optical properties. Nematic liquid crystal (NLC) can be used as waveplates[1] or phase shifters (PS's)[2].

When using the NLC PS, the direction of the polarization of the light incident on the NLC cell should be parallel to the director of NLC molecules. So a linear polarizer (LP) is used for this purpose unless one has a polarized laser. Randomly polarized beam from common multimode He-Ne lasers will then cause intensity variation to the beam that transmitted the LP, which might produce severe errors in surface testing using phase shifting interferometry.

In this paper, we describe a phase shifting interferometer (PSI) system which uses a cholesteric liquid crystal (CLC) cell that makes the intensity of the interferograms stable, even if an NLC PS is used with the nonpolarized laser.

NLC PHASE SHIFTER

The molecules of NLC start to reorientate when the voltage applied to the cell exceeds the threshold value for electrical Freedericksz transition[3]. The change in effective extraordinary refractive index across the cell as a function of the applied voltage enables the NLC to be used as a PS.

We designed and fabricated an NLC PS that can induce a phase shift of 2π rad for He-Ne laser beam (λ=632.8 nm) with the applied voltage of about 10 V to the cell. A 12 μm thick NLC cell with homogeneous texture of ZLI-2244-100 (Merck Ltd.) was fabricated.

We placed the NLC cell between two crossed LP's with NLC's fast axis at 45° with the transmitting axes of LP's to investigate the electro-optical characteristics of the cell. The intensity of the transmitted laser beam were measured as a function of voltage applied to the cell. The results and the corresponding phase retardation of the NLC cell are shown in Figure 1. We can see that phase shift of 2π rad can be achieved by applying about 10 V to the cell.

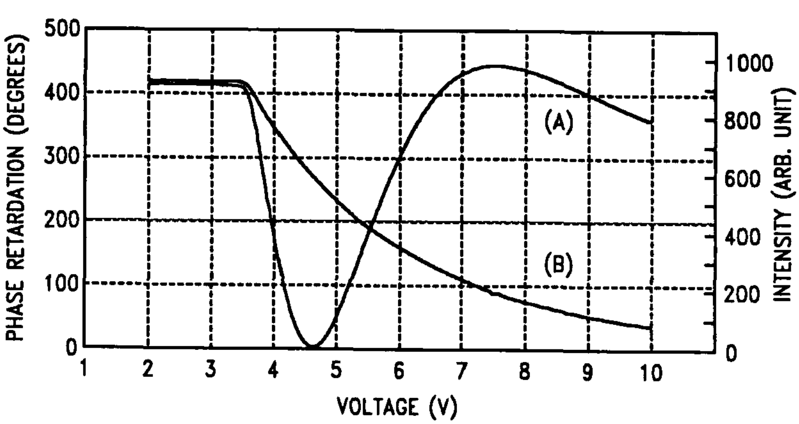

FIGURE 1 Transmitted intensity (A), and its corresponding phase retardation (B) of NLC cell placed between crossed polarizers, as a function of applied voltage to the cell.

CLC INTENSITY STABILIZER

As it was mentioned at the introduction, when the randomly polarized multi-mode

He-Ne laser is employed as a light source in the PSI which uses an NLC PS, an LP is placed between the laser and the beam splitter to make the light incident on the NLC be polarized with its direction parallel to the director of NLC. This will then cause intensity fluctuation of the beam transmitted the LP, owing to the random orientation of the incoming beam polarity. Intensity fluctuation would be minimized if the beam incident on the LP could be circularly polarized. Combination of an LP with a quarter waveplate – common method of producing circularly polarized light – cannot solve the problem since it already contains an LP itself.

We solved this problem by using a CLC cell for intensity stabilization. We placed the CLC cell between the laser and LP. Due to the selective reflection property of the CLC, the beam which transmitted the CLC became circularly polarized. Thereby the beam which transmitted the LP became free from intensity fluctuation due to random polarization of input laser beam. Only the intensity fluctuation due to polarization changes of the longitudinal modes would remain.

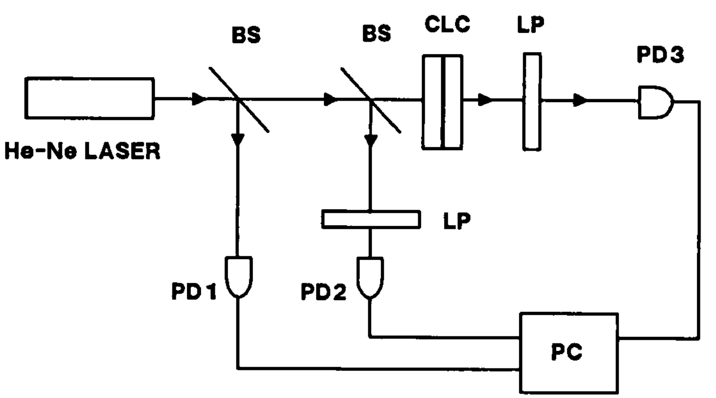

FIGURE 2 Experimental setup for testing CLC as an intensity stabilizer. BS: beam splitter; LP: linear polarizer; PD1, PD2, PD3: photo-detectors; PC: personal computer.

A CLC cell was designed and fabricated to exhibit its selective reflection peak at 632.8 nm. 12 μm thick cell was filled with the mixture of CB15 (33.19 %) and ZLI1167 (66.81 %), and shearing was imparted to the cell to produce Grandjean texture.

We examined the intensity stabilization property of the CLC with an experimental setup shown in Figure 2. Photo-detector PD1 measured the laser intensity, PD2 measured the intensity of the beam transmitted the LP, and PD3 measured the beam intensity after the CLC and the LP. The results are depicted in Figure 3. It is remarkable to see that the intensity of the laser beam which transmitted the CLC and LP shows better stability than that of the laser itself. Theoretical analysis of this property is now under investigation.

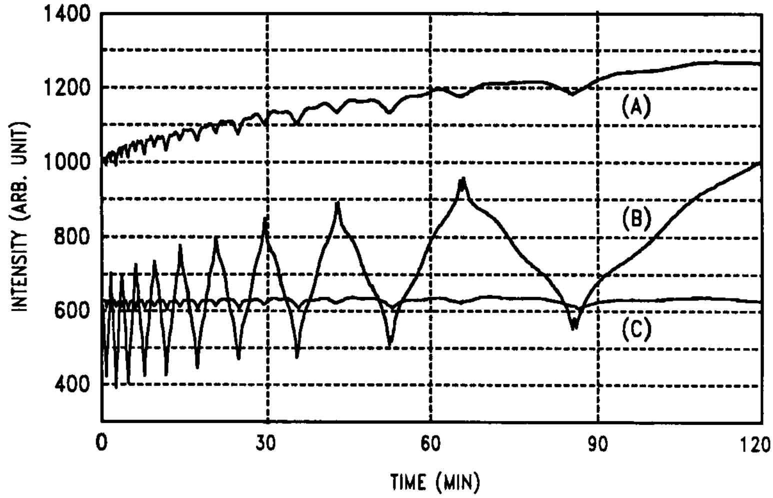

FIGURE 3 Intensity of laser measured at point (A) after the laser, (B) after LP, and (C) after LP and CLC.

TWYMAN-GREEN PHASE SHIFTING INTERFEROMETER

The schematic of a Twyman-Green PSI which uses an NLC cell as a PS and a CLC cell as an intensity stabilizer is shown in Figure 4. First, the phase error of the interferometer itself was measured by placing a flat mirror M_2 of good quality at the focus of the lens L_1. The voltages of 4.625, 5.070, 5.660 and 6.445 V were applied to the NLC cell to obtain four interferograms differing in phase by 0, $\pi/2$, π, and $3\pi/2$ rad respectively. Interferograms were recorded by CCD camera (Sony CCD-IRIS SSC-350) and a frame grabber (Data Translation DT2851). These interferograms are shown in Figure 5. Denoting these interferograms as I_{R_i} (i=1,2,3,4), the phase error of the interferometer system is obtained by[4]

$$\phi_R(x,y) = \tan^{-1}\left[\frac{I_{R_2}(x,y) - I_{R_4}(x,y)}{I_{R_1}(x,y) - I_{R_3}(x,y)}\right]. \tag{1}$$

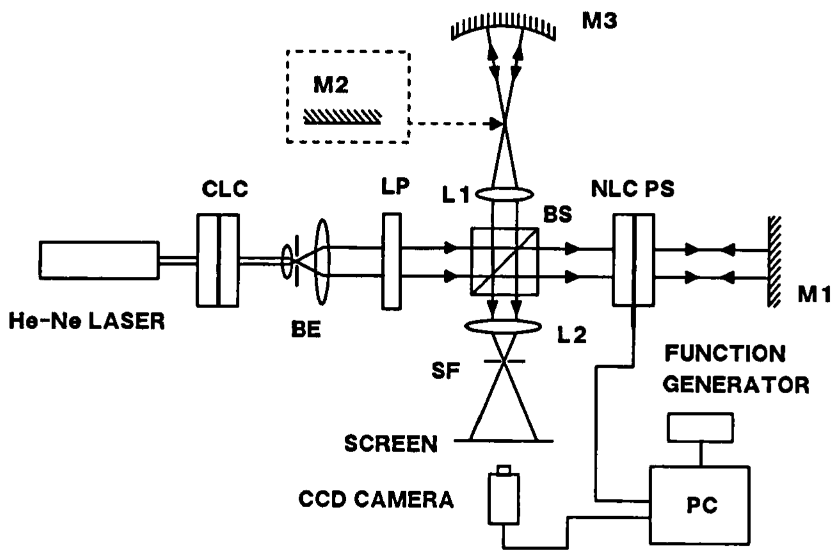

FIGURE 4 Schematic of Twyman-Green interferometer using an NLC cell as a phase shifter. BE: beam expander; LP: linear polarizer; BS: beam splitter; L1, L2: lens; SF: spatial filter; M1, M2: reference mirror; M3: test mirror; PS: phase shifter; PC: personal computer.

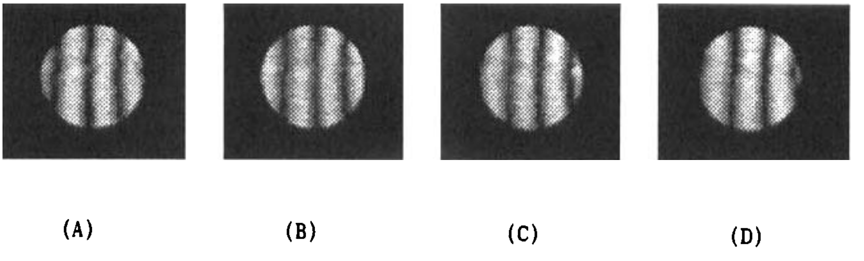

FIGURE 5 Phase shifted interferograms showing the phase error of the interferometer itself. Voltage applied to NLC PS is (A) 4.625, (B) 5.070, (C) 5.660, and (D) 6.445 volts, respectively.

Next, we took out the mirror M_2 and put the concave mirror M_3 being tested at the place where the center of curvature of M_3 exactly coincides with the focus of L_1.

Another set of four interferograms shown in Figure 6 were grabbed, and the phase error $\phi_T(x, y)$ was calculated.

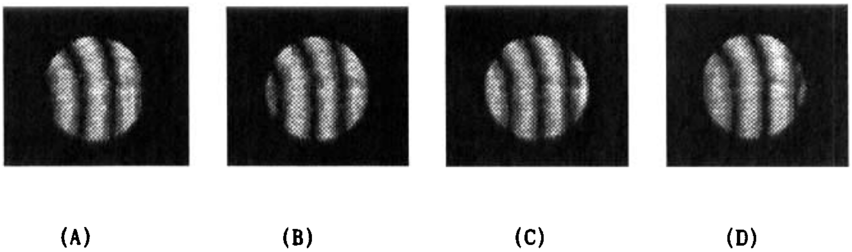

FIGURE 6 Phase shifted interferograms for the test mirror. Voltage applied to the NLC PS is (A) 4.625, (B) 5.070, (C) 5.660, and (D) 6.445 volts, respectively.

These phase errors were fitted by using Zernike-like polynomials[5] which are orthogonal over the data points. The phase error due to surface of the mirror M_3 only was obtained by subtracting the fitted coefficients of ϕ_R from those of ϕ_T, after removing the piston, tilts, and defocus errors. Three dimensional perspective of the phase error due to the concave mirror under test is shown in Figure 7.

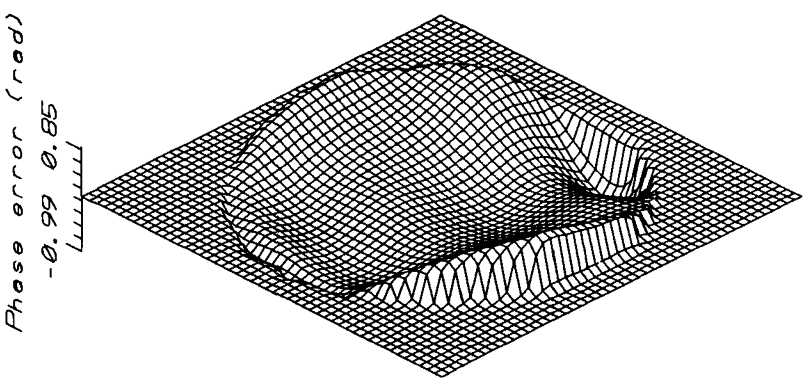

FIGURE 7 Three dimensional perspective of the wavefront aberration due to test mirror.

CONCLUSION

An NLC cell was fabricated, and used as a PS in a phase shifting Twyman-Green interferometer. It has advantages of being driven under low voltage (< 10 V) and showing no hysterisis, compared to piezoelectric transducers (PZT).

The CLC cell which was placed between randomly polarized laser and LP acted as an intensity stabilizer. The results showed better stability than the intensity stability of the laser itself. Theoretical analysis of this property is under investigation.

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