Polarization Fizeau interferometer based on birefringent thin film

Linglin Zhu (朱玲琳)[1,2], Aijun Zeng (曾爱军)[1,2*], Fanyue Li (李凡月)[1,2], and Huijie Huang (黄惠杰)[1,2]

[1] *Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China*

[2] *Graduate University of Chinese Academy of Sciences, Beijing 100049, China*

* *Corresponding author: aijunzeng@siom.ac.cn*

Received September 21, 2011; accepted January 5, 2012; posted online March 15, 2012

A polarization Fizeau interferometer based on birefringent thin film is presented. The interferometer adopts a birefringent thin film to obtain orthogonally polarized and strictly common-path reference and test beams. Advantages include ease of implementation on large-aperture interferometer, measuring test optics from long distance, and achieving high fringe visibility. The phase shift is obtained by combining a quarterwave plate and an analyzer. The concepts illustrated are verified experimentally.

OCIS codes: 120.5410, 120.3180, 260.5430.

doi: 10.3788/COL201210.061201.

The accuracy of Fizeau interferometry can be improved by polarization phase-shifting technology. The key of achieving polarization phase-shifting Fizeau interferometer is how to produce spatially separated and orthogonally polarized test and reference beams. The most efficient method is to insert a birefringent crystal with retardation of 90° between the reference plate and test surface[1]. However, this method is difficult to implement on large-aperture optical elements because of the size limitation of the birefringent crystal. For engineering application, Millerd *et al.*[2] and Szwaykowski *et al.*[3] respectively proposed to combine a beam splitter or a beam combiner with the tilted test surface to generate spatially separated and orthogonally polarized reference and test beams. However, in these two methods, the interferometers are susceptible to retrace error (i.e., the test and reference beams are no longer common path and are not easy to operate). Recently, Kimbrough *et al.* proposed to use polarization frequency shift device[4]; however, this method results in low-visibility interferograms and a complex structure. To overcome these disadvantages, in this letter, we propose a new polarization Fizeau interferometer based on birefringent thin film.

The diagram of the polarization Fizeau interferometer based on birefringent thin film is shown in Fig. 1. The interferometer is composed of a laser (L), a polarizer (P), a focusing lens (FL), a pinhole (H), a nonpolarized beam splitter (NBS), two collimators (C1 and C2), a polarization phase shifter, a reference plate (RP), and the test surface (TS). The pinhole is placed at the back focus of the focusing lens, and at the front focus of C1. The surface of the reference plate near C1 is the reference surface without the film. The surface of the reference plate near the test surface is alternately coated with birefringent thin film (BTF) and antireflection film (AF). The BTF is a sculptured thin film fabricated by oblique-angle deposition (OAD)[5−7]. The sculptured thin film is anisotropic in structure and possesses birefringent property[8]. When used as a polarization element, the film has no size limitation (unlike the crystal) and good surface profile can be achieved by controlling the surface profile of the substrate and the deposition velocity of the film[9,10]. The AF cannot only eliminate the reflection beam degrading the fringe visibility, but also protects the birefringent thin film to improve its optical stability. In this letter, the retardation of the birefringent thin film is $\pi/2$. The angle between the fast axis of the birefringent thin film and the transmission axis of the polarizer is 45°. The polarization phase shifter can be a temporal phase shifter or a spatial phase shifter. The temporal phase shifter could be composed of a quarterwave plate and an analyzer[1]. The spatial phase shifter could be composed of micropolarizer array[11]. In this letter, we use the former kind.

A collimated linearly polarized light is filtered spatially by the pinhole, split by the nonpolarized beam splitter and then collimated by C1. The collimated light is reflected to form the reference beam (indicated by black dot) by the reference surface. The collimated light is transmitted by the reference plate, and then reflected by the test surface to form the test beam (indicated by short line). The test beam passes through the reference plate twice, and its polarization direction is rotated 90°. Thus, its polarization direction is perpendicular to that of the reference beam. The reference and test beams are

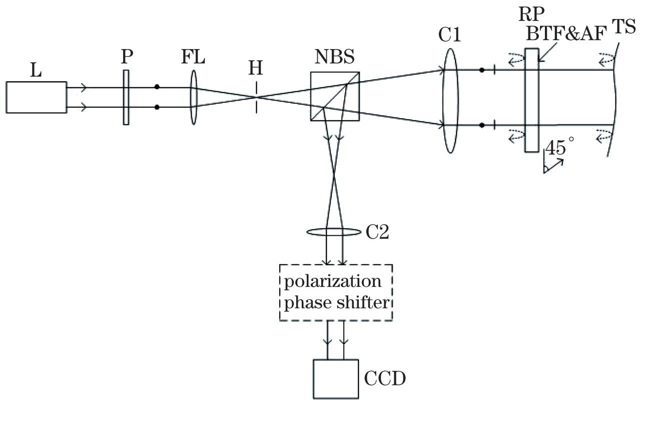

Fig. 1. Diagram of polarization Fizeau interferometer based on birefringent thin film.

split by the nonpolarized beam splitter, collimated by C2, and then enter the polarization phase shifter to form an interferogram. The interferogram is captured by a charge-coupled device (CCD).

The birefringent thin film can be integrated with the reference plate and made sufficiently large. The proposed approach can be used on large-aperture optics and as a strictly common-path system. Therefore, no retrace error is introduced in its measurement result. Using a high-coherence laser source, the polarization Fizeau interferometer has long coherence length; therefore, the test optics can be located a far distance away from the main test setup. In theory, without background light, the measurement results of the polarization Fizeau interferometer can have high interference visibility.

In experiments, the optical layout was arranged as shown in Fig. 1. The source was a He-Ne laser with wavelength of 632.8 nm. The extinction ratio of the polarizer was 10^{-4}. The focusing lens was a microscope objective lens with magnification of 10×. The aperture diameter of the pinhole was 25 μm. The transmission difference and reflection difference between P-wave and S-wave of the nonpolarized beam splitter were all less than 5%. The effective focal length of C1 with aperture diameter of 32 mm was ~314 mm. The aperture diameter of the reference plate was 50 mm. The reference plate was made of K9 and its refractive index was 1.515. The birefringent thin film was made of sculptured TiO_2 deposited at glancing angle of 70°. Its thickness was 4 654 nm when refractive index of P-wave was 1.560 at 633 nm and S-wave was 1.594. The non-uniformity of its retardation was measured to be less than 1% with photoelastic modulator (PEM) polarization modulation method. The light at the interface between the reference plate and birefringent thin film only had 0.04% reflectivity according to Frensnel formula, with a refractive index 1.515 of K9 and the average refractive index 1.577 of TiO_2 thin film. A parallel plate with aperture diameter of 50 mm was tested. The effective focal length of the C2 with aperture diameter of 25 mm was ~90 mm. The polarization phase shifter was composed of a quarter-wave plate and an analyzer. The quarterwave plate was a zero-order crystal quartz quarterwave plate with less than $\lambda/500$ retardation tolerance. The angles between the fast axis of the quarterwave plate and the polarization directions of the reference beam and the test beam were all 45°. The extinction ratio of the analyzer was 10^{-4}. When the analyzer was rotated, the interference fringes could be observed to move. The corresponding interferograms when the transmission axes of the analyzer were 0°, 45°, 90°, 135°, and 180° (i.e., the phase shifts were 0°, 90°, 180°, 270°, and 360°) are shown in Figs. 2(a)–(e), respectively.

For measurements, the angles between the fast axes of the birefringent thin film and the quarterwave plate and the transmission axis of the polarizer were all adjusted to 45° according to the light-extinction method. Figures 2(a)–(e) verify that phase shifting is generated with the rotation of the analyzer[12,13]. These results indicate that phase-shifting interferograms can be achieved when the polarization Fizeau interferometer is combined with the polarization phase shifter.

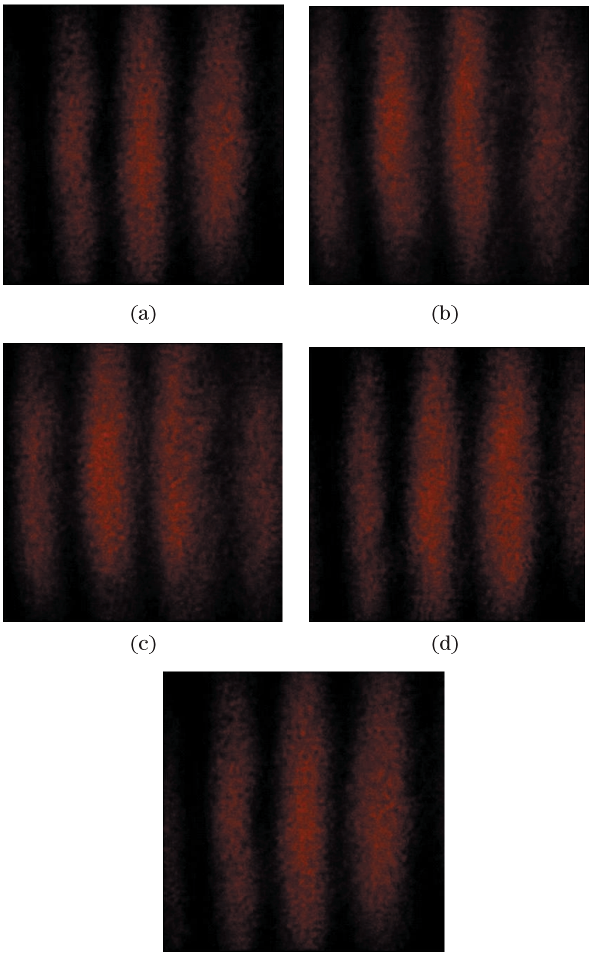
(a) (b) (c) (d) (e)

Fig. 2. Phase-shifting interferograms in the experiment. Phase shift: (a) 0°, (b) 90°, (c) 180°, (d) 270°, and (e) 360°.

In conclusion, a polarization Fizeau interferometer based on the birefringent thin film is presented. By using the birefringent thin film, the interferometer can obtain large measurement aperture, long measurement distance, simple structure, easy operation, and high interferometric visibility. The experimental results verify the usefulness of the proposed interferometer.

The authors thank Prof. Hongji Qi for providing the birefringent thin film. This work was supported by the National Natural Science Foundation of China (No. 60808018) and the State Key Laboratory of Applied Optics, China (No. Y1Q03FQK06).

References

1. S. Chatterjee, Y. P. Kumar, and B. Bhaduri, Opt. Laser Technol. **39,** 268 (2007).
2. J. E. Millerd and J. C. Wyant, "Simultaneous phase-shifitng Fizeau interferometer", US 2005/0046864 A1 (2005).
3. P. Szwaykowski and F. N. Bushroe, "Interferometric system with reduced vibration sensitivity and related method", US 2006/0146341 A1 (2006).
4. B. Kimbrough, E. Frey, and J. Mllerd, Proc. SPIE **7063,** 706307 (2008).
5. K. Robbie, G. Beydaghyan, T. Brown, C. Dean, and J.

Adams, Rev. Sci. Instrum. **75,** 1089 (2004).

6. J.-Q. Xi, Jong Kyu Kim, E. F. Schubert, D. Ye, T. M. Lu, and S. Y. Lin, Opt. Lett. **31,** 601 (2006).
7. X. Xiao, G. Dong, H. He, H. Ji, Z. Fan, and J. Shao, Chin. Opt. Lett. **7,** 967 (2009)
8. A. Lakhtakia and J. B. Geddes, *Trends in Nanophysics* (Springer, Germany, 2006).
9. T. Motohiro and Y. Taga, Appl. Opt. **28,** 2466 (1989).
10. I. Hodgkinson and Q. H. Wu, Appl. Phys. Lett. **74,** 1794 (1999).
11. M. Novak, J. Millerd, N. Brock, M. North-Morris, J. Hayes, and J. Wyant, Appl. Opt. **44,** 6861 (2005).
12. J. Millerd, N. Brock, J. Hayes, M. North-Morris, B. Kimbrough, and J. Wyant, *Fringe 2005* (Springer, Germany, 2010).
13. C. Xu, "Study of dynamic interferometry technology and application" (in Chinse), PhD. Thesis (Nanjing University of Science and Technology, 2009).