Optik 127 (2016) 6735–6741

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

Principle and analysis of a birefringent beam splitter

Naicheng Quan, Chunmin Zhang*, Tingkui Mu

Institute of Space optics, School of Science, Xi'an Jiaotong University, No.28 Xianning West Road, Xi'an 710049, Shaanxi, PR China

ARTICLE INFO

Article history:
Received 4 March 2016
Accepted 25 April 2016

Keywords:
Interference imaging spectrometer
Birefringent beam splitter
Wide field of view

ABSTRACT

A method to extend the field of view of Savart ploariscope is presented in this paper. By using a combination of Savart polariscope and a pair of uniaxial crystal plates cut parallel to the optic axis which are fabricated from birefringent materials with opposite sign relative to that of SP with their principle sections perpendicular to each other, the useful field of view to void distortions of interference fringes can be increased by a large amount in broad spectral coverage. Compared to the combination of two Savart polariscopes, the optical path difference is higher by one order in magnitude. To demonstrate the effectiveness, a design example operating at 480–960 nm with a large solid angle exceeding ±30° is presented in detail.

1. Introduction

Interference imaging spectrometer (IIS) has been widely used in remote sensing, resource investigation, environment observation and object identification for several decades [1–4]. Traditional IIS is based on Michelson interferometer [2,4]. This instrument needs high-quality mirror-scanning mechanisms to produce the interferogram, and the temporal resolution is limited by the maximum mechanical scanning rate. Therefore, it is not suitable for real-time application. To overcome these drawbacks, many stationary imaging spectrometer without moving parts have been developed [5–9]. Zhang et al. have presented a static polarization interference imaging spectrometer (SPIIS) based on Savart polariscope (SP) [9]. Compared to the static IIS based on Wollaston prism, the biggest advantage of the SPIIS is that there is no narrow slit. Therefore, the throughput of the system is raised markedly. High optical throughput increases the instrument sensitivity and allows the recording of high resolution spectra at low light levels. The optical throughput E of SPIIS is defined as $E = \Omega A$, where Ω is the solid angle of the field of view (FOV) for the instrument, A is the area of its input aperture. Because the straight interference fringes can only be produced by the SP in small angles of incidence, the optical throughput of SPIIS is still limited by the FOV of the instrument [8,9]. For certain applications, the fringes are required to be straight and the incident angles cannot be restricted to small values, so Francon demonstrated a modified Savart polariscope (MSP) by using an achromatic half wave plate (AHWP) sandwiched between the two Savart plates [10]. The FOV to acquire straight interference fringes can be very large theoretically. Since the rotation angle of the half-waveplate is variable with the incidence angle and wavelength of the incident light, the FOV of MSP is still restricted severely [11].

To overcome this shortcoming, Mu. et al. and Li. et al. presented their designs to increase the FOV of SP by combination of two SPs fabricated from positive and negative birefringent materials respectively [12,13]. This principle is similar to extending the FOV of Wollaston prism, and has potential benefits at all wavelengths with the same FOV. But the lateral displacement between the two rays sheared by the pair of SPs is reduced significantly.

---

* Corresponding author.
E-mail address: zcm@mail.xjtu.edu.cn (C. Zhang).

http://dx.doi.org/10.1016/j.ijleo.2016.04.124
0030-4026/

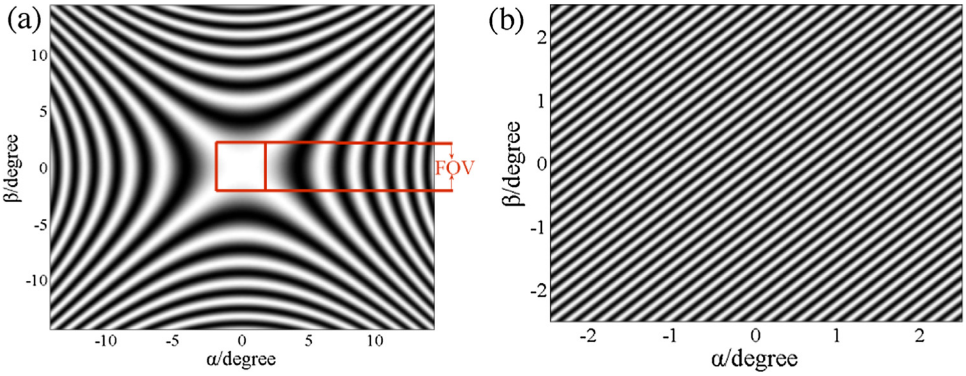

Fig. 1. Calculated FOV interference fringes of the SP (a) incident angle over $i_{\max}$ (b) incident angle under $i_{\max.}$

In this paper, we present a novel design of SP with wide field of view (WSP) that not only combines the preceding advantages but also can overcome the fringe distortion over a relatively wider FOV. It is demonstrated that by combining the SP and a pair of uniaxial crystal plates cut parallel to the optic axis, which are fabricated from birefringent materials with opposite sign relative to that of SP with their principle sections perpendicular to each other, the FOV to acquire straight interference fringes is much wider than that of SP, and the optical path difference (OPD) is much larger than that of previous designs.

2. Theory

2.1. Savart polariscope

To clearly explain the principles of WSP, we need to briefly review a typical Savart polariscope and the previous designs. The configuration and principle of SP can be found from the literature [9]. The OPD introduced by SP can be written as

$$\Delta_{sp} = t\frac{{n_o}^2-{n_e}^2}{{n_o}^2+{n_e}^2}(\cos\omega+\sin\omega)\sin i + \frac{t}{\sqrt{2}}\frac{n_o}{n_e}\frac{\left({n_o}^2-{n_e}^2\right)}{\left({n_o}^2+{n_e}^2\right)^{3/2}}(\cos^2\omega-\sin^2\omega)\sin^2 i \tag{1}$$

here the coefficient of sin$i$ term is lateral displacement produced by the SP; n_e and n_o are refractive indices of the uniaxial crystal material of SP for extraordinary and ordinary rays, respectively; i is the incident angle; ω is the angle between the incident plane and the principal section of the plate, usually $\omega = 0°$; t is the thickness of the single crystal plate.

FOV of the SP is restricted by the requirement that the interference fringes should be nearly straight [13]. As is shown in Eq. (1), the term with $\sin^2 i$ can be ignored only in a small angle of incidence. When the incident angle is relatively large, the term with $\sin^2 i$ cannot be vanished anymore, this square term will produce the hyperbolic interference fringes. Thus we could not retrieve the spectrum from the interferogram. This is the reason why the IIS based on Savart polariscope has a very small FOV. In practical applications, the following condition of quasi zero optical path difference is adopted to calculate the FOV in a range of incident wavelength [14] (Fig. 1).

$$\frac{t}{\sqrt{2}}\frac{n_o}{n_e}\frac{\left({n_o}^2-{n_e}^2\right)}{\left({n_o}^2+{n_e}^2\right)^{3/2}}\sin^2 i \leq \frac{\lambda_{\min}}{2} \tag{2}$$

where $\lambda_{\min}$ is the start wavelength of the incident waveband.

Thus, the FOV of SP can be obtained

$$i_{\max} = \arcsin\sqrt{\frac{\lambda_{\min}}{\sqrt{2}t}\frac{n_e\left({n_o}^2+{n_e}^2\right)^{3/2}}{n_o\left({n_o}^2-{n_e}^2\right)}} \tag{3}$$

Then, the OPD can be expressed as

$$\Delta_{sp} \approx t\frac{{n_o}^2-{n_e}^2}{{n_o}^2+{n_e}^2}\sin i i \leq i_{\max} \tag{4}$$

The $\sin^2 i$ term has been eliminated and straight interference fringes will be acquired. Fig. 2 shows the calculated interference fringes produced by the SP that is made up of two-5.3 mm thick YVO_4 Savart plates. $i_{\max}$ of 2.5 °Can be obtained by Eq. (3) in the waveband of 486–960 nm. The interference fringes are calculated using optical ray tracing method at nominal central wavelength (723 nm). The angle α and β are the projections of the incident angle i onto the principle sections of the first and second crystal plates of the SP, respectively.