# The spectral characteristics of the splitting angle for double Wollaston prism

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The spectral characteristics of the splitting angle and its asymmetry for double-Wollaston prism are analyzed theoretically. With the increase of the prism structure angle, the splitting angle of the double Wollaston prism and its asymmetry increase. However, the splitting angle decreases with the increase of the wavelength of incident light. The influence of the incident light wavelength on the splitting angle in the ultraviolet wave band is much greater than that in visible and near-infrared wave band. To verify the theoretical analysis, the characteristics of the double Wollaston prism are also studied experimentally.

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The splitting angle of the double Wollaston prism is larger than 20°, so it can be used as the beam splitter and the polarizer in high precision optical instruments[1,2]. However, many relative reports are mainly on the splitting angle and its asymmetry. To the best of our knowledge, there are few reports on the spectral characteristics of the double-Wollaston prism's splitting angle[3-5]. In this paper, the spectral characteristics of the splitting angle and its asymmetry are analyzed.

The double Wollaston prism is composed of three parts, and can be classified into two kinds according to the optical axis' orientation. The structure and the light path of the two kinds of double Wollaston prisms are shown in Fig.1.

With Fig.1(b), according to the Snell law, the reflective equation on the first interface can be expressed as,

$$\left.\begin{aligned} n_e \sin S &= n_o \sin\alpha_3 \\ n_o \sin S &= n_e' \sin(S+\alpha_2) \end{aligned}\right\}, \tag{1}$$

on the second interface,

$$\left.\begin{aligned} n_e' \sin\alpha_4 &= n_o \sin\alpha_5 \\ n_o \sin\alpha_6 &= n_e \sin\alpha_7 \end{aligned}\right\}, \tag{2}$$

on the exiting interface,

$$\left.\begin{aligned} n_e \sin\alpha_8 &= \sin\varphi_e \\ n_o \sin\alpha_9 &= \sin\varphi_o \end{aligned}\right\}, \tag{3}$$

where $n'_e$ is the refractive index of e-ray in arbitrary direction and can be expressed as[6]

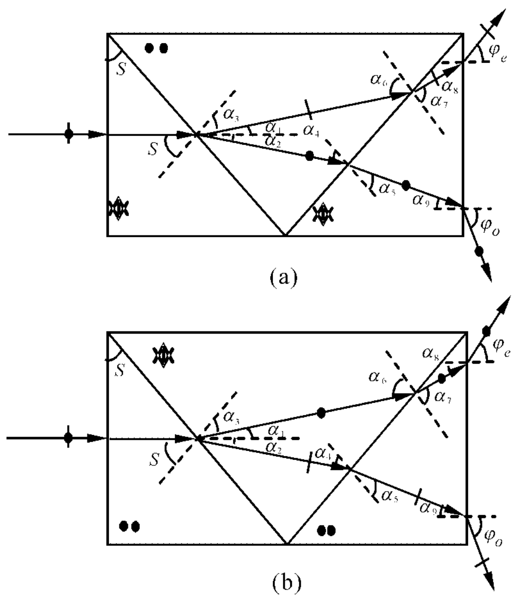


**Fig.1 The schematic and the ray-tracing of two kinds of double Wollaston prism**

$$n_e' = \frac{n_o n_e}{\left(n_o^2 \sin^2\phi + n_e^2 \cos^2\phi\right)^{\frac{1}{2}}} \quad . \tag{4}$$

Here $\phi$ is the acute angle formed by the crystal's optical axis and the e-ray. It satisfies the relation $\phi = 90^o - \alpha_2$.

From Fig.1(b), the following equations can be obtained by the trigonometric relation,

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$$\left.\begin{aligned}\alpha_3 &= S-\alpha_1\\ \alpha_4 &= S-\alpha_2\\ \alpha_6 &= S+\alpha_1\\ \alpha_8 &= \alpha_7 - S\\ \alpha_9 &= S-\alpha_5\end{aligned}\right\} . \tag{5}$$

Substituting Eq.(5) into Eqs.(1), (2) and (3), we can get the expression of the splitting angles of o- and e-ray as follows,

$$\varphi_o = \arcsin\left\{ n_o \sin\left[ S - \arcsin\frac{n_e' \sin\left(2S - \arcsin\frac{n_o \sin S}{n_e'}\right)}{n_o} \right]\right\} , \tag{6}$$

$$\varphi_e = \arcsin\left\{ n_e \sin\left[ \arcsin\frac{n_o \sin\left(2S - \arcsin\frac{n_e \sin S}{n_o}\right)}{n_e} - S \right]\right\} . \tag{7}$$

Eqs.(6) and (7) show that the splitting angles of o- and e-ray are different. The difference between o- and e-ray' splitting angles is defined as the degree of asymmetry of the splitting angle, specifically $R = |\varphi_e - \varphi_o|$. At the same time, the value of the splitting angle of the double Wollaston prism and its asymmetry are related to the structure angle $S$ of the prism and the refractive index of o/e-ray.

When the wavelength of incident light are 257 nm, 533 nm and 1497 nm, the splitting angles are calculated for the structure angle in the range of 5°- 35° by Eqs.(6) and (7), as shown in Fig.2. From Fig.2, the splitting angle $\varphi$ increases with the increase of structure angle $S$ when the incident light is monochromatic light. When the wavelength of the incident light is 257 nm and the structure angle is larger than

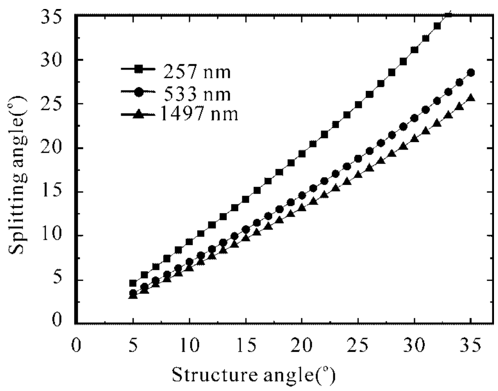


**Fig.2 The splitting angle versus the structure angle**

25.416°, the prism's splitting angle $j$ is larger than the structure angle $S$.

When the structure angles of prisms are 15°, 25° and 35° respectively, the curves of the splitting angle $\varphi$ versus the wavelength of incident light are shown in Fig.3. From Fig.3, the splitting angle $\varphi$ decreases with increasing wavelength in the range of 257 nm-1600 nm. The variation of the splitting angle along with the wavelength in the ultraviolet waveband is greater than that in the visible and near-infrared waveband. That is to say, the influence of the wavelength on the splitting angle $\varphi$ in the near-ultraviolet waveband is greater than that in the visible and near-infrared waveband. This is a very important conclusion in the practical application.

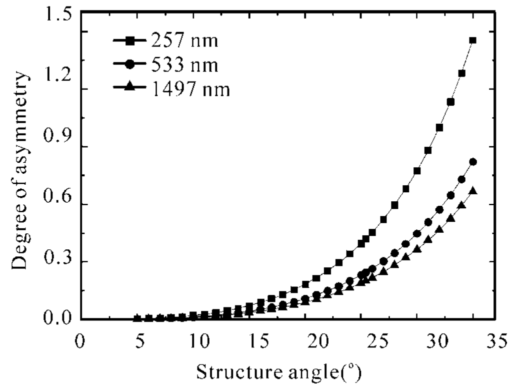


**Fig.3 The splitting angle versus the wavelength**

When the incident wavelength are 257 nm, 533 nm and 1497 nm, the curves of the degree of asymmetry of the splitting angle versus the structure angle of prism are shown in Fig.4. From Fig.4, it is shown that the asymmetry increases with the increase of the structure angle, and the variation of the degree of asymmetry is much greater.

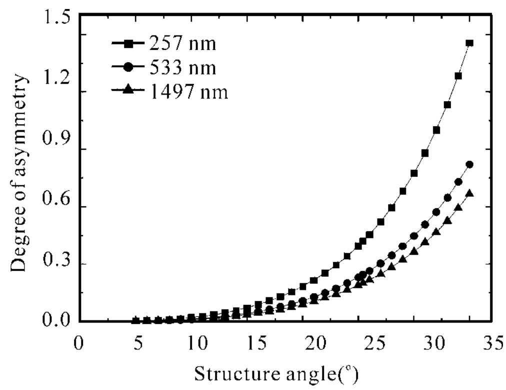


**Fig.4 The degree of asymmetry versus the stucture angle**

When the structure angles of prism are 15°, 25° and 35°, the curves of the degree of asymmetry of the splitting angle versus the wavelength of incident light, are shown in Fig.5. The asymmetry decreases with the increase of the wavelength in the range of 257 nm-1600 nm, and the variation of the asymmetry in the ultraviolet waveband is greater than that in the visible and near infrared waveband, which means that the symmetry of the splitting angle improves greatly in visible and near infrared waveband.

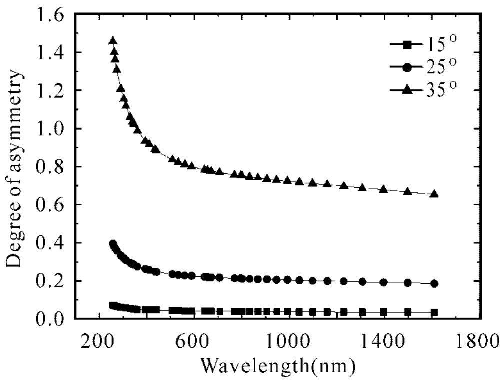


**Fig.5 The degree of asymmetry versus the structure angle**

To verify the theoretical analysis, the characteristics of the double Wollaston prism are also studied experimentally. The experimental system is composed of a laser source and an angular instrument, shown as Fig.6. First, the sample is put into the centre of specimen holder of the angular instrument. Second, the laser light is adjusted to let the incident rays perpendicular to the sample. Third, the angle between the two rays from the sample is measured using the angular instrument and the splitting angle $\varphi$ is calculated. Fourth, the laser is changed for different wavelength, the second and the third steps are repeated. Fifth, all the procedures above with different samples are repeated.

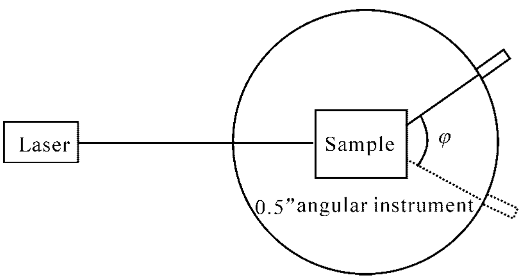


**Fig.6 The schematic diagram of experimental set-up**

The lasers for 473 nm, 532 nm, 633 nm, and 670nm are utilized and the structure angles of double Wollaston prism of 20°, 27.5°, 30° and 38° are chosen. The measured values of the splitting angle $\varphi$ are shown in Tab.1. It is shown that the experimental results are in good agreement with the theoretical ones.

**Tab.1 The theoretical and experimental values of the double Wollaston prism's splitting angle $\varphi$**

| | | 473 nm | 532 nm | 633 nm | 670 nm |
|---|---|---|---|---|---|
| S=20° | Theoretical value | 14.83° | 14.68° | 14.33° | 14.15° |
| | Experiment value | 14.93° | 14.60° | 14.28° | 14.18° |
| S=27.5° | Theoretical value | 21.43° | 21.06° | 20.51° | 20.45° |
| | Experiment value | 21.47° | 21.00° | 20.53° | 20.39° |
| S=30° | Theoretical value | 23.75° | 23.25° | 22.76° | 22.67° |
| | Experiment value | 23.88° | 23.35° | 22.82° | 22.67° |
| S=38° | Theoretical value | 32.68° | 32.36° | 31.28° | 31.26° |
| | Experiment value | 32.79° | 32.05° | 31.30° | 31.09° |

In conclusion, the double Wollaston prism's splitting angle increases with the increase of structure angle. However, it decreases with the increase of wavelength. In ultraviolet wavelengths, the double Wollaston prism's splitting angle is more greatly influenced by the incident wavelength than that in visible and infrared region. The asymmetry increases with the increase of the structure angle. The symmetry of the splitting angle in visible and near-infrared region is superior to that in the ultraviolet waveband. The above results are meaningful for the design and application of the double Wollaston prism.

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