Spectral index of optical coating – polarized light

1. What is the polarization of light?

1.1 Definition

Polarization refers to the ability of light to vibrate in multiple directions.

1.2 Explanation

Light is an electromagnetic wave, which is a shear wave, which is expressed as an electric field (the propagation of light is generally regarded as the propagation of electric field). The vibration direction is perpendicular to the propagation direction. On the plane perpendicular to the propagation direction, the electric field is in a random vibration state and vibrates in all directions. This kind of light is called unpolarized light. Unpolarized light is also known as natural light, including sunlight, incandescent lamp, halogen lamp and other light sources. Some light contains electric fields that vibrate in a fixed direction, but with the participation of natural light. This light is called partially polarized light. Other lights (or their components) vibrate completely in a fixed direction, so these lights are called fully / completely polarized light. Generally speaking, polarized light is completely polarized light, and its typical light sources include some laser light sources (also non polarized, such as fiber lasers).

2. What are the polarization classifications?

2.1 Linear polarization

The electric field of linear polarization only along a single plane in the propagation direction (Z-axis direction). It can be decomposed into two vertical components, along the X-Z plane and Y-Z plane respectively, and one component of linearly polarized light can be 0. The phase difference between the two vertical components is 0, which can be synthesized into a wave propagating in a single plane.

2.2 Circular polarization

The electric field of circular polarization can also be decomposed into two vertical components, along the X-Z plane and Y-Z plane respectively. They have the same amplitude and the phase difference is π/2. The electric field rotates around the propagation axis and propagates like a circle. According to the rotation direction, it is divided into left-handed or right-handed circularly polarized light.

2.3 Elliptical polarization

Elliptical polarization is similar to circularly polarized light, except that the amplitude of its components is not equal or the phase difference is not 0 or π /2. The synthesized waveform looks like an ellipse and rotates and propagates along the axis. Both linearly polarized light and circularly polarized light can be regarded as special cases of elliptically polarized light.

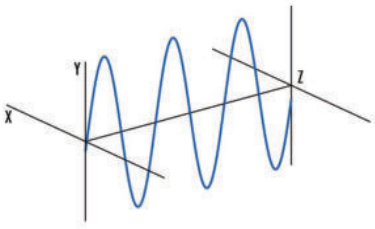

Fig. 1 Schematic diagram of linear polarization

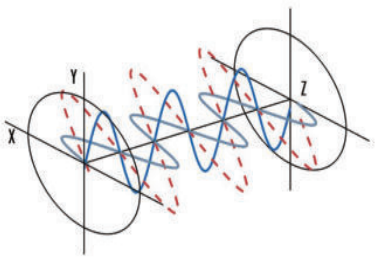

Fig. 2 Schematic diagram of circular polariztion

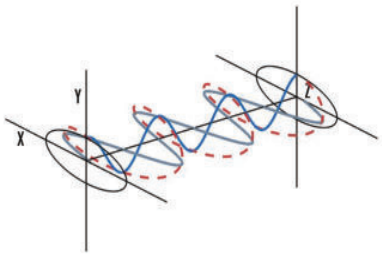

Fig. 3 Schematic diagram of elliptically polarized light

3. What are the important terms of polarized light?

3.1 Amplitude

For the sine/cosine wave propagating along the axis, its amplitude represents the absolute value of the highest point (peak) or lowest point (trough) of the wave, the symbol is A.

3.2 Phase/Phase angle

Phase can be simply understood as the relationship between the position of waveform arrival and time, expressed in angle or radian. For periodic waves, phase can also be called phase angle. It should be noted that the phase has no absolute value, and its size is based on the defined zero phase. Therefore, generally speaking, it is meaningless to talk about phase alone, and phase difference is the focus we need to pay attention to.

When the frequencies of two waves are the same and the time corresponding to the zero point and peak and trough are consistent, the phases of two waves are said to be the same.

In the mathematical expression $y=A\cos(\omega t+\phi)$, $\omega t+\phi$ is called phase, ϕ is the initial phase.

3.3 Phase difference

For waves with the same frequency, the phase difference can reflect the time difference between two trains of waves reaching the same point in the same period. It is numerically equal to the difference between the initial phases of the two trains of waves.

3.4 S / P light

S-light and P-light are taken from German senkrecht (vertical) and parallel (parallel), respectively. Both S-light and P-light are linearly polarized light. The vibration direction of S-light is perpendicular to the incident plane, and the vibration direction of P-light is parallel to the incident plane.

In polarized optics, the concepts of S-light and P-light are very important. Generally, S-light and P-light exist in both reflected and transmitted light, except for a special case, that is, the incident light is incident at Brewster's angle. In the case of incidence in a certain range centered on Brewster's angle, there are also some cases where S-light is more reflected and P-light is more transmitted. This feature is usually used for anti-glare and various occasions requiring light splitting.

3.5 Brewster's angle/polarization angle

Brewster's angle is an incidence angle (θ in Figure 4 is Brewster's angle, $\theta=\arctan(n_2/n_1)$). Light is incident at Brewster's angle, and P-light is perfectly transmitted through the transparent surface without reflection. At the same time, when the unpolarized light is incident at Brewster's angle, the reflected light is fully polarized as S-light. Transmitted light and reflected light are at right angles.

3.6 Polarization extinction ratio

The ratio of the minimum transmitted light intensity perpendicular to the transmission axes of the two polarizers to the maximum transmitted light intensity parallel to the transmission axes of the two polarizers is called extinction ratio, and the unit is dB.

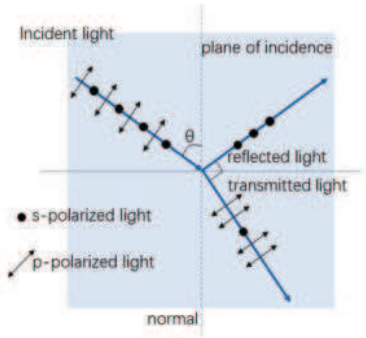

Fig. 4 S / P light at Brewster's angle

4. Why is polarization important?

In laser application, polarization phenomenon will occur due to the influence of laser gain medium material itself (such as anisotropy, that is, material properties change with direction), polarization loss of optical cavity, participation of birefringent crystal and so on. Some lasers, such as fiber lasers, produce non polarized light sources. Polarized optical elements can be used to reduce or filter unwanted high-power polarized reflected light that may cause damage to the system.

In addition, polarized light elements are also used in interferometry, optical amplification, optical modulation, nonlinear frequency conversion, polarization coupling and so on. Polarized light element mainly plays the role of light splitting.

5. What is the reflection spectrum of polarized light?

The reflection spectrum of polarized light is similar to the general reflection spectrum. However, the reflection spectrum of polarized light especially shows the reflectivity curve of the film to S-light and P-light at different wavelengths.

Fig. 5 is a reflection spectrum of a polarization optical coating product. It contains the curves of S-light polarization component and P-light polarization component. Some spectra also contain curves of unpolarized light components. It can be seen that when the wavelength is about 532nm, the film has high transmittance to S-light and low transmittance to P-light; At about 1064nm, the film has high transmittance to P-light and low transmittance to S-light. Thus, the polarization and spectral characteristics of the film at 532 nm and 1064 nm can be seen.

In addition, the extinction ratio at the corresponding wavelength can be read out in the reflection spectrum to measure the performance of the element.

It should also be noted that the angle of incidence is very important for polarization. If the description of the incident angle is not marked on the figure, the subsequent parameters must be indicated. As shown in Figure 4, the incident angles are all 45 °.

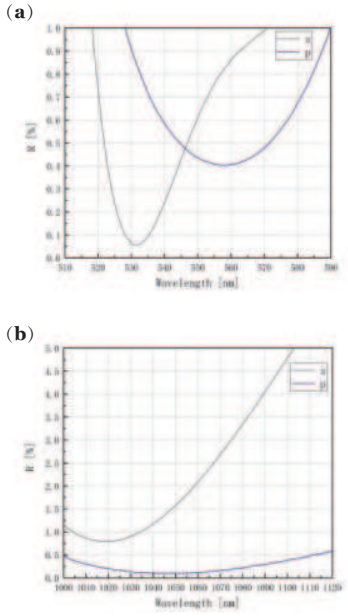

Fig. 5 reflection spectrum of polarized light (a) ARs (45 °, 532nm) < 0.5% (b) ARp (45 °, 1064nm) < 0.5%

6. How to test the reflection spectrum of polarizing film?

The reflection spectrum test of polarizing film is the same as the general reflection spectrum, which requires the use of spectrometer (spectrophotometer). However, the difference is that an additional analytical polarizer needs to be placed in the test system to separate the required polarized light. Commonly used analytical polarizers include Glan-Taylor or Glan-Thompson polarizers. Due to the different wavelength range of different polarizers, the appropriate polarizer should be selected in the test.

In addition, the test also includes the baseline calibration of the analytical polarizer. During S / P light test, it should be noted that the position of the measured polarizer cannot be moved during two spectral measurements.

7. What is a spectroscopic film?

Light splitting film is an optical film that can divide a beam of light into two beams. Spectroscopic films mainly include wavelength spectroscopic films (distinguishing light of different colors), light intensity spectroscopic films (distinguishing light of different intensities) and polarization spectroscopic films (distinguishing light of different polarizations).

8. What is polarizing spectroscopic film?

Polarization beam splitting film is a transparent film with the function of splitting S-light and P-light. Generally, there are two forms of polarization beam splitter: Brewster's angle polarization beam splitter and multilayer interference polarization beam splitter. Brewster's angle polarization spectroscopic film is commonly used. When the light is incident at Brewster's angle, P-light is completely transmitted and only S-light is contained in the reflected light. In general applications, for convenience, the incident angle is limited to 45 ° (not necessary), and the reflection and transmission characteristics similar to Brewster angle are required.

9. What are the polarization beam splitter?

Polarizing beam splitter is an optical element that can distinguish S-light and P-light. The traditional polarization beam splitter generally uses birefringent crystal, but its application is limited because it is difficult to achieve large volume. Thin film polarizers are widely used as polarization beam splitter. Thin film polarizers can generally be divided into two types:

（1）Cubic polarization beam splitter

The cube polarizing beam splitter is formed by bonding two triangular prisms, and the polarizing beam splitter film is coated in the middle. Usually, the input and output surfaces are also covered with antireflection films. The common MacNeille cube is based on the principle of Brewster's angle, while the others rely on interference effect to suppress the reflection of P-light.

Advantages of cubic polarization beam splitter:

- 0 ° incidence angle is easy to integrate;
- No beam offset;
- The optical paths of reflection and transmission are equal;

It can effectively shorten the optical path of the system

Disadvantages of cubic polarization beam splitter:

- The two triangular prisms are of heavy solid glass structure;
- Difficult to achieve large size;
- Higher cost.

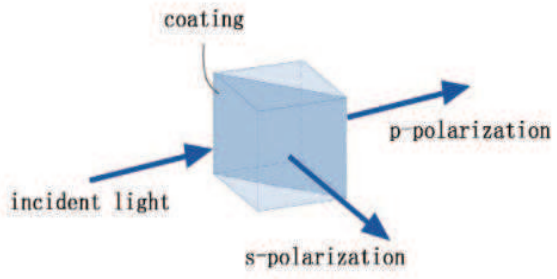

Fig. 6 Schematic diagram of cubic polarization beam

（2）Flat polarization beam splitter

The flat polarization beam splitter is only composed of coated glass plate. This design usually requires that it must be incident at Brewster's angle to avoid reflection loss. For other incident angles, such as 45 °, the second side needs to be coated with antireflection film to obtain higher spectral efficiency.

Advantages of flat polarization beam splitter:

- Lighter;
- Low cost;
- Convenient manufacture;
- Easy to obtain large size;

Disadvantages of flat polarization beam splitter:

- The lengths of reflected and transmitted light paths are different;
- The transmitted light is deflected by the refraction of the plate;
- 45° / Brewster's angle incidence may require additional calibration time.

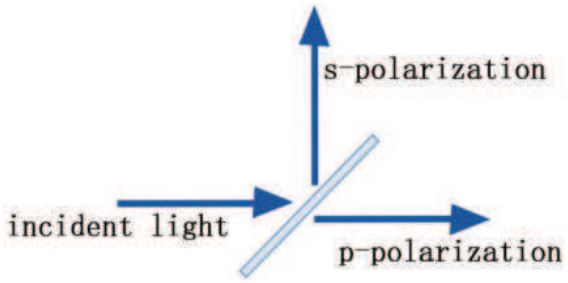

Fig. 8 Schematic diagram of flat polarization beam

10. What should we pay attention to when using polarization beam splitter?

10.1 Incident angle

There is a great correlation between polarization and incident angle. The manufacturer will also design the type and thickness of the coating on the basis of the set incident angle. If the incident angle deviates from the set incident angle, it will inevitably lead to the performance degradation of the element.

10.2 Wavelength range

Polarizing beam splitter, like other optical elements, is not suitable for all wavelength ranges. The wavelength range of each element shall refer to the reflection spectrum of the polarizing element. Generally speaking, the polarizing beam splitter is mostly used in narrow-band applications, and special attention should be paid to the extreme points of S-light and P-light in the spectrum.

10.3 Reflectivity / transmittance

Reflectivity and transmittance are also points that should be paid attention to when selecting or using

polarizing spectroscope. Transmittance is generally also reflected in the reflection spectrum (but it does not mean that the transmission spectrum is unnecessary). In the reflection spectrum of polarizing film, the transmittance of S-light and P-light reflects the light utilization efficiency of the film, which is an important index to measure the quality of components. The transmittance of antireflection film should also be paid attention to in flat plate and cube polarization spectroscope. High transmittance can reduce the ghost phenomenon caused by reflected light and improve the performance of the element.

10.4 extinction ratio

The extinction ratio can also be obtained from the spectrum. For the definition of extinction ratio, see the topic of extinction ratio of crystal. High extinction ratio means that the spectral performance of the element is better. For example, for the polarizing beam splitter placed in the optical path of high-power laser, please try to select the polarizing beam splitter with high extinction ratio to reduce the possibility of unnecessary polarized light damaging the system.

Reference

[1]Polarization. https://en.wikipedia.org/wiki/Polarization, 2021

[2]Introduction to Polarization. https://www.edmundoptics.com/knowledge-center/application-notes/optics/introduction-to-polarization/, 2021

[3]Amplitude. https://en.wikipedia.org/wiki/Amplitude, 2021

[4]https://en.wikipedia.org/wiki/Phase_(waves), 2021

[5]https://en.wikipedia.org/wiki/Brewster%27s_angle, 2021

[6]Measuring S and P Polarization Spectra With A UV/Vis/NIR Spectrophotometer. https://molecularspectroscopy.blog/2020/02/18/measuring-s-and-p-polarization-spectra-with-a-uv-vis-nir-spectrophotometer/, 2020

[7]Rüdiger Paschotta. Thin-film Polarizers. https://www.rp-photonics.com/thin_film_polarizers.html, 2021

[8]https://www.edmundoptics.com/knowledge-center/application-notes/optics/what-are-beamsplitters, 2021

[8]Rüdiger Paschotta. Thin-film Polarizers. https://www.rp-photonics.com/thin_film_polarizers.html, 2021

[9] J. Larry Pezzaniti, Russell A. Chipman. Angular dependence of polarizing beam-splitter cubes. Applied Optics, 1994, 33: 1916-1929