Spectral index of optical coating—Reflectivity R

1、What is reflection / transmission spectrum?

Spectrum is the result of the interaction between light and matter. When light irradiates an interface, reflection, transmission or absorption will occur, and light of different wavelengths will produce different degrees of reflection or transmission and absorption loss. Therefore, different wavelengths of light will receive different light intensity signals at the receiving end through the action of the same interface. The information of light received at these different wavelengths is drawn into spectral lines, which is commonly referred to as spectra. Studying the variation curve of reflected light with wavelength is called reflection spectrum; The study of the variation curve of transmitted light with wavelength is called transmission spectrum. (reflection spectrum is generally used as characterization in crylink specification table, so the following examples are generally reflection spectrum.)

2. Why do I need reflection / transmission spectra?

First of all, the spectrogram is more intuitive than the parameter table and can get a lot of information from the graph.

（1）We can see the peak reflectivity / transmittance and peak wavelength of a film, which plays a key role in our selection of narrow-band laser window;

（2）For broadband applications, we can see the wavelength range of the film and whether it is stable and flat;

（3）Through the drawing of multi spectrum in the same coordinate system, we can directly see the advantages and disadvantages of the film from the figure.

In addition, there are some special spectral legends, such as polarized light reflection spectrum or certain processing of the information obtained through the reflection spectrum and transmission spectrum, which can also obtain the group dispersion (GD), group dispersion delay (GDD) and absorption loss under the film. We will explain it in detail in a later topic.

3、What do you think of the reflection / transmission spectrum?

The reflectance / transmittance spectrum represents the variation of reflectance / transmittance with wavelength. Therefore, in general, the reflection / transmission spectrum takes "wavelength" as the abscissa and "reflectivity / transmittance" as the ordinate. It should be noted that in different coordinate systems, it is meaningless to directly compare the shapes of spectral lines.

Spectral curve is the most intuitive expression of spectral information we can see. Here are three examples of how to read information directly from a spectrogram.

3.1 Simple broadband flat spectral curve

This kind of spectral curve is very simple and clear, but it is the most typical. We can see the line shape of the spectral line is inverted U-shaped, and the top is extremely flat. As shown in the red lettering in Figure 2, we can see that the coordinates of the vertices of the curve are (536, 99.997). It shows that the peak value of the curve, that is, the maximum reflectivity is about 99.997%, and the peak wavelength is around 536 nm. But for a broadband spectrum, we should pay more attention to the reflectivity in a certain wavelength range than the single point peak. Assuming that the wavelength range of 500-560nm is selected, as shown in the blue mark, we can clearly see that all the spectral curves of this section are above 99.99%. It can be seen from the data that the film is very suitable for applications with high reflection of green light in the range of 500-560nm and requiring stability.

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3.2 Multiple spectral curves with small fluctuations

Some spectral curves are not as direct as Fig. 2, as shown in Fig. 3. Figure 3 contains two curves. From the center of Figure 3, we can see that the gray line is 0° incidence and the blue line is 5° incidence (AOI = angle of incidence). Through the image, it can be found that the two curves almost overlap, so it can be inferred that the spectrum is approximately irrelevant to the incident angle under the change of small angle incident angle. Therefore, this kind of film system can be suitable for optical applications with small angle oblique incidence.

Then from a single curve, such as the gray line, it is not so flat compared with the curve in Figure 2. However, we can still see from the figure that the reflectivity is less than or equal to 1.3% in the range of 495-570nm; Reflectivity in the range of 500-570nm is less than or equal to 0.7%; The reflectivity is lower than 0.4% in the range of 525-565nm. The range from which to read the data needs to be based on the actual application. If the customer needs to apply it to the coating with a transmittance greater than 99% at 532nm, the product corresponding to the spectrum can well meet the demand. Therefore, spectrogram can assist in personalized selection.

3.3 Spectral curve with large fluctuation and obvious peak value

Some spectral curves are not suitable for broadband application scenarios. They generally have narrow stability range, large fluctuation and obvious peak, as shown in Figure 4. The spectral curve has two obvious characteristic points, which are located near 808nm and 1064nm respectively. The reflectivity of these two points is close to 0, that is, they have very high transmittance. Therefore, the film represented by this spectrum can be well applied to narrow-band high transmittance applications at 808nm and 1064nm, such as spectroscope.

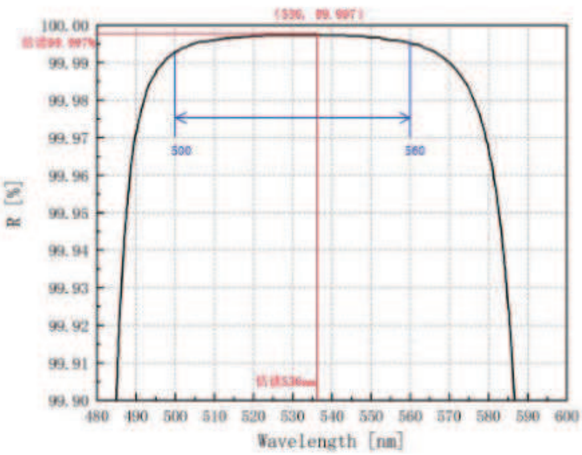

Fig. 2. simple broadband flat spectral curve

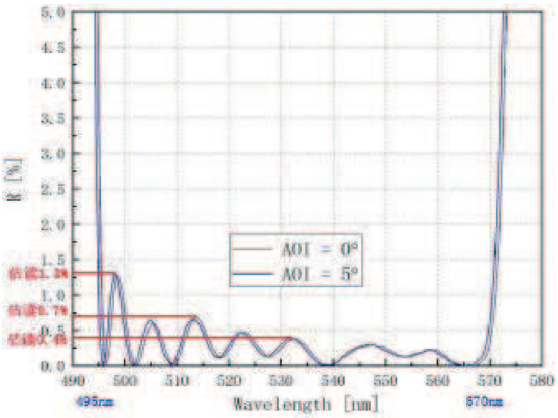

Fig. 3. multiple spectral curves with small fluctuations

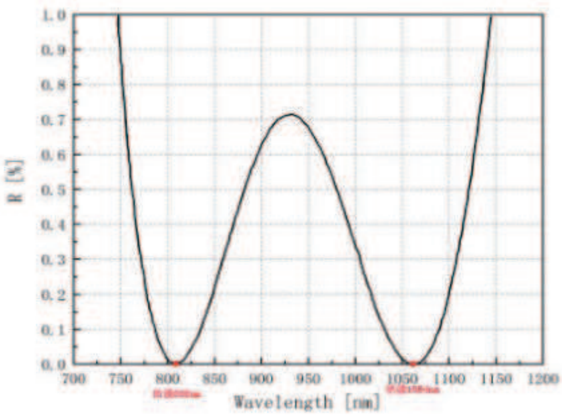

Fig. 4. spectral curve with obvious peak value in large fluctuation

4. What is the difference between the spectra of anti-reflective film and high-reflective film?

The light irradiates an interface to produce reflection, transmission and absorption. According to the law of energy conservation, the incident light = reflected light + transmitted light + absorption loss. Reflectivity R and transmittance T are the ratio of reflected light and transmitted light to incident light respectively, and absorptivity A is the ratio of absorption loss to incident light, so r = 1-t-a can be obtained. If the absorption loss of the anti-reflection film is known to be 0 or close to 0, the transmission spectrum of the anti-reflection film can also be expressed by the reflection spectrum (it should be noted that the transmission spectrum cannot be completely replaced by the reflection spectrum. If relevant experiments are carried out, the influence of absorption still needs to be considered, and the absorption loss will be described in detail in a special topic later). In the specification table of crylink, the anti-reflective film (AR film) and high-reflective film (HR film) basically use the reflection spectrum as the presentation index. The reflection spectrum of anti-reflection film generally presents the shape of positive u, and the reflection spectrum of anti-reflection film generally presents the shape of inverted U, as shown in Figure 1 above. The larger the reflection spectrum curve value of the anti-reflection film, the greater the reflectivity and the better the quality; The smaller the reflection spectrum curve value of the anti-reflection film, the greater the transmittance (assuming minimal absorption) and the better the quality. The light irradiates an interface to produce reflection, transmission and absorption. According to the law of energy conservation, the incident light = reflected light + transmitted light + absorption loss. Reflectivity R and transmittance T are the ratio of reflected light and transmitted light to incident light respectively, and absorptivity A is the ratio of absorption loss to incident light, so r = 1-t-a can be obtained. If the absorption loss of the anti-reflection film is known to be 0 or close to 0, the transmission spectrum of the anti-reflection film can also be expressed by the reflection spectrum (it should be noted that the transmission spectrum cannot be completely replaced by the reflection spectrum. If relevant experiments are carried out, the influence of absorption still needs to be considered, and the absorption loss will be described in detail in a special topic later). In the specification table of crylink, the anti-reflective film (AR film) and high-reflective film (HR film) basically use the reflection spectrum as the presentation index. The reflection spectrum of anti-reflection film generally presents the shape of positive U, and the reflection spectrum of high-reflection film generally presents the shape of inverted U, as shown in Figure 1 above. The larger the reflection spectrum curve value of the high-reflection film, the greater the reflectivity and the better the quality; The smaller the reflection spectrum curve value of the anti-reflection film, the greater the transmittance (assuming minimal absorption) and the better the quality.

5. What do the relevant key terms mean?

5.1 Reflection

Reflection is a parameter used to describe how many waves are reflected by impedance discontinuities in the transmission medium. The fraction of reflected power from the interface and incident power is called reflectivity (or power reflection coefficient-R).

Reflection depends on the wavelength of light, the direction of incident and reflected light, the polarization of light, the type of material (metal, plastic, etc.), the chemical composition and structure of the material, and the state of the material and its surface (temperature, surface roughness, oxidation and pollution degree).

5.1 Transmittance

The fraction of the transmitted power and the incident power refracted into the second medium is called the transmittance (or power transmission coefficient-T).

The dependence factor of transmittance is similar to that of reflectivity, transmittance depends on the wavelength of light, the direction of incident and reflected light, the polarization of light, the type of material (metal, plastic, etc.), the chemical composition and structure of the material, and the state of the material and its surface (temperature, surface roughness, oxidation and pollution degree).

5.3 Peak

The highest point / lowest point on the variation waveform (for the reflection spectrum, the anti-reflection film looks at the highest point and the high-reflection film looks at the lowest point).

5.4 Peak wavelength

In the reflection spectrum, the peak wavelength is a single wavelength that reaches the maximum reflectivity. Typically, the peak wavelength is treated as a specific design wavelength (DWL).

5.4 Bandwidth

Bandwidth is a wavelength range used to indicate that the incident energy in the spectrum is transmitted or reflected at a specific part of the optical element interface. Bandwidth is also called half height and full width (generally used in filter elements).

5.6 FWHM

Full width at half maximum describes the spectral bandwidth of optical element transmission. The upper and lower limits of the bandwidth are defined at the wavelength when 50% of the reflectivity / transmittance is reached. The FWHM of 10nm or less is considered as narrow band, which is usually used for laser purification and chemical detection; The full width at half height of 25-50nm is often used in machine vision applications; FWHM exceeding 50 nm is considered to be broadband and is usually used in fluorescence microscope applications.

5.7 Wavelength range

The wavelength range is used to describe the value between one wavelength and another. The selection of optical components usually depends on the application of the wavelength range required by the customer.

6. How to test the spectrum more accurately?

There are generally two methods to test the reflection spectrum:

6.1 Direct spectroscopy

Direct spectroscopy is the direct use of a commercial spectrometer (spectrophotometer) for testing. The test is relatively simple and does not need complex equipment to support. However, the absolute accuracy of the spectrometer is 0.2%, which makes it difficult for this method to achieve high resolution and cannot accurately test the film with reflectivity greater than 99.5%.

6.2 Cavity ring-down spectroscopy

For films larger than 99.5%, higher resolution and more accurate spectral test methods must be used, such as cavity ring down spectroscopy. This method is a high-precision absolute measurement method. The high reflectivity and transmittance values in the range of 99.5-99.9999% are determined by the measurement of cavity ring down time. The error range can be minimized by this method, for example, r = 99.995% ± 0.001%. For high reflectivity laser mirrors, appropriate measurement techniques must be used to reduce the error between the measured value and the actual value. This difference between the test value and the actual value may lead to performance degradation, security problems, and even catastrophic system damage. In the next section, the optical cavity ring down spectroscopy test will be described in more detail. If you are interested in this part, you can continue to pay attention to it.that of reflectivity, so we will not repeat it here.

7. What is the effect of reflectivity / transmittance on the use of optical elements?

7.1 High reflectivity improves the power and quality of laser cavity mirror

In the application of laser cavity mirror, the improvement of the reflectivity of the mirror can reduce unnecessary energy loss, so as to improve the output power of the laser. At the same time, the thermal distortion of the cavity mirror can be reduced and the quality of the laser beam can be improved.

7.2High transmittance improves the resolution of detection and detection instruments

Some instruments require very high accuracy, such as medical treatment, scientific research, and commercial fields have increasingly emphasized the key index of resolution. The transmittance of the light emitting surface of the optical element affects the primary light output rate and light output, which can affect the time resolution of the detector to improve the resolution of the instrument.

7.3 Low reflectivity and high transmittance improve the protection and utilization of the instrument

In the use of optical elements, excessive reflected laser will reduce the flux, which may cause laser-induced damage and harm caused by ghost (usually defocus). Coating anti-reflection film on the surface of optical elements to improve the transmittance can improve the flux of the system and reduce the damage of excessive reflected laser. Antireflective coating is particularly important for systems containing multiple transmission optical elements. Many low light systems use antireflective film optics to make effective use of light.

7.4 Low reflectivity and high transmittance enhance the imaging quality of imaging instruments

Taking the telescope system as an example, the reflected light will not only cause energy loss and darken the imaging, but also reflect many times, and part of it will penetrate the eyepiece into the eyes, resulting in reduced contrast image and obvious fog feeling. The application of high anti-reflection film in astronomy, military field, or some professional fields (such as photography) can greatly improve the imaging.

8. Why does the selected coating element not work?

There are generally two methods to test the reflection spectrum:

8.1 Is the wavelength range right

Optical elements are generally not suitable for full wavelength, especially after coating, they will show different characteristics. For example, 532nm high reflection optical elements do not necessarily exhibit high reflection characteristics at 1064nm.

8.2 Is the bandwidth appropriate

Fixed wavelength laser cavity mirror or detection equipment only need a fixed wavelength narrow-band high reflection / transmission, while imaging instruments generally require wide-band high transmission in the visible light range.

8.3 Is the test data of reflection spectrum correct

If the component does not play its due role, you can first check the official spectrum of the component to see whether it has better reflection / transmittance within the application range of your own equipment. If there is no problem, the spectral test of the component can be compared with the official data. If there is any discrepancy, the data can be combined to analyze whether there is damage to the component itself or the film. You can seek the help of official technicians. If there is still no problem, you can focus on the application and testing of your own equipment.

9. What are the typical reflection spectra of high-reflection films?

9.1 Reflection spectrum of metal film

The conductivity of metal materials leads to the complex refractive index, which makes the imaginary part very large in a wide wavelength range. This makes metal materials produce high reflectivity insensitive to wavelength, which can be applied to a wide spectral range. The metal film is usually made of silver, gold or aluminum, which is relatively soft. Therefore, it is easy to be damaged and must be cleaned with special care. Note that metal films used in high-power laser systems are also prone to damage.

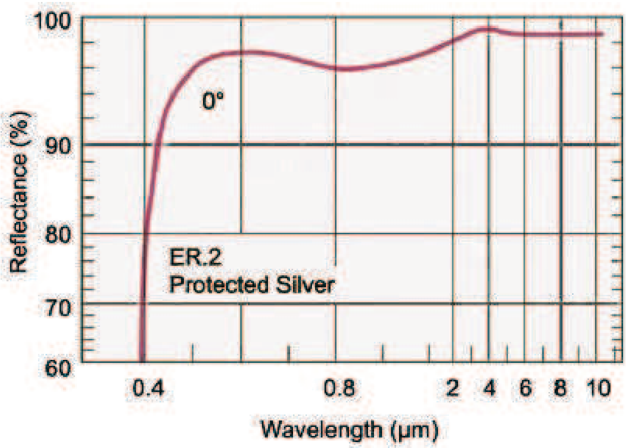

Fig. 5 reflection spectrum of silver mirror with broadband reflectivity

9.2 Reflection spectrum of dielectric film

Compared with metal film, dielectric film is more durable, easier to clean and has higher damage threshold. However, due to its dispersion effect and the refractive index of the electrolyte film is mainly the real part, its reflection spectrum is narrow, which is usually used in the visible (VIS) and near infrared (NIR) spectral regions. Compared with metal films, electrolyte films can provide higher reflectivity in some spectral ranges and provide customized spectral response.

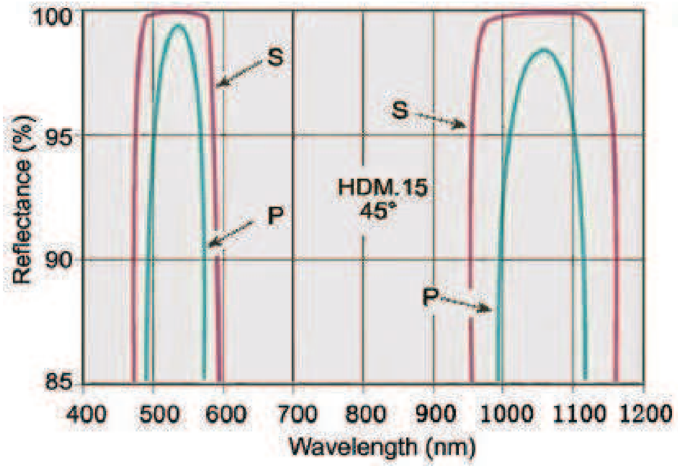

Fig. 6 (polarized) reflection spectra of two dielectric film laser linear mirrors with narrow reflection bands

10. What are the typical reflection spectra of antireflective films?

10.1 Reflection spectrum of V-type antireflective film

V-type antireflective film is designed to enhance the transmittance of narrow band at design wavelength (DWL). The minimum value in the reflection spectrum is the set wavelength. V-type antireflective film is an ideal film for single frequency narrow bandwidth laser or narrow bandwidth light source to obtain maximum transmittance. The reflectivity of V-type antireflective film is generally less than 0.25% when applied at a set wavelength. However, it should be noted that the local reflectivity outside the set wavelength will increase sharply.

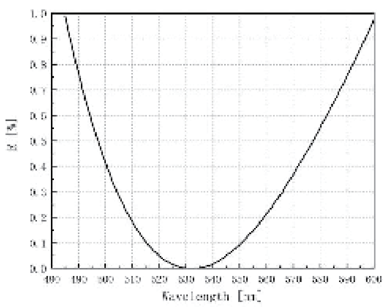

Fig. 7 reflection spectrum of V-type antireflective film with minimum reflectivity obtained at 532 nm

10.2 Reflection spectra of multilayer antireflective films

V-type coating usually contains only two layers. If you want to obtain a wide transmission range, you can choose multi-layer coating. Multilayer coatings can compensate for different incident angles, but they are more complex and costly.

Reference

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