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# Infrared optical coatings in SITP

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**Abstract :** Infrared optical coatings in SITP (Shanghai Institute of Technical Physics) mainly cover the spectrum range from 0.7  $\mu\text{m}$  to 15  $\mu\text{m}$ , and visible and near-UV range are also been included. The coatings are mainly used for metal-reflectance mirrors, Anti-reflection(AR) lens and windows, filters, and dichroic beam splitters. Coatings passed some dependability tests. These optical coated devices usually consist in a remote observing instrument. Most coating materials are commercial products. And one kind of special material PbTe is made by ourselves. Some main results of our research department are reported.

**Key words :** optical coating; infrared; remote observing instrument

## 1 Introduction

Shanghai Institute of Technical Physics (SITP) is a national research institute under the Chinese Academy of Sciences. The main research field of SITP is infrared optics-electronic science and engineering. SITP sometimes make some optical remote observing instruments for meteorological satellite.

Optical coatings are always the essential elements in modern optical instruments. It is very important to get high optical efficiency for an infrared remote observing instrument<sup>[1]</sup>. In order to get high spectrum resolution, some super-narrow passband filters must be used. We use metal-dielectric coatings to reflect broad spectrum from visible to far infrared; use dichroic beam splitter with metal-dielectric coatings to split visible and infrared into two different directions; use dichroic beamsplitter with dielectric coatings to split different infrared spectrum

ranges into different directions. In far infrared range, the absorption of coatings is very serious. And decreasing the absorption becomes a key work. In following section, the detailed description of these coatings will be presented.

## 2 Coatings for infrared remote observing instruments

### 2.1 Basic requirement for infrared coatings

For infrared remote observing instruments, optical coatings should have high optical efficiency, board spectrum range and good reliability.

Fig. 1 is a schematic diagram of an infrared remote observing instrument. After scan mirror and reflection mirrors (1, 2 in Fig. 1), the target radiation arrives dichroic beam splitters (4, 6, 24, 39 in Fig. 1), and then goes through lens, windows, filters (11, 19, 27, 30, 33, 36, 48 in Fig. 1), finally reaches detectors (13, 21, 29, 32, 35, 38, 45, 50 in Fig. 1). The target radiation has

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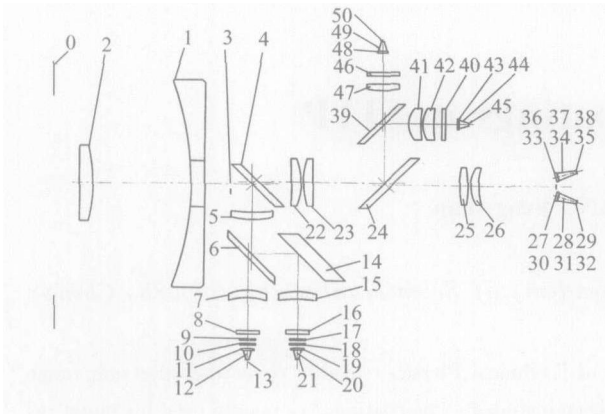


Fig. 1 Schematic diagram of a infrared remote observing instrument

been divided into 5 beams, and 26 spectrum channels. The spectrum ranges of 4 beams is listed in Tab. 1.

Tab. 1 Spectrum ranges of 4 beams of a infrared remote observing instrument

Beam No.	Spectrum range ( $\mu\text{m}$ )	Optical efficiency	Detector No.
1	6.5 ~ 15.0	0.17	13
2	3.5 ~ 4.8	0.21	21
3	0.6 ~ 1.0	0.28	29, 32, 35, 38
4	1.5 ~ 1.8	0.28	45
5	1.0 ~ 1.3	0.26	50

All the infrared optical coatings have to pass environmental test before their placement on the earth and use in space. Usual environmental test items are as follows:

(1) Adhesion. Cellophane tape is pressed firmly against the coatings and quickly removed at an angle normal to the surface.

(2) Humidity. Exposure to an atmosphere at 45% and 95% to 100% relative humidity for 24 h.

(3) Water solubility. Immersion in a distilled water for 8 h at 45%.

(4) Temperature Change. Kept at a temperature of 45°C for 30 min and then in -15°C for 30 min. After that the temperature go back to 45°C again. All above build up one circle. The rate of temperature change shall not exceed

5 per min. Coatings should experience three circles.

(5) Solubility and cleanability. After immersion in acetone, ethyl alcohol, aether respectively, wipe with cheesecloth or fine silk.

(6) Low temperature impact. For (some) coatings, low temperature (below 100 K) impact test is necessary. Put coated substrates into liquid nitrogen and keep it there 3 min, and then get them out. Let the coated substrates warm naturally to room temperature. Repeats twice (total 3 times).

Upon completion of all these tests above, the coated optical surface should show no evidence of coating removal or scratches.

## 2.2 Coatings for broad spectrum range reflection

For most infrared optical remote observing instruments, the full spectrum usually covers from 0.4  $\mu\text{m}$  to 12.5  $\mu\text{m}$ , sometimes to 15.0  $\mu\text{m}$ . Metal Ag reflection film and dielectric protection films are the best combination. Because they have high reflectance from visible light to far infrared, and the polarization is faintest.

In order to get good reflectance and environmental durability, silver should be vaped quickly, and the layer thickness should be within 100 ~ 150 nm. The dielectric protection film should be as thin as possible. Fig. 2 is a typical reflectance curve (measured at 45°) of a scan mirror. Protection film thickness is about 30 ~ 40 nm. Ion beam bombarded the dielectric protection film surface during deposition. Coatings passed all tests for environmental durability as in part 2.1.

## 2.3 Coatings for broad spectrum range anti-reflection

AR coating is the most universally used coating in optical system. Today it is still difficult to design and fabricate AR coatings for broad-spectrum range. When the wavelength ratio ( $\lambda_2/\lambda_1$ ,  $\lambda_2$  is the long end wavelength,  $\lambda_1$  is

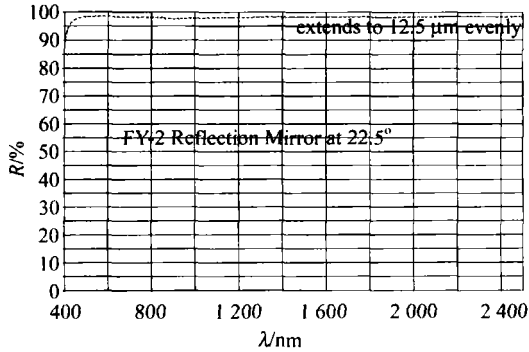


Fig. 2 A typical reflectance curve (measured at 22.5°) of Ag-dielectric coating for broad spectrum observing instrument

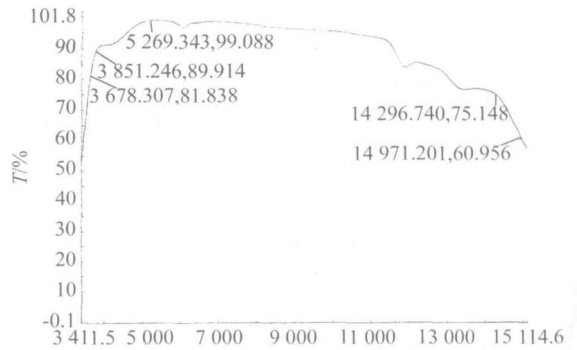


Fig. 3 Transmittance curve of Ge lens with AR coatings for the range of 3.6 ~ 15.0 μm

short end wavelength) reaches 4, AR coating usually exhibits an uneven transmittance. To get good transmittance for full range, it is necessary to use many no-quarter layers. The following is a design of AR coating on Ge substrate for the range from 3.6 to 15.0 μm.

(the same as the other side)// Ge substrate//  
1.790M 6.497H 5.236M 2.380H 4.095M 1.820L 5.205M 7.777L 1.111M

in the design M-ZnS, H-Ge, L-YF3, wavelength  $\lambda_0$  is 460 nm.

When the wavelength is large than 11.5 μm, the optical absorption of most infrared coatings become greater and greater. Low-index layer can't endure tests for environmental durability as in part 2.1, you have to use a thin ZnS layer as the most outside layer for protection. So, it is very difficult to get a high transmittance in the range of after 12 μm. Fig. 3 is a transmittance curve of a Ge lens.

### 2.4 Coatings for dichroic beamsplitter

Dichroic beamsplitter is commonly used in infrared observing instruments. If the spectrum is not too broad, all dielectric reflection coatings should be used, such as the dichroic beamsplitters in Fig. 1 (6,24,39). If the spectrum is too broad, you have to use a broad and steep induced-transmission filter to reach the aim. Of course, the filter is placed aslant.

Usually, the first dichroic beamsplitter covers the full spectrum of an optical system, just like that one in Fig. 1 (4).

For the metal-dielectric induced-transmission filters, if the transmission range have a broad and high transmittance, the metal layer should be thin; if it has steep edges between transmission range and reflection range, more than one metal layers should be used and each metal layer becomes thinner. Usually, we use 2 silver layers in such kind of dichroic beamsplitter, and the thickness of silver layer is no more than 20 nm, even less than 10 nm. It is not easy to deposit such thin silver layer fast and accurately<sup>[2]</sup>. The following is a design of a dichroic beamsplitter with visible-near IR (0.4 ~ 0.9 μm) transmission and IR (3.4 ~ 12.5 μm) reflection.

AR coating// Quartz Sub.// H A 2H A H  
In the design, H-ZnS,  $\lambda_0 = 360$  nm; A-Ag, about 17 nm thickness.

Fig. 4 is a transmittance curve of a fabricated dichroic beamsplitter, measured at 45°. The design is just like the one above, in the mode of metal-dielectric induced-transmission.

### 2.5 Narrow passband infrared filters

When the bandwidth (band width at half  $T_p$ ) less than 2% of the center wavelength in far infrared (more than 10 μm), the passband infrared filter will face some problems to solve:

- (1) absorption of layer and material;

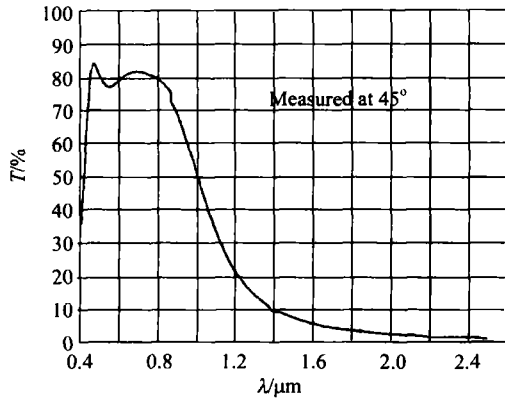


Fig. 4 Transmittance curve of a dichroic beamsplitter measured at  $45^\circ$

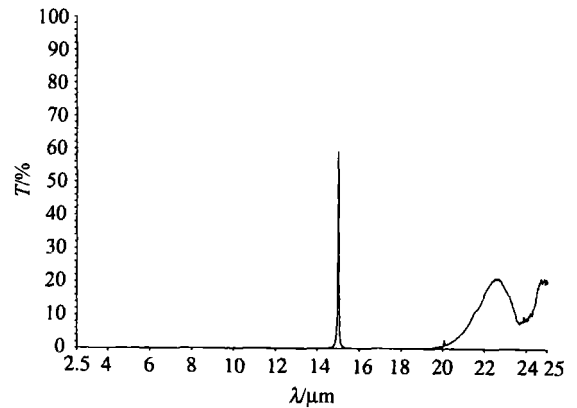


Fig. 5 Transmittance curve of a fabricated filter at room temperature

(2) temperature sensitivity during deposition;

(3) spectrum shift when used at a low temperature.

To solve the problem of absorption, (1) choose pure and low-defect crystals as the layer materials. We choose ZnS as the low-index layer, produce low-defect crystal PbTe as the high-index layer materials. (2) vapor ZnS quickly relatively, and vapor PbTe slowly relatively.

To overcome the difficulty of temperature sensitivity, keep the temperature of production (the filter) substrates the same as that of the monitoring substrate.

To weaken the problem of spectrum shift, we modulate the index-temperature coefficient of PbTe materials.

Fig. 5 is a transmittance curve of a fabricated filter, the bandwidth is about 1.5% at  $14.7 \mu\text{m}$ .

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### Brief professional biography of the author :

**LIU Ding quan**, male, was born in Aug, 1964 in Shanxi Province and graduated from Xi'an Jiaotong University in 1986. Then, he has been working in the field of optical coatings research, specially infrared optical coatings. Now, as the professor and director of the Department of Optical Coatings & Materials, Shanghai Institute of Technical Physics, his main research work focuses on infrared coatings and their application in space environment.

### 3 Conclusion

Dislike optical films in visible range, infrared coatings have different characteristics:

- (1) Most are soft coatings.
- (2) Environmental durability is weak.
- (4) Absorption is heavy.
- (5) Be more sensitive during deposition.
- (6) Hard to find low-index (less than 1.5)

materials in far-infrared (more than  $10 \mu\text{m}$ ). So, it is difficult to get high transmittance for a broad spectrum.

By effort on technology and material, infrared coatings can meet the requirements of infrared optical system.

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