Design and preparation of LWIR narrow-band filter with wide rejection band

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In this letter, using mult-half-wave structure and some chosen films optimized method, the long-wave infrared (LWIR) narrow-band pass filter is investigated, meanwhile the opposite of the substrate coated with long-wavelength pass film. The transmittance of design spectrum is more than 80% at wavelength region of 8.05–8.35 μm, and the average transmittance is less than 0.5% at wavelength region of less than 7.95 and 8.45–14 μm. The filter is prepared by thermal evaporation method, and plasma-assisted deposition technology. The experiment result shows that the average transmittance is about 75% in the transmission wavelength range, and the average transmittance of cut-off band is about 0.3%. The results show that multi-half-wave structure and some chosen films optimized method for the preparation LWIR narrow-band pass filter are feasible. The film system is simplified and is convenient to prepare the film.

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Long-wave infrared (LWIR) band-pass filters are widely used in space optical remote sensing system, infrared camera, and multi-spectral imager. Most infrared cameras are panchromatic, that is because they sense radiation over a wide band of the spectrum. It does not work so well for picking out camouflaged or concealed targets in high thermal clutter backgrounds. There has been a lot of recent interest in the potential for exploiting infrared spectral information for enhancing target detection performance and reducing false alarm rates. Early analysis of the spectral signatures in vegetated backgrounds shows that it is possible to obtain good target to background spectral contrast even when the panchromatic (broadband) contrast is low. The key to accurate target detection will be the choice of narrow spectral bands. The requirements of space applications may be realized by using LWIR band-pass filter. The membrane thickness and bandwidth cut-off width resulting in the complex process of membrane system and deposited, so we focus on studying infrared optical thin films.

Infrared coating material is quite limited, and most are quite soft, poor durability. Currently we only chose ZnS, ZnSe, PbTe, Ge, etc., in the range of 4–16 μm, absorption coefficient is small, easy deposition. Considered from the perspective of reducing the film layers, the ratio of the refractive index is higher the cut-off bandwidth is wider. The refractive index of PbTe as high as 5.5, is the highest refractive index value in the actual use of the coating material. Its short-wave absorption limit is at 3.4 μm, so we need not design additional film system to cut-off the spectrum before 3.4 μm. PbTe film helps to reduce the film layers, and improve the environmental stability and reliability of the filter. The refractive index of ZnS is 2.2, which is quite good adhesion to other materials such as Ge and PbTe.

There are usually two ways to constitute a band-pass filter. One is both sides of the substrate coated with long-wave pass and short-wave pass films, and the other is both sides of the substrate coated with multiple cavities of the band-pass membrane department and the cut-off film system[1,2]. The first method has a wide band and cut-off spectral range, but the long-wave pass and short-wave pass films are required to have an accurate position, and in order to eliminate the passband ripple, it is difficult to monitor non-normalized coating system; the second method only requires accurately positioning the film system, while the cut-off of film spectral positioning could be less strict, and the drawback is the limited passband width. The second method's advantage is the passband shape easy to ensure, and the number of film is less and has better passband edge steepness than the first method[3]. If the two design methods all can be achieved the design goals, the second method is the better choice.

The high refractive index material is PbTe, the refractive index about 5.5; low refractive index material is ZnS, the refractive index about 2.2. According to the following formula, the center wavelength λ_0 is

$$\lambda_0 = 2\lambda_1\lambda_2/(\lambda_1+\lambda_2). \qquad (1)$$

According to the target requirement, the width of two half power points ($2\Delta\lambda$) is about 0.4 μm. The cavity film structure is the reflective film | the interval layer| the reflective film. Such as HLH. . . H | LL | H. . . HLH, or HLH. . . HL |HH | LH. . . HLH, where H, L are on behalf of the high and low refractive index film layers, the optical thickness is 1/4 of the reference wavelength. Passband bandwidth can be estimated by[4,5]

$$2\Delta\lambda = \frac{4\lambda_0 n_{\rm L}^{2x} n_{\rm g}}{m\pi n_{\rm H}^{2x+1}} \cdot \frac{n_{\rm H}-n_{\rm L}}{n_{\rm H}-n_{\rm L}+n_{\rm L}/m}, \qquad (2)$$

$$2\Delta\lambda = \frac{4\lambda_0 n_{\mathrm{L}}^{2x-1} n_{\mathrm{g}}}{m\pi n_{\mathrm{H}}^{2x}} \cdot \frac{n_{\mathrm{H}} - n_{\mathrm{L}}}{n_{\mathrm{H}} - n_{\mathrm{L}} + n_{\mathrm{L}}/m}, \quad (3)$$

where n_{L}, n_{H} are the high refractive index and low refractive index; n_{g} is the substrate refractive index. The substrate is Ge; x is the numbers of the reflective membrane layer; m is the cavity interference orders.

The basic structure of the film system is HLH|LL|HLH. Two or more of the basic structure can make the spectral curve shape more square. The system including three resonator band-pass membrane is Ge |LHL(LHLHLHL)^{3}LH. The spectral curve (the back reflection of substrate is not considered and material absorption can be ignored) is shown in the Fig. 1.

Regular band-pass spectral curve of the coating system has deep ripples in the passband. With the increasing number of the reflective film, the ripple will become more intensive. Compression of the passband ripple is the most difficult in the band-pass coating system design.

The usually method for compressing passband ripple is to increase the matching layer in the substrate side and air side[6]. The selected substrate material Ge is a high refractive index, and the refractive index vary greatly. In order to achieve good optical match, we consider adjusting the film thickness. By the coating design software optimization algorithm[7], the optimization results are shown in Fig. 2. The transmittance of design spectra is more than 80% at wavelength region of 8.05–8.35 μm, and the average transmittance is less than 0.5% at wavelength region of less than 7.95 and 8.45–14 μm.

According to target requirements, the filters need coated passband on one side; the other side is the antireflection film system which is relatively simple. So the following introduces interference as of membrane department of coated process. The device is a self developed vacuum coating machine; the device is equipped with two pairs of thermal evaporation electrodes, and a Hall

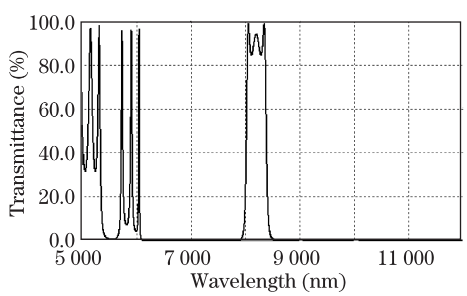

Fig. 1. Design curve of three cavities band-pass membrane.

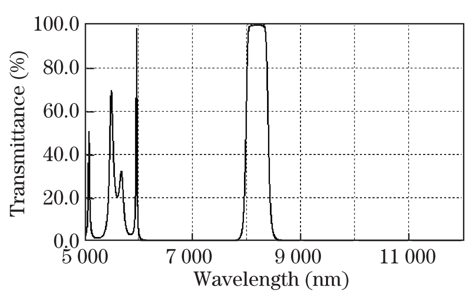

Fig. 2. Optimized design spectrum of three cavity structure band-pass membranes.

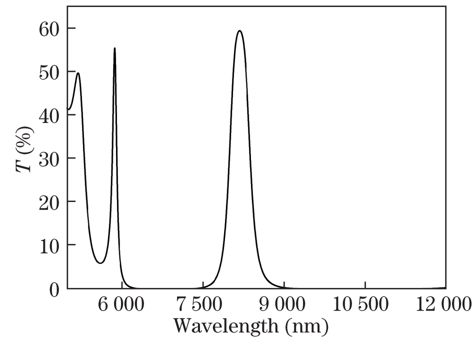

Fig. 3. Measured spectrum of band-pass membrane.

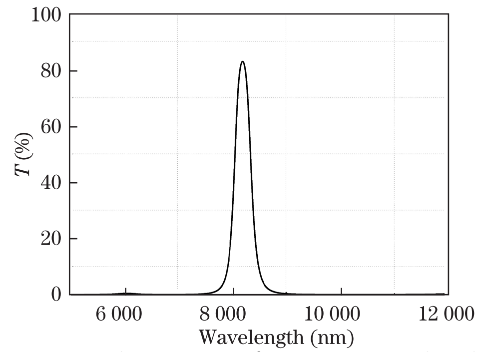

Fig. 4. Measured spectrum of LWIR narrow-band filter.

ion source. When the vacuum is 3×10^{-3} Pa, the baking temperature is set at 150 °C, the charge of Ar gas flowed to the vacuum chamber is 15 sccm, open ion source and bombard the substrate for 15 min. In order to improve the adhesion and environmental stability of the long-wave infrared band-pass filter, people generally use ion beam assisted deposition (IBAD) or plasma-assisted deposition (PAD). The film is attached to the substrate solidly, and has compact structure.

The reflective optical monitoring method is used for film thickness monitoring. To improve the monitoring accuracy, the film order and monitoring wavelength must be alternate reasonably. Adjust the film uniformity, and select appropriate surveillance methods, filter spectral curves are shown in Fig. 3.

On the back of substrate is the cut-off membrane system, the closing film system does not require very precise positioning, but only have a high transmittance in the channel band range. So we use the (0.5HL0.5H)^n structure. The final spectrum is shown in Fig. 4. The experiment result shows that the average transmittance is about 75% in the transmission wavelength range, and the average transmittance of cut-off band is about 0.3%.

PbTe and ZnS are used as the high and low refractive index coating materials, the 8.05–8.35-μm band-pass filter designed with three resonator band-pass membrane systems and the cutoff film system. Reflective layer thickness in the cavity is adjusted to compress the passband ripple. The filter spectral meets the requirements of the inside and outside the rectangular, while wavelength of less than 14 μm besides passband spectrum is inhibition.

The bandwidth of the measured spectrum is narrower than the design spectrum. Due to the system errors and the narrow bandwidth, it is easy to form peak and cause the transmittance lower. High precision coating systems would be beneficial for coating narrow band-pass filter.

In conclusion, the LWIR passband filter is designed by multi-half-wave membrane system. Adjust the reflective layers of film system; make the refractive index of film, substrate and the incident medium match, which can effectively reduce the passband ripple. Multi-half-wave structure and some chosen films optimized method for the preparation LWIR narrow band-pass filter are feasible. The film system is simplified and it is convenient to prepare the film. Long-wave pass band can realize wide cutoff of the LWIR band-pass filter. The infrared optical monitoring system can be effective to achieve accurately monitoring LWIR filter thickness. The use of low energy, high-density PAD is more conducive to LWIR filter layer, which can improve the microstructure and relief residual stress of the film system.

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