Antireflective films optimization of ZnS ceramics infrared windows

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The transmittance characteristics of ZnS ceramics with infrared (IR) (3 − 5 and 8 − 12 μm) antireflective coatings are studied. The film designs are optimized with programmed software. A double-side and double-layer scheme is employed. Two different double-layers with proper parameters are coated onto each side of a ZnS substrate. The measurement methods for transmittance are investigated. The measured transmittance for IR (3 − 5 and 8 − 12 μm) surpasses 70%.

OCIS codes: 260.3060, 310.1210, 310.1620.

Zinc sulfide, one of the frequently used optical materials in photoelectric systems, possesses good mechanical and optical properties. However, as an infrared (IR) window material, its property of IR transmitting cannot satisfy practical requirements. The reflective losses of lights of wavelength of 3 − 5 and 8 − 12 μm in the first surface exceed 15%. Therefore, it is necessary to study anti-reflective films in the two bands in order to reduce the surface losses. With the optimized design of double-layer film, the transmitting properties of ZnS ceramic are improved, and the experimental results satisfy the application requirements as an IR window material.

The reflectance of double-layer film is a function of refractive index and thickness of the double film materials[1−3]. To make antireflective film, a design of double-layer film is used. The double-layer films refractive indexes are n_1 and n_2 ($n_1 = 2.55$, $n_2 = 1.47$), respectively. According to the conditions, the thicknesses of double layers are also calculated. The relations of reflectivity R and thicknesses of film layer d_1 and d_2, refractive indexes n_1, n_2, n_g (substrate $n_g = 2.25$) and wavelength λ are

$$R = \frac{\left[(1-n_g)A + \left(\frac{n_1 n_g}{n_2} - \frac{n_2}{n_1}\right)B\right]^2 + \left[\left(\frac{n_g}{n_2} - n_2\right)C + \left(\frac{n_g}{n_1} - n_1\right)D\right]^2}{\left[(1+n_g)A - \left(\frac{n_1 n_g}{n_2} + \frac{n_2}{n_1}\right)B\right]^2 + \left[\left(\frac{n_g}{n_2} + n_2\right)C + \left(\frac{n_g}{n_1} + n_1\right)D\right]^2}$$

where

$$A = \cos(q_1)\cos(q_2);\ B = \sin(q_1)\sin(q_2);$$

$$C = \cos(q_1)\sin(q_2);\ D = \sin(q_1)\cos(q_2);$$

$$q_1 = 2\pi d_1/\lambda;\ q_2 = 2\pi d_2/\lambda.$$

The Mathematical software is used to program. The thicknesses d_1 and d_2 of the selected anti-reflection film layers on ZnS ceramic substrate are calculated[4,5]. The method first emphasizes one more important waveband, and gets an approximate value by using 3-dimensional (3D) simulation and successive optimization. Finally the effects of the two wavebands are considered.

The numerical simulations for different film systems were conducted using the film design program. The 3D figures (Figs. 1 and 2) were studied to analyze the anti-reflection emphasizing $3-5$ μm band and taking account of 8 − 12 μm band. It was found that the better antireflection corresponds to $d_1 = 1.2$ μm, $d_2 \approx 1.5$ μm, or $d_2 \cong 2.5$ μm, the effect of anti-reflection is better.

Further optimization of the simulation curves shows that the better reflectivity curves are obtained when d_1 and d_2 are 1.25 and 1.47 μm, respectively, as shown in Fig. 3. Double-bottom wide-band anti-reflection in the double wavebands is achieved.

The experimental IR coated and uncoated transmitting curves (Figs. 4 and 5) were obtained with FTS135 Fourier transform IR spectrometer. The average transmittances of film coated ZnS ceramic sample increase from 62% to 70% ($3-5$ μm band) and 69% to 82% ($8-12$ μm band), and their IR peak transmittances are up to 77% and 90%, respectively. The transmittance in 3 − 5 and 8 − 12 μm band increased by 13% and 19%, respectively.

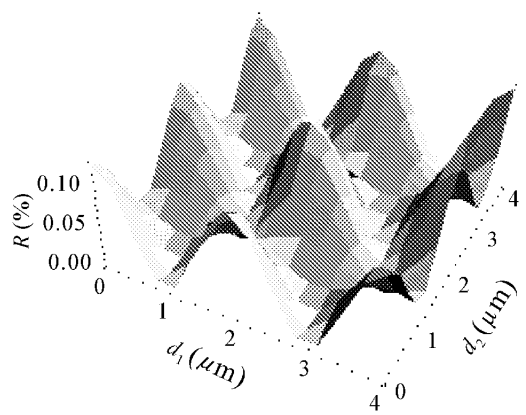

Fig. 1. 3D simulation for λ=4 μm, d_1 (0−4 μm), d_2 (0−4 μm).

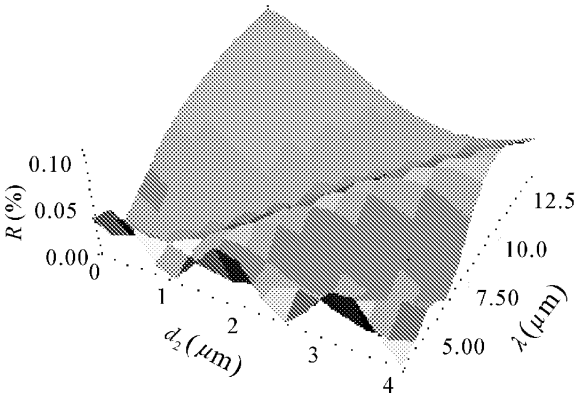

Fig. 2. 3D simulation for $d_1 = 1.2$ μm, λ (3 – 14 μm), d_2 (0 – 4 μm).

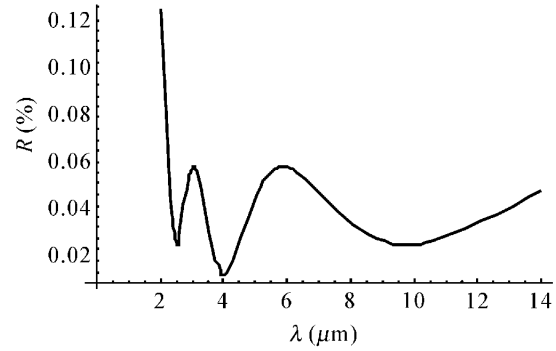

Fig. 3. The simulation curve of reflectance versus wavelength.

It can be seen that the measured value of transmittance is lower than the theoretical value. It might be attributed to intrinsic absorption, extrinsic absorption and scattering losses in IR transmission band. The intrinsic absorption includes electron absorption and phonon absorption. The extrinsic absorption includes absorption by free electron (or hole) generated by donor (acceptor) impurity and absorption by some transitions between impurity bound states and phonon absorption by lattice impurity, etc. To minimize the absorption of free carrier, the impurity level must be controlled.

As for the material with impurity level in transmission band, the impurity can even change the transmitting cut-off wavelength of the materials. The extrinsic absorption can also be caused by coating material and deposit impurity or defects of material interface. The scattering losses may be caused by the ceramic surface, inter-lattice defect, crystal grain boundaries and tiny air holes in polycrystalline material.

Experimental results show that the presented method effectively solved the hard problems of complicated

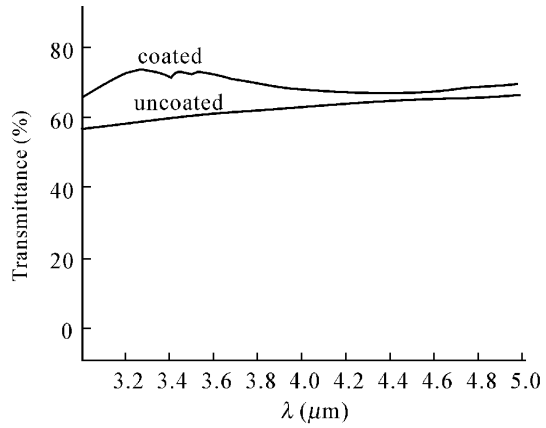

Fig. 4. Transmittance of ZnS ceramics as a function of wavelengths (3 – 5 μm) before and after coating.

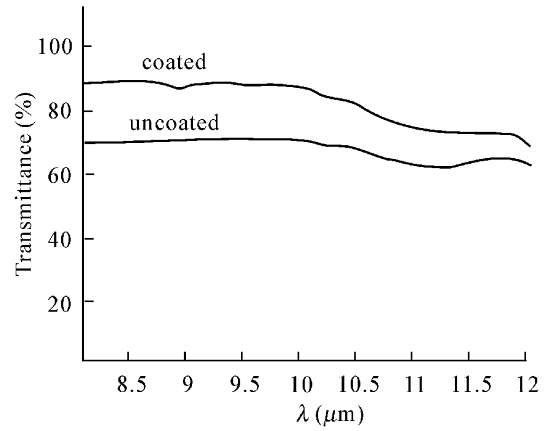

Fig. 5. Transmittance of ZnS ceramics as a function of wavelengths (8 – 12 μm) before and after coating.

calculations and optimizing the design of two wavebands double-layer film.

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