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Optical Properties of Ta_2O_5/SiO_2 Antireflection Coating System

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Abstract. The Ta_2O_5/SiO_2 multi-layer Antireflection coating is prepared on K9 glass by RF magnetron sputtering technology in the experiment. The growth parameters are changed to get multi-layer Antireflection film with good optical properties. In the technical research, the influence of various growth parameters, including working pressure, oxygen content, substrate temperature, etc., on the optical properties and structures of the coatings are studied. Optical properties and morphological features such as surface, structure are investigated by UV-VIS spectrophotometer and AFM, respectively. The detecting results further verify the important influences of proper growth parameters on optical properties of antireflection coating.

Introduction

Antireflection coating is most widely used optical coating, which can be used on camera lens, telescope, microscope and rangefinder etc.. Almost all the optical instruments use Antireflection coating for its improvement on the transmittance or image quality. The preparation technology of coating greatly influences its ultimate performance, especially for optical coating that needs precision processes [1]. How to well control process parameters is an important problem for the preparation of optical coating.

The research is based on the pre-design of the coating system, in which it is assumed that material refractive index is constant, and the coating thickness is determined according to this assumption. In fact, in order to obtain design results of multilayer coating system in the experiment, the premise is that required refractive index of each used coating material can be precisely determined, which puts forward an important issue for coating process: when the coating materials are chosen, the process parameters must maintain steady to ensure stable and repeated refractive index of coating material[2, 3, 4, 5].

Equipment device and preparation technologies

The preparations of SiO_2 and Ta_2O_5 coatings are carried on FJL560CIl ultra-high vacuum magnetron sputtering combined with ion beam coating machine, as shown in Fig.1.

After K9 glass substrate is cleaned, SiO_2 and Ta_2O_5 coatings are prepared using O_2(purity 99.99%) as reactive gas and Ar(purity 99.99%) as working gas by RF magnetron sputtering, and the deposition rate of single-layer film is determined through the research of process parameters. It's not so easy to get Ta_2O_5 coating of high density, high quality and excellent optical properties on technology. The research for preparation and performance of Ta_2O_5 coating have made a lot in international, while domestic studies on this issue are rarely seen.

Through the research of various deposition parameters, such as working pressure, oxygen content and substrate temperature, and so on, the properties closely related to Antireflection coating optical performance, including refractive index, structure and surface morphology are obtained. Based on the technology research, Ta_2O_5/SiO_2 multi-layer Antireflection coating with excellent optical properties on K9 optical glass is gained finally.

Fig. 1. FJL560CI1 ultra high vacuum magnetron sputtering combined with ion beam coating machine

Experiment results and analysis

Influence of working pressure on coating performance. During the experiment processing, working pressure is changed to investigate its influence on film structure and optical constant. The preparation parameters of SiO_2 coating are as followed: target-substrate distance of 65 mm, sputtering power of 100W and oxygen content of 20%, that of Ta_2O_5 coating are: target-substrate distance of 85 mm, sputtering power of 100W and oxygen content of 100%. The relation curve of working pressure and index of refraction for SiO_2 coating is shown in Fig.2, and that of Ta_2O_5 coating is shown in Fig.3.

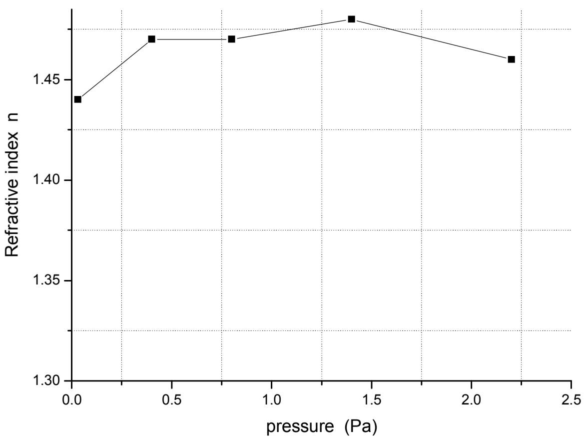


Fig. 2. Refractive index of SiO_2 deposited deposited at different pressure

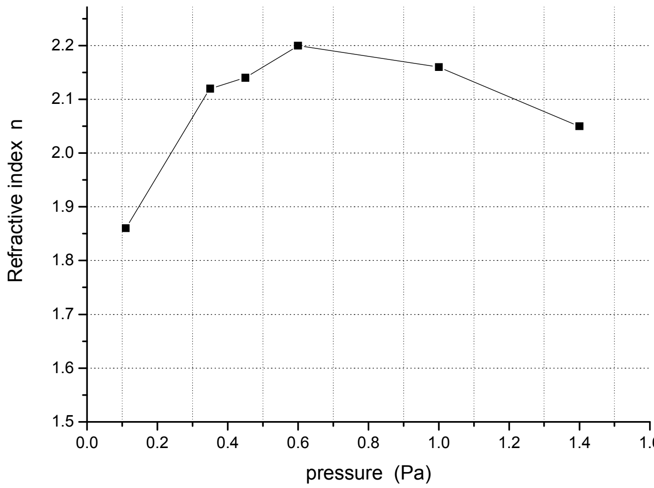


Fig. 3. Refractive index of Ta_2O_5 at different pressure

It can be seen that refractive index of SiO_2 film firstly increases and then decreases when the working pressure increases from 0.03Pa to 2.2Pa. The difference between maximum value and minimum one of refractive index is only 0.04. When the coating is deposited at 0.03Pa, its refractive index is low because of the low deposition rate which leads to loose structure. Refractive index decreases while working pressure rises to 1.4Pa, which can be explained that excess gas molecules in vacuum chamber lead to the scattering of target particles and low deposition rate, so the coating is not dense enough and the refractive index decreases as a result.

The changing trend of Ta_2O_5 film's refractive index with the change of working pressure is roughly the same with SiO_2. As shown in Fig.3, when working pressure is lower, the reaction of tantalum atoms is not sufficient, the deposition rate is low and the produced oxide is not dense enough, so the refractive index is low. When the working pressure rises to 0.4Pa, the deposition rate is appropriate for getting high quality coating, and the transmittance is the highest.

Table 1 Refractive index of SiO_2 coating at different deposition conditions

Sample	Pressure[Pa]	Target-substrate distance[mm]	O_2 content[%]	Power[W]	Refractive index
1	0.4	65	0	100	2.14
2	0.4	65	5	100	1.680
3	0.4	65	15.0	100	1.460
4	0.4	65	24.0	100	1.440
5	0.4	65	32.1	100	1.450

Influence of O_2 content on coating performance. Different refractive index of SiO_2 coating is prepared at different O_2 content, as shown in table 1. When oxygen content reaches 13%, the refractive index of SiO_2 coating is approach to 1.46. While the oxygen content continues to increase, refractive index becomes stable, as shown in Fig.4.

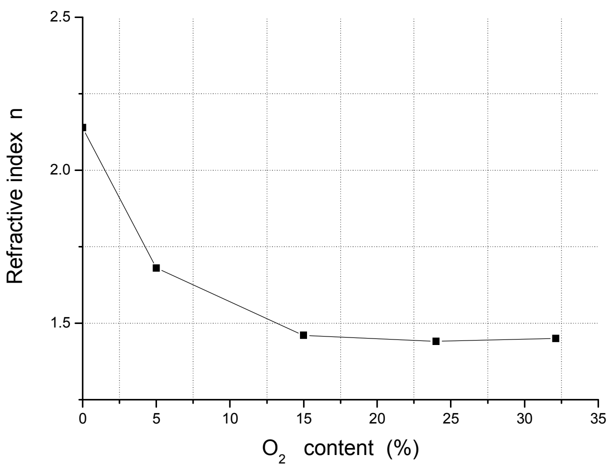


Fig. 4. Refractive index of SiO_2 coating versus O_2 content

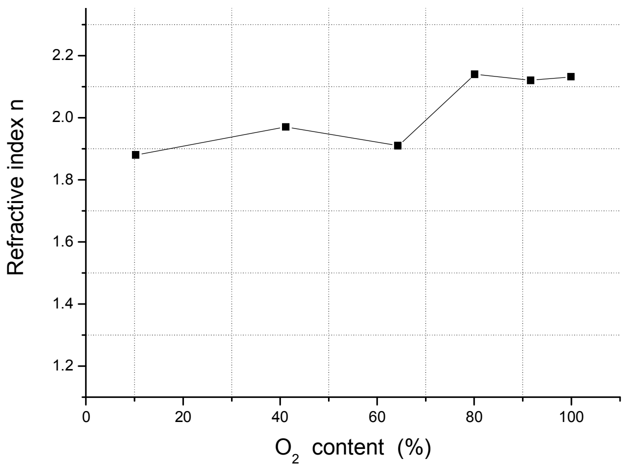


Fig. 5. Refractive index of Ta_2O_5 coating versus O_2 content

Ta_2O_5 film tends to produce oxygen vacancies, so it's necessary to improve the oxygen content in reactive gases. Deposition process parameters of Ta_2O_5 film is shown in table 2.

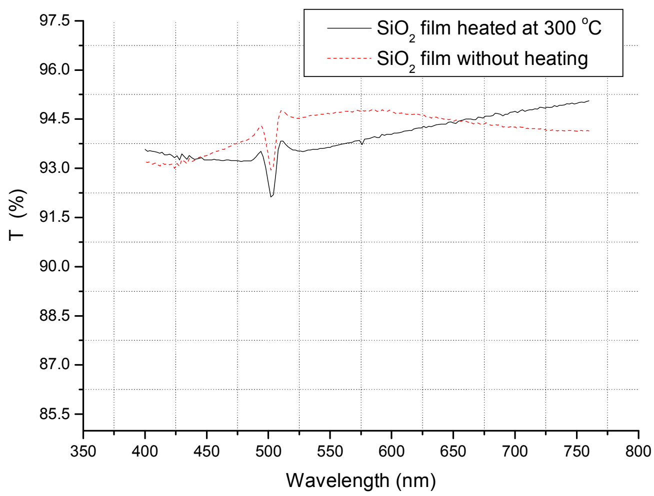
The change of refractive index with oxygen content for Ta_2O_5 film is shown in Fig.5. When oxygen content is less than 10%~40%, the refractive index is smaller; when oxygen content increases to 60%~80%, tantalum oxide film with higher oxygen content is prone to produce; and when oxygen content reaches 80%~100%, the film has shown high transparency, and the refractive index tends to be stable.

Table 2 Deposition parameters of Ta_2O_5 coating

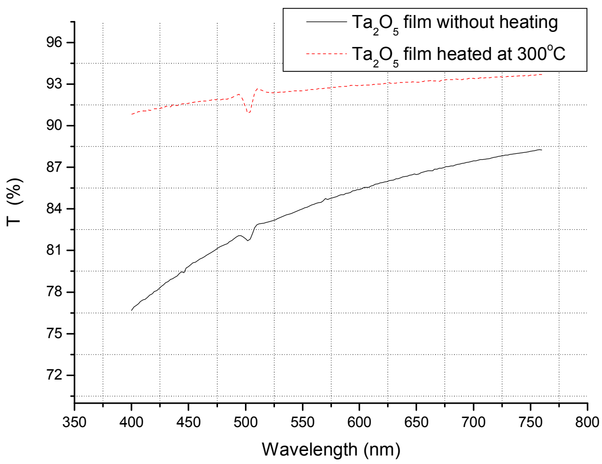
Sample	Pressure[Pa]	Target-substrate distance[mm]	O_2 content[%]	Power[W]
1	0.4	85	10.24	70
2	0.4	85	41.20	70
3	0.4	85	64.31	70
4	0.4	85	80.14	70
5	0.4	85	91.66	70
6	0.4	85	100.00	70

Influence of substrate temperature on coating performance.

Influence of substrate temperature on transmittance of film. The transmittances of films deposited at different substrate temperature are detected, as shown in Fig.6. When the substrates is heated to 300℃, the maximum transmittance of SiO_2 film increases, and also dose the difference between maximum transmittance and minimum one, which shows that the refractive index of SiO_2 film increases.



(a) Transmittance of SiO_2 coating



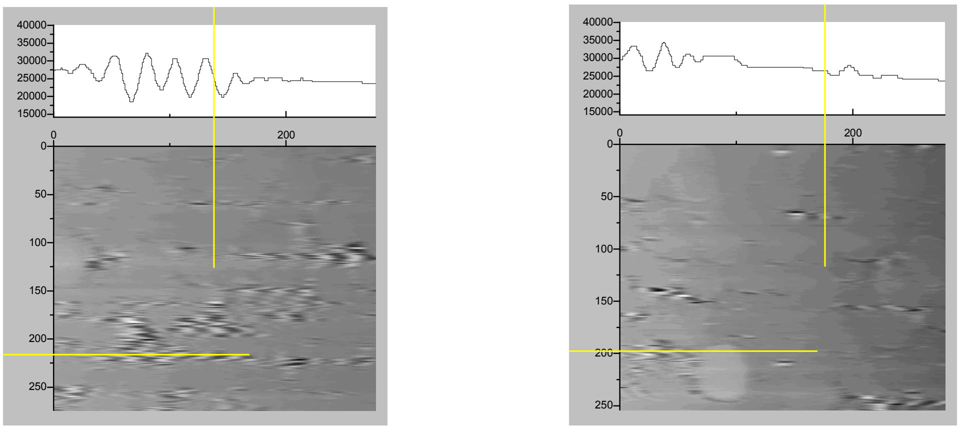
(b) Transmittance of Ta_2O_5 coating

Fig. 6. Transmittances of coatings deposited at different temperature

Transmittance of Ta_2O_5 film changes a lot with the increase of substrate temperature, as shown in Fig.6 (b). It can be seen that substrate temperature greatly influences transmittance of Ta_2O_5 film in visible band, while the transmittance of not heated sample is 14% lower than that of sample heated to 300℃ in band of purple light.

AFM morphological features analysis on samples at different substrate temperature. The SiO_2 coatings prepared at different substrate temperatures are detected by AFM, as shown in Fig.7 (a). When the sample is not heated, the surface structure of film shows different microscopic lightness and shades. The uneven surface structure scatters the light so that the transmittance of film is influenced. When the sample is heated to 300 ℃, surface structure of film looks smoother and has fewer defects than film whose substrate is not heated, as shown in Fig.7 (b).

The analysis results show that, density of film increases with the increase of substrate temperature obviously, then the refractive index increases as a result. Substrate temperature is an important factor affecting the refractive index, so it has great significance to control substrate temperature for improving of film's density and refractive index.



(a) sample unheated (b) sample heated to 300 ℃

Fig. 7. AFM images of SiO_2 film deposited at different temperature

Conclusions

Through technical research, it is found that technology parameters including working pressure, O_2 content and substrate temperature have much important influences on coating's optical properties.

Refractive indexes of SiO_2 and Ta_2O_5 coatings show the same changing trend with the change of working pressure. When the working pressure rises to 2.2Pa, the deposition rate of SiO_2 coating is appropriate for getting high transmittance coating, while the suitable working pressure for Ta_2O_5 coating is only 0.4Pa.

O_2 content greatly affects the refractive index of film. Deposited SiO_2 film will meet the design requirement when O_2 content is higher than 13%; while O_2 content in Ta_2O_5 film growth should be over 80%.

Substrate temperature has much important influence on film's optical properties. With the rise of substrate temperature, the surface of coating becomes more smoother and having fewer defects, and the coating's density also increases, so that the refractive index increases correspondingly.

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