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Fabrication of broadband antireflection coatings using wavelength-indirect broadband optical monitoring

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ABSTRACT

Multi-layer optical coatings with complex spectrum requirements, such as multi-band pass filters, notch filters, ultra-broadband antireflection coating and etc., whose working wavelength is out of monitoring wavelength range, are difficult to be fabricated using direct broadband optical monitoring (BBOM). In this paper, a broadband antireflection (AR) coating in the wavelength range from 1300 nm to 2000 nm at 45° incident was designed and deposited by dual ion beam sputtering (DIBS). Ta_2O_5 and SiO_2 were chosen as high and low refractive index coating materials, respectively. The optimized coating structure contains 4 non-quarter-wave (QW) layers. In order to obtain high transmittance, the most important is to realize the thickness accurate control. Due to the limitation of the monitoring wavelength range, which is only from 450 nm to 1000 nm, a wavelength-indirect broadband optical monitoring strategy was successfully employed to control the layers thickness during the deposition process. At last, a good agreement between theoretical and measured transmittance is obtained. The maximum error (the first layer) is only about 5.3% and the minimum error (the third layer) is about −0.25% base on the results of reverse engineering analysis.

1. Introduction

Demands on optical coatings with complex spectral performances [1,2], such as multi-bandpass filters, notch filters and ultra-broadband antireflection (AR) coatings [3–5], are increasingly growing. Reliable monitoring of their production becomes a key to ensure accurate control of the thickness of each layer during deposition. There exists many different monitoring methods [6–8], which can be used to control layer thickness, such as, quartz crystal monitoring method and single wavelength optical monitoring system (SWLOMS) [9,10]. Quartz crystal monitoring is a precision method, which is only used to control the deposition rate due to the lack of spectrum information acquired during the deposition process. SWLOMS, working as an optical monitoring method, has a great variety of advantages, but it can't be used to monitor coating with ultra-thin layers due to its intrinsic defects and limitations. To surpass the limitation of these methods, great efforts have been made on improving the broadband optical monitoring (BBOM) technique for decades [11–14].

Compared to quartz crystal monitoring method and SWLOMS, the BBOM is an available method currently and has many advantages, such as error self-compensation, higher monitor precision, adaptation to non-quarter-wave and sensitive film deposition. For decades of efforts on improving the BBOM techniques, with the availability of fast computing capacity,

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today's optical monitoring system can incorporate real time complex fitting routines including the full thin film model. However, the lack of the light source and corresponding spectrometer in a broad wavelength band from UV to IRS is still an obstacle for the application of BBOM [15]. Tao Han and Qingyuan Cai have developed an infrared BBOM system only with the monitoring wavelength range from 1450–1650 nm and 1430–1630 nm, respectively. However, the monitoring wavelength range is still not enough to control the layer thickness of a broadband antireflection (AR) coating applied in the wavelength range from 1300 nm to 2000 nm using wavelength-direct BBOM method. Thus, it is difficult to control the layer thickness using wavelength-direct BBOM method. This broadband antireflection (AR) coating, which can permit multiple wavelengths simultaneously pass through the optical component, is very important in laser system. Consequently, BBOM, working as wavelength-indirect monitoring, is proposed and employed to monitor the layer thickness. Wavelength-indirect monitoring in this paper is an indirect monitoring strategy in the scope of wavelengths, which is different from the position-indirect monitoring mentioned in other reports [9,16].

In this paper, a BBOM system only with monitoring wavelength range from 450 nm to 1000 nm can be employed to control the layer thickness. Using the BBOM system, the transmission spectrum of the coating during deposition process can be acquired in-situ by using a charge coupled detector (CCD) spectrometer, which is equipped in the deposition chamber. The machine-installed software fits the acquired spectrum immediately, based on which the deposition process is terminated when the value of merit function meets the target.

In this paper, a broadband antireflection (AR) coating in the wavelength range from 1300 nm to 2000 nm at 45° incident was designed and deposited by dual ion beam sputtering (DIBS). Ta_2O_5 and SiO_2 were chosen as high and low refraction coating materials, respectively. The optimized structure contains 4 non-quarter-wave layers. In order to obtain high transmittance, the most important is to realize the thickness accurate control. A wavelength-indirect broadband optical monitoring strategy was successfully employed to control the layers thickness during the deposition process.

2. Experiment

2.1. Equipment

The broadband AR coating was fabricated by dual ion beam sputtering (DIBS). Ta_2O_5 and SiO_2 were used as high and low refractive index coating materials, respectively. The physical deposition rate of Ta_2O_5 was ~0.39 nm/s and SiO_2 was ~0.62 nm/s. The coating machine was equipped with a 2 planet 425 mm diameter planetary fixture and a BBOM system using intermittent transmission monitoring through the center of one of the planets. Fig. 1 shows the scheme of the BBOM system. As can be seen in Fig. 1, broadband light comes out of the light source and is conducted through a fiber. The beam is reflected by a mirror and goes through the witness substrate from the backside of the witness substrate vertically. Then the beam is reflected by another mirror and conducted through another fiber, and finally collected by the spectrometer [17]. The monitoring wavelength range is from 450 nm to 1000 nm, which is shown in Fig. 2(a). Various materials can be used as monitoring witness substrate. In this paper, fused silica (shown in Fig. 2(a)) was chosen as the monitoring and deposition substrate. The diameter of sample substrates is 25.4 mm. As we know, broadband optical monitoring needs to acquire the optical parameters of the monitoring witness (substrate) before the deposition process and use these related parameters together with the transmission spectrum of each layers in-situ to fit refractive index and deposition rate. Then the stop time will be calculated. Before deposition, the refractive index of substrate in the range from 450 nm to 1000 nm was described in Fig. 2(b) by the well-known Cauchy formula:

$$n\left(\lambda\right) = A_0 + A_1/\lambda^2 + A_2/\lambda^4 \tag{1}$$

As can be seen in Fig. 2(b), the refractive index of substrate in the range from 600 nm to 1000 nm is quite smooth. It is easier to use this wavelength region to fit than the wavelength range from 450 nm to 1000 nm.

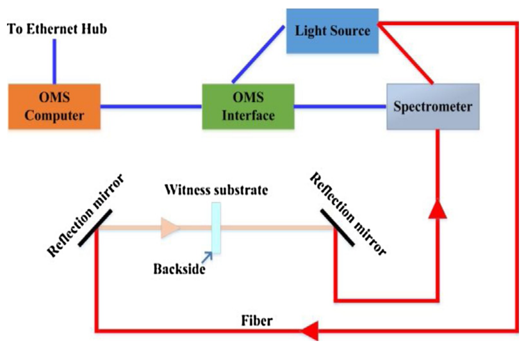

Fig. 1. Scheme diagram of the BBOM system.