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Optical Admittance Monitor through a Dynamic Interferometer

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Abstract: A way to increase the optical monitoring sensitivity in quarterwave stack fabrication by modified optical admittance loci was demonstrated. The optical admittance value was obtained from an in-situ dynamic interferometer combing with a photodetector, and the result was compared with ellipsometer measurement.

OCIS codes: (310.01860) Deposition and fabrication; (310.1620) Coatings, (120.3180) Interferometry

1. Introduction

The conventional optical monitoring methods for optical coatings have their own defects and have been reported in many articles. In fabrications of some exquisite elements such as narrow band pass filters requiring very high controlling precision, an advanced monitor is needed to increase the yield efficiency. In recent years, some monitoring methods applying optical admittance loci analysis have been proposed to provide more precise control and proper error compensations.

Optical admittances include both magnitude and phase information and are generally applied in filter designs. By analyzing the optical admittance in one single reference wavelength, the whole output spectrum can be kept to satisfy the original designs. Monochromatic optical admittance loci monitor offers clearer rule than the broadband monitor on the determination of the proper termination points. In the monitoring methods developed in recent years [1-3], optical admittance loci were acquired from the turning point of transmittance curve, and the termination points with error compensations need to be converted back to corresponding transmittance points. Most of those methods are under one assumption, that is, the refractive index of each material doesn't change during the whole coating process. However, it is not true, and the corresponding calculation errors derived from this assumption would be accumulated as layer number increase.

The real time refractive index variation could be observed only in a monitor system from which the optical phase of a growing film stack can be extracted, like an ellipsometry monitor. But using the ellipsometry monitor we cannot obtain the reflection coefficient at normal incident due to the working principle and needs numerical algorithm fitting to guess the real answers.

2. Optical admittance monitoring system and working principle

A monitor system based on reference [4] is proposed to extract the optical phase, but a quarter-wave plat (QWP) is inserted in front of the camera to increase the sensitivity as shown in Fig. 1. This QWP converts two polarized beams coming from two arms of interferometer into two orthogonally circular polarization states, and the reflectance phase of thin films can be derived from arctangent form of intensities rather than cosine form. It provides higher sensitivity [5]. The detector of the dynamic interferometer is a micro-polarizer pixelated camera, and phase-shifted interferograms can be acquired in a single camera frame to freeze vibration effect. Air turbulence can also be reduced by averaging several frames of data [6]. The polarization Twyman-Green interferometer was employed to eliminate the optical path difference between test and reference beams so that the corresponding interference fringes can be observed under low coherence light source, and other interference would be suppressed. The test surface is the coated side and the reference surface is the blank side of the substrate. There is a photo-detector placed under the coater to receive the transmittance change from substrate. After reflectance magnitude and phase are acquired, the reflection coefficient and optical admittance can be calculated. For non-absorption films, refractive index and thickness can also be calculated. Unlike other optical admittance monitor, the calculation error would not be accumulated in this system, because the calculation is not relative to the previous calculations.

To acquire monitoring sensitivities, we took partial derivatives of optical admittance with respect to optical thickness. The motion of an optical admittance locus is two-dimensional. It was composed of two orthogonal components in real and imaginary axis directions, respectively. Therefore, the sensitivity acquirements should be operated in real and imaginary dimensions, respectively, and then sum them up to obtain the total sensitivity.

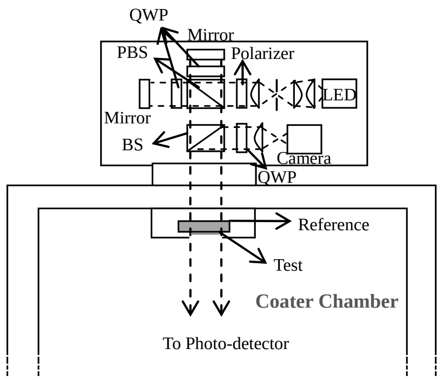

Fig. 1 Monitor system layout

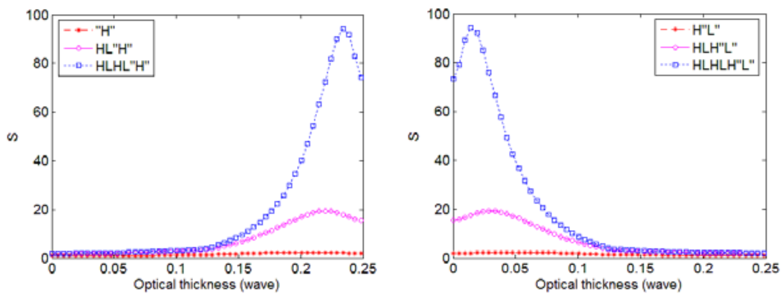

Fig. 2 Simulation of sensitivity distribution (n_H=2.1, n_L=1.46, n_S=1.5)

In Fig. 2, the monitoring sensitivity at terminations points in the high refractive index (H) layers in a quarter wave stack is much higher than that of the terminations points of the low index (L) layers, and the sensitivity distribution of the two are basically symmetric.

Fig. 3 shows admittance locus of a quarter-wave stack coating in which one point was plotted every 1nm optical thickness. From the figures, one can see that it is good to monitor for those termination points locating on the right side of the admittance locus circles but is bad to those on the left side of the admittance locus. For a specific admittance locus, the sensitivity has the maximum and minimum values on the right and left cross points on the real axis, respectively.

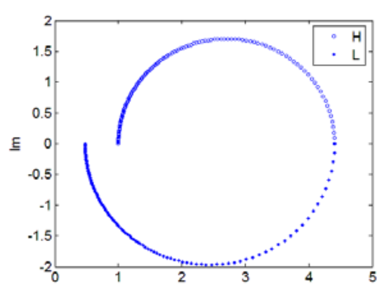

Fig. 3 Optical admittance loci of H Layer and L Layer

In a quarterwave stack deposition, one can also found that the sensitivity with respective to thickness will dramatically increase as the thin film layer number increase.

However, if we add a phase shift of π on the phase of reflection coefficients of a thin film obtained from our monitor system and convert it to the optical admittance, then those layers with their termination points locate on the left side of admittance loci circle will turn out to have their termination points on the right sides as shown in Fig. 4.

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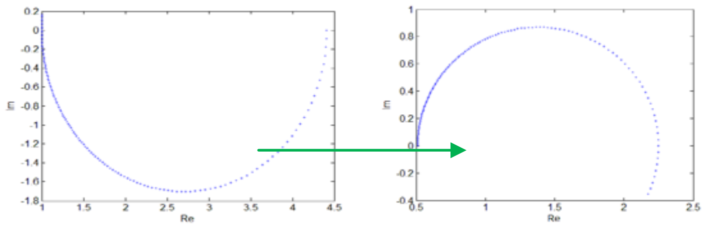

Fig. 4 Admittance locus of L layer deposition with pi phase shift on reflection coefficient

By applying this technique to other similar layers depositions, the sensitivity of optical admittance monitor would be greatly improved in the quarterwave stack production. Unlike Turning Point monitor, which is generally applied in quarterwave stack manufacture to have good error compensation but is insensitive on termination points, this monitor not only have good error compensations, but also offers better sensitivity on the termination points that are the turning points on the transmittance runsheet or reflectance runsheet. Furthermore, the sensitivities increase as the thin film layer number increase.

3. Experimental result

A radio frequency ion-beam sputtering deposition system was employed to fabricate Ta_2O_5 thin films. The monitoring light source was a LED of 660nm with bandwidth 20nm. The substrate is a 1.65mm thick glass (n_s= 1.464 @660nm). The exposure time of the micropolarizer pixelated camera was set in 85 microseconds. All the phases are measured from a dynamic interferometer set on a vibrating deposition system. A non-transmitted Ta film layer was precoated on one part of the substrate surface as the reference area. By comparing the phase difference between the reference area and the monitoring area before the deposition and after the deposition, the reflectance and reflection phase (average of 30 pixels) of films can be acquired, as 16.21% and -2.1112 (radians), respectively. Table 1 shows the results from the monitor system and ellipsometer measurement.

Table 1 Comparison of the results by monitor system and ellipsometer measurements

	Refractive index	Thickness	Reflection coefficient	Optical admittance
Monitor system measurement	2.119	39.039nm	-0.20708 - 0.34514i	1.6405 + 1.3513i
Ellipsometer measurement	2.168	39.04nm	-0.23321 - 0.35071i	1.6939 +1.4443i

The experimental result is very close to the ellipsometer measurement fitting results. But unlike ellipsometer, the phases were directly grabbed from the normal incident light.

The camera recorded the surface distribution of phase, so it could be developed to analytically calculate the thickness and refractive index distribution of a non-absorption film deposited on a substrate in the future.

4. Conclusions

A dynamic interferometer was employed to monitor the reflectance phase change of the deposited films and the corresponding optical admittance was obtained. The corresponding analysis was demonstrated to show that the optical admittance monitor has superior characteristics in the quarterwave stack manufacture.

Acknowledgements

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5. Reference

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