Stray light minimised optical coatings and their application in UV inspection optics

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In high quality UV optical systems, dielectric coatings play an important role in maximising the system transmittance of refractive optical systems. But not only the system transmittance is influenced by the coatings. Several effects have to be considered in order achieve the best possible system performance. In this paper the impacts of coatings on the image performance and the stray light level are discussed in an instance of an UV microscope inspection optics with a high numerical aperture. Solutions to minimise the stray light level including scattering are given and results are presented.

1 Introduction

The reduction of stray light is particularly important in UV inspection systems. As stray light is induced by many different sources, residual reflections and scattering of micro rough surfaces are the most pronounced for multilayer coatings.

Optical coatings are used to maximise the transmittance of lenses in optical systems and play an important role in minimising residual reflections in refracting optical systems. As a consequence, they reduce the stray light level to maintain a high image quality of low signal to noise ratio.

In the following sections the impact of coatings on the image quality, including aperture transmittance and residual reflections, are investigated. Additionally, the scattering of the micro rough multilayers is considered.

2 The UV micro-inspection lens system

In this paper the impact of an anti reflective coating on the optical performance and stray light level is investigated. The optical system is introduced here with its basic data.

The micro-inspection lens system used as an instance was made for a single wavelength of 266nm. All its seven lenses are made of fused silica. The numerical aperture is 0.7 and the effective focal lens is 15.8mm. An object field diameter of 300µm can be imaged with the use of a tube lens. The working distance is 14mm. With the nominal design a Strehl ratio of 99.7% on axis and 99.1% at the edge is achieved.

3 Coating designs

Three different coating designs were considered for comparison of the system performance of the UV micro inspection lens.

A Magnesium-Fluorid (MgF_2) single layer is a common choice for this type of problem because of the insensitivity to tolerances and blue shift. So this will be one design to compare to.

A second design is a three layer design with the materials MgF_2, Al_2O_3, and HfO_2. As MgF_2 is only available in industrial production on conventional e-beam or boat evapuration coating plants, this design is called ARB conv. throughout the paper.

Studies have shown that the coating process of ion beam sputtering (IBS) produces very smooth surfaces and interfaces in a multilayer [1]. This should keep the scattering lower in comparison to the conventional processes. So a third design is made for an IBS coating plant. As no MgF_2 is available on IBS machines, the material with the lowest index of refraction is SiO_2. Due to this necessary replacement more layer are needed for the IBS design to achieve comparable transmittances. This may increase the scattering to a level higher than for the conventional coating. The IBS coating has 9 layers.

To optimise the system transmittance and to cover the blue shift, two different designs for the ARB coatings had to be made. One version has a slightly higher residual reflectance but covering stronger blue shift by being broader in the wavelengths range. This coating is applied to lens surfaces with high radii of curvature.

4 Coating performance

In the tabular Tab. 1 the transmittance data for the complete optical system with the different coatings applied are shown. Additionally, the stray light was simulated using raytracing software and its power values are stated in Tab. 1 also. The ghost level is the power in the object plane that originates from reflections inside the transmitting optics.

Coating	MgF_2 single layer	ARB Conventional	ARB IBS
System transm.*	0.79	0.97	0.95
Ghost-level [ppm]*	90	1.3	2.3

***Tab. 1** Comparison of total system transmittance and the amount of stray light in the object plane of the UV inspection system.*

Clearly, the MgF_2 single layer has the worst system transmittance and the highest ghost level. Therefore it is discarded from further investigations.

5 Image performance

The coatings have also an influence on the image performance by variations of the transmittance with aperture radius. This is similar to a pupil apodisation and thus results in a change of modulation transfer function and accordingly also in the strehl ratio.

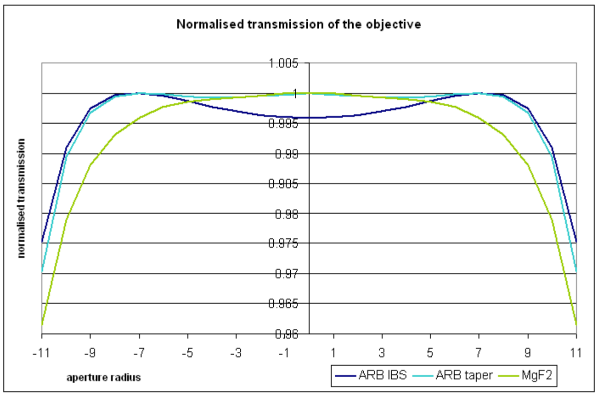

***Fig. 1** Variation of full system transmittance with aperture radius*

Coating	ARB Conventional	ARB IBS
Strehl ratio [%]	99.4	99.0

***Tab. 2** On axis strehl ratio for the optical system with different coatings*

Tabular Tab. 2 shows the difference in image performance for the two types of coatings. There is a slight drop of the Strehl ratio from 99.7% but not considering the blue shift due to the lens curvature and the angles of incidence on the lens surfaces would the Strehl ratio more significantly.

6 Scattered power in the optical system

The angular scatter model was derived by the method purposed by Elson [2]. Measurements of single and multilayer designs were carried out on a white light interferometer and on a total integrating scattering set up to determine the necessary parameter. Because of the rough surface that is produced by the MgF_2 columnar film growth [3], the total scattering (TS) value of the conventional coating is higher. It has a TS value of 29ppm compared to 20ppm of the IBS coating.

The scatter models of both coating types were used in raytrace software to determine the amount of scattered power in the object plane. Surprisingly, the system simulated with IBS coatings had a higher amount of scattered power in the object plane than the conventional coating. Letter has 14ppm compared to 23ppm.

The reason can be found in the angular distribution of the scattered radiation. By comparing the two curves in Fig. 2 one can see that the curve of the conventional coating (red) is above the one of the IBS coating (blue) but only for higher scattering angles θ_s. For small scatter angles the blue curve is above the red curve, which means that in this range more scattered power is induced by the IBS coating.

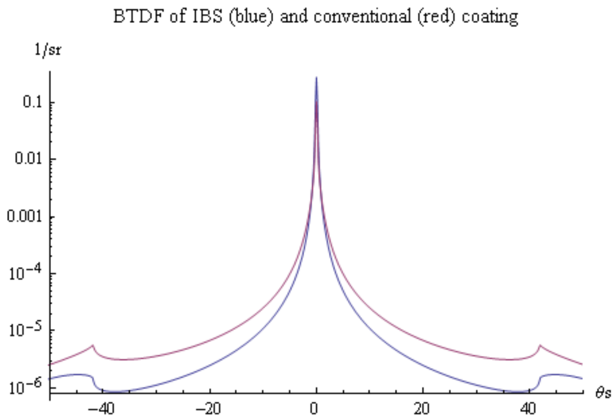

***Fig. 2** Angular distribution of the scattered radiation modelled for the conventional coating (red) and the IBS coating (blue)*

The raytracing revealed that these low scatter angles are the only once that are carried from the surface of scattering through the system to the object plane.

7 Conclusion

Coatings designs for high performance micro-inspection systems need to be chosen carefully, as they influence the achievable image performance and the signal to noise ratio. To judge the finally best coating design tolerance sensitivity and in system performance needs to be determined.

References

[1] M. Gupta, Appl. Surface Science 205 (2003) p. 309ff

[2] Elson; Applied Optics / Vol. 16, No. 11 / 1977

[3] Seouk-Hoon Woo, Journal of the Korean Physical Society, Vol. 45, No. 1, July 2004, pp. 99-107