Light & Engineering
Vol. 28, No. 5, pp. 48–52, 2020

https://doi.org/10.33383/2020-017
Svetotekhnika #4, 2020, pp. 51–54

CONTEMPORARY SYSTEM OF DIRECT BROADBAND OPTICAL MONITORING OF THICKNESS OF SPRAY OPTICAL COATINGS

Oleg F. Prosovsky[1]*, Alexander Yu. Budnev[1], Dmitry G. Denisov[2]**, Nikolay V. Baryshnikov[2], Yuri O. Prosovsky[2]

[1] *Obninsk Research and Production Enterprise Technologiya named after A.G. Romashin (Romashin ORPE Technologiya), Obninsk*
[2] *Bauman Moscow State Technical University (BMSTU, NRU), Moscow*
*E-mail: * pof@mail.ru, **denisov_dg@mail.ru*

ABSTRACT

In this article, construction schemes direct and indirect control systems were analyzed, and new construction, providing high operating characteristics for optic filters, was introduced. Authors introduce the original decision for creation modern broadband optic control system. Based on the proposed method, approbation of created system was made, and output characteristics control system – spectral transmission dependencies were introduced as a result. Spectral transmission dependencies of interference optical filters, made with different optical control systems were analyzed. Conclusions and prognoses about further developments of direct broadband optic control system for thickness sprayed coatings were made.

Keywords: interference optical filters, straight broadband optic control, thickness of films, vacuum system, spectrum, spectral transmittance factor (reflection factor) curve

1.INTRODUCTION

Nowadays, it is hard to find any optical device manufactured without application of any coating on its surface. For instance, coatings modifying surfaces to increase their resistance against external factors (wear and tear, effects of aggressive substances), to enhance their optical properties (antireflection) and to provide them with new optical properties (polarisation and radiation filtering, etc.) have become widely used.

One of the most important components of spraying equipment is the system for thickness of applied films monitoring, which (primarily) defines process capabilities of spraying equipment in applying multi-layer interference structures. Moreover, monitoring of optical constants is directly linked with quality and repeatability of the process of formation of multi-layer optical coatings [1].

2. CONTEMPORARY METHODS OF OPTICAL COATING THICKNESS MONITORING

Modern spraying equipment is based on the principles of direct and indirect monitoring, and precision of measurement of thickness of the films of applied optical coatings therefore is not always satisfactory for customer's requirements. Today, optical monitoring systems can be divided into 2 major types [2]:

1. Indirect optical monitoring systems, which apply accompanying samples (witnesses) for measurement of spectral transmittance (reflectance) factor of an applied coating (usually placed in the centre of the vacuum jig);

2. Systems of direct optical monitoring, in which measurement of spectral transmittance (reflectance) factor is conducted directly on a product fixed in a rotating vacuum jig.

Fig. 1. Example of an operating broadband optic monitoring system

Only a broadband optical monitoring system may provide the most complete information about the structure of an applied film [3]. It analyses the information on spectral dependence of transmittance factor (SDT) of a coating in the set wavelength range, allows us to define dispersion of optical constants (refractive index and absorption index) and thicknesses of sprayed films right in the course of coating formation on a product in vacuum. Usually contemporary equipment is equipped with ion-assisted sprayers, which in turn provide persistence of optical constants after a coated product is taken out of a vacuum chamber. This fact demonstrates undeniable advantage of modern spraying equipment.

Functioning of the contemporary system of direct broadband optical monitoring implies three cycles of measurement at each rotation of the jig, which is caused by necessity of high precision measurements [4]. Fig. 1 shows the vacuum jig with 3 marked areas which relate to the system of direct optical monitoring:

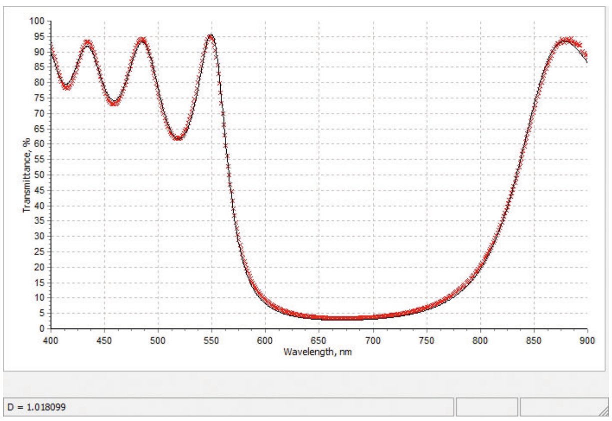

Fig. 3. Example of a design and experimental SDT of multi-layer optic coating

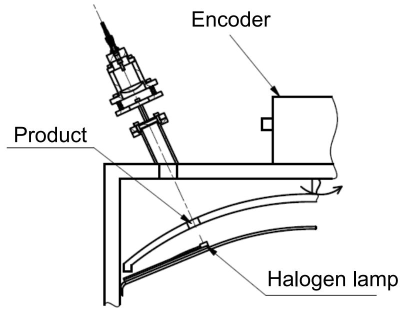

Fig. 2. Structural diagram of the proposed system of direct broadband optic monitoring of thickness of spray coatings

– Area 1 is the product on which SDT of the sprayed coating is measured;

– Area 2 is the section of the jig that does not transmit radiation (0 % transmittance) and used for dark current measurement;

– Area 3 is the hole (100 % transmittance) where transmittance factor has to be measured.

The proposed modern method of direct broadband optical monitoring of layer thicknesses has the following features:

– Transmittance is measured right on a product fixed in a rotating jig;

– To ensure high accuracy of measurement, a digital encoder (Fig. 2) is used, which allows us to make measurements almost at one physical point of a product;

– At each rotation of the jig, measurements are made in 2 major steps: calibration and measurement; calibration consists of transmittance measurements at 100 % and 0 % (areas 2 and 3 in Fig. 1), then the transmittance factor of the product itself is measured (area 1 in Fig. 1);

– Broad wavelength measurement range of (400–1100) nm;

– Application of a mathematical apparatus for processing of information on SDT of applied coatings in a broad spectral range, which allows reanalysis to conduct of the structure of a sprayed coating and to correct errors made during application of previous layers in the course of application of the remaining non-sprayed layers of coating;

– Provision of virtually complete concordance between the acquired design and experimental values of SDT.

Based on the proposed method, the authors conducted testing of the monitoring system they had developed and the result of this test was the system's output characteristics: SDT. Fig. 3 demonstrates the graphs of SDT which characterise precision of the

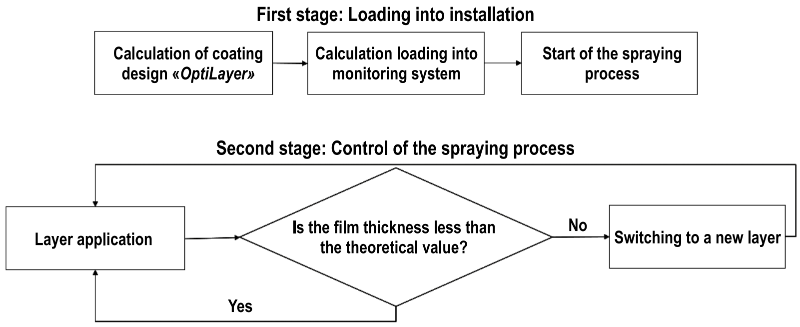

Fig. 4. The process of thickness monitoring of the spray coating

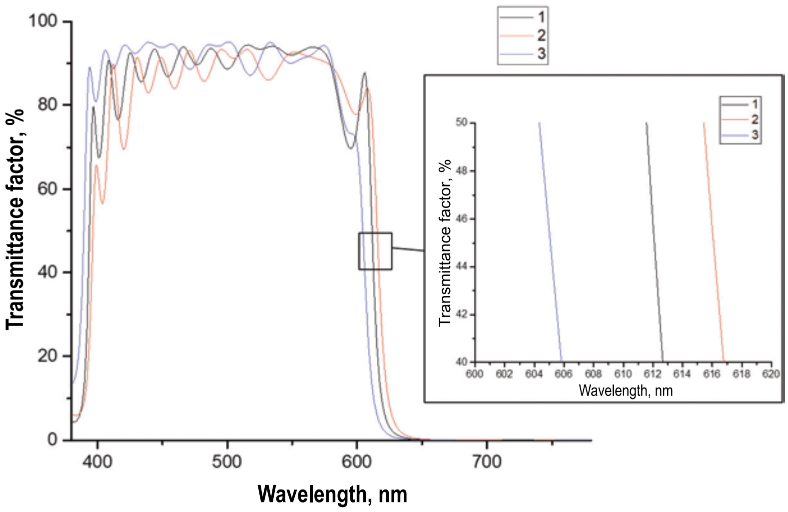

Fig. 5. SDT of a cut-off filter acquired during three processes with use of the monitoring system with an optical witness sample in the centre of the camera

monitoring system by means of which thickness of films sprayed during production of a 9-layer dichroic coating was measured. As the figure shows, SDT of the manufactured filter (the red curve) almost completely corresponds with SDT calculated by means of *OptiLayer*[1] (the black curve).

In the course of manufacturing, monitoring of thickness of an optical coating is conducted by an operator based on analysis of SDT calculated by means of the said software for each layer of the coating.

During spraying, SDT measured on the product shall correspond with the calculated (theoretical) SDT set by the operator. In case of superimposition of the two SDT graphs, the operator stops spraying of the current layer and launches spraying of the following one. Fig. 4 contains the comprehensive algorithm of the developed system of monitoring of thickness of applied coatings and the automated design system *OptiLayer* in the form of a block diagram.

3. COMPARISON OF PRECISION CHARACTERISTICS OF THE DEVELOPED DIRECT MONITORING SYSTEM AND THE SYSTEM OF INDIRECT MONITORING OF THICKNESS OF OPTICAL COATINGS

Fig. 5 demonstrates spectral characteristics of the filters manufactured by means of 3 different processes using the indirect monitoring system with a witness sample in the centre. The insert in this figure shows the variation of $\lambda_{0.5}$ within the spectral region of (605–620) nm equal to 14 nm in more detail. Such variation leads to defects of some of manufactured parts. More detailed analysis of the run of the curves in the insert by means of *OptiRe*[2] shows the

[1] *OptiLayer* is the software for modelling, optimization and calculation of optical coatings and their characteristics. The scope of application is thin-film coatings. It allows the operator to recalculate parameters of coating layers in order to correct errors in previously applied layers [5].

[2] The *OptiRe* software computation module is designed for measurement of parameters of the layers of sprayed optical coatings based on the data of spectral photometry and/or ellipsometry. The results obtained by means of *OptiRe* provide feed-

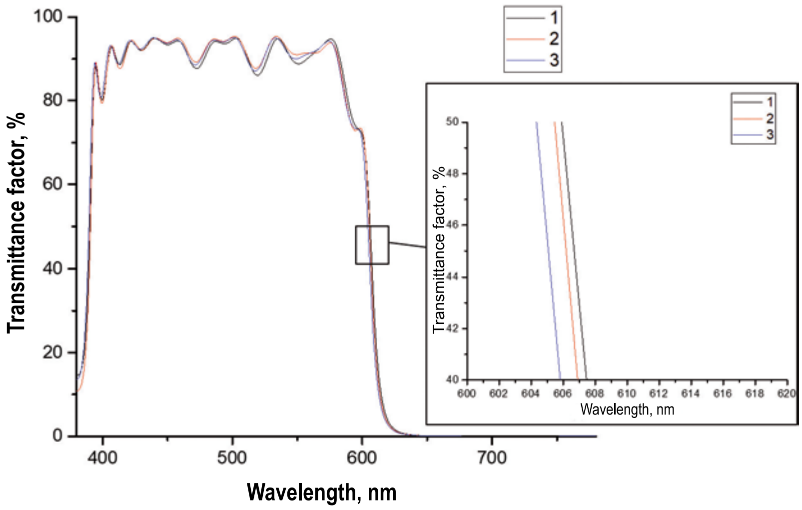

Fig. 6. SDT of a cut-off filter acquired during three processes with use of the direct optic monitoring

values of random deviations of layer thicknesses when repeating the optical structure within the range of (3–5)%. Different runs of the curves in each process confirm availability of a non-systematic error, which significantly complicates automation of the process of application and coating monitoring by an engineer.

It is likely that such high errors of repeating of layer thickness are caused by the change in the solid angle of the flow of vapours of the substance evaporated from the pot due to change in the shape of the substance crater in the pot over the course of the lengthy process which takes (4–5) hours. As a result, the films with different thicknesses are applied on the witness sample and the product. The nature of such errors is non-systematic, they depend on many factors and are very difficult to forecast in most cases.

In order to minimise the errors of the indirect monitoring system, the system of direct broadband optical monitoring was developed and experimentally studied. Its structural elements are shown in Fig. 2 and the results of the experimental studies are shown in Fig. 6, which contains the graphs of spectral dependences of filters obtained in the course of three different processes with use of direct optical monitoring of thickness of applied coatings.

The insert in Fig. 6 demonstrates the variation of $\lambda_{0.5}$ in more detail – it is only equal to 3 nm. With that, the analysis of the run of the curves in this insert makes it possible to conclude that, in the course of application of the optical structure layers, thanks to use of direct optical monitoring, high-precision repeatability of each layer is observed in the series of three processes. The analysis of the achieved results by means of the *OptiRe* modules shows that deviations of actually applied layers from the design ones are less than 0.5 %.

back of the spraying process. Using these results, it is possible to adjust the parameters of the spraying process or the process of layer monitoring and thus to increase the quality of the sprayed coatings. The module is a part of *OptiLayer*.

4. DISCUSSION OF THE RESULTS

The system of direct broadband optical monitoring described above is currently being tested by Romashin ORPE Technologiya. It is planned to supplement it with the *OptiReopt* software module (part of the *OptiLayer* software) which is a library for support of optical coatings application monitoring.

Since errors still accumulate in the course of spraying (they are determined by the damper closure time, non-ideality of operation condition, etc.), when a larger (≥30) number of layers is applied, these errors turn out to be significant, which may lead to non-satisfactory quality of a product. Moreover, it is planned to implement a completely automatic spraying process eliminating the human factor.

To conclude, as a result of the conducted studies:

– A prospective optical monitoring system is developed – the system of direct broadband optical monitoring, which has demonstrated high repeatability of thicknesses of dichroic coating layers in production conditions;

– The system of direct broadband optical control is practically implemented on an electron-beam evaporation installation;

– The system of direct broadband optical control is introduced in the production process of dichroic filters for optical devices (cut-off, narrow-band and other types of filters).

REFERENCES

1. Lequime M., Nadji S., Stojcevski D., Koc C., Grézes-Besset C., Lumeau J. Determination of the optical constants of a dielectric layer by processing in situ spectral transmittance measurements along the time dimension // Appl. Opt., 2017, Vol. 56, pp. C181–C187.

2. Okatov M.A., Antonov E.A., Baygozhin A. Optic Engineer's Handbook [Spravochnik tekhnologa-optika]. St. Petersburg: Politekhnika, 2004, 679 p.

3. Nadji S.L., Lequime M., Begou T., Koc C., Grézes-Besset C., Lumeau J. Use of a broadband monitoring system for the determination of the optical constants of a dielectric bilayer // Appl. Opt. 2018, Vol. 57, pp. 877–883.

4. Zhupanov V.G., Kozlov I.V., Fedoseev V.N., Konotopov P., Trubetskov M.K., Tikhonravov A.V. Production of Brewster angle thin film polarizers using a ZrO2/SiO2 pair of materials // Appl. Opt., 2017, Vol. 56, pp. C30–C34.

5. URL: https://www.optilayer.com/ (accessed on: 20.01.2020).

Oleg F. Prosovsky,
an engineer. Head of the Optic Coatings Laboratory of AO ONPP Romashin Tekhnologiya

Alexander Yu. Budnev,
an engineer 3rd category, technical engineer of the Optic Coatings Laboratory of Romashin ORPE Technologiya

Dmitry G. Denisov,
an engineer. Associate professor of the RL-2 sub-department of Baumann MSTU (NRU)

Nikolay V. Baryshnikov,
an engineer. Associate professor of the RL-2 sub-department of Baumann MGTU (NIU)

Yuri O. Prosovsky,
student of the 4th year of the RL-2 sub-department of Baumann MGTU (NIU)