Method of the coating thickness and transmittance control during the film deposition process

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Abstract. A method of the coating thickness and transmittance control during the film deposition is proposed. The photometric setup on the basis of vacuum resistive evaporation installation is presented. The stages of the spectral data processing algorithm are described. The substrate holder carousel is shown as part of the installation.

1. Introduction
Optical methods of in situ film thickness control during deposition are currently widely used in the production of opto- and microelectronics [1–4]. Photometric method is most common thanks to the ease of its implementation. The principle of photometric measurements is based on the film layer transmittance dependence on its thickness. In the production of microelectronics the control is usually carried out by a witness substrate for which the optically transparent materials such as quartz, sapphire and glass are used. An incandescent lamp with a small glow body is used as the light source.

When evaporating metals and materials with a high absorption coefficient in the visible and near infrared region, the control is carried out by monitoring of the transmittance for white light, i.e. integrally over all wavelengths of the visible spectral range; the optical arrangement of the measuring setup in this case is quite simple. To determine the thickness for each material it is necessary to have a calibration curve. The metal films thickness can be controlled with an error of less than 1 %.

Photometric thickness control of optically transparent layers of dielectrics and semiconductors is more complex [5]. The most effective methods are measurements of the spectral transmittance at single or several wavelengths.

The main difficulty arising in the practical application of the photometric method is associated with insufficient operational speed of the equipment used and with the need to develop an algorithm for processing the measured transmission spectra of coatings during the deposition process on a rotating witness substrate.

2. Photometric setup for film coatings thickness measurement
The authors have developed a photometric control setup (figure 1) mounted on a typical installation of vacuum resistive evaporation UVN-71 P3. To control the transmittance of metal film coatings directly during the deposition process, a small-sized spectrometer with the Aspect 2010 software developed at SPbSETU "LETI" is used [6]. As a source of radiation, a halogen incandescent lamp with a focusing lens is used. The radiation is focused on the end of the lighting quartz optical fiber with a diameter of
0.4 mm. The output end of the optical fiber is located above the carousel of the substrate holders in the position of passing the optically transparent samples with the coating deposited on them. The radiation transmitted through the coated sample is directed to the receiving optical fiber connected via the vacuum optical input Vacom T-MM600UV-FSMA to the spectrometer.

Figure 1. Photometric setup for film coatings thickness measurement.

In the process of spraying, the carousel of the substrate holders rotates and the radiation from the lighting fiber alternately passes through all the substrates placed on the holder. The substrate and their replacement holders accordingly may have different geometrical dimensions (the authors developed the technique for measurements of film beam-splitting mirrors with dimensions $82 \times 82$ mm, $64 \times 102$ mm, $96 \times 125$ mm and a transmittance of 65%, 40% and 52% respectively). The number of simultaneously sprayed substrates changes depending on the size. All of the above does not allow simple means to synchronize the measurement of the transmission spectrum with the position of the substrate in the desired position. In addition, not all substrates can be installed on the holder. Thus, in the process of spectra registration the following states may occur:

- The moment of spectrum registration can correspond to the correct position of the substrate with the sprayed film;
- The time of registration of the spectrum might correspond to the lack of spectral signal spectrum registration between substrates (holder carousel is made of metal which is optically opaque);
- The moment of spectrum registration can correspond to the maximum signal in the absence of a substrate in one or several positions (radiation passes freely from the lighting fiber to the receiving one);
- The moment of spectrum registration can correspond to the edge of the substrate, with part of the time of full registration of the spectral signal is absent (illumination of the substrate holder), and the rest of the spectral signal corresponds to the correct position of the substrate, which ultimately gives the correct distribution of the signal across the spectrum, but less amplitude.

3. Processing of the obtained spectra

Under the given conditions the algorithm of spectral data processing includes several stages.
3.1. Registration of the base spectrum

Before the start of the process cycle and the measurement process, a transparent uncoated substrate is placed under the lighting fiber and the transmission spectrum of the substrate (base spectrum) is recorded. With further measurements, all spectra will be divided into the base spectrum and multiplied by 100 %, which will allow for each measurement to obtain the spectral transmittance of the film coating. The substrate without film coating will correspond to the transmission of 100 %. It’s necessary to register the base spectrum without the substrate installed in the holder in order to obtain a given transmittance of the film coating with the substrate.

3.2. Setting film coating parameters

The developed software sets the required parameters of the film coating (figure 2):

- Transmittance, %;
- The tolerance on the value of the transmission coefficient, ±%;
- Initial and final wavelength of the spectral range, nm.

![Figure 2. Dialog box for setting film coating parameters.](image)

3.3. Spectral data processing

Simultaneously with the beginning of the deposition process, the registration of the transmission spectra of the samples is started. Not all spectra will correspond to the correct location of the substrate in the measurement area. The following calculations exclude spectra that have:

- Signal in a predetermined range exceeding 100 % (the substrate is absent);
- Signal in a given range of less than 5 % (spectrum registration at the time of passing the substrate holders’ carousel in the measurement zone).

During the registration of spectra for each of the signals in a given spectral region for all wavelengths, the average value of the difference between the transmittance and the required transmittance, its minimum and maximum values (figure 3) is calculated. If the average difference exceeds the specified tolerance, the spectrum area for which measurements are made is colored red on the screen.

If the average transmittance doesn’t exceed the specified tolerance, the control zone is colored green as shown in figure 4.

Since it’s possible that the signal changes during the registration process (the edge of the substrate), signals with incorrect values will periodically appear during the measurement. Statistically, such situations are quite rare (the substrate area is usually large). To eliminate such cases, statistical analysis of data for a sample of the last 20 measurements is performed and data with significant differences from the average value for the last 20 spectra are excluded from consideration.

As a result, the operator monitors the coating process, the correct average value of the transmittance in the predetermined spectral range, and adopts the decision on the deposition termination, when the signal is stable (it’s in the "green zone") and the coating film transmittance doesn’t go beyond the specified tolerances.
Figure 3. Calculation of the transmittance parameters.

Figure 4. The transmittance is close to the specified value.

Figure 5. The substrate holder carousel (a) with the substrates (b).
4. Conclusion
The proposed photometric method for transmittance controlling was successfully implemented through the creation of vacuum coaters. The appearance of the holder carousel as part of the vacuum installation is presented in figure 5.

These coaters are dedicated for the production of dichroic mirrors produced on the basis of Mylar films with a metallic coating for JSC NPO "Electropribor-Voronezh".

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