Optical Thickness Determination on Structured Samples

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Transparent films of several microns thickness are often reduced on smaller areas in technical applications. Then, optical thickness determination of the film is rendered more difficult, because the reflection of the film is superposed or mixed with the reflection of the substrate. We demonstrate that it is possible to determine the film thickness exactly from the superposed signal when the portion x as percentage of the film area to the total area of the detection spot becomes larger than a threshold value.

1 Introduction

Transparent films with thickness of several microns are almost everywhere present as food packaging, wrapping, foils, membranes, lamination, photoresist layers and in display technology and solar cells, to give some examples.

In some of these examples, a further treatment of the films, e.g. in photolithography, leads to structured surfaces where the original layer is reduced on smaller areas. Then, the optical thickness determination of the film is rendered more difficult, because the reflection of the layer is superposed or mixed with the reflection of the substrate or a second layer of another material adjacent to the film under consideration.

In these cases, a possibility to get information on the thickness of the film is to use a microscope when measuring the film reflectance. Then, however one must take care of the aperture angle of the microscope objective since it provides angles of incidence beyond the normal incidence. In [1] we showed how this affects the film thickness determination and how this aperture can be taken into account with an effective angle of incidence.

Another method is to analyse the superposed signal in detail. Li and Lee [2] proposed an enhanced thin-film model to simulate the reflected intensity of a patterned thin-film structure received by a CCD. Here, we adopt this idea but concentrate on transparent films that are as thick as one can apply the Fast Fourier Transform (FFT) for analysis of the film thickness.

2 Fast Fourier Transform

For a single layer on a substrate the reflectance is approximately given by

$$R(\lambda,d) = R_{01}(\lambda) + R_{12}(\lambda)\cdot\left(1-R_{01}^{2}(\lambda)\right) + 2\sqrt{R_{01}(\lambda)\cdot R_{12}(\lambda)\cdot\left(1-R_{01}^{2}(\lambda)\right)}\cdot\cos\left(\frac{4\pi}{\lambda}n(\lambda)\cdot d\right) \tag{1}$$

where we neglected multiple reflections at the two interfaces of the layer. R_{01} is the reflectivity at the boundary air-film and R_{12} is the reflectivity at the boundary film-substrate. The quantity n is the refractive index of the film.

If the thickness of the films is as large as the Fast Fourier Transform (FFT) can be applied to determine the film thickness, it follows from

$$d = \frac{m}{2\cdot\left(\frac{n(\lambda_{min})}{\lambda_{min}} - \frac{n(\lambda_{max})}{\lambda_{max}}\right)}. \tag{2}$$

It is given by the product of the minimum thickness that is achievable from FFT in the spectral range $[\lambda_{min}, \lambda_{max}]$ and a FFT pixel number m.

3 Patterned Film on Substrate

When looking at a patterned thin film structure we have the reflectance in Eq. (1) in regions of the layer and the reflectance of the substrate in regions without layer. Then, a clear distinction between both regions should be possible. Nevertheless, in real investigations the detection spot is often as large as both signals superpose.

$$R(\lambda) = x\cdot R_{film\ stack}(\lambda) + (1-x)\cdot R_{substrate}(\lambda) \tag{2}$$

Anyway it is possible to determine the film thickness exactly from the superposed signal when the portion x as percentage of the film area to the total area of the detection spot becomes larger than a threshold value.

We studied numerically films of SiO_2, Si_3N_4 and of the photoresist material Durimide on substrates of Si or GaAs and varied the film thickness from d = 2 µm to d = 20 µm to determine this threshold value. To get more realistic results that are comparable to measured values the computed reflectance spectra were also made noisy.

In Fig. 1a we exemplarily show the smooth spectra of a silica film of d = 5 µm on a silicon substrate for x = 0.05 and x = 0.10 in comparison to the spectrum of the uncoated silicon substrate (x=0), and in

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Fig. 1b the corresponding power spectra from FFT analysis where the blue curve is the power spectrum for x = 1.0. The power spectra exhibit a peak at a certain FFT pixel from which the thickness can be derived. The magnitude of the peak increases with increasing x, but, in particular for the noisy spectra, for an unambiguous determination of the thickness a threshold value of x should be reached.

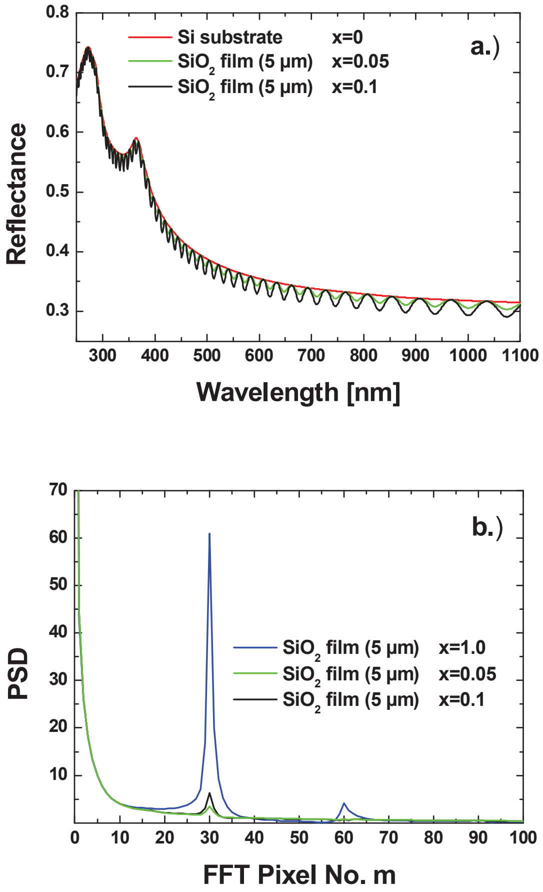

***Fig. 1** a.) Exemplaric calculated spectra of a silica film on silicon substrate for x = 0 (substrate only), x = 0.05, and x = 0.1, b.) Corresponding power spectral distributions in comparison to the PSD of the homogeneous film (x = 1.0).*

This threshold value is derived from our calculations and the results are summarised in the following Table 1.

We can conclude that in all investigated cases a threshold value of x = 0.1 for smooth spectra and x = 0.15 is sufficient to determine unambiguously the thickness of the film from the mixed reflectance spectrum.

Film material	Substrate	smooth spectra x ≥	noisy spectra x ≥
Al_2O_3	Al	0.05	0.08
SiO_2	Si	0.10	0.10
Si_3N_4		0.10	0.12
Durimide		0.10	0.15
SiO_2	GaAs	0.10	0.10
Si_3N_4		0.10	0.12
Durimide		0.10	0.12

***Tab. 1** Results for the threshold value.*

References

[1] F. Houta, M. Quinten, Layer Thickness Determination - The Influence of the Aperture of a Measuring Head, Optik & Photonik 10 (4) (2015), 54 - 56

[2] Ya-Ping Li and Cheng-Chung Lee, Simulation of intensity of a patterned thin-film structure, Appl. Opt. 46, No. 12 (2007), 2244 - 2247