Characterization of an anisotropic film

Introduction

Optical anisotropy of a material means that the refractive index depends on the propagation direction of light. The anisotropy is caused by a net macroscopic orientation of the microscopic constituents, e.g. molecules or crystal domains of the anisotropic material. Anisotropy appears in many thin polymer films, liquid crystals, light emitting organic devices (OLEDs), and non linear optical materials. These thin anisotropic films appear structured as a matrix in many different types of displays. Ellipsometry measures the film thickness (fig.1) and the principal refractive index components n_x, n_y, n_z and evaluates an effective refractive index (fig.2) as a function of the angles of incidence and orientation of the sample. Additionally imaging ellipsometry measures these material properties with high lateral resolution at precisely defined sites of the sample and makes refractive index domains with high contrast visible (fig.3).

Sample

Uniaxial red polymer film on SiO_2 glass substrate, maximum of absorption at 500 nm

Instrumentation

Spectroscopic Imaging Ellipsometer EP³-SE (365-901nm), 2x objective, EP³View Software Version 2.0

Task

Measurement of film thickness d and principal refractive indices n_x and n_z

Steps of evaluation

1. All measurements are done at 901 nm wavelength where absorption can be neglected and consequently the number of free parameters in the optical model is minimal
2. Automatic measurement of delta/psi in four zones as a function of the angle of incidence
3. Fit with isotropic optical model in order to obtain thickness and effective refractive index
4. Fit with anisotropic model in order to obtain principal refractive indices

Measurements and results

Screenshot from EP³View 2.0 Software:

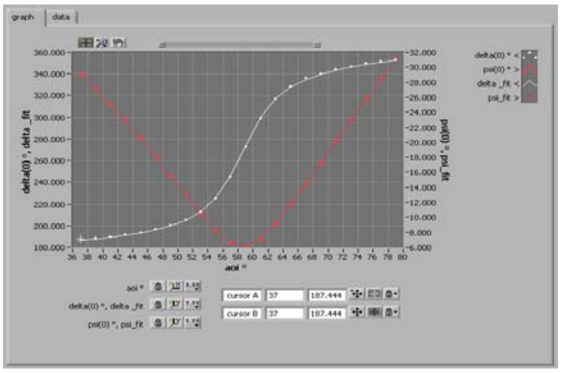

Fig. 1: Delta/Psi as angle of incidence (aoi) spectra, 2-zone average at 901 nm wavelength, fit with isotropic optical model gives **thickness d = 45 nm and effective refractive index n_{eff}=1.77**

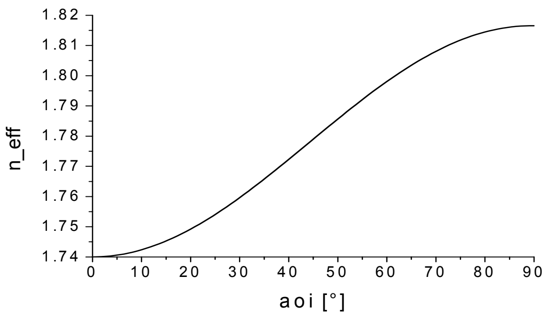

Fig. 2: Effective refractive index (equation 1) with **n_x = 1.74 and n_z = 1.89** obtained with an anisotropic optical model from the fit of the aoi spectrum (left)

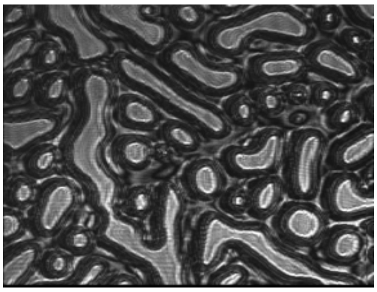

Fig. 3: Contrast image (0.2 mm x 0.25 mm): domains of polymer with high and low refractive index

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Excursion

Null-Ellipsometry of Refractive indices in anisotropic media

The dielectric tensor **ε** is a measure of the electric flux density **D** = **ε E** which is caused by the electric field **E** of an optical wave in a dielectric medium. In general **E** is not parallel to **D**. There are 3 principal axes where **E** is parallel **D** and where $D_i = \varepsilon_i E_i$ for the i-th axis. These axes are in general not perpendicular to each other. Each principal axis has a principal index of refraction $n_i = \sqrt{\varepsilon_i / \varepsilon_0}$

The effective dielectric constant of the medium for an optical wave is the projection of the dielectric tensor on the direction of the polarization of the wave. The effective dielectric constant (and effective refractive index) depend on the propagation direction of the optical wave where the direction is given by the angle of incidence φ and the angle of rotation θ around the normal vector of the sample surface. An effective dielectric constant and effective refractive index is measured with a nulling-ellipsometer through 2- or 4-zone mean values of the observables delta and psi. In this case measured delta and psi can be fitted with an isotropic optical model of the film and the corresponding refractive index of this film are obtained. Alternatively angular spectra of delta/psi can be recorded and the principal refractive indices n_i can be obtained from an anisotropic optical model.

With the principal refractive indices the effective refractive index can be calculated as a function of the angles Φ and θ. E.g. in the special case of an uniaxial medium with the ordinary refractive index $n_o \equiv n_x = n_y$ different from the extraordinary refractive index $n_e \equiv n_z$ (where the z direction is perpendicular to the x-y sample surface) one has:

$$n_{eff}(\Phi) = n_x \sqrt{\frac{1}{2} + \frac{1}{2}\frac{1}{\cos^2(\Phi) + \frac{n_x^2}{n_z^2}\sin^2(\Phi)}} \qquad (1)$$

Results

Ordinary and extraordinary refractive indices, and thickness of a birefringent polymer film have been obtained through fitting an angular spectrum of delta/psi.

Conclusion

Domains of different optical properties, i.e. ordinary and extraordinary refractive indices, can easily be observed with Nanofilm's imaging ellipsometer EP³. These refractive indices can be measured within each domain through angle spectra with such a high lateral resolution, which is only featured by the EP³.

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