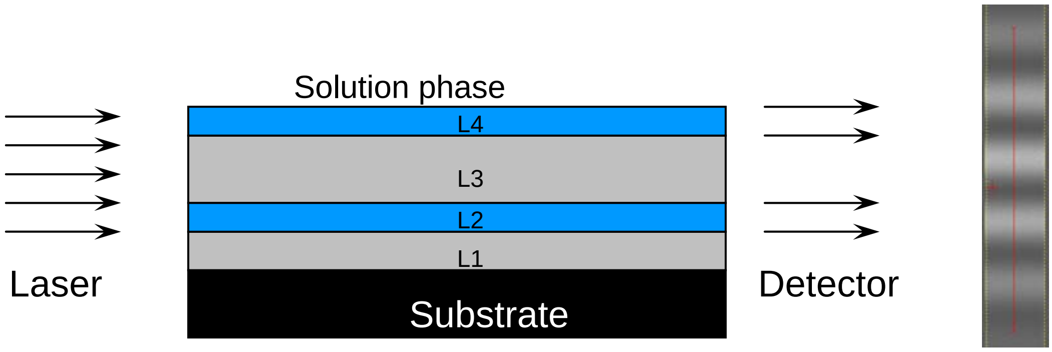
Dual Polarization Interferometry (DPI)

DPI is an evanescent wave technique that can probe molecular scale layers adsorbed on the surface of a waveguide. The method is based on the determination of the phase shift of a laser beam traveling through a sensing waveguide, which is induced by the adsorption of molecules on the waveguide surface. The heart of this instrument is the waveguide chip, which is a four-layer sandwich-like waveguide structure (see below). The bottom high refractive index waveguide layer (reference waveguide, L2) is sandwiched between two low refractive index cladding layers (L1 and L3), while the top waveguide (sensing waveguide, L4) is on top of L3 and exposed to the bulk solution. When plane-polarized laser light is shone on the end of the waveguide structure, it splits and travels separately through the two waveguides (sensing – L4 and reference – L2). As it emerges on the other side of the chip, the two signals interfere with each other; this interference can be detected by a camera as a fringe pattern in the far field.



Schematic representation of the bare waveguide structure and the fringe pattern given by the light emerging.from the waveguides.

Since the sensing waveguide emits an evanescent field into the solution phase above the waveguide, the light propagation through the sensing wave guide is affected by the formation of additional layers on top of the sensing waveguide. Thus, due to the formation of an adsorption layer, the effective refractive index of the waveguide (n_{eff}) is changed and as a consequence the light propagation through the sensing waveguide is also changed resulting in a phase change ($\Delta\Phi$) of the light emerging from this waveguide:

$$\Delta\Phi = \Delta n_{eff} L k_0 ,$$

where L is the length of the waveguide and k_0 is the free space wave number of the laser light. At the same time the light traveling through the reference waveguide remains unaffected, thus, the phase change (and the change of the effective refractive index) of the sensing waveguide can be obtained directly by monitoring the Fourier transform of the fringe pattern.

Theoretical Model

To determine the characteristics (thickness and refractive index) of the adsorption layer deposited above the sensing waveguide a theoretical model is required. To describe the propagation of light through the waveguide structure the Maxwell's equations are used. If the formation of homogeneous, isotropic layers is assumed on top of the sensing waveguide the transfer matrix method can be used to determine the guided mode (the effective refractive index) of a waveguide structure. The transfer matrix method allows the inclusion of an arbitrary number of layers in the model. Each layer is represented by its own layer matrix, which ensures that the relevant field amplitudes are matched at each layer boundary. A valid effective refractive index for a given waveguide structure is represented by a value for which the electric field decays outside the waveguide structure. Since the detailed description of the transfer matrix method exceeds the limitations of this paper, the interested reader is referred to the literature.[1]

The general assumption in the evaluations of the DPI data is that a single, isotropic and homogenous adsorption layer forms on the top of the sensing waveguide. In this case unique layer parameters (thickness and refractive index) can be assigned to the adsorption layer, since in a DPI experiment two independent polarizations (TE and TM) are measured. This way two independent experimental parameters (the effective refractive index change for both polarizations) are determined that allows the determination of two layer parameters. In practice this means that the layer thickness and refractive index are varied until the guided modes provide effective refractive indices that are equal to the experimentally determined values.

In principle a more detailed characterization of the adsorption layer structure is possible if further independent experimental data are available. E.g. to resolve the characteristics of a bilayer structure (d_1, n_1, d_2, n_2) two more experimental parameters are needed (four altogether). In principle these two experimental parameters can be provided by ellipsometry measurements (Δ and Ψ). Unfortunately, even if the experimental data are available, finding the proper parameters (d_1, n_1, d_2, n_2) in the four-dimensional parameter space is a rather calculation intensive task that is practically possible only with a software that can fit the DPI and ellipsometry data together. Unfortunately, such a program or function libraries that could "feed" a parameter estimator program with the necessary simulated DPI and ellipsometry signals are not available currently. In the lack of appropriate software our work is limited to the qualitative analysis of the combined DPI and ellipsometry data as described in the Discussion. Further work is in progress to develop a program for the combined fitting of the ellipsometry and DPI data.

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[1] C. Vassallo, in *Optical waveguide concepts*, Elsevier, Amsterdam, 1991.
A. Hayder, in *Analysis of Planar Optical Waveguides Using Different Techniques*, Lambert, 2011.