HF-Sputtered Glass Waveguide Slides for Waveguide Evanescent Field Microscopy

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Planar step-index glass waveguide slides with three grating excited guided modes for both s- and p-polarization were produced by depositing a high refractive index glass film on silica substrate slides by a HF-sputtering technique. They showed homogeneous etched coupling gratings, very narrow m-lines and proved resistance against combined chemical/ultrasonic cleaning procedures. The refractive index of the deposited glass film increased with respect to its bulk value by approx. 2%.

1 Introduction

Waveguide evanescent field microscopy (WEFM) relies on a particular strongly interface confined dark field illumination technique where guided modes interact with the specimen deposited on top of a thin film by their evanescent field tails as shown in figure 1. Using a planar step-index waveguide slide has several advantages for the examination of surface structures attached to the waveguiding layer. The specimen can be observed through the waveguide slide and the use of multiple modes makes it possible to calculate distances perpendicular to the slide surface in the range of a few nanometers. The WEFM setup even allows the observation of living specimen and their interaction with the surface.

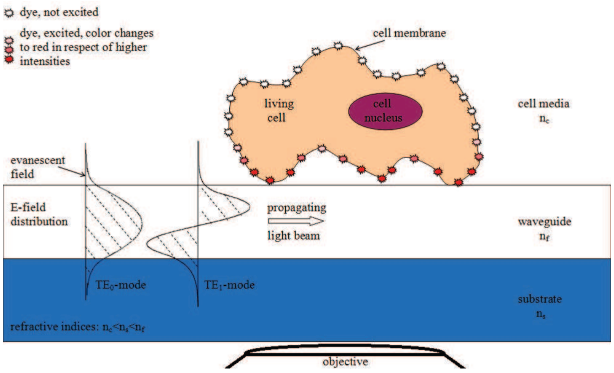

Fig. 1 *Guided modes propagating in a planar step-index waveguide slide illuminating the specimen with their evanescent field tails in close proximity to the waveguide surface only*

2 Specification of the Waveguide Slides

As being the key-part of WEFM the waveguide slides need to fulfill several requirements. The substrates and the deposited thin film have to be transparent for the wavelengths of the used lasers and the emitted light of the fluorescent dies as well if the specimen is stained. Optimized for green and red HeNe-laser radiation three modes both for s- and p-polarization have been used for the detection of adhered living cells and the determination of the cell surface to waveguide slide distances. For biological applications the waveguide slides need to be compact and sterilizable, hence a permanent coupling grating for mode excitation has been integrated.

3 Manufacturing of the Waveguide Slides (Planar Step-Index)

The substrates (25x50mm) used for our waveguide slide fabrication consist of the Float Glass BF33 (Schott, Mainz, Germany) or the Fused Quartz Glass FQVIS2 (Hebo Spezialglas, Aalen, Germany). The grating constant of approx. 630 nm is determined by mode coupling angles realizable by the microscopic set up. The sinusoidal coupling grating with a modulation depth of approx. 30-40 nm has been formed by interference lithography and subsequent reactive ion etching using sulfur hexafluoride as reactive gas. Figure 2 shows the setup to deposit high refractive index P-LASF 47 glass films (Schott, Mainz, Germany) on the silica substrates which are placed on a rotating substrate mount in the plasma chamber. A high-frequency plasma generated between target and substrates enables the layer deposition whereas the homogeneity of the sputtered layers increases with the distance to the target. The etched grating profile will be transferred to the surface of the waveguide film.

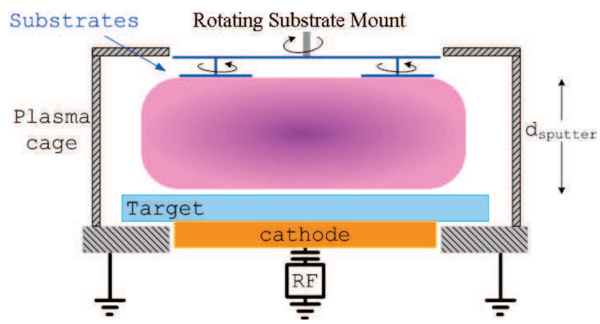

Fig. 2 *HF-sputter setup for thin glass film deposition*

4 Characterization of the Waveguide Slides

The waveguide films have been characterized by m-line spectroscopy, spectral reflectometry and AFM scans. The coupling gratings were examined before and after the sputter process. Figure 3 shows a grating profile after the sputtering process which has kept its sinusoidal shape almost completely. Evidently the grating pattern etched into the substrate has been well reproduced at the surface of the waveguiding film. The grating has a modulation depth of 34 nm which is suitable for the WEFM application. The depth of the grating on both sides of the sputtered layer is approximately the same. The grating constant shown in figure 3 is 626 nm which has been confirmed by Littrow reflex technique.

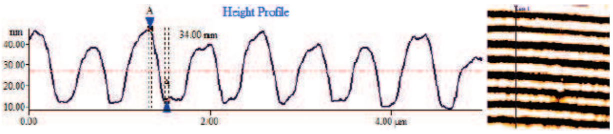

Fig. 3 *AFM profile and picture of an etched grating*

The m-line spectroscopy is used for the inspection of the layer properties thickness and refractive index by measuring the coupling angles of the excitable modes. Figure 4 displays the six very narrow m-lines of a waveguide slide. The waveguide thickness derived from these angles is 640 nm.

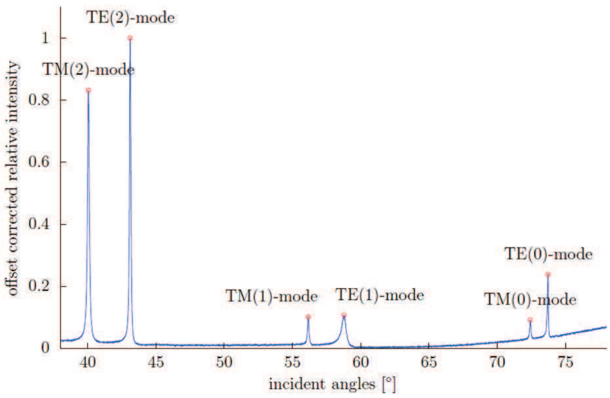

Fig. 4 *M-Line peaks of a waveguide slide*

The refractive index is 1.853 at 543 nm wavelength. Interestingly, the refractive waveguide index proves to be shifted to slightly higher values compared to the bulk material value of P-LASF 47 which is 1.81125. For all glasses tested we found an increased refractive index by 1 to 2% which is listed in table 1.

Glass type	wavelength	bulk	sputtered film
P-LASF 47	543 nm	1,81125	1,849 - 1,857
P-LASF 47	633 nm	1,80203	1,837 - 1,847
N-LAK 7	543 nm	1,65451	1,668 - 1,670
N-LAK 7	633 nm	1,64925	1,663 - 1,665

Tab. 1 *Refractive index shift of sputtered thin glass films*

Thickness profiles across the waveguide layer have been recorded by spectral reflectometry measurements with an OceanOptics NanoCalc XR optical profilometer. The thickness has been determined at 36 different positions with a distance of 5 mm in each direction. Figure 5 shows the surface height profile of a waveguide slide. At the far ends the layer thickness is decreasing which is due to the sputtering geometry in the plasma chamber. In the most relevant part for WEFM, the center of the slide and close to the edge of the etched coupling grating, the thickness homogeneity proved satisfactory.

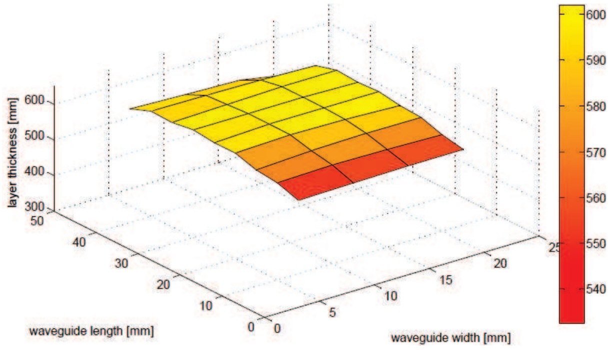

Fig. 5 *Thickness homogeneity measurement with OceanOptics NanoCalc XR*

As cleaning and sterealizing of the waveguides slides is important for biological applications the stability of the sputtered layers has been examined. After each cleaning process the thickness and the refractive index have been determined by m-line spectroscopy. The P-LASF 47 waveguide layers have been cleaned several times with water and organic solvents in an ultrasonic bath for 5 min at 40°C. For these cleaning processes the thin films proved stable and no alteration in thickness or refractive index could be observed. The N-LAK 7 layers lost thickness during the cleaning processes and have been discarded.

5 Results/Outlook

Waveguide slides suitable for WEFM applications have been fabricated successfully. The slide performance after the successful integration into a WEFM setup has been demonstrated[1]. AFM measurements showed stable and homogeneous sinusoidal gratings. Shifts to higher refractive indices of the sputtered layers with respect to the bulk material has been observed. The glass films proved resistant against ultrasonic cleaning procedures with water and organic solvents.

The thickness homogeneity of the sputtered waveguide layers needs further improvement and the application of other layer materials is under way.

[1] Darryl K. Knight, Rebecca Stutchbury, Daniel Imruck, Christopher Halfpap, Shigang Lin, Uwe Langbein, Elizabeth R. Gillies, Silvia Mittler, and Kibret Mequanint. Focal Contact Formation of Vascular Smooth Muscle Cells on Langmuir-Blodgett and Solvent-Cast Films of Biodegradable Poly(ester amide)s. *ACS Applied Materials & Interfaces*, **4(3)**:1303-1312, 2012