Modelling of intensity planar waveguide transducers supporting surface plasmon polaritons

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Planar evanescent wave sensors (EWS) are important tools for detection of the presence of (bio)chemical compounds as well as for studying kinetics of biochemical reactions [1]. An optical transducer is a part of the EWS, in which the measurand is transduced on a change of the guided wave parameters: an intensity, a phase, a polarization. An interaction between the measurand and a guided wave is being realized by a sensitive film. A planar waveguide is a fundamental part of the optical transducers, which can be categorized into two general categories: phase transducers and intensity transducers [2,3]. Theoretical analysis allows optimization of EWS parameters allowing achievement of its desirable sensitive parameters. This work is devoted to modeling of the planar multilayer waveguide intensity transducer utilizing surface plasmon polariton (SPP) modes for detection of refractive index changes.

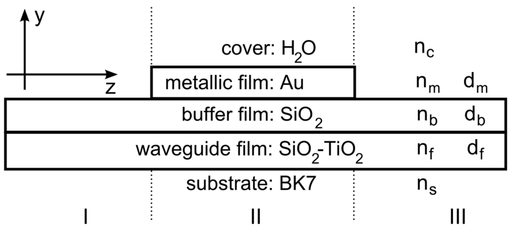

Fig. 47. Scheme of the planar optical waveguide transducer.

The modeled structure (Fig.1) is composed of three sections: input (I), sensing (II) and output (III). First and third section are four layered structures composed of a substrate (BK7), a monomode silica-titania waveguide film characterized by high-refractive index value (~1.81 for λ=677 nm) and a silica buffer film. In the second section (five layered sensing section) the waveguide structure is loaded by a metallic film (gold). A semi infinite layer of water is considered as a cover. The following naming convention is taken: a TM_0 mode, supported by this structure in sections I and III is called unloaded, whereas this mode in the section II, is called loaded. Beside the loaded TM_0 mode, the section II supports two types of surface plasmon polariton modes: symmetric and antysymmetric [4]. They are denoted as SPP_b and SPP_t respectively. For such structure there are presented and analyzed spectral characteristics of effective indexes of loaded and unloaded TM_0 waveguide modes and both SPP modes. The analysis of these characteristics is aimed at finding the best conditions for exciting the loaded TM_0 mode and SPP modes, taking assumption that the exciting is done by the field distribution of the unloaded TM_0 mode. There are three conditions that must be met for successfully excitement: polarization, phase and wavelength matching. The analysis was carried out in a wavelength ranging from λ=400 nm to 800 nm. A thickness of silica titania film was assumed to be constant and equal to 180 nm, which is slightly higher than a cut-off thickness. At this thickness, an optical power density is maximized on the silica-titania film interface. A thickness of the silica film was changed from d_b=0 nm to d_b=100 nm with a 10 nm step. Finally, analysis was carried for three values of gold film thickness:

d_m=50 nm, 60 nm and 70 nm. The FDM method implemented in the FIMMWAVE solver was used. It was shown that the presence of silica film is indispensable for reduction of a difference between effective indexes of unloaded and loaded TM_0 modes. Conditions for matching effective indexes of either loaded or unloaded TM_0 modes with SPP_t modes are met in a broad range of silica film thickness only for a gold film of thickness 50 nm. Increasing a thickness of the gold film requires increasing the silica film thickness in order to reduce the difference between both TM_0 modes. However it's possible only in a range of wavelengths in which SPP_t modes have effective indexes lower than BK7 refractive index, rendering their excitement impossible. For d_m=60 nm and 70 nm there are conditions for matching TM_0 modes with SPP_b modes, however effective refractive index characteristics of loaded and unloaded TM_0 modes are strongly separated. Moreover, in order to characterize this structure from the sensory point of view, there were calculated spectral characteristics of its sensitivity toward changes of cover refractive index. This sensitivity is defined as a derivative of attenuation coefficient α in respect to cover refractive index n_c for a given wavelength:

$$S_{\alpha H} = \frac{d\alpha}{dn_c} \tag{1}$$

This definition was derived analogously to the homogeneous sensitivity, that characterizes sensitive properties of phase EWS. It was shown that for structure with gold film thickness d_m=50 nm there is a single maximum which initially is moving toward longer wavelengths along with an increase of the silica film thickness and after that moves back toward shorter wavelengths. Within a range of change of above defined parameters, only for SPP_t modes there is a range of silica film thickness allowing excitation of the loaded TM_0 mode that is matching the SPP_t mode whose sensitivity is close to maximum on its spectral characteristic.

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References

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