Optimization Study of Bimodal Waveguide Interferometric Biosensors

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Clinical diagnosis of diseases dependant on genetics of patients is still limited due to the lack of quick, precise, cheap and reliable technological tools. Such diagnostic tools would allow the design of personalized treatments for each patient according to its genetic profile. Photonic biosensors based on evanescent wave detection can afford such diagnostic tools. Using the evanescent wave detection principle, a new bimodal interferometer sensor has been proposed[1]. This device is comprised of a single mode rib waveguide which abruptly increases its core thickness to guide two transversal modes (TX_{00} and TX_{10}) propagating until the output of the chip. A sensing area is defined in the bimodal part of the waveguide and, as the fundamental and first order modes have different intensity distribution at the core-cladding interface, the interface pattern is a function of the refractive index in the sensing area. A complete study is made starting from the previous device in order to improve its characteristics. The model used for simulations consisted of a variable thickness core layer (260-380 nm) of Si_3N_4 with n = 2.0 over a 2 µm SiO_2 cladding layer with n = 1.46 and water (n=1.33) in the sensing area over the waveguide core using Film Mode Matching (FMM) Method in Photon Design 5.4[2].

Firstly, nominal device dimensions were evaluated obtaining a 19% of coupling for η_{10} and 69% for η_{00} under current conditions (total length of 3.1 cm). Modifying the lengths of each section would make possible to obtain up to 26% for η_{10} and 61% for η_{00} while having a more compact design (1.7 cm). Secondly, the step junction can be located within or outside the sensing area (buried under water or under the cladding). Both scenarios were simulated obtaining a total coupling coefficient of 27.8% for η_{10} when the step junction was located 450 µm within the sensing area. Finally, the most relevant parameter to evaluate the performance of an evanescent wave biosensor is the surface sensitivity. In this case a thin layer of bioreceptors is immobilized on the sensor surface and interacts selectively with the corresponding analyte. In order to know the effect of the biolayer thickness on the surface sensitivity we have done a numerical study. We have considered a homogeneous biolayer with refractive index of 1.45 (standard value for a protein bioreceptor layer) that will result in a new effective refractive index for each mode as its thickness increases. The surface sensitivity is, therefore, defined as the phase variation as a function of the thickness d of such a biolayer $S_{surface} = \partial\varphi/\partial d = (2\pi L/\lambda) * \partial(N_{TE10} - N_{TE00})/\partial d$. The biolayer is assumed to grow uniformly over the core-water interface. Biolayer thicknesses between 0.1 nm and 1 µm in logarithmic scale were simulated for each core size. Figure 1 shows the derivative of the difference of the effective index of each mode ($TX_{10} - TX_{00}$) respect to the changes of the biolayer thickness when having different core sizes and light polarizations.

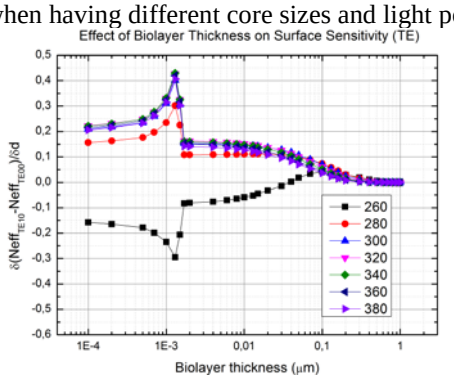

Fig. 1. Effect on surface sensitivity of a biolayer growing in the surface of the bimodal waveguide for different cores

As the biolayer grows, some light becomes guided in it and radiated further away of the core rib and an increasing behaviour is observed (0.1 – 2 nm). However, once the biolayer thickness reaches the rib size of 2 nm, a discontinuity and a decreasing behaviour is observed instead. The change in the orientation is assumed to be related to the critical working point effect which is a set of conditions in hetero modal interferometer based biosensors where a divergence in spectral sensitivity is expected[3]. When moving to the right or left of the critical point a switch in the increasing or decreasing behaviour is expected. Nevertheless, biolayers between 3 and 100 nm will provide the most stable surface sensitivity value which is within the usual range for biological interactions (as antigen-antibody) relevant for clinical diagnosis. As observed in the graphic, core sizes below 270 nm will show a decreasing behaviour and the best sensitivity will be obtained with cores of 340 nm which is in a good agreement with our physical design.

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