Simulation and Experimental Evaluation of Optical Chirp Modulation for Bimodal Waveguide Interferometer Biosensors

Daniel GRAJALES[1], Jose Ramón SENDRA[2], Laura M. LECHUGA[1 *]
[1]Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and the Barcelona Institute of Science and Technology, and CIBER-BBN. Campus UAB. Barcelona, Spain.
[2]IUMA, Institute for Applied Microelectronics, University of Las Palmas GC, Campus de Tafira, Las Palmas, Gran Canaria, Spain.
[*] Laura.Lechuga@icn2.cat

We report the simulation and implementation of an optical chirp modulation system for interferometric optical waveguides operating in the visible range to explore the sensor response to different wavelengths in order to ensure the maximum sensitivity.

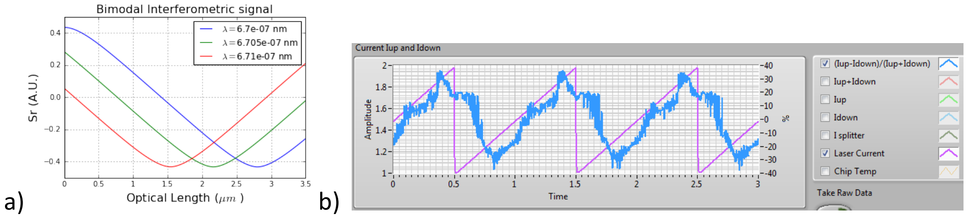
Optical interferometers are powerful and sensitive tools for detecting small changes at nanometric scale. When working as biosensor devices they can provide the highest sensitivities for real-time and label-free biomolecular detection, without the need of additional amplification steps. Our group proposed a Bimodal Waveguide Interferometer (BiMW) as a high performance biosensor, which is an elegant, robust, simple yet powerful and sensitive device [1]–[3]. Nonetheless, due to the nature of the interferometric signals, sensitivity fades or signal ambiguities can be present. To overcome such difficulties we proposed an all-optical phase modulation [4]. However, this technique required the individual analysis of the visibility (signal amplitude) inherent to each BiMW sensor, previously to any experiment, in order to ensure that we can get the maximum sensitivity. As a replacement, we propose a chirp modulation as an exploratory mechanism previous to the detection.

Some Fabry-Perot laser diodes (LD) can exhibit the defect of wavelength excursions of a few nanometers as a function of the variation of the injected power current. Thus, while varying (modulating) the LD current we can obtain a wavelength and intensity sweep. Each wavelength will have a different propagation constant and effective index thus, some of them will be in the maximum sensitivity position. In the case of the bimodal interferometer, the interferometric signal is obtained from the variation of the phase difference of the two modes. Since the first order mode has a larger evanescent tail, it will be more affected by changes occurring in the sensing area. The changes of intensity distribution at the output can be related to the variations occurring in the sensing area. By placing a two quadrants photodiode, the output intensities can be used to recreate the interferometric signal:

$Sr = (I_{up} - I_{down})/(I_{up} + I_{down})$, where I_{up} and I_{down} are the light intensities in the upper and lower photodiode quadrant, respectively. For a constant wavelength, the interferometric signal is related to the phase change $\Delta\varphi(t)$ by $Sr \propto V\cos(\Delta\varphi(t))$, where V is the visibility factor or fringe amplitude. The interferometric phase change as a function of the optical wavelength λ is given by:

$$\Delta\varphi_S(\lambda) = \frac{2\pi L}{\lambda}[(N_S - N_R)] \quad (1)$$

where L is the length of the waveguide and N_S and N_R are the effective index of the fundamental and first order mode of the BiMW. We start simulating the intensity response to wavelengths variations of 1 nm in steps of 0.5 nm using numerical and scientific python libraries. Figure 1a shows the simulated intensity response of a BiMW device as a function of different laser wavelengths and optical path length.



☑ (Iup-Idown)/(Iup+Idown)
☐ Iup+Idown
☐ Iup
☐ Idown
☐ I splitter
☑ Laser Current
☐ Chip Temp

Fig. 1. Example of a simulated (a) and experimental (b) BiMW response for small wavelengths variations.

Using an experimental approach, different signal waveforms, amplitudes and offsets were evaluated modulating the LD current until finding the suitable ones for the BiMW devices. Because the biomolecular interactions taking place in the sensing area are slow (in the order of seconds), we can use slow modulation frequencies (1-100 Hz). The algorithm was implemented in LabView, modulating a Mitsubishi ML101J27 LD and using a Hamamatsu - S4349 Photodiode with micrometric positioning to obtain the signal. Figure 1b shows the response for a laser current sweep when having a constant refractive index in the sensing area. The micrometric positioning can help us to ensure a symmetric placement of the read-out photodiode thus obtaining an interferometric signal centred and ensuring the maximum sensitivity.

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