SU-8 micro-biosensor based on Mach-Zehnder interferometer

Rev.Adv.Mater.Sci. 10 (2005) 295-299

SU-8 MICRO-BIOSENSOR BASED ON MACH-ZEHNDER INTERFEROMETER

D. Esinenco[1], S.D. Psoma[2], M. Kusko[1], A. Schneider[2] and R. Muller[1]

[1]IMT, Dept of Multidisciplinary Research, National Institute for Research and Development in Microtechnologies, P.O. Box 38-160, Bucharest, Romania

[2]Central Microstructure Facility, Engineering and Instrumentation Dept., CCLRC, Rutherford Appleton Laboratory, Chilton, Didcot, Oxfordshire OX11 0QX, U.K.

Received: June 18, 2005

Abstract. In this paper design, simulations and preliminary experimental results for an optical biosensor, using a Mach-Zehnder interferometer as basic configuration, are presented. This type of sensor offered a lot of advantages such as compactness, real time analysis, low cost and high sensitivity and the possibility of integration of electronic detection components on the same chip. The integrated optical structure is sensitive to refractive index change induced due to the interaction of the evanescent field with an immobilised biological sample placed on one of the two arms of the interferometer (the sensitive one). A window is open in the upper cladding of the waveguide. Changing the bio specimen produces a variation of the refractive index of the cladding layer, which can be observed through the phase shift difference between the light of the two interferometer arms.

SU-8 polymer was tested as the core of the optical waveguides, an epoxy-based negative photoresist material, which presented very good transmission properties providing low propagation losses and SiO_2 and PMMA positive photoresist were utilised as lower, respective upper claddings. The Optiwave FDTD software was used for the simulation of the propagation of the electromagnetic field at λ=630 nm and for the optimisation of the Mach Zehnder interferometer parameters.

1. INTRODUCTION

Because of the huge demand for smaller biosensors, capable of transforming a biological reaction into a measurable signal, integarted optic sensors attracted considerable interest, taking into account their advantages such as small size, easy to handle, possibility to obtain integrated analysing microsystems [1-3]. Biosensors are also becoming more important devices for the determination of the mechanisms and kinetics of biological events [4,5].

The properties of light propagation can be modified in different ways due to variations of absorptive, refractive or luminescent properties of the biological layer [1]. There are many techniques used to detect properties of biosamples: luminescence, interference, Surface Plasmon Resonance (SPR), depending on the way that the bio-layer manifests itself during the interaction with light field [6,7]. The SPR method for the detection of thin biological films outputs a single value comprising of two parameters describing the biological layer: its thickness and its refractive index.

The fabrication and operation of robust integrated optical refractometers, suitable for precise measurements of small changes without ambiguity over a

Corresponding author: S.D. Psoma, e-mail: S.Psoma@rl.ac.uk

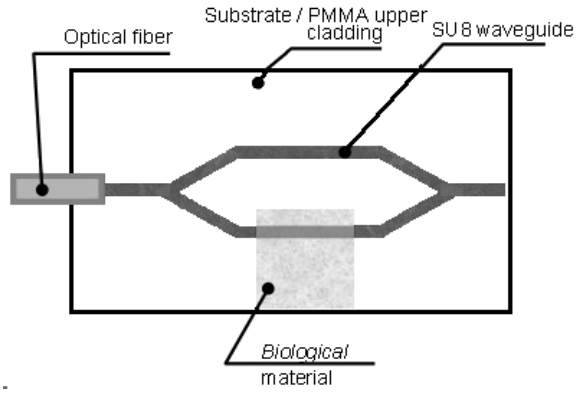

Fig. 1. Schematic presentation of the Mach-Zehnder biosensor.

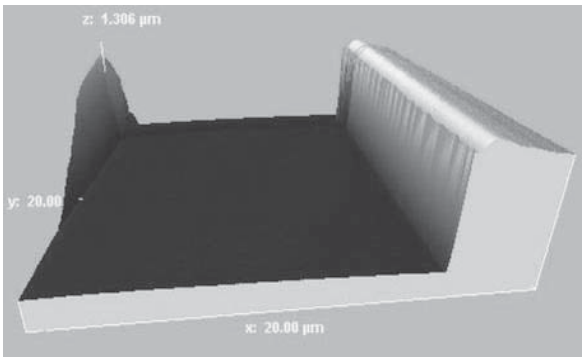

Fig. 2. AFM profile of an SU-8 waveguide edge.

wide range of refractive indices have been developed [8-11].

In this study, a sensing principle is presented that is based on mono-mode planar optical waveguides which are integrated using an interferometric architecture: a Mach-Zehnder Y splitter waveguide with far field interference. The shift in the effective refractive index will be induced by the biological sample immobilised on the surface of the core or the waveguide, in the open window which allows the interaction with the surrounding medium and subsequently will be sensed at the output signal. The main idea is to obtain cheap miniaturized sensors that can be integrated with the light source and field detector with a high working accuracy. Simulation and preliminary experimental results are also presented and discussed.

2. SENSOR CONFIGURATION

The main interest of the present research is focused in DNA genome and enzyme detection [4,5]. The basic preliminary tested structure of the sensor has the architecture presented in Fig. 1. As it can be observed, a polymer (typically PMMA or other) with a lower refractive index, than SU-8, covers all sensor's surface except the sensing area. The sensing area presents an opening in the cladding at the top of the waveguide. Through this window the bio material can directly contact the surface of the waveguide.

The purpose is to determine more precisely the interaction between the wave front and the bio specimens, which results mainly from the main modes and propagation principles of light through the waveguide. Bio interaction also changes the effective refractive index and absorbance coefficient of the layer at a certain frequency.

The structure has to be designed in such a way that the profile of the electric field components to extend above the waveguide top surface. In this way the waveguide lets out an evanescent wave, which is sensitive on materials deposited on the top [2]. This structure is obtained by thermally grown SiO_2 coating with a thickness of 1.6-1.7 mm. A positive photoresist (PMMA) was used as the upper cladding, with a lower refractive index than SU-8. Strip optical waveguides were defined using photolithographic techniques. The dimensions of the SU-8 core were: thickness 0.9 μm, width 1-12 μm and a refractive index of n = 1.58-1.59.

Special attention should be given to the waveguide top surface relief and cladding. In SU-8 photo-resist, a deformation near the edges was obtained (Fig. 2) maybe due to the hydrophobic properties of the resist. In some cases this kind of surface non-uniformities could be helpful in more precise quantitative detection, as described in [2].

As it will be described below, these deformed edges extend the TE (Ey in the current case) mode outside the waveguide, increasing its sensibility. Typically thin gold nano-particles layer can be used to bind complementary DNA strands and to amplify bio sample reaction with the evanescent field. The biomolecules must be somehow aligned or selected. The hybridization process of DNA strands leads to 'in plane' amino acids aligning, resulting amino-acids planes parallel to the binding surface. When DNA molecules bind to the waveguide top surface, they form an amino-layered cladding. Each of the cladding's plane, during the interaction with the evanescent field, can act as a floating refractive index

layer. The TE and TM modes are affected depending on the 'bio cladding' composition. TE and/or TM modes interference analysis should give enough information about the qualitative and quantitative aspect of the bio samples.

The difference in refractive index values between the reference arm and the sensing one results in a phase shift between the two arms that can be read whether at the end of the waveguide with an integrated photo-detector or in the far field using CCD and numeric analyses.

3. SIMULATION AND RESULTS

Optiware FDTD tools were used in order to optimise the size of the design and to improve the Mach-Zehnder interferometer parameters. The first step was to establish the thickness of the SU-8 optical waveguide in order to have low losses and monomode propagation. Fig. 3 presents the results of the simulation: the normalised intensity of light versus the SU-8 core thickness. As it can be observed, for values less than 1 μm, the losses become higher. The light intensity is strongly dependent on the waveguide thickness up to a certain value. As anticipated, increasing thickness shows less attenuation on superior modes, which makes it a multimodal waveguide.

For monomode propagation, the thickness of the guiding layer has to be reduced, so that a value between 1.1 – 1.5 μm was chosen in order to respect both conditions.

The second step was the design of Y beam splitter. Low losses can be obtained only if small separation angles are used. Fig. 4 shows the simulation results.

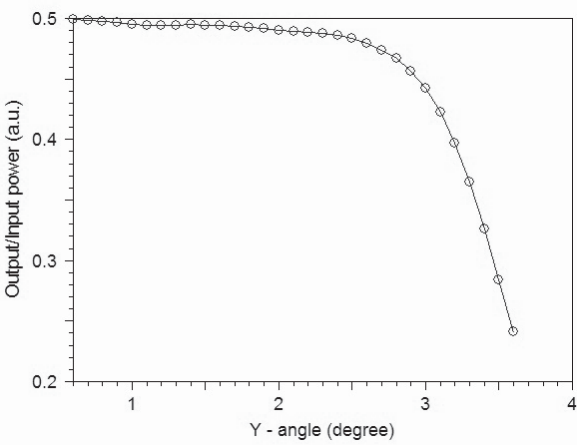

Fig. 4. Light intensity losses in the Y-splitter versuss angle value.

A number of computations and measurements for the interferometric sensor were carried out. The simulation results showed that very small refractive index changes in the cladding of one arm, cause a notable light intensity change at the merging point of the two arms that can be read at the end of the Mach- Zehnder interferometer. In addition, the fundamental transverse mode for the designed configuration was simulated. The corresponding results are illustrated in Fig. 5.

The test structure of the Mach-Zehnder biosensor was coupled to an optical fiber, for an electromagnetic wavelegth of 635 nm.

Both the SU-8 waveguide itself without any bio layer or cladding and the final sensor structure were tested. In Fig. 6, the far field CCD image of a MZI without any bio sample on it is shown. Two CCD data collected for both cases: intensity maxima (due

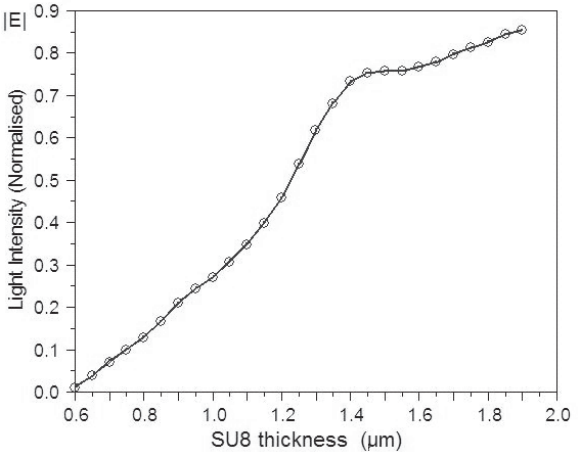

Fig. 3. Output SU-8 waveguide power function of the core thickness.

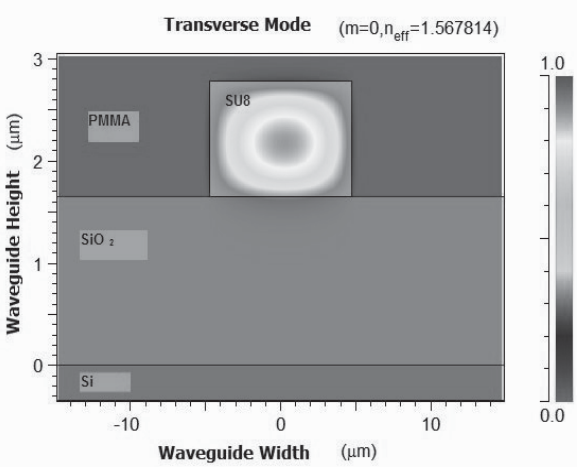

Fig. 5. Field distribution of the fundamental mode of the SU-8 waveguide.

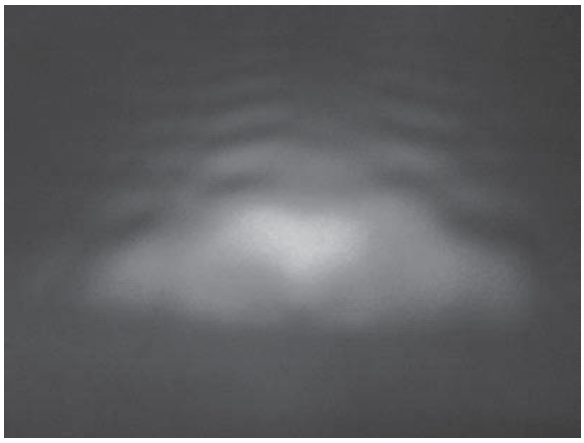

Fig. 6. CCD photo of the MZ far field.

to the absence of any bio sample) and a lower intensity value (due to the presence of the bio layer) are presented in Fig. 7. For better measurement results and higher accuracy the analyzes should be done for TE and TM modes separately.

Fig. 8 presents a SEM photo of the region of the sensitive arm of the interferometer.

4. CONCLUSIONS

Design, simulation, and fabrication of an integrated optical biosensor based on a interferometric arhitecture is described. This biosensor consisted of SU-8 polymer strip optical waveguides integrated on silicon substrate and is based on the evanescent field interaction of the electromagnetic radiation with an immobilised bio-sample on the top of the core of a waveguide, in a defined sensing region. The output signal can be detected and analysed with a CCD or an integrated photodiode. The refractive index of the specimen is sensitive to density, sample composition and layer thickness of the cladding. The effective refractive index is also strongly dependent on the light polarization showing differences in response for TE and TM waves.

Using polymers as basic materials for integrated micro biosensors, compared with other materials as SiON or Si_3N_4 it allows the production of cheaper sensing structures. These devices are expected to find application in multi-purpose instrumentation for biological and chemical sensing due to their high sensitivity, and low cost, and response to changes in the optical properties of surface layers used to add specificity.

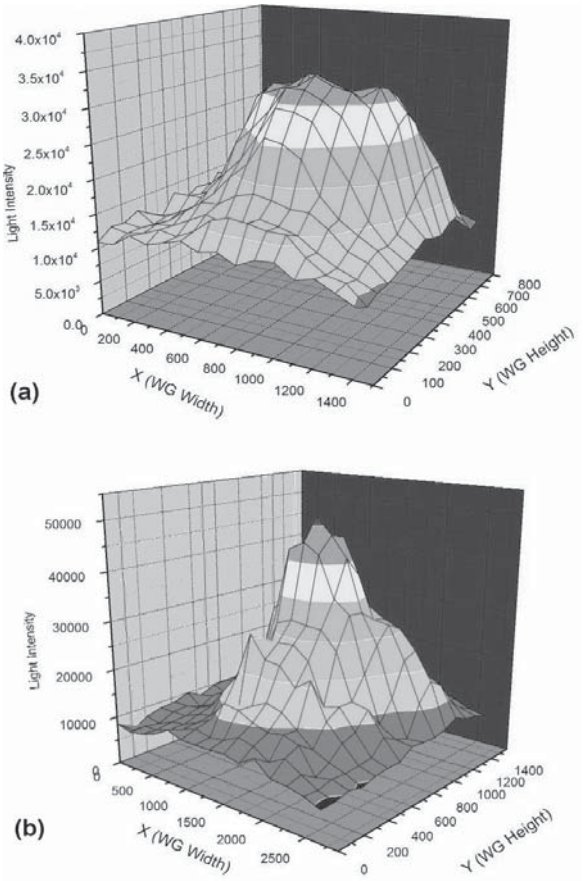

Fig. 7. CCD analyzed data of the far field for the MZI: *a)* absence of the bio layer; *b)* presence of the active bio layer.

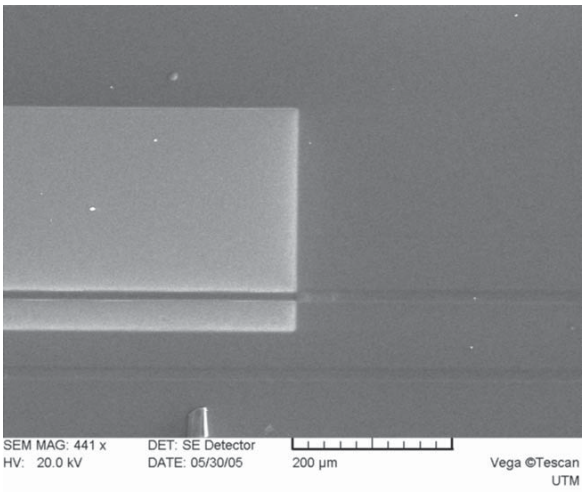

Fig. 8. SEM photo of the test configuration of the biosensor.

ACKNOWLEDGEMENTS

This work was supported by EU FP6 Marie Curie MRTN CT 2003-504826 ASSEMIC Project, and the National Romanian Program MATNANTECH 'New Materials, Micro and Nano-technologies'.

REFERENCES

[1] B.H. Schneider, J.G. Edwards and N.F. Hartman // *Clinical Chemistry* **43** (1997) 1757.
[2] R. Műller, P Obreja, M. Kusko, D. Esinenco, C. Tibeica, G. Conache, L.Buia, D. Apostol, V. Damian, M. Mateescu, M. Diaconu and L. Moldovan,In: *SPIE- ATOM'04 Conference* (November 2004, Bucharest, Romania) 43.
[3] J.J. Storhoff, S.S. Marla, P. Bao, S. Hagenow, H. Mehta, A. Lucas, V. Garimella, T. Patno, W. Buckingham, W. Cork and U.R. Muller // *Biosensors & Bioelectronics* **19** (2004) 875.
[4] F. Lucarelli, G. Marrazza, A.P.F. Turner and M. Mascini // *Biosensors & Bioelectronics* **19** (2004) 515.
[5] J. Vörös, R. Graf, G.L. Kenausis, A. Bruinink, J. Mayer, M. Textor, E. Wintermantel and N.D. Spencer // *Biosensors & Bioelectronics* **15** (2000) 423.
[6] R. Cush, J.M. Cronin, W.J. Stewart, C.H. Maule, J. Molloy and N.J. Goddard // *Biosensors and Bioelectronics* ***8*** (1993) 347.
[7] P.E. Buckle, R.J. Davies, T. Kinning, D. Yeung, P.R. Edwards and D. Pollard-Knight // *Biosensors and Bioelectronics* **8** (1993) 355.
[8] P. Hua, B.J. Luff, G.R. Quigley, J.S. Wilkinson and K. Kawguchi // *Sensors and Actuators B* **87** (2002) 250.
[9] P. V. Lambeck, In: *Proceedings of the 10th European Conference on Integrated Optics* (Paderborn, Germany, 4-6 April 2001) p. 153.
[10] K.B. Mogensen, J. El-Ali, A. Wolff and J.P. Kutter // *Applied Optics* **42** (2003) 4072.
[11] C. Gorecki, M. De Labachelerie and L. Thiery // *IEEE Sensors Journal* **3** (2003) 121.