Exchangeable low cost polymer biosensor chip for surface plasmon resonance spectroscopy

Cleumar S. Moreira\textsuperscript{a,b,*}, Arlindo G. S. Barreto Neto\textsuperscript{a,c}, Antonio M. N. Lima\textsuperscript{a}, Carsten Thirstrup\textsuperscript{d} and Helmut Neffe \textsuperscript{e} *

\textsuperscript{a}Universidade Federal de Campina Grande, CEEI/DEE, Campina Grande, PB, Brazil
\textsuperscript{b}Electronic Department, IF-AL, Maceio, AL, Brazil
\textsuperscript{c}Electromechanical Department, IF-PB, Cajazeiras, PB, Brazil
\textsuperscript{d}Coloplast A/S Holtedam 1, 3050 Humlebaek, Denmark
\textsuperscript{e}CETENE/LINCS, PE, Brazil

Abstract

An exchangeable low cost surface plasmon resonance biosensor chip for real-time monitoring of biochemical interactions has been developed. It is based on a simple patented prism design, fabricated from a cyclic-olefin co-polymer (COC), which thus allows for high throughput fabrication, using injection molding techniques. The sensor chip can be operated in both, angular and wavelength interrogation modes, and ray tracing simulations have investigated the light beams focalization.

Keywords: surface plasmon resonance, polymer chip, injection molding.

1. Introduction

Biosensors, employing the surface plasmon resonance (SPR) phenomenon, are considered as optically and mechanically complex instruments. They reveal exceptionally high surface sensitivity and selectivity, non-labeling detection capability and are widely used for monitoring of biochemical interactions [1]. They are devices composed by normally 4 layers of different materials arranged as is shown in Fig. 1a. Under total internal reflection and energy-momentum conservation conditions, when a p-polarized light beam impinges the optical substrate, the incoming photons can be partial or totally transmitted to the thin gold film. Longitudinal oscillations on the gold surface, called surface plasmons, are excited and a dip in the reflectance curve can be observed (Fig. 1b). High surface sensitivity is achieved, and minimal changes in the sample layer (Fig. 1a), passing through the microfluidic cell, can be monitored by two approaches: one called angular interrogation mode or AIM, where a CCD camera detects the reflected monochromatic angle-varying light beams (Fig. 1b); and other named wavelength interrogation method or WIM, where a spectrometer detects the reflected polychromatic wavelength-varying light beams.

* Corresponding author. Tel.: +55 83 33101405; fax: +55 83 3310.
E-mail address: cleumar@ee.ufcg.edu.br.

1876-6196/09/$– See front matter © 2009 Published by Elsevier B.V.
doi:10.1016/j.proche.2009.07.369
Although exhibiting a bulky, complex and expensive configuration, the first commercial SPR biosensor is still the most used [1]. A small and low-cost biosensor has been successfully used in portable applications [2]. Nevertheless, external temperature fluctuations greatly affect its performance [3]. Another configuration comprised a holographic grating structure without the need of index matching oil or gel [4]. However, the high initial design cost and complexity reduces its applicability. These aforementioned biosensors and the majority of the proposed SPR devices are based on AIM configuration, which provides high refractometric sensitivity and portability. On the other hand, WIM SPR biosensors provide a more simple geometry and instrumentation with comparable refractometric sensitivity [3]. The combination of AIM and WIM is not discussed in the literature yet, but it can incorporate flexibility for various uses.

Here, an attempt has been made to construct a robust optical biosensor chip which can be operated in both, the AIM and WIM configurations. Simple cyclic-olefin co-polymer (COC) prism-based chips have been manufactured using injection molding. It reduces the design cost considerably, when compared to the holographic grating approach [4]. Our approach also excludes the need for use of index matching oil or gel. Ray tracing simulations were achieved to analysis the light beams focalization on the sensing region (Fig. 2a) and to check our proposal.

2. Proposed SPR biosensor set-up

A simple prism-based patented design proposed a small optical chip with an adequate incoming light beam focalization based on two integrated lenses (one for incoming light beams and another for outgoing light beams). It reduces the quantity of optical components and the final cost [5]. Due to angled mirror planes, the incoming light beams are perpendicular to the prism base plane. Nevertheless, the integration of cylindrical lens is not an easy task and external cylindrical lenses can be used.

The optical chip proposed in [5] has been developed using a COC prism-based manufactured by injection molding applied for both AIM and WIM configurations. Fig. 2 illustrates the proposed prism and its associated dimensions. The gold thin layers for both top and angled sides were sputtered, where for the later the thin layer works with a mirror and thus guarantee the total internal reflection in the prism. It is also noted only one reflection occurs from the incoming angled side until the sensing region. The thickness of the prism was previously defined, following the patent recommendations [5]. The incoming cylindrical lens is associated to the light rays focus on the sensing region (Fig. 2a). Ray tracing simulations have investigated the incoming light beams focalization for AIM and WIM cases. Using these results, the cylindrical lenses can be specified. These results and associated discussions are shown below.

1.1. AIM case

A collimated monochromatic light beam was generated by a red laser diode (670 nm). The optical prism is located at a distance $D$ from the lens. After only one reflection (Fig. 2a), the light beam impinges the middle of top side, on the sensing region. All the dimensions of a cylindrical lens [6] were changed, however only the thickness (Fig. 2b), $t$, and the curvature radius (Fig. 2b), $R$, affected the light beam focalization. The thickness of 4 mm was chosen (Fig 3a). If $t$ increased, the focus displaces to left and the opposite behavior was observed when $t$ was reduced (Fig. 3b for $t = 2$ mm). The variation of $R$ was more pronounced (Fig. 3c-d) and $R = 11.2$ mm (Fig. 3c) was
the chosen radius. When $R$ was reduced, the focus displaced to the left side and the opposite was obtained when $R$ was increased (Fig. 3d, for $R = 13\text{mm}$).

![Diagram](image)

Fig. 2. The proposed optical prism set-up (a), where all dimensions are in mm; and the cylindrical lens configuration.

Through the chosen values for $t$ and $R$, the plan-convex cylindrical lens LJ1638L1 was chosen. Besides of the geometry of the lens, changes in the distance $D$ affected also the focus $F$. When $D$ was reduced, the focus was displaced to the right from the sensing point (Fig. 3f, for $D = 1\text{mm}$) and for an increase in $D$, the focus was displaced for the opposite direction. For $D = 5\text{mm}$ (Fig. 3e), the focus was correctly positioned.

The reflectance curve was also obtained (Fig. 3g). Although the SPR phenomenon had been observed, the resonance angle ($78.5^\circ$) was quite different from the theoretical specification ($68^\circ$). It can be explained due to the used approximations to specify the wavelength dependence on the refractive index of the gold and water layers.

1.2. WIM case

Using a collimated light beam as the input source and the changing the input wavelength, we investigate the WIM approach. The cylindrical lenses, used in AIM case, were removed.

Figure 3h illustrates the obtained ray tracing for a wavelength of 670 nm. The same behavior was observed for the other used wavelengths. The rays hit the sensing region at the same angle, as was expected.

For larger parallel beams, it was noted a higher scattering of the rays, which validates the use of WIM sensors for multiple sensing spot applications. A pin-hole device is necessary for experiments to obtain an appropriate width of the parallel light beam, which avoids the rays scattering observed in the simulations.

3. Conclusion

The design of an exchangeable low cost surface plasmon resonance biosensor chip for real-time monitoring of biochemical interactions was presented here. It uses a co-polymer optical prism apparatus and it can be operated in both, angular and wavelength interrogation modes. Simulation results have shown the tradeoff among the geometry and position of a cylindrical lens to the performance of the biosensor in the AIM case. For WIM configuration, scattering of incoming rays were observed when the width of the parallel light beam was increased.

The proposed optical prism was developed and a photo is shown in Fig. 4a. As can be seen, the top and inclined sides are covered with a gold layer (Fig. 1a), as aforementioned. Furthermore, a FPGA-based instrument associated to an autosampler is under developing. Its structure is illustrated in Fig. 4b.

Our optical chip apparatus associated to a portable SPR instrument is interesting and makes flexibility for various fields of application, like in the detection of viruses and water quality monitoring.

Acknowledgements

The authors would like to thank CNPq for the research grant, financial support and study fellowship.

References

1. Homola J. *Surface Plasmon Resonance Sensors*, Springer, Vol. 4 (2006).
2. Naimushin AN, Spinelli CB, Soelberg SD, Mannand T, Stevens RC, Chinowsky T, Kauffman P, Yee SS and Furlong CE. Airborne analyte detection with an aircraft-adapted surface plasmon resonance sensor system. *Sensors and Actuators* B, 104, 237-248 (2005).
3. Moreira CS, Lima AMN, Neff H and Thirstrup C. Temperature-dependent sensitivity of surface plasmon resonance sensors at the gold–water interface. *Sensors and Actuators B*, Vol. 134 (2008), 854-862.

4. C. Thirstrup, W. Zong, M. Borre, H. Neff, H. C. Pedersen and G. Holzhueter. Diffractive optical coupling element for surface plasmon resonance sensors. *Sensors and Actuators B*, Vol. 100 (2004), 298-308.

5. Thirstrup C, Zong W, Neff H. *Surface plasmon resonance sensor*, Patent Application Publication, Vol. 0018194A1 (2005), 137-141.

6. Thorlabs. Thorlabs catalog available on http://www.thorlabs.com/support.cfm?viewTab=6.

Fig. 3. The simulation results for AIM case, with changes on the thickness (a-b) and aperture radius (c-d) of the incoming cylindrical lens and the distance D (e-f). The circles represent the obtained focus. The reflectance curve (g) and ray tracing results for WIM case (h) are also shown.

Fig. 4. A photo of the optical chip (a), with top and angled sides covered by a thin gold layer; the proposed instrumentation under developing (b).