THE DESCRIPTION OF A LOCAL BIOSENSOR FOR BIOPHOTONICS

Elena Prokopyeva

Doctoral Degree Programme (2), FEEC BUT

E-mail: xproko24@stud.feec.vutbr.cz

Supervised by: Pavel Tománek

E-mail: tomanek@feec.vutbr.cz

Abstract: A model of a local biosensor is described in the paper. The model takes into account the interaction of the particle with a glass prism and a final viewing angle of the optical lens. Results for the layered particle made of a polystyrene latex core covered by a golden outer shell are presented. The influence of the metal shell thickness and the particle diameter on the location of dissipation spectrum maximum is analyzed.

Keywords: local biosensor, nanoparticle

1. INTRODUCTION

Nanotechnology opens the possibility of working on the level of the supramolecular system size from units up to 100 nm. Its aim is understanding the fundamentally new characteristics arising from the particles dimensions of this ¨nanoworld¨, creating the technology leading to the exactly proposed nanoparticles with the required properties and finding the technology how to deal with them.

Metal and semiconductor nanoparticles have excellent optical and electrochemical properties, which dramatically depend on their shape and size. Various biological molecules (enzymes, antibodies, other proteins, DNA and oligonucleotides) can be deposited on a nanoparticle by different techniques including physical adsorption, electrostatic bonds, specific recognition and covalent connection. It is well known that both polymers and small molecules can influence the behavior of biomolecules. The nanoparticles modified in such a way have a significant therapeutic effect. Biomolecules marking by different fluorescent dyes (probes) could provide information about their dynamics or conformation and could be widely used in diagnostics, DNA analysis, virus detection.

The development of biotechnology is becoming a determinative factor of progress in science and technology in many domains. There is an intensive need in development of effective ways of solution diagnosis for immunological blood test, detection of virus presence or DNA changes. When developing modern tools of diagnostics in solutions, the effect of nonradiating wave transformation appearing near the interface glass-solution under special conditions is used, that provides the resolution dozens times higher than the diffraction limit. [1]

A biosensor is a device comprising a biological recognition layer designed to bind a specific substance and a physical transducer that can translate the biochemical interaction into a quantifiable signal. The recent progress in highly sensitive optical transducers combined with the particular character of biomolecular interactions has driven the development of a wide variety of optical biosensors with applications in different fields including environmental control, food industry, drug design, clinical diagnosis or biomolecular engineering. [2, 3]

The most advanced devices are local biosensors, whose basic working principle is analysis of noble metal nanoparticles spectra. These particles transform the nonradiating wave, located near the particle, into an evanescent field, which is collected then by an optical lens. The lens each time analyses the spectrum of only one particle, that is why the viewing angle of the lens is narrow. [1]

The major problem of existing constructions improvement is a synthesis of particles that allows shifting the maximum of dissipation spectrum to the longer wave region. Such a shift is necessary for hitting the so-called spectral window of biological materials, located in the wavelength range starting from 700 nm. Experiments proved that such a shift can be realized both by nanoscale layered particles consisting of dielectric nucleus with a shell made of noble metals, and by rods made of noble metals. However, the theoretical analysis of such constructions is performed on the basis of phenomenological models without considering both the interaction of particle and prism surface, and a final viewing angle of the lens, that significantly reduces its practical meaning. [1]

2. THE MODEL OF A LOCAL BIOSENSOR

Here a model of a local biosensor is described. It was developed on the basis of discrete sources method. Distinctive features of this approach are the following:

1) it allows to analyze effectively scattering by local structures, with the presence of multilayer environment as well;

2) it contains an explicit scheme for construction of complete and closed systems of discrete sources fields which are determined only by the structure of the discrete sources carrier;

3) in case of axially symmetric structures, discrete sources are located on the scatterer axis of symmetry or in the complex plane adjoining to the axis;

4) representation for the approximate solution in case of axially symmetric structure directly takes into account the axial symmetry and polarization of external excitation;

5) the method of discrete sources enables to make an effective posterior error estimation of the obtained approximate solution. [1]

2.1. DESCRIPTION OF THE BIOSENSOR

Let’s consider the case of P-polarized plane wave propagating from under the prism with an angle θ_1 to the axis OZ (Figure 1).

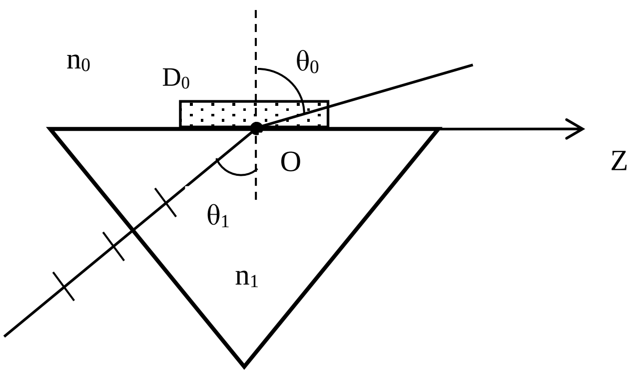

Figure 1: Propagation of wave and its refraction to the object area D_0

The electrical and magnetic fields of the wave refracted to the object area D_0 can be then written in the following way:

$$E = n\{-e_x \cos\theta_0 + e_z \sin\theta_0\}\, exp\{-jk_0(x\sin\theta_0 + z\cos\theta_0)\}, \qquad (1)$$

and

$$H = -n\, e_y\, exp\{-jk_0(x\sin\theta_0 + z\cos\theta_0)\}n_0. \qquad (2)$$

Here n is a refraction index, θ_0 is a refraction angle with which a wave propagates to the set of particles D that have a core of polystyrene latex (PSL) and an outer shell of gold (Au) of thickness t dispersed in water, used as object. In this case the Snell's law of refraction gives us: $sin\,\theta_0 = \frac{n_1}{n_0} sin\,\theta_1$. The refraction index of glass is higher than the refraction index of water, $n_1 > n_0$, that is why when the angle of incidence θ_1 increases from 0 to $\pi/2$, a moment appears from which $|\sin\theta_0| > 1$.

Then in the upper half-space a nonradiating (evanescent) wave appears, that propagates along the interface and exponentially attenuates normally to the interface. For considering this fact, it is necessary to choose the corresponding part of cosine function θ_0. This leads to the expression: $\cos\theta_0 = -j\sqrt{\sin^2\theta_0 - 1}$, that is true for the whole range of refraction angles $\theta_0 \in [0, \pi/2)$.

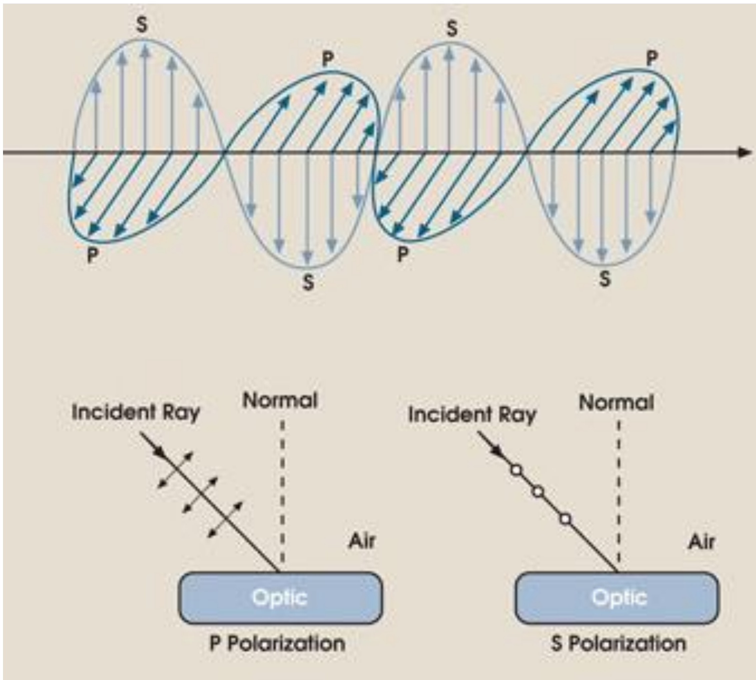

Figure 2: Polarization of light [4]

As a principal characteristic the intensity of nonpolarized light dissipation is concerned:

$$I(\lambda,\theta,\varphi) = \frac{1}{2}[I^P(\lambda,\theta,\varphi) + I^S(\lambda,\theta,\varphi)]. \qquad (3)$$

Here I^P is the intensity of P-polarized wave, I^S is the intensity of S-polarized wave (Figure 2).

The intensity dissipated to some spatial angle Ω is:

$$\sigma(\lambda) = \int_{\Omega} I(\lambda, \theta, \varphi) d\omega;$$

spatial angle Ω is here $\Omega = \{0 \le \varphi \le 360°; 0 \le \theta \le 22.08°\}$, that corresponds to the lens aperture *NA=0.5*.

2.2. Presentation of calculation results

Nonpolarized light in the wavelength range 400 nm $\le \lambda \le$ 1050 nm is considered as an external excitation, glass BK7 – as a material of prism. The refraction index of water is considered to be constant and equal n_0=1,33. In this case the critical angle $\theta_c = \theta_1$ for $\theta_0 = 90°$, behind which the nonradiating wave area is located, depends on the wavelength (due to the frequency dispersion of glass), but its value does not exceed 62°.

Figure 3 presents calculation results of *σ(λ)* depending on the wavelength for the layered particle D_0. The angle of incidence is 62°, the outer diameter of the shell is D = 50 nm.

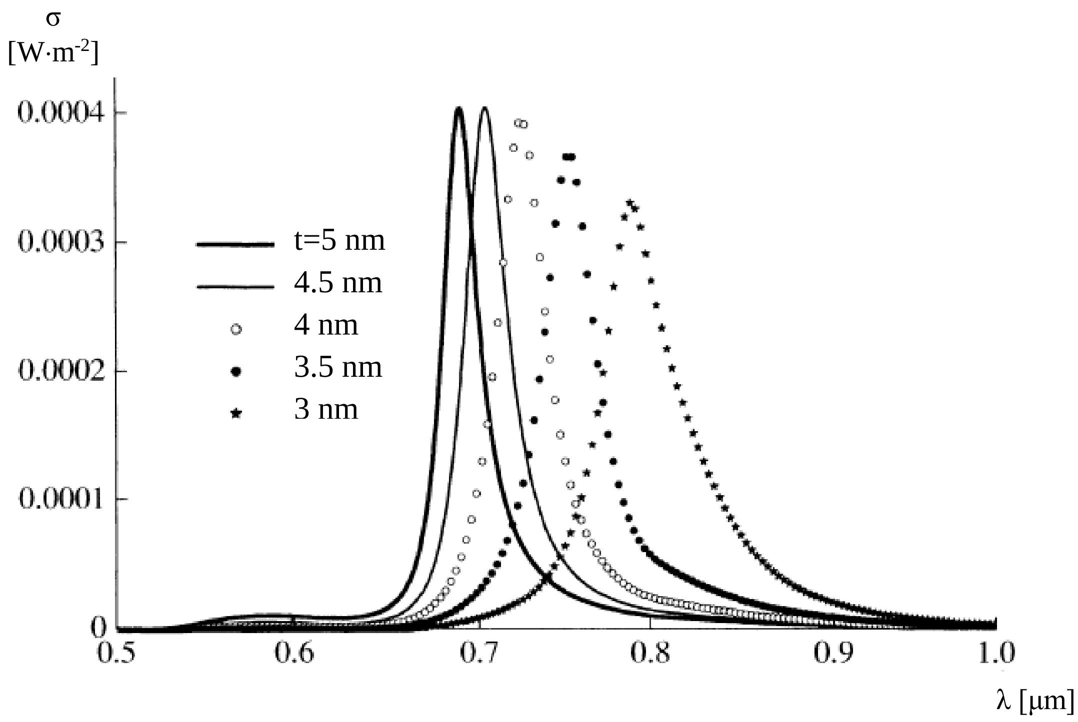

Figure 3: Shift of spectrum maximum with decreasing of outer metal shell thickness

We can see from the graph that with decrease of the outer metal shell thickness, the maximum of the spectrum shifts to the long-wave region, and for shell thickness t = 3.5 nm it falls to the right of 700 nm, that satisfies the requirements above.

The results corresponding to the particles of different diameters D with the layer thickness t = 4 nm are represented on Figure 4.

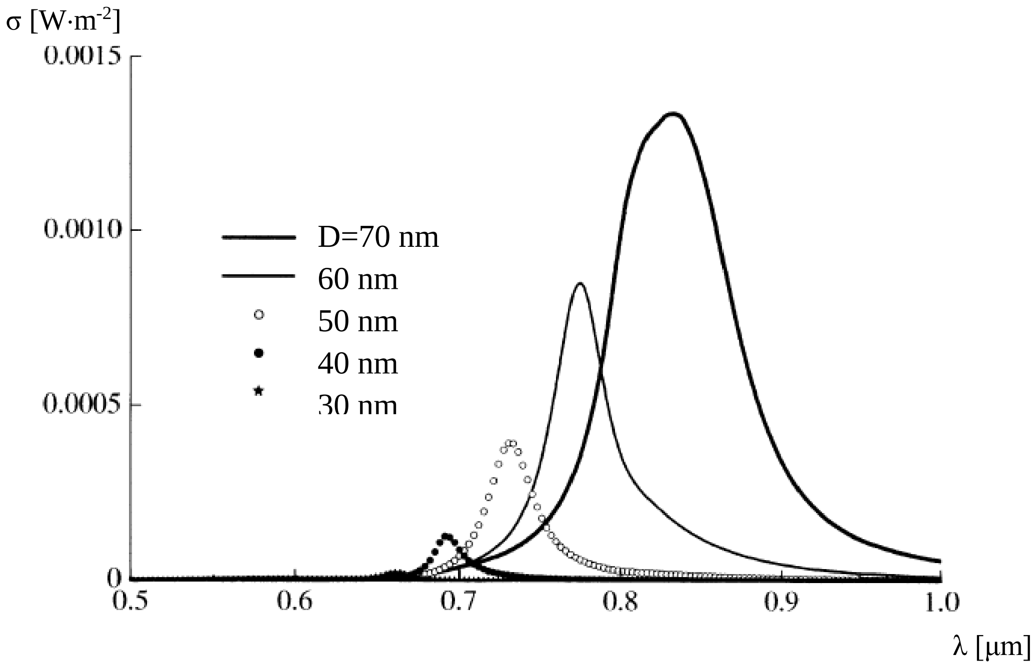

Figure 4: Spectrum changing with different particle diameters

We can see from the graph that increase of the layered particle diameter leads to additional shift of the spectrum maximum to the right. At the same time the curve itself obtains more subdued form.

3. CONCLUSION

In this paper a model of a local biosensor is described on the basis of discrete sources method. The results for the layered particle made of a polystyrene latex core and a golden outer shell are presented. The influence of the outer shell thickness and the particle diameter on the location of dissipation spectrum maximum is analyzed. When the thickness of the metal shell or the particle diameter is growing, the maximum of the spectrum is shifting to the long-wave region, where starting from $\lambda = 700$ nm the spectral window of biological materials is located.

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