Nanorod-based glucose sensor

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Abstract

In this paper, a metamaterial-based sensor consisting of an array of nanorods is proposed. An analytical model, describing the electromagnetic response of the nanorods, is proposed. Such model is verified through the comparison to full-wave numerical simulations. A good agreement between analytical and numerical results is achieved (above 95%). The sensor is able to detect the presence of glucose and its concentration in aqueous solutions. The presence of the compound under study modify the sensor electromagnetic response, allowing to measure its concentration in an accurate way. The designed sensor may find application in many fields of medical diagnostics.

1. Introduction

Several studies have highlighted the importance of using bio-electromagnetic sensors in a wide range of application fields, such as medicine, biology, physics, environmental and personal safety [1]. Recent researches have explored the potentiality to make use of such sensors in analytical chemistry for the identification and quantification of the chemical components in the sample under study. Classical methods use qualitative analyses by specific markers. Quantitative analyses are performed by means of electromagnetic phenomena, such as light absorption, fluorescence, and conductivity [2].Thought being rather sensitive, such structure need large dimensions. In order to overcome such limitations, new technologies are needed. Metamaterial-based sensors represent an interesting alternative solution, being more compact and sensible compared to other sensors already proposed in literature [3]. It's well known that nanorods particles exhibit optimal performances for sensing applications [4]. The purpose of this study is to propose a new sensor based on gold nanorods, with high selectivity and sensitivity performances. More specifically, this paper has the following two objectives:

- to develop an analytical model describing the electromagnetic behaviour of such nanoparticles, in terms of absorption and scattering cross-section;
- to explore the ability of such sensor to detect the presence of a specific compound and measure its concentration.

The paper is structured as follows: first, the electromagnetic properties of the nanorods are studied by means of a proper analytical model. Next, the results are compared to the ones obtained from full-wave simulations. Finally, an application of the sensor to detect glucose and evaluate its concentration in aqueous solutions is presented.

2. Analytical model and electromagnetic properties of gold nanorods

The proposed sensor consists of an array of gold nanorods. Let us consider the individual nanorod and assume that the structure is excited by an impinging plane-wave, having the electric field parallel and

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the propagation vector **k** perpendicular to the nanorod principal axis, as depicted in Fig. 1. When the nanorod is excited by an external source, the electric field is highly localized in the neighbourhood of the nanostructure and strongly depends on the inclusion geometry, its metallic electromagnetic properties, and the permittivity of the surrounding dielectric environment [5]. To describe and exploit such phenomenon, it is necessary evaluating the extinction cross-section of the nanorod, in terms of scattering and absorption [6]. The study of such properties will allow exploring the appropriateness of the proposed setup as a sensing device. At the present time, the analytical model is under development. For the sake of brevity, only the scattering term is reported here, as shown in formula (1).

$$\sigma_{scattering} = \frac{k^4}{6\pi}\left| \frac{a^2\pi\left(\frac{4a}{3}+h\right)(\varepsilon_i-\varepsilon_e)}{1+\frac{\left(1+\frac{-4a-3h}{\sqrt{52a^2+24ah+9h^2}}\right)(\varepsilon_i-\varepsilon_e)}{\varepsilon_e}} \right|^2 \qquad (1)$$

where $k = 2\pi/\lambda$, λ is the wavelength, a the hemisphere radius, h the height (Fig.1), ε_i the nanorod permittivity and ε_e the permittivity of the surrounding dielectric medium.

Such an analytical model allows relating the resonant wavelength of the nanoparticle, in terms of position, magnitude, and amplitude width, to its geometrical parameters, to the metallic properties, and to the permittivity ε_e of the surrounding dielectric environment. In the scattering cross-section formula the predominant dependence is the geometric one. By means of such analytical formulas, it is possible to design the particles for the specific requirements. The results obtained from the analytical solution are compared to the ones obtained by using the full-wave simulator CST Studio Suite. Different particle dimensions were considered. For gold nanorods, experimental values of the complex permittivity function of gold [7] have been used. In all cases a good agreement (more than 95%) between analytical and numerical results has been achieved, as shown in Fig. 2.

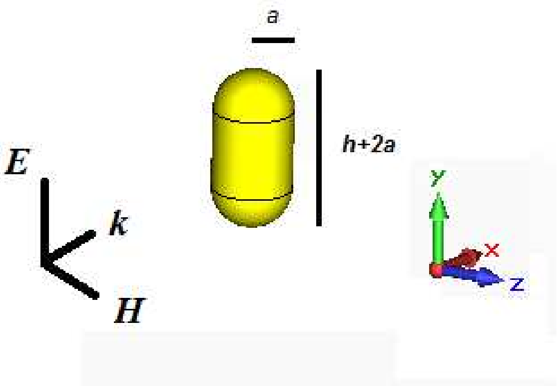

Fig. 1: Geometrical sketch of the nanostructures, hemisphere radius thickness *a*, height *h*.

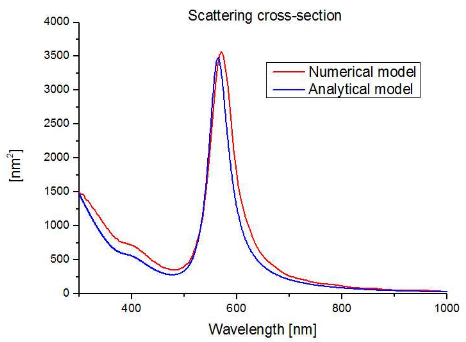

Fig. 2: Comparison between numerical and analytical model for the resonant wavelength (e.g. a=20 nm, h=40 nm).

3. Results

The sensor has been designed to detect the presence of specific compounds by means of refractive index measurements. The particle without any material under test (MUT) has a specific resonant wavelength. Once MUT is placed, the system "nanoparticle-MUT" is illuminated by an electromagnetic field. Scattering and absorption cross-sections will have a resonant frequency and an amplitude that are both dependent on the electromagnetic characteristics of the overall system nanoparticle-MUT. A shift in the position of the sensor response is related to the different values of the refractive index of the MUT. In this case, the structure has been tested to reveal the glucose concentration in aqueous solutions, from the shift in the resonant wavelength position. We have selected the following physical dimensions for the nanorod particle: a = 20 *nm*, h = 100 *nm*. In order to test the sensor, the refractive index experimental values reported in [8] have been used. The corresponding numerical results are reported in Fig. 3.

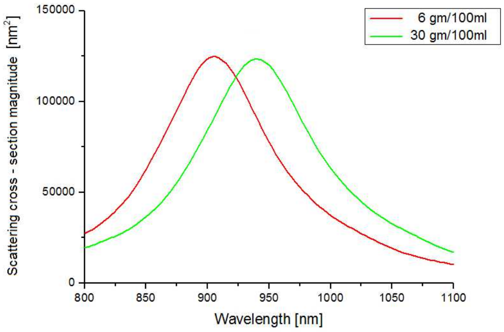

Fig. 3: Resonant wavelength shift for different glucose concentrations.

4. Conclusion

In this paper, the design of a metamaterial-based sensor, consisting in an array of gold nanorods is proposed. The aim has been to verify the possibility of using the proposed structure for the detection of glucose in aqueous solutions, measuring its concentration. An analytical model, describing the electromagnetic sensor behaviour has been developed. The proposed model has been verified by comparing the analytical results to the ones obtained from full-wave numerical simulations and a good agreement has been found. The designed sensor can be successfully applied in the recognition of the concentration of several compounds in aqueous solutions (such as sucrose, sodium chloride, etc) with possible applications in medical diagnostics.

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