Electric Field Investigation for Ag Nanosquare Blood Cancer Sensor with Finite Difference Time Domain (FDTD) Simulation

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Abstract. Blood carrying more leukocytes can induce differences in electrical and magnetic properties. This work describes the effect of leukocyte concentration on the distribution of electric fields. The finite difference time domain approach of electric field distribution using normal blood and leukocyte has been analyzed. The electric field in the blood and leukocytes have the same peak at a wavelength of 400nm. Ag nanosquare with dimensions of 350×350nm² in blood and leukocyte medium has a different maximum electric field of 7.35 × 10⁷ V/m with a peak wavelength difference of 0.22nm. The results of this work are beneficial to expected and provide an interpretation of blood cancer detection using an Ag nanosquare arrays sensor.

1. Introduction
Blood cancer cases in the world are increasing year by year [1]. Blood cancer has been detected by some techniques like a liquid biopsy and blood tests [2,3]. Other ways to detect blood cancer are still being developed, especially non-invasive [3,4]. Blood cancer causes a significant increase in leukocyte concentration in the blood [5], and cancer cells are probably using the handling of specific treatments [6]. There are differences in the parameters of the electric and magnetic fields in normal blood and leukocytes. Magnetic and electrical parameters of normal blood are dielectric constant (1.6925), relative magnetic permeability (0.72), and electrical conductivity (1.12 S/m) [7]. While the dielectric constant, relative magnetic permeability, and conductivity in leukocytes are (1.35), (0.99999987), and (0.35 S/m) [8], respectively. Where the difference in the parameters generated in the electric field and magnetic field result [9].

In this case, cancer detection with nanostructures has been widely developed. Nanostructure has a high degree of accuracy, and sensitivity to detect cancer biomarkers causes ion mobile in between, regularity, and attractive with molecules to be applied for bio-sensing [6]. Silver (Ag) is a type of metal that can be used as an electrode because it is not polarized when there is a weak and flowing current. Ag can also measure weak bioelectric signals [10]. The electrical and magnetic properties of Ag investigated as the dielectric constant (-15,243), relative magnetic permeability 0.9999, and conductivity (6.3×10⁷ S/m), respectively[11].

Another application of electrodes to detect glucose concentration in the blood has been all over to investigate. The result shows that different concentrations of glucose purpose the distinct electrical responses produced, which is the greater the concentration of glucose indicated higher the oxidation peak voltage, and the lower the reduction voltage [12]. Mi, et al. investigated the composition of
nanostructures that can be affected the distribution of electric fields when irradiated with a specific electromagnetic wave. And this electric field analysis figures out determine photoactivity in materials [13,14]. Both of these researches are based on making blood cancer sensors with nanostructured electrodes.

Analyzes of this studied, describe the influence of Ag nanostructure on the distribution of electrode electric fields for blood cancer detection sensing, where the object used in this work are leukocytes and normal blood.

2. Method

2.1. Finite Difference Time Domain

This study used the time difference domain for analyzing the distribution of the electric field in Ag nanosquares. The limited-time domain difference equation is derived from Maxwell's equation. The FDTD magnetic field and electric field equation used in this study:

\[ H_{z}^{q+1}[i + \frac{1}{2}, j + \frac{1}{2}] = \frac{1 - \sigma m \Delta t}{1 + \sigma m \Delta t} H_{z}^{q-1}[i + \frac{1}{2}, j + \frac{1}{2}] + \frac{1}{1 + \sigma m \Delta t} \left( \frac{\Delta t}{\epsilon \Delta x} \right) \left( E_{y}^{q}[i + 1, j + \frac{1}{2}] - E_{y}^{q}[i, j + \frac{1}{2}] \right) - \frac{\Delta t}{\mu \Delta y} \left( E_{x}^{q}[i + \frac{1}{2}, j + 1] - E_{x}^{q}[i + \frac{1}{2}, j] \right) \]  

\[ E_{x}^{q+1}[i + \frac{1}{2}, j] = \frac{1 - \sigma \Delta t}{1 + \sigma \Delta t} E_{x}^{q}[i + \frac{1}{2}, j] + \frac{\Delta t}{\Delta x} \left( H_{z}^{q+1}[i + \frac{1}{2}, j + \frac{1}{2}] - H_{z}^{q+1}[i + \frac{1}{2}, j - \frac{1}{2}] \right) \]  

\[ E_{y}^{q+1}[i, j + \frac{1}{2}] = \frac{1 - \sigma \Delta t}{1 + \sigma \Delta t} E_{y}^{q}[i, j + \frac{1}{2}] + \frac{\Delta t}{\epsilon \Delta y} \left( H_{z}^{q+1}[i + \frac{1}{2}, j + \frac{1}{2}] - H_{z}^{q+1}[i - \frac{1}{2}, j + \frac{1}{2}] \right) \]

[15]  

\( E \) on FDTD represents the electric field, \( H \) represents a magnetic field, \( \Delta t \) is the interval of time, \( \Delta y \) is the interval of space on the y-axis element, and \( \Delta x \) is the interval of space on the x-axis element. Meanwhile, \( \mu, \sigma, \sigma m, \) and \( \epsilon \) are magnetic permeability, electrical conductivity, magnetic conductivity, and permittivity, respectively. The control variables used in this study are the space intervals \( \Delta x \) and \( \Delta y \), the value of relative magnetic permeability, the electrical conductivity of materials, and also the value of the input electric field amplitude, which is valued at 1 V m. This study's independent variables are the nanostructures' size, the time interval \( \Delta t \) adjusted according to the value of a period of the electromagnetic wave with a wavelength between 200 to 700nm, and the dielectric constant of the material as a function of wavelength.

2.2. Simulation

The analysis of the electric field distribution by the FDTD method was carried out using COMSOL Multiphysics 5.4 software. The study was conducted using variations in the dimensions of the nanosquare Ag, medium, and wavelength. Nanosquares Ag is varied with the side sizes of the 200nm, 250nm, 300nm, 350nm, and 400nm. The nanosquare Ag is irradiated with electromagnetic waves at wavelengths between 200nm to 700nm. Figure 1 shows the shape of the Ag nanostructure used in this study based on the SEM image as a model dimension for FDTD. The medium on the outside of Ag is normal blood and leukocytes. The difference in the electric field in different mediums was analyzed using OriginPro 2015.
3. Result and Discussion

The Ag nano structure is planted on Indium Tin-Oxide glass as a substrate and placed in the medium then will be irradiated with electromagnetic waves perpendicularly. Electromagnetic waves are emitted from the upper side of the medium. In this study, blood and leukocyte are used as the mediums. The simulated electromagnetic waves are based on electromagnetic (TEM) modes. The electromagnetic waves will be absorbed, reflected, and transmitted by the medium, Ag nanosquares, and ITO glass.

Figures 2 and 3 show the distribution of the electric field of top and a cross-sectional view of Ag nanosquares irradiated by electromagnetic waves at a wavelength of a) 200 nm, b) 300 nm, c) 400 nm, d) 500 nm, e) 600 nm, and f) 700 nm. Each wavelength has a different electric field response, both on the medium and Ag nanosquare. This electric field's distribution depends on the value of the dielectric constant, electrical conductivity, and magnetic permeability. The dielectric values as a function of wavelength caused by differences in the ability of nanosquares to absorption, transmittance, and reflectance electromagnetic waves. The electric field in the Ag nanostructure is smaller than the electric field in the surrounding medium.

Figure 1. Shape and dimension of Ag nanosquare a) Top view and b) Cross-sectional view for electric field simulation.

Figure 2. Top View of electric field distributions in nanoquare Ag irradiated with wavelengths a) 200 nm, b) 300 nm, c) 400 nm, d) 500 nm, e) 600 nm and f) 700 nm, respectively.
Figure 3. Cross-sectional view of electric field distributions in nanoquare Ag irradiated with wavelengths a) 200 nm, b) 300 nm, c) 400 nm, d) 500 nm, e) 600 nm and f) 700 nm, respectively.

From equations (1) and (2), FDTD explains that the electric and magnetic fields at each point depend on the position of the point under review, the shape and dimensions of the material. Figure 4 shows the electric field values of the Ag nanosquares in the leukocyte medium with different nanosquare dimensions. It can be seen that the color description shows that the Ag nanosquare dimension describes the value of the electric field taken from the center point of the Ag nanosquare. On the other hand, the electric field taken at the center of the Ag nanosquare center point results in a superposition of electromagnetic waves that are emitted into the nanosquare. Therefore, it is considered to represent the characteristics of the electric field emitted by Ag nanosquares.

Figure 4. Electric Field Ag Nanosquare on Leukocyte Medium with Ag Nanosquare Dimensions 200×200nm², 250×250nm², 300×300nm², 350×350nm², and 400×400nm².
Figure 4 shows that each nanosquare with different dimensions has a different distribution of the electric field, either in the blood or in the leukocyte medium. Where the electric field of the Ag nanostructures has one peak at a wavelength of 300 nm. The peak distribution of the electric field is correlated with its transmittance value.

Besides, several parameters determine the distribution of the electric field, namely dielectric constant, magnetic permeability, medium conductivity, and material properties. Basically, each material has different electrical and magnetic properties. Therefore, the ability of each type of material to conduct electromagnetic waves is also different. The better the conductivity value and the dielectric constant are associated with the smaller the electric field value. Conversely, the greater the permeability value of the magnet, the greater the value of the electric field.

The difference in the parameters of the electrical and magnetic properties between blood and leukocytes is due to differences in their physical components. Normal blood contains not only leukocytes but also erythrocytes, blood plasma, and platelets. However, most normal blood consists of blood plasma. Where the blood plasma, platelets, and erythrocytes have conductivity and dielectric constant that is much greater than that of leukocytes. Because the electric and magnetic parameters between leukocytes and blood have almost the same values, the distribution of the electric fields in blood and leukocytes has a similar value, which has a peak at a wavelength of 400 nm. This indicates that the electric field between blood and leukocytes cannot be distinguished when exposed to electromagnetic waves, as shown in the electric field values in blood and leukocytes in Figure 5.

If a nanosquare Ag is placed in the middle of the blood and leukocytes, it will then show a difference in the electric field between the two. In a nanosquare with a size of 350 x 350nm², the maximum electric field size in a blood medium is $30.39 \times 10^{-7}$ V/m at a wavelength of 298.49 nm. At the same dimension, the maximum electric field value in the leukocyte medium is $23.04 \times 10^{-7}$ V/m at a wavelength of 298.27 nm. The graph of the electric field value of nanosquares with 350 x 350nm² in blood and leukocyte mediums in Figure 5. It shows the difference between the electric field value in nanosquares with normal blood and leukocytes medium.

![Figure 5. Electrical field comparison of Ag nanosquare on blood and leukocyte medium.](image)

Blood cancer can also be caused by an increase in the number of leukocytes in the blood. In normal blood also contains leukocytes, it can be shown from Figure 5 that an increase in the concentration of leukocytes can cause a lower value of the maximum electric field and a shift in the peak wavelength to
a higher one caused by Ag nanosquare. The presence of different electric field peaks can be used to analyze the concentration of leukocytes in the blood. So it can be used as the basis for blood cancer detection sensors.

4. Conclusion
In conclusion, different mediums can cause different electric field responses in the Ag nanosquare array. The electric field in blood and leukocytes has the same peak at a wavelength of 400 nm, whereas the peak of the electric field in Ag is at a wavelength of 300 nm. In Ag nanosquare with dimensions of 350 nm × 350 nm as electrodes placed in blood and leukocyte medium, it has a maximum electric field difference of \(7.35 \times 10^{-7}\) V/m with a peak wavelength difference of 0.22 nm. Thus, the lower the concentration of leukocytes, the higher the peak of the electric field in the Ag nanosquare. Furthermore, the maximum electric field wavelength represents a shift at a higher wavelength due to the greater concentration of leukocytes. These results will provide an initial interpretation of blood cancer detection using the Ag nanosquare sensor array.

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