The influence of the Ag nanostructures dimensions on the pattern of electric field distribution in cases of blood cancer

U Farahdina¹, V Z Zulfa¹, M Firdhaus¹, E Endarko¹, A Rubiyanto¹ and N Nasori*¹

¹ Laboratory of Medical Physics and Biophysics, Department of Physics, Institut Teknologi Sepuluh Nopember, Kampus ITS - Surabaya 60111, East Java, Indonesia

Abstract. Above normal concentrations of leukocyte can indicate blood cancer in humans. This study uses a finite difference time domain (FDTD) based on the Ag nanostructure array experiment from previous study. The influence of leukocyte and blood medium and also Ag nanostructures dimensions the on the pattern of electric field distributions in Ag nanostructure arrays was described on this study. The electric field distribution and transmittance of Ag nanostructure arrays using different medium was analysed. The electric field in Ag nanosquare with side size 50 nm irradiated with electromagnetic wave at a wavelength of 350 nm has value 1.78 × 10⁻⁵ V/m and has the highest electric field value compared to the other dimensions and wavelengths of electromagnetic wave. The maximum difference value of transmittance Ag nanosquare array between blood and leukocyte is 8.06 a.u. This value is resulted from Ag nanosquare with side size 50 nm irradiated with electromagnetic wave at a wavelength of 250 nm. These result provide an initial interpretation of optimum wavelength of electromagnetic wave and size of Ag nanosquare arrays for therapy and detection of blood cancer.

1. Introduction

Blood cancer sufferers in the world increase every year [1]. White blood cells concentration become 11000 per mm³ in the blood of blood cancer sufferers [2]. Thus, blood cancer can cause changes in the value of blood electrical parameters [3]. Various methods are still being developed to detect blood cancer. The method that can be used to detect cancer is using laser induction in combination with the chelometric method, because it can describe a direct comparison of the intensity or the ratio of the intensity of specific line of atoms of malignant and normal tissue [4]. In addition, there is a spectroscopic method by identifying the absorbance peaks of biological material. The weakness of this method is the possibility of overlapping absorption peaks for several biological substances [5]. Simulations and experiments using ZnO for other blood diseases have also been carried out [6, 7]

The electromagnetic waves can cause the propagation of electric and magnetic fields in the medium. The propagation of electromagnetic waves depends on the value of dielectric constant, magnetic permeability and electrical conductivity [8]. Dielectric constant, magnetic susceptibility, and electrical conductivity of blood around visible light wavelength have value of 1.6925, 6.6×10⁻⁷, and 16 S/m respectively [7, 8]. Blood and leukocytes have different components [9]. Therefore, the magnetic and electrical parameter between blood and leukocyte are also different. The dielectric constant, magnetic permeability, and electrical conductivity of leukocytes around visible light wavelength have
values of 0.4, 1, and 0.35 S/m, respectively. Different magnetic and electrical parameter can cause different electric field distribution. Different electric field distribution can use to detect different concentration composition of nanostructure medium [8, 10].

The electric field responses can also be influenced by the composition and shape of the nanostructures [13]. Silver (Ag) can be used as a constituent of nanostructures because it can measure weak bioelectric signals [14]. Silver has a maximum dielectric constant value of 0.83987 at a wavelength of 300 nm. Silver has magnetic permeability and electrical conductivity values 0.99998 and $6.3 \times 10^7$ S/m [15]. Large electric fields can cause cell damage. In addition, inhomogeneous electric field can direct the dipole molecules towards the higher electric field intensity. This phenomenon is called dielectrophoresis [16].

Using difference of electrical and magnetic parameters of leukocytes and blood which cause differences in the electric field and transmittance, it can be identified the effect of the medium on the transmittance value of Ag nanostructures. The maximum electric field value of the Ag nanostructures with different side size of the nanostructures was also analyzed. The results of this study can be used as basic of optimum parameters for manufacturing electrodes for detection and therapy of blood cancer using Ag nanostructures.

2. Method
The method used in this research is simulation. The analysis of the electric field distribution 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. The Ag structure are varied with the size of the 50 nm, 100 nm, 150 nm, and 200 nm. Figure 1 shows the shapes of Ag nanosquare arrays used in this study based on SEM image as model dimension. The nanosquare arrays are irradiated with electromagnetic waves at wavelengths between 200 nm to 1000 nm through the upper side of the medium perpendicularly. The medium outside the Ag nanostructure are normal blood and leukocyte. Electromagnetic waves will transmit through the medium, Ag nanostructures, and ITO glass. The transmittance calculations, analysis of the maximum and distribution of the electric field were carried out using the OriginPro 2015 software.

![Figure 1](image1.png)

**Figure 1.** Top and Cross Sectional View of Ag Nanosquare Arrays with Side Size of a) 200 nm, b) 150 nm, c) 100 nm, and d) 50 nm.

3. Result and Discussion
The simulation of the electric field distribution in the Ag nanostructures is a basis for manufacturing of electrodes for blood cancer detection and therapy. The arrangement of shapes and materials used in this study are based on the design of the formation of Ag nanostructures. Ag nanostructures with dimensions and shapes of top and cross sectional view are in the Figure 1 and Figure 2. The Ag nanosquare arrays are grown on Indium Tin Oxide glass. The nanostructures are placed on the blood and leukocyte medium.

Electromagnetic waves consist of electric and magnetic fields that propagate perpendicularly. Figure 3 and Figure 4 show the distribution of the electric field in the Ag nanostructures from the top
view and side view irradiated with electromagnetic waves at a wavelength of 250 nm. Although irradiated at the same wavelength, the distribution of the electric field is different. It is affected by the dimensions of the Ag nanostructures. The larger the size of the Ag nanostructures, the more electric fields are reflected and absorbed by the Ag nanostructures [17].

![Figure 2](image1.png)

**Figure 2.** Top View of Electric Field Distribution of Ag Nanosquare Arrays Irradiated with Electromagnetic Wave at a Wavelength of 250 nm with Side Size of a) 200 nm, b) 150 nm, c) 100 nm, and d) 50 nm Has an Optimum Electric Field 2.6 V/m; 1.3 V/m; 1.3 V/m and 1.6 V/m, Respectively.

![Figure 3](image2.png)

**Figure 3.** Cross-Sectional View of Electric Field Distribution Ag Nanosquare Arrays with Side Size of a) 200 nm, b) 150 nm, c) 100 nm, and d) 50 nm Irradiated with Electromagnetic Wave at a Wavelength of 250 nm.

The differences in dielectric constant, magnetic permeability, and electrical conductivity of the medium and nanostructures can cause differences in the distribution of the electric field. The dielectric constant in silver has different values as a function of the wavelength [18]. Therefore, the ability to transmit, absorb, and reflect electromagnetic waves on Ag nanostructures at various wavelength values are different [19]. The different distribution of the electric field on the top and cross sectional view of Ag nanostructures with various wavelengths are shown in Figure 5 and Figure 6.

The method to diagnose blood cancer using Ag nanostructured electrodes is comparing the transmittance value of Ag nanostructures in medium of normal blood and blood containing cancer. Blood that contains cancer tends to have a higher concentration of leukocytes. Blood and leukocytes have different values of dielectric constant, magnetic permeability, and electrical conductivity due to differences in their constituent components. The difference in these parameters of the medium can cause differences in the distribution of the electric field in the medium and the nanostructures.

The transmission is obtained by comparing the electric field values on the surface and the electric fields in the Ag nanostructures. Difference component of the Ag nanosquare's medium can cause differences in the transmittance value. Figure 7 shows the difference in the transmittance value of Ag nanostructures using blood and leukocytes medium. The transmittance of Ag nanostructures in medium leukocytes is smaller compared to blood because blood has a greater value of dielectric
constant and electrical conductivity than leukocytes. Therefore, blood medium transmittance has a lower value than leukocytes. Fewer photons penetrate the surface of Ag nanostructures in the blood medium than using leukocyte medium. Thus, the ratio between the squared of electric field at the nanostructures and the surface which is calculated as the transmittance of the Ag nanostructures has a greater value in blood when compared to medium leukocytes. The difference in the transmittance value can be used as the basis for making blood cancer sensor detection.

Figure 4. Top View of Electric Field Distribution Ag Nanosquare Arrays with Side Size of 50 nm Irradiated with Electromagnetic Wave at a Wavelength of a) 250 nm, b) 350 nm, c) 450 nm, and 550 nm Has an Optimum Electric Field 1.6 V/m; 2.1 V/m; 3.5 V/m and 9.6 V/m, Respectively.

Figure 5. Cross-Sectional View of Electric Field Distribution Ag Nanosquare Arrays with Side Size of 200 nm Irradiated with Electromagnetic Wave at a Wavelength of a) 250 nm, b) 350 nm, c) 450 nm, and 550 nm.

Figure 6. Ag Nanosquare Array Transmittance in Blood and Leukocyte Medium.

The transmission is obtained by comparing the electric field values on the surface and the electric fields in the Ag nanostructures. Difference component of the Ag nanosquare's medium can cause differences in the transmittance value. Figure 7 shows the difference in the transmittance value of Ag nanostructures using blood and leukocytes medium. The transmittance of Ag nanostructures in medium leukocytes is smaller compared to blood because blood has a greater value of dielectric constant and electrical conductivity than leukocytes. Therefore, blood medium transmittance has a lower value than leukocytes. Fewer photons penetrate the surface of Ag nanostructures in the blood medium than using leukocyte medium. Thus, the ratio between the squared of electric field at the
nanostructures and the surface which is calculated as the transmittance of the Ag nanostructures has a greater value in blood when compared to medium leukocytes. The difference in the transmittance value can be used as the basis for making blood cancer sensor detection. The larger difference of transmittance of Ag nanostructures in blood and leukocytes, the greater sensitivity Ag nanostructures to measure difference component of blood. The simulation results show that the Ag nanostructure with a side size of 50 nm has the greatest difference of transmittance value between medium blood and leukocytes compared to other models. The maximum difference of transmittance value obtained when the Ag nanostructures are irradiated with a wavelength 250 nm. Its difference transmittance value is 8.06 a.u. Compared with the research of Chen, et al., The results of this study can also be used as a basis for detecting blood cancer using the spectroscopic method [4]. Therefore, the size of the Ag 50 nm nanostructure irradiated by 250 nm electromagnetic waves are the optimal parameter that can be used to detect blood cancer.

The parameters of the dielectric constant, magnetic permeability, and electrical conductivity also affect the value of the electric field contained in the Ag nanostructures. The greater the value of the electric field in the nanostructures, the greater the ability of the Ag nanostructures to break down blood cells. Apart from that, particles in a medium also tend to move towards the higher electric fields. This can be used as the basis for making blood therapy electrodes using Ag nanostructures.

The distribution of the electric field is influenced by the size of the Ag nanostructures and the wavelength of electromagnetic. It variables can be used to determine the optimum Ag nanostructure-dimensional as electrodes for blood cancer therapy. Figure 8 shows the electric field value of the Ag nanostructures with variations in the size of the Ag nanostructures. The maximum value of the electric field in the Ag nanostructures is $1.78 \times 10^{-5}$ V/m. This value is obtained from the Ag nanostructures with a size of 50 nm irradiated with electromagnetic waves at a wavelength of 350 nm.

![Figure 7. Electric Fields of Nanosquare Ag Arrays with Side Sizes of 50 nm (Insert : 100 nm, 150 nm and 200 nm) Irradiated with Electromagnetic Waves at Wavelength of 200 nm to 1000 nm.](image)

The electric field value of the Ag nanostructures has maximum value at wavelengths between 250 nm to 400 nm using variations in the size of the nanostructures. The maximum value of the electric field is due to the highest value of the dielectric constant Ag at a wavelength of about 300 nm. Therefore, the highest maximum electric field of Ag nanostructure is at a wavelength of 350 nm.

The greatest value of the electric field was found in the Ag nanostructures with a side size of 50 nm. This is because more electromagnetic waves will be transmitted to the Ag nanostructures with smaller dimensions compared to larger dimensions [20]. The small side size of the Ag nanostructure has a larger surface area in contact with the medium. Therefore, the 50 nm side size of the Ag
nanostructures irradiated with electromagnetic waves at a wavelength of 350 nm is the optimal parameter that can be used for manufacturing of blood cancer therapy electrodes.

4. Conclusion
Different mediums and dimensions of nanosquare can cause different electric field responses in the Ag nanosquare array and its mediums. The electric field in Ag nanosquare with side size 50 nm irradiated with electromagnetic wave at a wavelength of 350 nm has value \(1.78 \times 10^{-5}\) V/m. This value is the highest electric field compared to the all dimensions and wavelengths of irradiated electromagnetic wave. The maximum difference value of transmittance Ag nanosquare array between blood and leukocyte is 8.06 a.u. This value is resulted from Ag nanosquare with size 50 nm irradiated with electromagnetic wave at a wavelength of 250 nm. These results provide an initial interpretation of optimum wavelength of electromagnetic wave and size of Ag nanosquare arrays for therapy and detection of blood cancer.

Acknowledgments
This work was supported by the Institut Teknologi Sepuluh Nopember (ITS) and RISTEK-BRIN under Penelitian Dasar (PD) (No. 1107/PKS/ITS/2020).

References
[1] LaRussa A 2015 Leukemia, lymphoma, myeloma and myelodysplastic syndromes (MDS) Fact and Statistics Fact and Statistics
[2] Riley L K and Rupert J 2015 Evaluation of Patients with Leukocytosis AFP 92 1004–11
[3] Nagulapalli R, Hayatleh K, Barker S, Raparth Y and Lidgey F J 2017 A CMOS blood cancer detection sensor based on frequency deviation detection Analog Integr Circ Sig Process 92 437–42
[4] Chen X, Li X, Yu X, Chen D and Liu A 2018 Diagnosis of human malignancies using laser-induced breakdown spectroscopy in combination with chemometric methods Spectrochim Acta Part B: Atomic Spectroscopy 139 63–9
[5] Webster J G 2009 Medical Instrumentation Application and Design, 4th Edition (John Wiley & Sons, Incorporated)
[6] Tahier A R H, Hafida N H, Rubiyanto A and Nasori N 2020 Two-dimensional electric field analysis for AAO structure of ZnO as an alternative glucose sensor INTERNATIONAL CONFERENCE ON SCIENCE AND APPLIED SCIENCE (ICSAS2020) (Surakarta, Indonesia) p 020110
[7] Nasori N, Hafida N H, Tahier A R H and Rubiyanto A 2020 Effect of phosphate buffer saline solution on the performance of zinc oxide thin film surface electrodes using electrochemical detection for glucose biosensor International Conference On Science And Applied Science (ICSAS2020) (Surakarta, Indonesia) p 020125
[8] Becherrawy T 2013 Electromagnetism: Maxwell Equations, Wave Propagation and Emission (John Wiley & Sons)
[9] Rowe D J, Smith D and Wilkinson J S 2017 Complex refractive index spectra of whole blood and aqueous solutions of anticoagulants, analgesics and buffers in the mid-infrared Sci Rep 7 7356
[10] Schenck J 1996 The role of magnetic susceptibility in magnetic resonance imaging: MRI magnetic compatibility of the first and second kinds Medical physics 23
[11] Fathima S J and Khanum F 2017 Blood Cells and Leukocyte Culture--A Short Review Blood Res Transfus J 1 1–2
[12] Rauf A 2013 A dielectric study on human blood and plasma International Journal of Science, Environment and Technology 2 1396–400
[13] Mi Y, Wen L, Xu R, Wang Z, Cao D, Fang Y and Lei Y 2015 Constructing a AZO/TiO$_2$ Core/Shell Nanocone Array with Uniformly Dispersed Au NPs for Enhancing Photoelectrochemical Water Splitting *Advanced Energy Materials* **6** n/a–n/a
[14] Xu P, Hao L, Zhang H, Tao X and Wang S 2011 Electrochemical Modification of Silver Coated Multifilament for Wearable ECG Monitoring Electrodes *Advanced Materials Research* **332–334** 1019–23
[15] Johnson P B and Christy R W 1972 Optical Constants of the Noble Metals *Phys. Rev. B* **6** 4370–9
[16] Ma W, Shi T, Tang Z, Liu S, Malik R and Zhang L 2011 High-throughput dielectrophoretic manipulation of bioparticles within fluids through biocompatible three-dimensional microelectrode array *ELECTROPHORESIS* **32** 494–505
[17] Abdellaoui N, Pereira A, Novotny M, Bulir J, Fitl P, Lancok J, Moine B and Pillonnet A 2017 In situ monitoring of electrical resistance during deposition of Ag and Al thin films by pulsed laser deposition: Comparative study *Applied Surface Science* **418** 517–21
[18] Lakowicz J R 2006 Plasmonics in Biology and Plasmon-Controlled Fluorescence *Plasmonics* **1** 5–33
[19] Bakr N A, Funde A M, Waman V S, Kamble M M, Hawaldar R R, Amalnerkar D P, Gosavi S W And Jadkar S R 2011 Determination of the optical parameters of a-Si:H thin films deposited by hot wire–chemical vapour deposition technique using transmission spectrum only *Pramana - J Phys* **76** 519–31
[20] Guler U and Turan R 2010 Effect of particle properties and light polarization on the plasmonic resonances in metallic nanoparticles *Opt. Express* **18** 17322