Indonesian Journal of Electrical Engineering and Computer Science
Vol. 15, No. 2, August 2019, pp. 671~677
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v15.i2.pp671-677

Characterizations of electrode geometrical shape for dielectrophoresis

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Article Info

Article history:

Received Oct 20, 2018
Revised Feb 23, 2019
Accepted Mar 19, 2019

Keywords:

COMSOL
DEP
Electrical gradient
Electrode
Material

ABSTRACT

This paper presents a characterization of geometrical shape on dielectrophoresis by determining and analysing the geometrical shape of electrodes. The structure or geometrical shape of dielectrophoresis electrode is design using COMSOL software to determine the maximum trapping efficiency of particles. The trapping efficiency of particles can be evaluated by analysing the best electrical gradient and investigated the behaviour of the particles if the existence of a non-uniform electric field. There are three geometrical shapes have been designed which is, peel chain shape, castle wall shape and comb shape. Each of the geometrical shapes have different magnetic field produce, hence each of the design have specific application. Furthermore, these three designed are analysed by varying the material of the electrode for the best trapping efficiency. From the various and previous study, for maximum trapping efficiency the shape used is peel chain shape which is suitable for biological and non-biological particles separation. But for the castle wall and comb shape is the most suitable for biological particles such as red blood cell and bacteria trapping. As for the result obtain, it is proven that peel chain shape could achieve maximum electrical gradient to trap biological or non-biological particles in the future.

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1. INTRODUCTION

The study of dielectropheresis (DEP) is started at late 80’s and booming in the early 2000’s. The most study done on the DEP is applied on biomedical science as it can contain the movement of red blood cell on either trapping them or deflect the red blood cell away from the electrodes. There are two type of DEP which is positive DEP (p-DEP) or negative DEP (n-DEP) based on the particle movement due to direction particles movement from high field region. p-DEP occurs for particles that are more polarizable than the medium. In the other hand, if the particle polarizability is low enough for the Re[FM] to become negative, i.e. when the particle effective permittivity and/or conductivity are smaller than those of the medium, the force DEP will tend to move the particle towards the weakest, or minimum, region of the electric field [1].

The motion of particles in DEP is highly influence by the electric field of the electrode. This motion is produced by the action of an electric field on dipole moments induced in the particle and the suspending fluid by the electric field [2]. With the alteration of the behaviour of the microorganism, the concept of the DEP is applied on red blood cell and other type of human DNA. Dielectrophoresis has captured much interest recently because it is an effective way to trap, manipulate, and separate particles ranging from DNA strands to blood cells and larger particles [2]. Furthermore, there are current trends suggest the theory and technology by applying DEP to meet the needs in such areas as biosensors, cell therapeutics, drug discovery, medical diagnostics, microfluidics, nano assembly, and particle filtration [3]. The geometrical shape of the electrode determines the application of the device. With different types of geometrical shape, it will produce different type of electric field. Moreover, the trapping efficiency will be different as it depends on the structure of the electrode. This electrode was designed to enhance corner phenomena where the electric field and charge accumulation increases [4].

This research proposed the behaviour of three types of electrode geometrical shapes for DEP applications. The behaviour of this electrode design is compared in term of trapping efficiency of particles and its electric field gradients. Through this simulation setup, the best structure of DEP electrode can be characterized regarding the manipulation of particles likes separation, focusing, sorting, trapping, concentrating, filtering and patterning of micro particles, cells, biological particles and nanoparticles inside microfluidic device [5-8]. There are three geometrical shapes for DEP which is peel chain, comb and castle wall shape. Each design trapping efficiency is depending on the application. Based on this research the characterization of electrode geometrical shape able to determine the application for each electrode. Furthermore, the type of material of electrode contribute the efficiency trapping. The material for DEP electrode may vary to study its conductivity properties in order to produce greater non-uniform electric fields for better trapping efficiency. The simulation is performed using COMSOL 5.2.

2. MATHEMATICAL MODELING

Despite with difference type of approach with the different geometrical shape and methods, the concept of the DEP is the same as which the particle's direction is heavily influence by the electric field. With all the variables that can change the behaviour of the DEP, the behaviour of the DEP can be explained thoroughly with mathematical expression. Briefly, classical theory models the DEP force FDEP induced by an ac field E with frequency _ on a spherical particle of radius a as:

$$F_{\text{DEP}} = 2\pi a^3 \varepsilon_{\text{medium}} \operatorname{Re}(f_{\text{cm}}) \nabla |E|^2,$$

where _medium is the real part of the suspending medium permittivity. The factor fcm is the frequency-dependent Clausius-Mossotti _cm_ factor for a lossy dielectric homogeneous spheroid and is dependent upon the permittivity and conductivity of both the particle and the suspending medium [9]. With the fundamental of the DEP mathematical model the geometrical shape of the electrode which is the permittivity and the electrical field.

3. SIMULATION

For COMSOL simulation setup, the model can be set whether 1D, 2D and 3D. In this paper, model for electrode geometrical shape is set 2D to make is easier to look and compare in term of the structure. 3D model is not preferable in this simulation because needs more memory to perform the simulation. The geometric shape is in 2 dimensional which the geometric shape is constructs by point and creating a dimension. The positive and negative electrode is assigned in this simulation to study the behaviour of electrode in term of its non-uniform electric gradient.

In this paper will discussed the behaviour of DEP electrode for different geometrical structure and material for each electrode. There are three type of electrode has been designed using COMSOL which are peel chain shape, castle wall shape and comb shape electrode. For each geometrical structure will varies with different material which is gold or platinum to study the electrical potential for each material.

In the first part of simulation is studied the geometrical structure of DEP electrode. There are three type of electrode modelling which is peel shape, castle wall and comb shape as shown in Figure 1. The particles will be trapped on the tip of electrode when the electrical potential is applied to the electrode. For each electrode, 5V voltage is applied for each electrode. According to Figure 1, the electrode designed is position in parallel each other except for comb shape electrode. The electrode would be trap on the tip of the electrode and there will be majorities of electron on the tip of the electrode. Figure 1 shows the modelling of peel chain shape on the simulation.

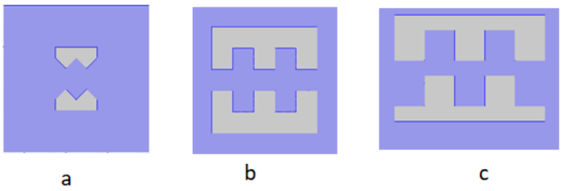


Figure 1. Geometrical electrode structure for DEP (a) peel chain (b) castle wall (c) comb shape

For this simulation setup, the top and bottom of electrode is aligned to parallel each other. The top of electrode is set as ground and the bottom electrode is supplied with 5V. The top of the electrode is set to ground whereby it will deflect the electron to the positive of the electrode. The design of the electrode is almost similar to the castle wall shape except the alignment of the positive electrode and negative electrode is design as comb shape. The majorities of the electron will be focused on the edge of the electrode.

In the second part of simulation will manipulate the material of DEP electrode to study the performance of its electric gradient for trapping particles. In COMSOL software there are several Multiphysics used to simulate the performance of DEP. Multiphysics electrostatics is used to perform this simulation. Since the research is on trapping particles, the medium used for trapping is water or fluid and the shape of electrode is constructed in line coordination.

For electrode material studies, the electrical potential will show in the colour code. The electrical potential has been set up 5V for bottom electrode. Meanwhile for top electrode has been set up as ground. The maximum electrical potential shows the maximum trapping happens on the electrode. The colour code will deflect the range of electric potential is happened. The red colour code starts with blue, green, yellow and red as it is the maximum electric potential is happened. The bottom of the electrode is the positive of the electrode and the top electrode is the negative electrode since gold is the better conductor, it will produce greater electric field and electric potential. The properties of the dielectrophoresis are still the same as it will repeal on the negative electrode and the positive electrode will attract electrons. According to Figure 2, shows the colour code for electrical potential occurred on electrode edge.

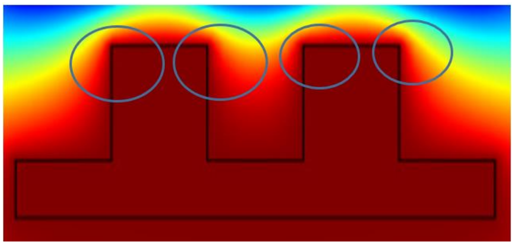


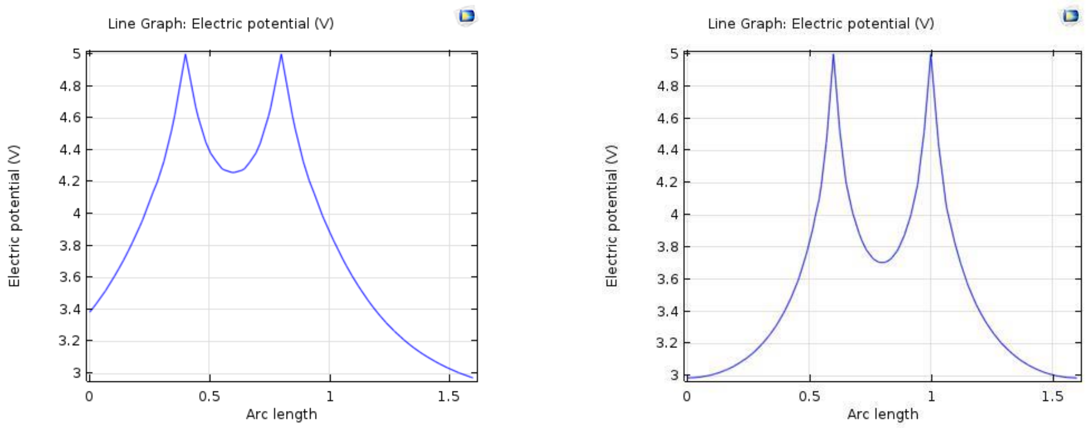
Figure 2. Electric potential that occur on the electrode edge

4. RESULT AND DISCUSSION

The movement of the electrode is dependent on the polarities of the electrode. If the electrode is positive, the particles will attract towards the positive electrode and if the polarity electrode is negative the particles will repel away from electrode. Since the direction of the force is determined by the spatial variation of the field, the particle always moves toward/against the direction of the electric field maxima [10-12]. The result of the electric potential or electric field that occur the edge of the electrode is obtained by construct a linear line on the edge of the electrode. Maximum electric potential can be determined when the electric potential have the same value with applied voltage on the electrode. Most of the particles will be trapped on the edge of the electrode. Particles trapped at the edge of microelectrode indicated as positive dielectrophoresis (pDEP).

On the other hand, there are several graphite un-trap bypasses through two poles microelectrodes [13-16]. With the change of the material, the material with better conductivity will produce a better electric potential on the edge of the electrode.

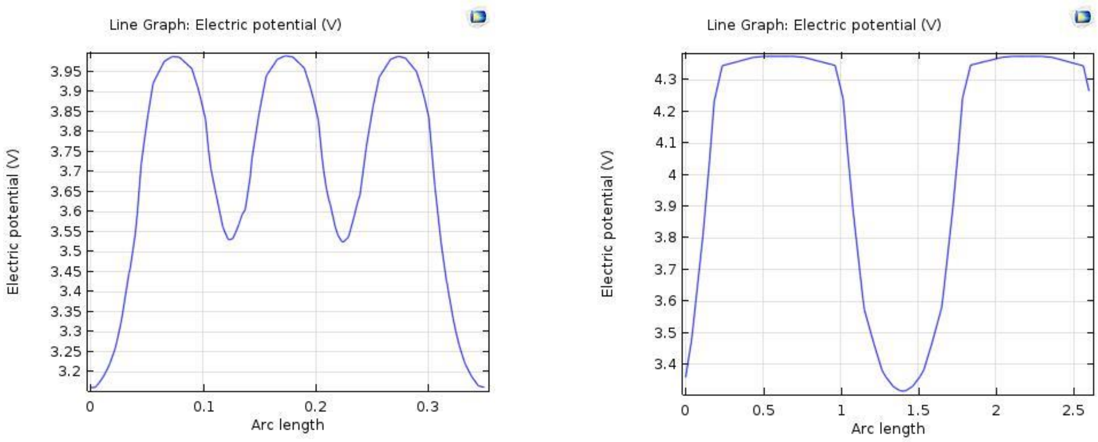
Figure 3 shows the line graph of electrical potential that occurred on the edge of peel chain electrode. The graph shows that the electric potential is maximise and resembles as maximum electric field on the edge of the electrode. The material used on the electrode is copper and gold. The graph shows that the electric potential has reach it maximum. Since gold is more conductive than copper it will produce more electric field or electric potential on the edge of the electrodes. However, the trapping efficiency of gold material is the same as the copper material due to its geometrical shape. In this case, the peel chain shape will give the best trapping with 100% efficiency based on the electrical potential value [17, 18]. Furthermore, this geometrical structure is the most suitable for separating or trapping biological and non-biological particles by manipulating the electrical potential.



(a) copper material (b) gold material

Figure 3. Electric potential for peel chain shape

For the second geometrical structure is castle wall shape with different material which is copper and gold shown in Figure 4. According to Figure 4 (a) and (b) shows that the electric potential that occurred on the edge does not reach it maximum potential. Based on electrical potential shows that the trapping efficiency of the electrode is not great as the peel chain shape electrode. The value of electric potential on the edge of the copper material is 3.95V while the gold material is 4.3V on the edge of electrode. The particles were trapped around the edge of electrode, where the electric field became higher, probably due to positive DEP. The trapped particles were aligned along the electric field line and bridged the electrode gap [19-22]. According to its electrical potential, the castle shape electrode is applicable for trapping biological cell such as red blood cell. Since the simulation is run on the particles such as water, the trapping efficiency can be analysed by varying the electrode material from copper to gold. For the gold material on the electrode, it will produce greater electric potential thus more trapping efficiency than copper [23-25].



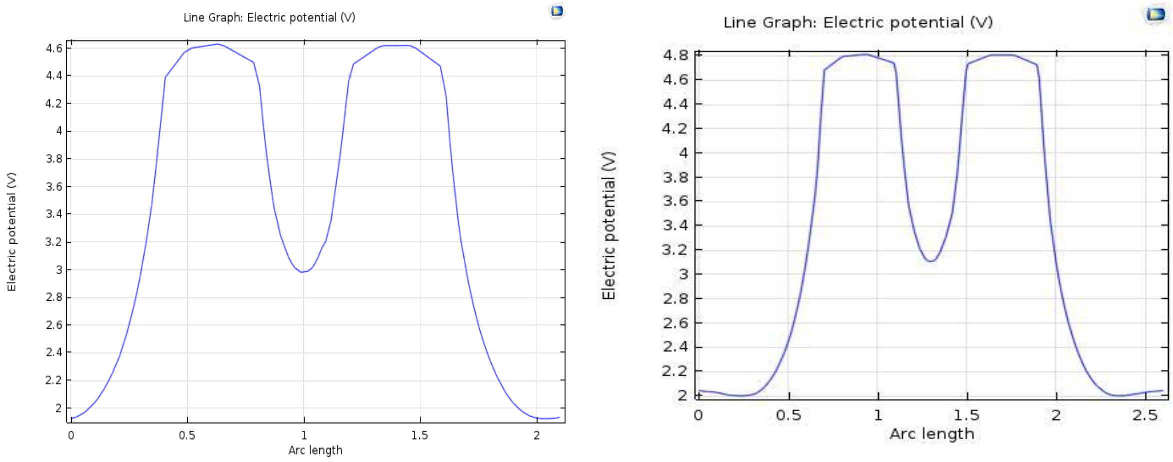
(a) copper material (b) gold material

Figure 4. Electric potential of castle wall shape electrode

The next geometrical structure is comb shape with aforementioned simulation setup. According to the graph in Figure 5 shows that the electric potential only reached 4.6V for copper and 4.8V for gold electrode. Based on the electrical potential shows that the comb shape electrode is used for trapping biological cell specifically for bacteria. The particles are collected through the edge of the electrode same as the castle wall shape electrode. As the dielectrophoresis properties are applied the positive electrode will attract the particles while the negative terminals will repeal the particles away.

From the three geometrical structure of DEP shows that the peel chain shape gives the best efficiency trapping compared to the castle wall and comb shape. It can be determined by comparing the electrical potential at the edge of each electrode to trapping particles.

In terms of biocompatibility, the castle wall and comb shape electrode are suitable for trapping bio-cells. Each of the electrodes has different application such as the castle shape is mostly used for trapping red blood cell and the comb shape electrode is used bacterial trapping. In addition, for the biocompatibility the electrode with less electrical gradient is chosen due to it is less contamination. In this case the castle wall shape is suitable for biocompatibility as it produces less electrical gradient.



(a) copper material (b) gold material

Figure 5. Electric potential of comb shape electrode

5. CONCLUSION

As conclusion, each electrode geometrical structure for DEP give the different electrical potential. The particle movement is depended on the polarities of the electrode which is if the electrode is positive the particles would be attracts toward the electrode and vice versa. In the context of trapping particles, the peal chain shape could obtain maximum electric potential even though the material of electrode is change from copper to gold for each geometrical design. From the result obtain, the gold electrode give high electric potential on the edge of the electrode because of gold is a great conductor. For peel chain shape electrode, there are not much differ for copper and gold because both materials achieve the maximum electrical potential on the edge of electrode. However, with gold material is applied into to castle wall shape and comb shape electrode the electric potential is increases on the edge of the electrode. Based on electrical potential, the geometrical structure can define the application for each structure which is peel chain shape electrode is suitable for trapping particles while the comb shape and castle shape electrode is applied on trapping biological particles.

ACKNOWLEDGEMENTS

The authors would like to thank Institute of Research Management and Innovation (IRMI) UiTM and Ministry of Higher Education for the financial supports. This research work is conducted at Faculty of Electrical Engineering, Universiti Teknologi MARA (UiTM), Malaysia under the support of Dana Lestari 600-IRMI/MyRA 5/3/LESTARI (014/2017).

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