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Geometrical Shape Investigation For Electrodes in Silent Discharge Chamber

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Abstract. Silent discharge is the most prominent method to carry out plasma reaction because. discharge is easily initiated by injecting alternating current in high voltage to the pair of separated electrodes. The electron emission from surface of dielectric placed on instantaneous cathode is stimulated by ion induced electron emission. In this method, spark is avoided by placing insulation material to either one or both of the electrodes. In practical, it is very difficult to determine the exact limit of the voltage that initiate the discharge by mathematical analysis because it depends on many factors, namely dimensions, type and geometrical shapes of electrode, thickness of insulation, and type of electric field inside the discharge gap. To get lower initial voltage for discharge, it is important to find the best geometrical shape of electrode in relation to skin effect that trigger electron emission. This work investigates the behaviour of charges, current, electric field and voltage surrounding electrodes with various geometrical shape.

1. Introduction

Silent discharge method covered larger area of excitation than pulse discharge method, and this meant that silent discharge method generated is able to generate more gas discharges inform of micro discharge than pulse. Basically the silent discharge chamber is constructed by two pair of electrode, air gap in between and a dielectric layer that covers at least one or both electrode. This paper presents an investigation for the construction of the chamber which is support the micro discharge with minimal discharge deformation. It can be shown through computer simulation that geometrical shape of electrode and chamber construction give influence to micro discharge initiation and prevent the deformation of plasma such as ozone.

2. Geometrical Construction for Electrodes

In design of the geometrical shape of the electrode for silent discharge application, it must be noted that alternating current (AC) high frequency will be injected inside the chamber and this event will create skin effect. Skin effect is physical phenomena which show the tendency of AC to distribute itself within a conductor so that the current density near the surface of the conductor is greater than that at its core. The electric current tends to flow at the skin of the conductor at average depth which is known as skin depth. The skin depth is defined as the depth below the surface of the conductor at which current density decays. The skin depth is calculated by empirical formula in Equation (1) [1-4].

$$\delta = \sqrt{\frac{2\rho}{\omega\mu}}$$

(1)

Where ρ is resistivity of conductor, ω is angular frequency of current that is equal to $2\pi \times$ frequency, and μ is absolute magnetic permeability of conductor that is equal to $\mu_o \cdot \mu_r$. The Value of permeability of free space (μ_o) is $4\pi \times 10\text{-}7$ and relative permeability of the material conductor is symbolized as μ_r.

Due to skin effect, the current flows in an extremely thin region near the surface of the electrode. When the electrode is injected by an external voltage source, an electric field (E) presents in the conductive material. The relationship between current density (J) and E can be written as [5-8]:

$$E = \frac{1}{\sigma} J$$

(2)

and

$$\nabla^2 E = -\nabla \frac{\partial B}{dt}$$

(3)

while

$$B = \mu H$$

(4)

By replacing E and B in equation (3) with equation (2) and (4) then new equation is obtain in equation (5).

$$\frac{1}{\sigma} \nabla^2 J = -\mu \nabla \frac{\partial H}{dt}$$

(5)

Equation (5) is possible to be modified in both side and it become equation

$$-\nabla^2 J = -\sigma\mu \frac{\partial}{dt} \left\{ J + \frac{\partial(\varepsilon E)}{dt} \right\}$$

(6)

where ε and σ are the permittivity and conductivity if the conductor, respectively. By considering the first and second derivative of E and J, the equation (6) can be written as [1,4,8,9]

$$\frac{1}{\sigma\mu\omega} \left(\frac{\partial^2 J}{dt} \right) + (j\sigma - \omega)E = 0$$

(7)

To have an idea on what would be the best geometrical shape of electrode in relation to skin effect; it is useful to investigate the behaviour of J and E. This can be carried by executing Equation (7) using the Partial Differential Equation (PDE) toolbox provided in Matlab [10]. The Simulation is conducted for two cases of geometrical configuration: (1) copper plane and (2) copper mesh electrodes. The conductivity and permittivity of copper are 57×10^{-6} S/m, and 8.8×10^{-12} F/m, respectively.

Figure 1 shows the distribution of J for a copper plane electrode, when the electrode is injected by electric field 10kV/m at 30 kHz ac supply. As can be seen the current concentrates at the edge of the electrode, while low current density are distributed at the centre of the plate. The low current density means that only few amount of charges or electrons per area provided for ionization which leads to less microdischarge to be generated. Since skin effect at high frequency cannot be avoided, the electrode need to be modified in order to increase the number of microdischarge per unit area.
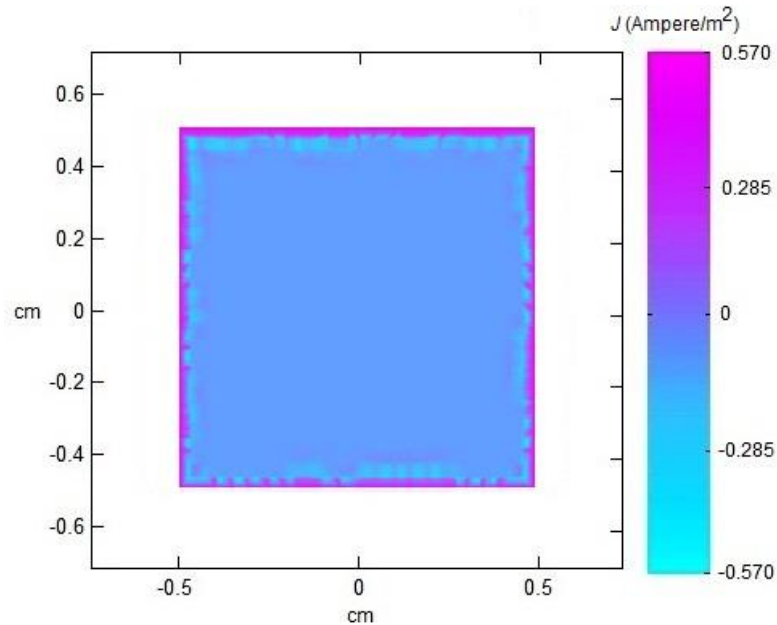
Figure 1. *J* in a copper plane electrode (1 x 1 cm) at 30 kHz 10 kV/

The copper electrode is modified as a mesh. The mesh configuration allows for numerous current paths to be established in a wider area. The distributions of *J* for the mesh electrode injected by electric field 10kV/m at 30kHz simulated by PDE toolbox in Matlab is shown in Figure 2. It can be observed higher *J* present not only in the most outer edge of the mesh, but instead it spreads in all region, i.e. in every small rectangular path. The larger J provides better ionization and generate more microdicharges intensively. This mesh configuration decreases the free path of electrons of injected gas and increase the number of collision among ions and electrons of injected gas to create more chemical reaction.
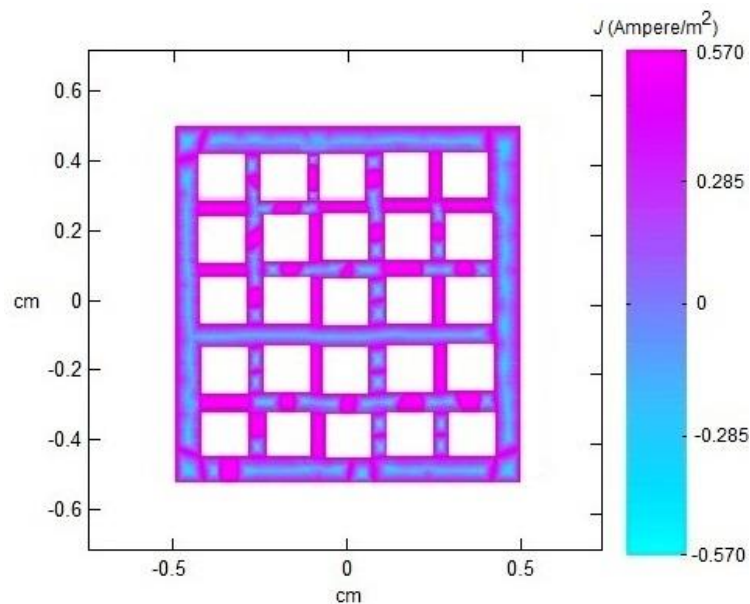

Figure 2. *J* in a copper mesh electrode (1 x 1 cm) at 30 kHz 10 kV/m

3. Experimental Result

To verify the performance of the chamber under various combinations of electrode and their geometrical shapes, a simple 50 Hz ozone generator is set up. Chambers with plane and mesh

electrodes are prepared. Three types of electrode materials are used i.e. (1) copper plate, (2) aluminium plate, and (3) aluminium mesh. The dimension of the chamber is 230 × 130 × 20 mm. All the electrodes and dielectric was installed chamber with 2 mm air discharge gap. A mica as an insulator is attached to one of the electrodes.

Oxygen gas is used in this experiment. When there are more oxygen gas is formatted into ozone gas inside the experimental chamber, then the micro discharge with particular geometrical shape is successful initiated. The experimental set up is shown in Figure 3.
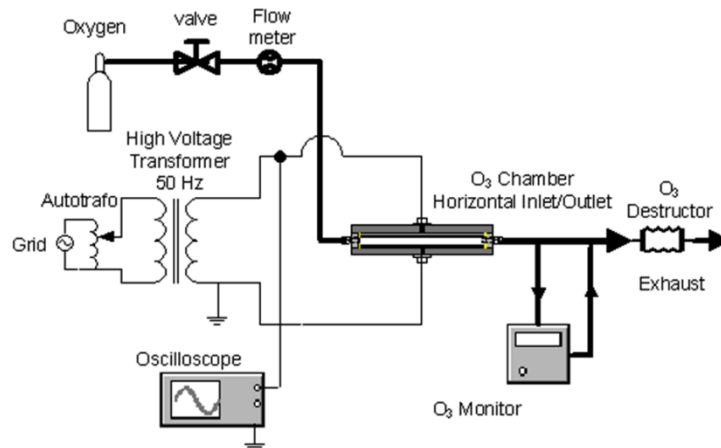

Figure 3. The experimental set up with 50 Hz AC supply

The experiment is conducted by injecting 6kVpp to the terminal of chamber. The experiment is repeated for several values of flow rate, i.e. 0.5, 1.0, and 1.5 Litre /minute. The ozone productions of different combination of electrodes are shown in Figure 4.
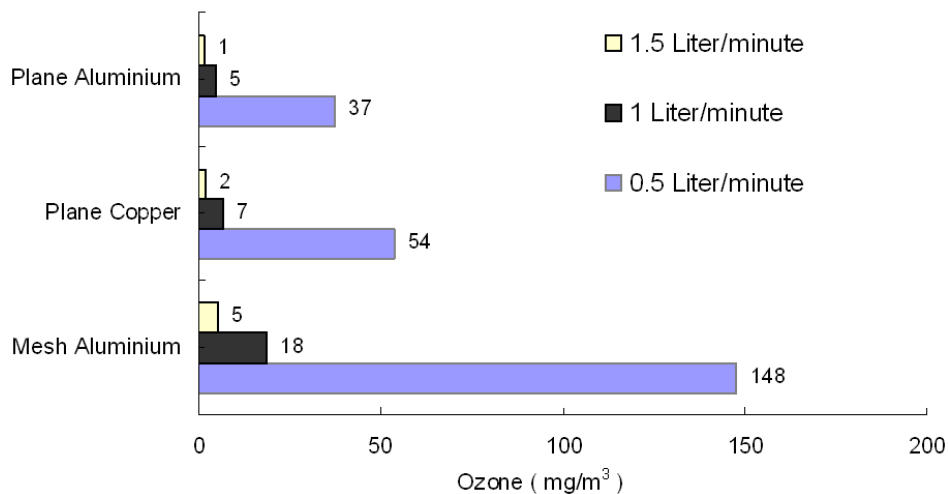

Figure 4. Comparison of the ozone production between chambers with plane electrode and mesh electrode

From Figure 4, it is clear that the mesh electrode produce the highest ozone yield compared to chamber with plane electrode for all flow rate. This significant result verified the simulation result that ionization in mesh electrode occurred in wider area than the plane electrode. The present of density current in every path of electrode provided more electrons to ionize in high electric field. These

electrons created more secondary emission to initiate microdischarges inside the chamber as main process in silent discharge mechanism.

4. Conclusion

The behavior of plane and mesh electrode under AC voltage are simulated through PDE Toolbox provided in Matlab, and the result shows that mesh electrode gave better distributed electric field and current density which are needed to make secondary emission and micro discharge inside the chamber. The experimental results also verified that geometrical shape of electrode give influence to micro discharge initiation of plasma such as ozone. The present of density current in every path of electrode provided more electrons to ionize in high electric field.

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