

A New Type of Planar Chamber for High Frequency Ozone Generator System

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Abstract. This paper proposes a new type of planar chamber ozone generation operated at atmospheric pressure, ambient temperature and high frequency. The chamber was constructed in planar type with easy adjustment using simple filler material and arrangement for different type of electrodes. A prototype was developed based on study to find the most effective geometrical electrode shape and dielectric material to produce micro-discharges without additional discharge gas, low pressure and temperature. The works were initially carried out by theoretical analysis and finite element simulations to find the best geometrical shape for the electrode and to prove theoretical prediction, the experimental works were set up to determine the preferable dielectric to be used along with the electrode. Finally, the best combination was revealed by using muscovite mica and aluminum mesh on copper plate to start generating ozone at 785 V and 30 kHz. This planar prototype chamber successfully delivered the highest ozone yield more than 3000 ppm and 120 g/kWh. Due to the simplicity and low cost design, this planar chamber can be suitably used for portable and home appliance.

Introduction

One of the well known methods to generate ozone in normal atmospheric environment is by using dielectric barrier discharge or sometimes referred to as silent discharge which is supplied by ac voltage [1]. The ac voltage is normally obtained using the 50 or 60 Hz a large step-up transformer with typically voltage above 20 kV for a 1 mm discharge gap [2]. For safety reason, this high voltage may not be suitable for certain household applications, such as domestic water and air treatment. In addition, low frequency transformer is less efficient [3].

A high frequency ac power supply provide a lower voltage to generate ozone [4, 5]. The main advantage of having a lower applied voltage is the opportunity to build ozone generators using non-conventional dielectric materials which have much lower dielectric breakdown voltage such as mica, alumina ceramic, and polymer. Furthermore, high frequency transformer with switching converter requires smaller footprint than the conventional transformer.

This paper describes a low cost ozone generator based on a new type of planar chamber ozone generation. This chamber is proposed to be operated at atmospheric pressure, ambient temperature and high frequency.

Planar Ozone Chamber

The proposed ozone chamber is designed with simplicity in dimension of 70 x 140 mm square as shown in Fig. 1. It is designed without special gas for cooling and discharge and operated at normal atmospheric environment. The advantages of a planar chamber are simple construction, easy adjustment for air gap using filler materials and simple arrangement for different type of electrode and dielectric.

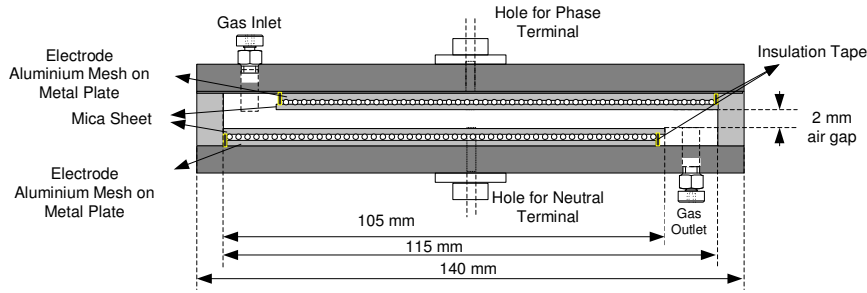


Figure 1. Planar chamber

Geometrical Shape for Electrode

At high frequency operation, the skin effect has made the ac current tends to distribute near the surface of the conductor; so it is important to have an idea on what would be the best geometrical shape of the electrode in relation to skin effect. For this purpose, it is useful to investigate the behavior of current density (J) and electrical field (E) at high frequency as shown in Eq.1 [6, 7].

$$-\nabla^2 J = -\sigma\mu \frac{\partial}{\partial t} \left\{ J + \frac{\partial(\varepsilon E)}{\partial t} \right\} \tag{1}$$

where ε and σ are the permittivity and conductivity of the conductor, respectively. By considering the first and second derivative of E and J , the Eq.1 can be written as

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

By using the Partial Differential Equation (PDE) toolbox provided in Matlab, it is possible to have finite element simulation from Eq.2. The simulation is conducted for: (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. As the result, Fig. 2 (a) shows the distribution of J for case of copper plane electrode when the electric field is 10kV/m at 30 kHz. It can be seen the current concentrates at the edge of the electrode, while low current densities are distributed at the centre of the plate and it produces less microdischarges. Since skin effect cannot be avoided, the electrode is modified into a mesh as shown in Fig. 2 (b). A higher J presents not only in the most outer edge of the mesh, but instead it spreads in all regions, i.e. in every small rectangular path. The larger J provides better ionization, generates more microdischarges, and increases collisions among ions to generate ozone. Form these results, it is concluded that the mesh electrode is the best geometrical shape to overcome the skin effect

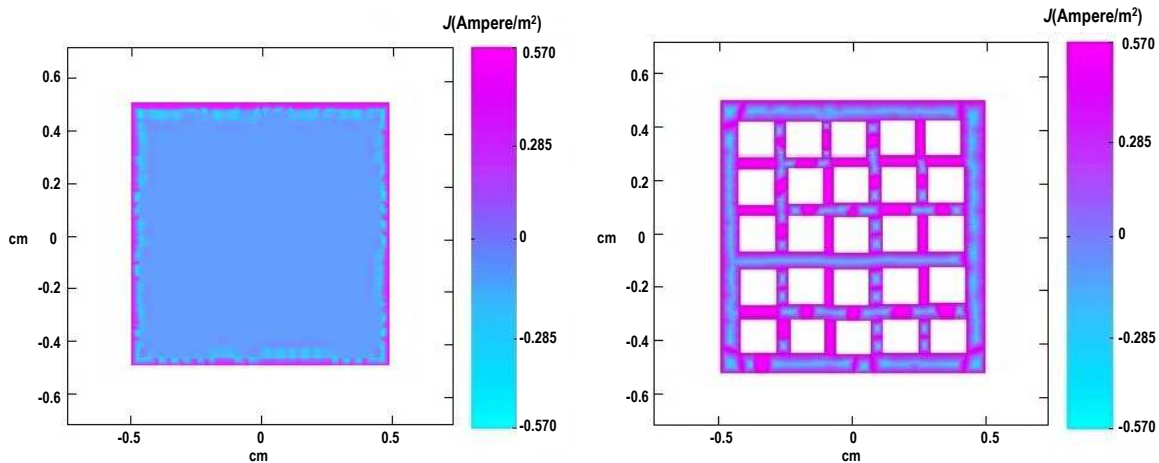


Figure 2. J at 30 kHz 10 kV/m in (a) copper plane electrode at (b) copper mesh electrode

Dielectric Material

It is crucial to estimate the maximum voltage applied to the chamber to avoid the dielectric breakdown. However, it is very difficult to determine by mathematical analysis because it depends on many factors such as chamber dimensions, geometrical shapes of electrode, electric field inside the discharge gap, temperature, frequency, pressure, and humidity [2-5, 8]. In view to these limitations, empirical approach is sought. Several materials with lower electrical breakdown such as muscovite mica, phlogopite mica, and *Polytetrafluoroethylene* (PTFE) are considered because they have lower initial voltage for microdischarges [9-11]. Destructive test is conducted by connecting each chamber with different materials to the power supply. The applied voltage is increased until the dielectric breakdown is achieved. Two experiments are carried out at (1) 50 Hz and (2) 30 kHz. The result showed that that breakdown voltage occurs at 12.5 kV for 50 Hz and 4.6 kV for 30 kHz, By realizing these limitations, the chamber will not be operated more than 12 kV_{p-p} at 50 Hz and 4.5 kV_{p-p} at 30 kHz.

Combination of Dielectric and Electrode

To determine the preferable dielectric, the chamber is fed by medical grade oxygen with flow rate of 1.0 L/m and 2 mm discharge gap is used. Three dielectric materials are tested: (1) muscovite mica, (2) phlogopite mica, and (3) PTFE with the thickness of each material are 0.1 mm. The electrodes used are aluminium and copper. All the electrodes and dielectrics have same dimension with the chamber. For all experiments carried out at 50 Hz, no burn sign is found on the mesh and dielectric layer. The current density is well spread over all region of mesh electrode and surface of dielectric. The results showed muscovite mica with aluminium mesh attached to the copper plate is the best combination because it has the highest ozone production at 6100 mg/m³ without any burnt hole at 11.5 kV, 50 Hz. This best combination is investigated further under high frequency experimental set-up as shown in Fig. 5. The high frequency transformer is used and made from ferrite. On high voltage side, the chamber is injected by oxygen gas with a variable flow rate and the output gas is connected to the ozone destructor before it is released to free air for safety.

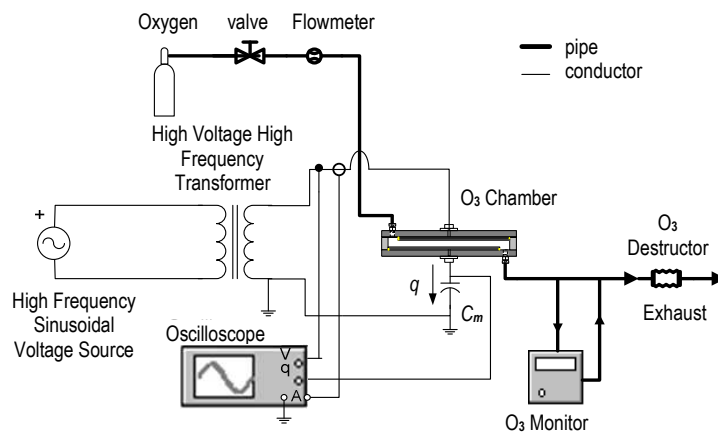


Figure 5. Experimental set up for high frequency operation

Figure 6 shows ozone production as function of voltage at different flow rate with 30 kHz frequency operation. Fig. 6 can be divided into several stages [12-14]. The first stage is on interval of voltage 2.0 – 2.2 kV_{p-p} (707 – 778 V_{rms}) where there is no ozone formation due to a very low microdischarges initiation. At interval 2.22 – 3.24 kV_{p-p} (785 – 1149 V_{rms}) the second stage shows an initial voltage when the ozone begin to be detected. The third stage is at 3.25 – 3.75 kV_{p-p} (1150 – 1325 V_{rms}). At this stage, a higher power is delivered and the maximum ozone concentration is 3785 ppm or 8.1 g/m³. To know the maximum efficacy of ozone system, then 3785 ppm is changed and equal to 120 g/kWh. The power consumed is relatively i.e. below 7.5 watt. Consequently, the current drawn for ozone formation is also low and it results in low temperature discharge. The fourth stage is indicated when the ozone concentration tends to decrease at interval 3.77 – 4.0 kV_{p-p} (1330 – 1414 V_{rms}). At this stage the voltage and power created ozone deformation.

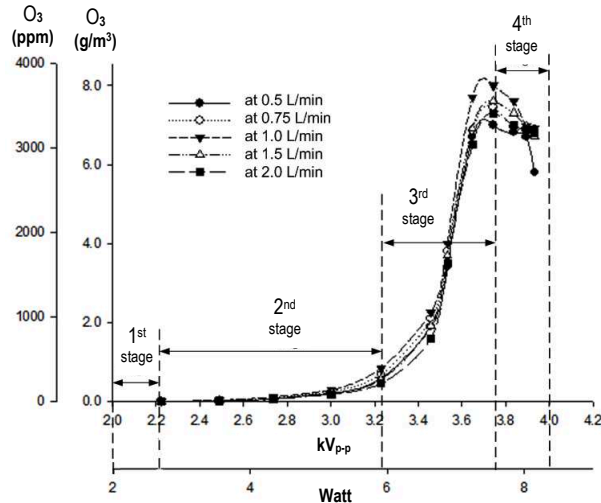


Figure 6. The ozone concentration as the function of voltage for different flow rate

Conclusion

The combination of aluminum mesh on copper plate with muscovite mica ensures the better current density and ionization without voltage breakdown from 2.0 kV_{p-p} up to 4.0 kV_{p-p}. The choice to use mica as insulation with lower electrical breakdown results in the lower initiation voltage at 785V_{rms} when the ozone begins to be detected. A planar chamber made from the combination of muscovite mica as dielectric and aluminum mesh on copper plate as electrode has been found to be the best combination to deliver a high ozone yield at 3785 ppm or 8.1 g/m³ with 120 g/kWh ozone efficacy.

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