Symetrical and simultaneous measurements of electrical potential on a parallel-plate dielectric barrier discharge

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Abstract: DBD has a wide range of applications such as ozone production, sterilization and medical treatment due to its ability to generate activated species. Accumulated surface charge is a dominant feature of DBD since it's existence will distort the electric field and affect the yield of activated species. Accurate measurement of accumulated charge is a classic problem in fundamental research of DBD. In this paper, a setup of accumulated charge measurement system based on Pockels effect is proposed, which can measure the spatiotemporal variation of net electric field between two dielectric barriers and accumulated charge density on the surface of dielectric barriers.

Keywords: DBD, surface charge, Pockels effect

1. Introduction

DBD(Dielectric barrier discharge) has been a popular topic in the field of high voltage discharge research. Activated species generated by discharge such as oxidizing particles plays a significant role in the application like ozone production, sterilization，medical treatment, etc. It is well known that the yield of activated species is related to the net electric field of the air gap in DBD[1]. However, the existence of accumulated charge on the surface of dielectric barrier will distort the electric field, which results in an impact on the yield of active species. Therefore, the accurate measurement of distribution and variation of accumulated charges has been of interest to many researchers[2]. The static characteristics of surface charge under different discharge conditions and its effect on discharge have been studied[3]. In addition, the relationship between charge distribution and gas has been experimentally investigated[4]. However, due to technical limitations, research on the dynamic patterns of surface charges during DBD process are merely found. In industry applications, DBD devices use repetitive discharges generated by alternating current voltage, and the distribution of charge will change in polarity and space with time. Therefore, spatiotemporal analysis of the dynamic characteristics and patterns of surface charges is necessary. Pockels effect has recently attracted the attention of researchers and has been introduced into DBD measurements[5]. The utilization of Pockels crystals offers many advantages, such as the realization of non-contact measurements of electric fields and charge density while enabling high temporal resolution with high-speed cameras[6]. In this paper, a DBD measurement system based on the Pockels effect is established. This system achieves high resolution measurements of the spatial and temporal distribution of surface charge density on both parallel dielectric plate during the discharge process.

2. Experiment setup

Overall, the DBD electrode consists of two specially treated BGO crystals and copper tapes as shown in Fig.1. BGO crystals are used as dielectric barriers with a thickness of 1 mm. The relative permittivity of BGO crystal ε_r is 16. One side of the BGO crystals has a mirror layer and the other side has a transparent electrode ITO (indium tin oxide) layer. The mirror layer mainly reflects light with wavelength of 536 nm. ITO layer is connected to the high voltage electrode or ground electrode by copper tapes and wires.

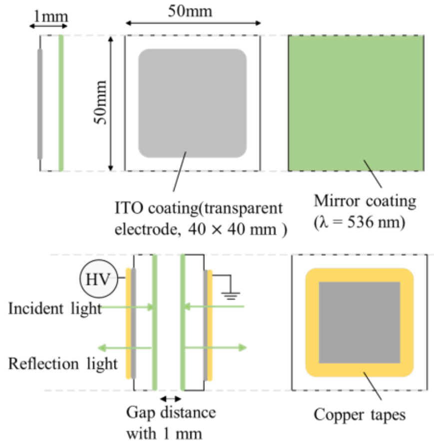

Fig. 1. Configuration of electrode and dielectric barrier.

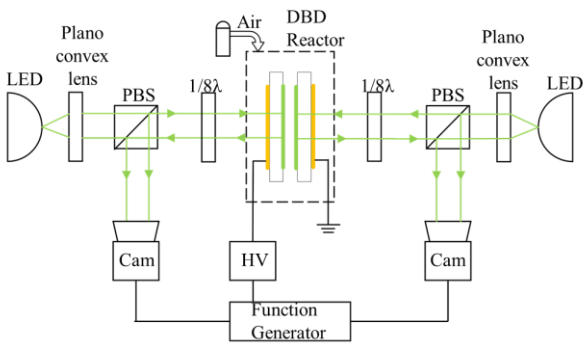

Fig. 2. Diagram of measurement system.

The diagram of the experimental system is shown in Fig.2. LED light source is used for the experiment, the main wavelength of which is 530 nm. The light from the LED passes through the PBS (Polarized beam splitter) and 1/8 waveplate and then enters the Pockels crystal, which is then reflected by the mirror and finally captured by the camera. The electric potential and surface charge density of the dielectric barriers can be calculated with the datas obtained by measuring the intensity of the reflected light. In this system, the relationship between the reflection light intensity I_{OUT} and incident light indensity I_{IN} is express as:

$$I_{OUT} = I_{IN} \times \frac{1}{2}(1 + \sin(2kV_{BGO})), k = \frac{2\pi}{\lambda} n_0^3 r_{41}, \quad (1)$$

where λ is the wavelength of incident light, n_0 is the ordinary refractive index of the Pockels crystal, r_{41} is the Pockels coefficient for Pockels crystal, V_{BGO} is the potential difference between two surfaces of the Pockels crystal.

It can be seen from Eq. (1) that I_{OUT} varies with V_{BGO} when the experimental conditions are determined, with a one-to-one matching relationship, which is only related to the properties of the Pockels crystal. The calibration curve for I_{OUT} and V_{BGO} measured in this experiment is shown in Fig. 3.

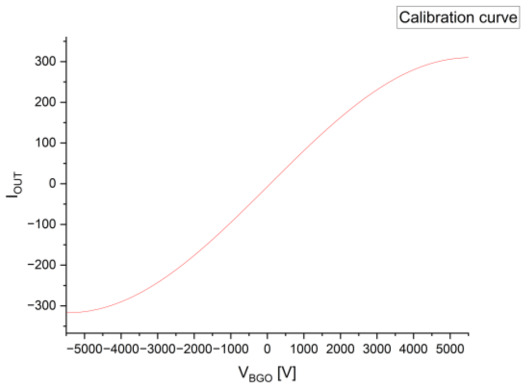

Fig. 3. The relationship between reflection light intensity I_{OUT} and the potential difference between two surfaces of the Pockels crystal V_{BGO} for ground electrode.

From Fig.2, it can be seen that this is a symmetrical system with the same principle on both sides. The net electric field of the gap can be obtained by subtracting the electric potential of both dielectric barriers. This experiment is performed by using marker dots to ensure that two high-speed cameras can simultaneously measure the potential at perfectly symmetrical locations of the two dielectrics barriers during discharge. Diagram of the locations of the marker dots and photos of the maker dots taken by cameras are shown in Fig. 4.

The gas used in the experiment is air, and the applied voltage is 6 kVpp with a frequency of 1 kHz. The high-speed cameras used in the experiment are MEMRECAM ACS-1 (nac Image Technology Inc) and BU030(Toshiba Teli Corp).

3. Results

The light intensity distribution of I_{OUT} on the two dielectric barriers at the positive peak of the first discharge cycle is shown in Fig.5(a). It can be found that the light intensity on two dielectric plates in the area of interest have a symmetric distribution according to the skeleton of the light intensity distribution in Fig. 5(c). Considering the symmetrical structure of DBD reactor, the distribution of the surface charge on the two dielectric barriers are likewise symmetrical by calculation from calibration curve. In addition, the photos of the light intensity distribution prove that the two cameras used in the experiment successfully achieve synchronous photography and the marker dots positioning method can successfully mark the symmetrical positions of the two dielectric barriers. The visual difference in the area of interest in the two photos in Fig. 5(b) is caused by the different resolutions of the two cameras, however, the actual sizes are both 4 mm x 3mm. The slight asymmetry of the marker dots is artificially caused by the fact that the area of interest is too small, the maker pen is too large and the hand shakes.

The light intensity distribution of discharge from the third cycle is shown in Fig. 6. A phenomenon can be observed that the distribution of surface charges becomes more uniform and the number of surface charges increases compared to Fig. 5(a). As a result, the symmetry of the surface charge distribution on the two dielectric barriers

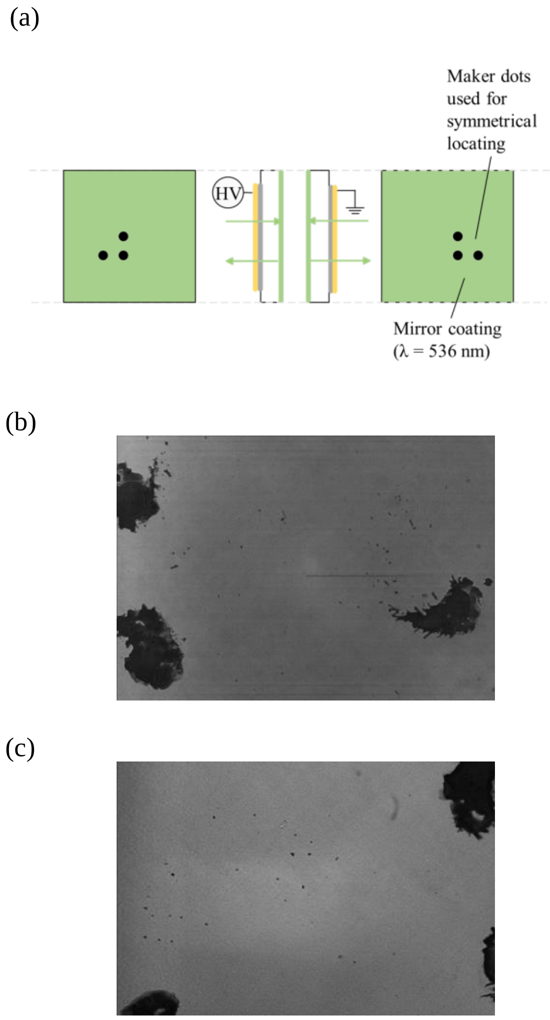

Fig. 4. (a)Diagram of the locations of the marker dots (b) photo of the maker dots in ground electrode (c) photo of the maker dots in high voltage electrode.

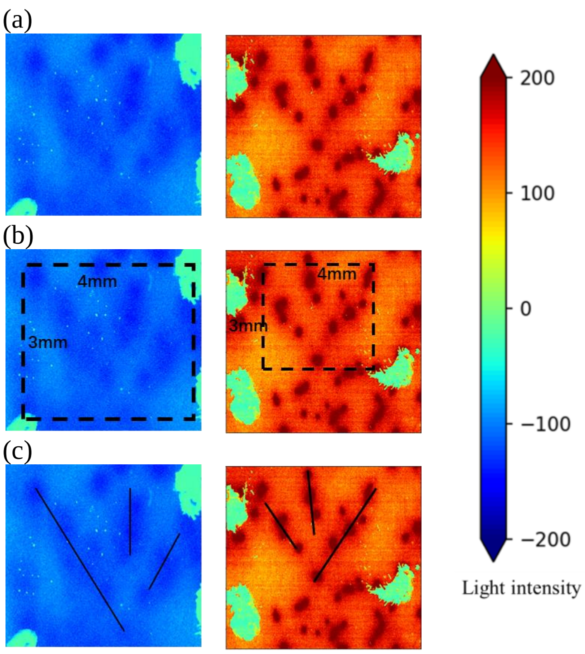

Fig. 5. (a)Photos of surfaces of two dielectric barriers at the positive peak of the first discharge cycle (b) area of interests with 4 mm×3 mm(c) the skeleton of the light intensity distribution represented by the black line used for comparison.

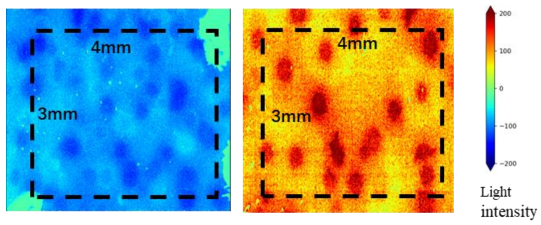

Fig. 6. Photos of surfaces of two dielectric barriers at the positive peak of the third discharge cycle.

becomes difficult to observe. The reason may be that the surface charge accumulated in the third cycle is not only relevant to the applied voltage but is also influenced by the surface charge of the second cycle. The residual charge at the end of the second cycle could accelerate the gas breakdown after the polarity shift of the applied voltage, so the discharge would appear earlier and more surface charge will be accumulated at the third discharge cycle.

4. Conclusion

In this paper, a DBD measurement system based on the Pockels effect is established, which successfully achieves high resolution measurements of the spatial and temporal distribution of surface charge density during the discharge process. In the first discharge cycle, the accumulated charges on the two dielectric surfaces are symmetrically distributed. However, the symmetry of the distribution of the surface charges in the third discharge cycle becomes difficult to observe due to the uniformity of discharge and the effect of the residual charges in the second discharge cycle.

5. References

[1] Eliasson B, Hirth M, Kogelschatz U. Ozone synthesis from oxygen in dielectric barrier discharges. *J. Phys. D: Appl. Phys.*, **20**, 1421-1437 (1987).
[2] Kumada A, Chiba M and Hidaka K 1998 Potential distribution measurement of surface discharge by Pockels sensing technique. *J. Appl. Phys.*, **84**, 3059-3065.
[3] Natsume C, Komuro A, and Ando A. Characterisation of surface charge density and net electric field during parallel-plate dielectric barrier discharge generated in atmospheric-pressure air. *Plasma Sources Sci. Technol.*, **31**, 095019 (2022).
[4] Wang X C, Bai J X, Zhang T H, et al. Comprehensive study on discharge characteristics in pulsed dielectric barrier discharges with atmospheric He and CO2. *Phys. Plasmas*, **29**, 083503 (2022).
[5] Zhang B, Xue J, Chen X, et al. Review of surface transient charge measurement on solid insulating materials via the Pockels technique. *High Voltage*, **6**, 608-624 (2021).
[6] Mitsuhashi K, Komuro A, Suzuki K, et al. Spatiotemporal variations of the electrical potential on surface dielectric barrier discharges. *Plasma Sources Sci. Technol.*, **30**, 04LT02 (2021).