EFFECTS OF GAS PRESSURE AND AMBIENCE ON SURFACE BARRIER DISCHARGE ALONG PVDF FILM

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ABSTRACT

This paper investigates the influence of gas pressure and ambience on surface barrier discharge by surface charge measurement device based on Pockels effect. The results show that, with decreasing of gas pressure, the length and radius of surface charge distribution have increased, but the charge densities have decreased. The product of pressure and diameter of diffuse discharge region in positive surface discharge is nearly constant. The value is about 260(kPa mm). The surface charge appears diffusely when *pd* is smaller than 260(kPa mm), surface charge appears diffusely, and while *pd* is larger than that value, they gradually develop to filamentous pattern. Compared surface charge distributions in air and nitrogen gas, it shows that positive discharges show more branches in nitrogen gas.

1. INTRODUCTION

Surface barrier discharge is an important configuration for generating low-temperature non-equilibrium plasma, which shows good application prospect in plasma aerodynamic actuation and plasma-assisted combustion.

Depending on the gas mixture, pressure, discharge cell geometry and other parameters, a wide range of discharge forms were observed, such as diffuse and continuously burning discharge, self-pulsing micro-discharge of short duration, which is randomly distributed in time and space over electrode surface [1]. Positive polarity discharge appears as many distinct discharge branches while negative polarity discharge shows a diffuse pattern under AC voltage excitation. The apparent uniform discharge is much easier to generate when decreasing the gas pressure.

In past years, appropriate methods have become available to study and analyse the mechanism of surface dielectric barrier discharge. High-speed photography, optical emission spectroscopy, cross-correlation spectroscopy and surface charge measurement have been used to investigate the characteristics of surface barrier discharge experimentally. Numerical simulations are also adopted to study the physics of surface barrier discharge, giving spatial and temporal evolution of surface barrier discharge. However, there has been a missing quantification of the role of different surface processes on the discharge development up to now [2]. Information on transition of discharge model, formation of streamer branches is still required to clarify the discharge process.

Recently, surface charge on dielectric material can be obtained dynamically by Pockels effect technique, which provides a more useful diagnostic tool for discharge. In this paper, a compact two-dimensional real-time surface charge measurement device based on Pockels effect is developed to investigate the characteristics of discharge patterns along polymer film under different pressure and ambience. This study might be helpful to make a better understanding of discharge pattern formation.

2. EXPERIMENTAL SETUP

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A compact two-dimensional real-time surface charge measurement device based on Pockels effect is developed. A $Bi_{12}SiO_{20}$ (BSO) crystal is used as electric field sensor. The BSO is of 20×20 mm^2 size and 0.2 mm thickness. It is fixed on a 1 mm thickness glass (BK7) and the opposite side of glass is coated by transparent Indium Tin Oxide (ITO) film as grounded electrode. Polyvinylidene fluoride film (PVDF, 4.5μm thickness, 6.7 in relative permittivity) is covered on BSO. A steel needle electrode is placed above PVDF with blunt tip which radius is 100μm. The electrode-sample configuration is shown in Fig. 1. As high voltage is applied on needle electrode, surface barrier discharge is generated on PVDF.

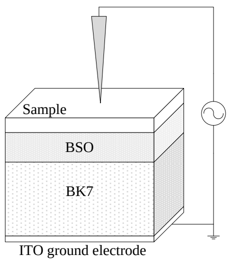

Fig. 1 Electrode-sample configuration

The measurement system based on Pockels effect can be seen in Fig. 2. One single cycle of 5kV sinusoidal AC voltage is generated by high voltage amplifier and applied on the needle electrode. The LED light beam is modulated by BSO cell due to surface potential distribution resulted from discharges. A high speed video camera is used to record the modulated light intensity used to calculate surface charge density. The photograph is focused on an area of 8×8.5 mm^2 of PVDF. Fifty successive frames of discharge images are recorded during one cycle of HVAC, and the exposure time of each frame is 1ms. The experiments are carried out in a chamber varying the pressure from 101kPa to 21kPa.

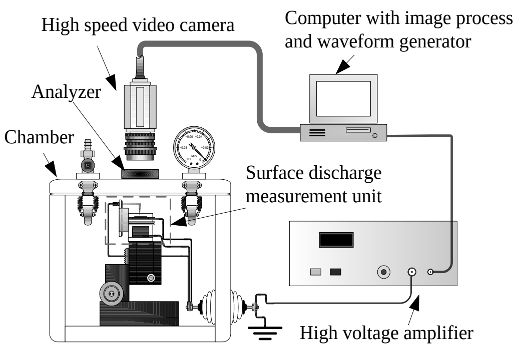

Fig. 2 Measurement system based on Pockels effect

3. EXPERIMENTAL RESULTS

Fig. 3 shows the surface barrier discharge developing process with voltage changing at 61kPa. It displays the typical discharge images at some critical times mark as red dots in a single cycle, and these times are marked with red color.

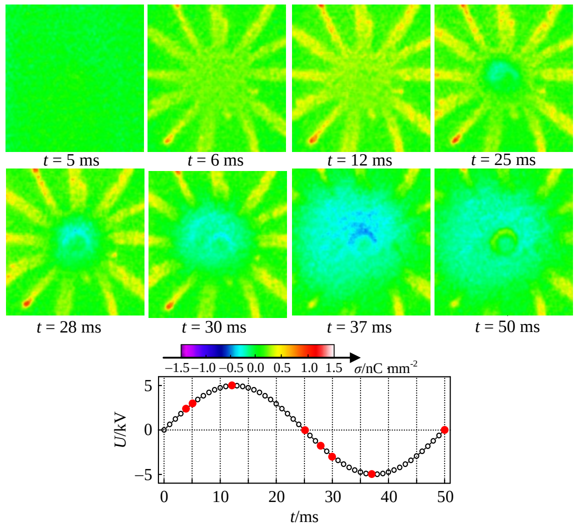

Fig. 3 Positive-cycle-initiated surface barrier discharges on PVDF at 61kPa

It can be seen that, positive surface barrier discharges burst out at t=6ms The applied voltage at this time is about 3.2 kV. The positive charges in a core region appear diffusely, and then they develop into streamer with spoke-like pattern. The image at t=12ms exhibits the charge distribution at positive peak voltage. In the falling scope of positive voltage, surface charge distribution keeps in the same pattern. Negative charges can be observed near the electrode since applied voltage is reduced to zero, i.e., t=25ms.

With the rise of negative voltage, discharge becomes intense gradually and the generated negative charges neutralize the residual positive charges, making negative charge region and density increases, as shown in the figures from t=28~37ms. During this process, negative charges always extend diffusely. The negative charge area is smaller than that of positive charge. Therefore, in successive cycles of AC voltage, residual positive charge still exists in the outer area. When the negative voltage decreases, negative charge distribution does not vary obviously.

After applied voltage decreases to zero at t=50ms, positive discharge can be observed again, which is often called "back discharges". That is because residual negative charges keep a high negative potential on PVDF surface, high potential appears between needle electrode and surface charge, leading to the discharge phenomena. The back discharges appear as the patterns of the opposite polarity: at positive polarity they look uniform, while at negative polarity they consist of branches.

The influence of pressure on discharge pattern is investigated. Experiments are performed under different pressure from 101kPa to 21kPa in air, shown in Fig. 4. Positive surface barrier discharge along PVDF burst out within 1ms. After that, the pattern does not change. For comparison, discharge pattern in Fig. 4 are all taken at positive peak voltage under different pressure.

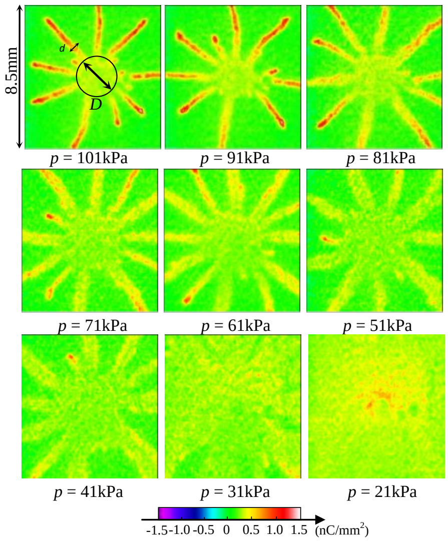

Fig. 4 Positive surface barrier discharges on PVDF at positive peak voltage under different pressures

It can be seen from experimental results that, with pressure decreasing, the discharge area, width of discharge branches and numbers of streamers increase, but charge densities reduce. With pressure decreasing, charge density is concentrated on the edge of streamer branches, but the center of branches has less positive charge, which can be seen clearly at p=41~61kPa. It is due to that quasineutral ionized channel along the centre axis of the streamer stem is developed for electron moving from streamer head to needle electrode, but positive ions remain outside of this quasineutral ionized channel. In fact, quasineutral ionized channel also may exit at air pressure, but it is difficult to distinguish with our experiment condition. When pressure decreases below 21kPa, positive charge appears as diffuse pattern in visible area.

Significantly, positive surface charge distribution near needle electrode uniformly appears in a core region, and then develops into streamer pattern away from the core. In order to quantitatively analyze this phenomenon, we measure the diameters D of the uniform discharge region and the widths d of branches. For measuring them more accurately, each image is magnified 10 times and then the measurements are carried out. And the mean value of streamer width is calculated. The results are shown in Table 1.

Table 1. The mean width d of discharge branch, diameter D of diffuse area, mean free path length l of electron in air under different pressure

Pressure p/kPa	101	91	81	71	61	51	41
d/mm	0.24	0.28	0.35	0.39	0.46	0.56	0.63
D/mm	2.6	2.9	3.2	3.7	4.3	5.1	6.3
l/μm	0.061	0.067	0.076	0.087	0.10	0.12	0.15

The mean free path of electron in air is a significant parameter effecting on gas discharge, so mean free path length l of electron in air is also shown in Table 1. In order to study the influence of pressure, the mean free path of electron, branch width, and the diameter of diffuse area are normalized and shown in Fig.5

As can be seen, with pressure decreasing, the branch width of streamer, diameter of diffuse area have almost the same trend with mean free path of electron in air indicating that surface barrier discharge on PVDF is dominated by gas discharge process.

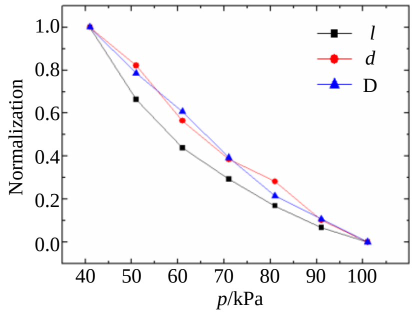

Fig. 5 The relationship between mean free path of electron in air and surface discharge

According to the value in Table 1, it is almost the same value of ~260 kPa mm (195 Torr cm) for the product of pD. In other words, positive surface discharge is relatively uniform near the needle electrode if D is less than (260/p)mm, but when D is larger than (260/p)mm, they gradually develop to filamentary pattern. According to the mechanism of streamer discharge formation, it must reach a sufficiently high amplification for an avalanche to transform into the streamer. The transition condition is that the charge field must increase to a level on the order of applied field. In our experiment, when avalanche length is smaller than D/2, electric filed produced avalanche does not reach the threshold for transition, generated charges deposit on the surface which produce diffuse charge region. When avalanche length is greater than D/2, electric filed is higher than the threshold and then filamentary streamer is formed. Due to electron moving from streamer head to needle electrode, part of positive charge is neutralized. The streamer tip has the highest positive charge density with the average and maximum value of 1.2 and 1.4nC/mm^2 respectively. Electric field in this region is about 24kV/cm.

The streamer is developed when electric filed is higher enough, but the physics of new branches generating in discharge is still not well understood. Photo-ionization is thought to be a vital part in streamer propagation, and the parameters of photo-ionization depend on the nitrogen : oxygen ratio [3]. Therefore, streamer developments in air and in nitrogen of ~99.8% are compared. Fig. 6 shows the discharge pattern on PVDF in air and in nitrogen.

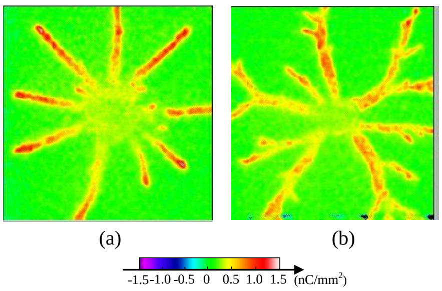

Fig. 6 Positive surface barrier discharges on PVDF in air (a) and nitrogen (b) at 101kPa

From surface charge distribution comparison of air and nitrogen, it can be seen that, there is no bifurcation branch in air on PVDF, while in nitrogen surface barrier discharge generates more branches in nitrogen.

According to photo-ionization theory, the oxygen concentration determines the absorption length l_{photo} of these photons, and therefore the range of availability of free electrons. The absorption length is about 1.3mm in air at standard temperature and pressure, and it scales linearly with inverse oxygen density [4]. During the development of surface barrier discharge, photons radiate from ionization region, henceforth leading to random photoionization phenomena away streamer channels. For nitrogen, the oxygen density is very low, so the l_{photo} is larger than that in air. Photon ionization areas are more scattered than that in air. New electron avalanches would be discretely formed at the area a little far from streamer heads. These new separated avalanches greatly distort local electric field and affect the propagation of surface positive streamers, which exhibits more branches. In air, due to l_{photo} is short, second electron could be formed near the tip of streamers. Thus, new avalanches connect former avalanches and make the streamer move forward, which presents circular charged spots connected with each other.

4. CONCLUSION

In this paper, the influence of gas pressure and ambience on surface barrier discharge is investigated by surface charge measurement device based on Pockels effect. The results shows that, with decreasing of gas pressure, the length and radius of surface charge distribution have increased, but the charge densities have decreased. The product of pressure and diameter of diffuse discharge region in positive surface discharge are nearly constant. The value is about 260(kPa mm). It indicates that when *pd* is smaller than 260(kPa mm), surface charge appears diffusely, and while *pd* is larger than that value, they gradually develop to filamentous pattern. Compared surface charge distributions in air and nitrogen gas, it shows that positive discharges show more branches in nitrogen gas.

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