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Study of the electric field and wall voltage in a high pressure ac-PDP cell by laser induced fluorescence spectroscopy

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The electric field in a surface discharge type ac-PDP cell with He or He/Xe(0.1%) mixture has been measured over a wide range of pressure (5–50 kPa) using laser induced fluorescence detection. The wall voltage was estimated from the measured electric field. The Stark manifolds of triplet atomic helium Rydberg state ($2s^3S$) with principal quantum numbers (n=8 and 9) have been used to measure the electric field, as the lifetime of $2s^3S$ is longer than the single atomic helium Rydberg state ($2s^1S$) in high pressure discharge. Comparison of the Stark manifolds between the n=9 and n=8 shows that the measurement accuracy of electric field can be increased by 10%. The maximum electric field strength during discharge and the wall voltage at the end of pulse decreases with the increase of pressure. The comparison of He and He/Xe(0.1%) discharge at 13 kPa showed that He/Xe gas mixture discharge can accumulate more wall charge on MgO surface and the electric field was somewhat higher than those of pure helium discharge during pulse off period under the same discharge conditions.

Keywords: plasma display panel, laser induced fluorescence, electric field measurement
PACC: 0130Q, 0670H, 0765E, 3260S

1. Introduction

The plasma display panel (PDP) has many advantages [1] over the CRT, such as its very large display size (over 152 cm), small thickness (<10 cm) and light weight. It has been widely used as an information display device in public places.

The memory effect caused by the wall charges accumulated on the dielectric surface plays an important role in the operation of ac-PDP.[2] Utilization of the wall voltage can decrease the sustained voltage. So understanding the wall voltage behaviour in ac-PDP is very important and has been the subject of many researches.[3,4]

Kim *et al*[5] first reported the measurement of electrical field in ac-PDP cell using helium $2s^1S$ metastable state by the laser induced fluorescence (LIF) technique and described the wall voltage behaviour of pure helium discharge at 13 kPa. However, in real PDPs, the working gas pressure is higher (>40 kPa) and the working gas contains xenon, which makes it more difficult to obtain a LIF signal using $2s^1S$ because of its fast quenching rate. In this paper, we have employed a Stark manifolds of helium triplet Rydberg atom ($2s^3S$) technique that allows the measurement of temporal electric field and wall voltage of the ac-PDP cell with high pressure He and He/Xe(0.1%) gas and study the electric field behaviour in high pressure discharge.

2. Experimental set-up

The experimental arrangement is shown in Fig.1. A test panel of a surface-type ac-PDP was placed in a chamber. The ac discharge was maintained between the two parallel electrodes in pure helium or helium and xenon (0.1%) mixture. The schematic diagram of cell geometry is shown in Fig.2. The coplanar

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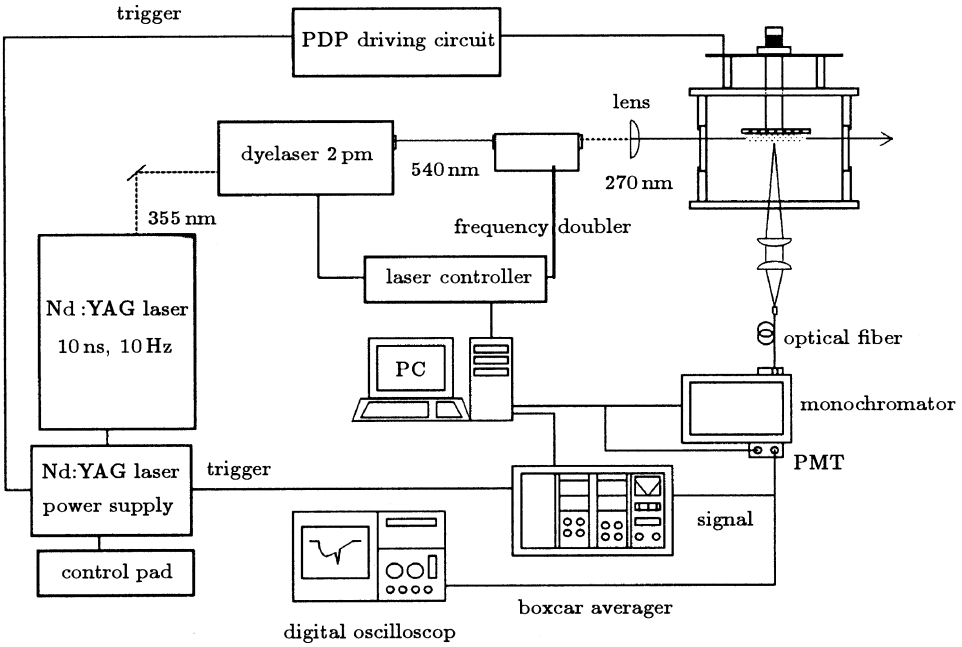


Fig.1. Schematic of the LIF signal measurement system for PDP test panel.

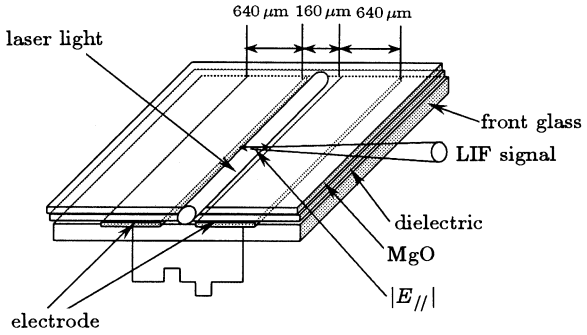


Fig.2. Schematic diagram of PDP panel configuration and measurement of electric field.

electrodes, whose width and gap were 640 and 160 μm, respectively, were covered with a 30 μm thick dielectric layer and e-beam evaporated 400 nm MgO protecting layer. The panel was driven by the 50 kHz square pulses with a duty ratio of 25%. The working gas pressure was varied from 5–50 kPa. The laser excitation source was a YAG pumped dye laser using Coumarin 485 dye. The output of the dye laser was frequency doubled using a BBO crystal, which is continuously angle tuned to produce 2 mJ, 0.1 cm^{-1} line width UV pulses. The UV laser can excite high-n atomic helium np^3P states from the $2s^3S$ mestastable state. In our experiment, n was chosen from 8 and 9. The laser beam was focused by a spherical lens and the diameter at the target plasma was about 70 μm. The direction of laser polarization was parallel to the electric field to be measured (Δm_j=0). LIF (587.56 nm,He $2p^3 \rightarrow 3d^3D$) was detected perpendicular to the incident beam and was collected by a lens, monochromator and photomultiplier system. The output signal of the photomultiplier was amplified, integrated and averaged by a boxcar averager before being recorded by a PC and an oscilloscope.

3. Experimental results and discussion

In our experiment the applied voltage to PDP cell electrodes has square waveform. During the afterglow period, the discharge current goes to zero, as the voltage drop across the gas becomes small. To obtain the LIF signal during the afterglow period, more abundant He metastable particles were needed. Figure 3 shows the plasma radiation at λ=587.56 nm (He $2p^3 \rightarrow 3d^3D$) at different gas pressures. We can see that the plasma is generated and decays faster as the gas pressure increases. Since the lifetime of He metastable decreases with the increase of gas pressure, we need metastables with longer lifetime to obtain LIF signal during afterglow period. As the lifetime of triplet atomic helium Rydberg state (He $2s^3S$) is longer than that of He $2s^1S$ in pure helium, and especially in He and Xe mixed gas,[6,7] the He $2s^3S$ metastable state was used in our experiments.[8]

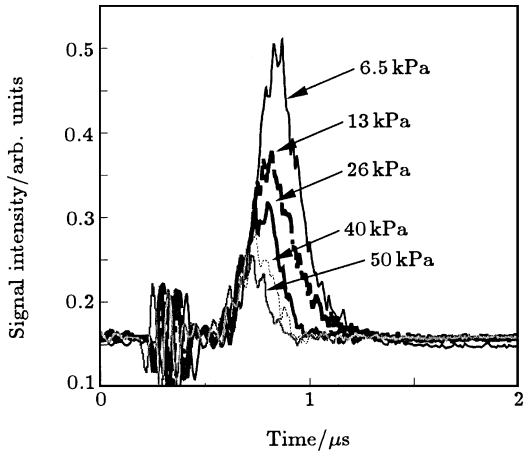


Fig.3. Plasma emission from He/Xe (0.1%) discharge at different pressures.

Figure 4 shows the n=9 fluorescence excitation spectra (587.56 nm, He $2p^3 \rightarrow 3d^3D$) during the glow and afterglow phases with 260 V applied voltage for pure helium discharge at 40 kPa. In the glow discharge phase the LIF signal was big and Stark manifolds were completely resolved due to the presence of the strong electric field and abundant metastable state particles. During the afterglow phase the manifolds were only partially resolved and the LIF signal's S/N ratio decreased. Measuring the interval between the manifolds, the electric field strength can be determined by calculating the helium Stark broadening of the $2s^3S \rightarrow np^3P$ transition.[9]

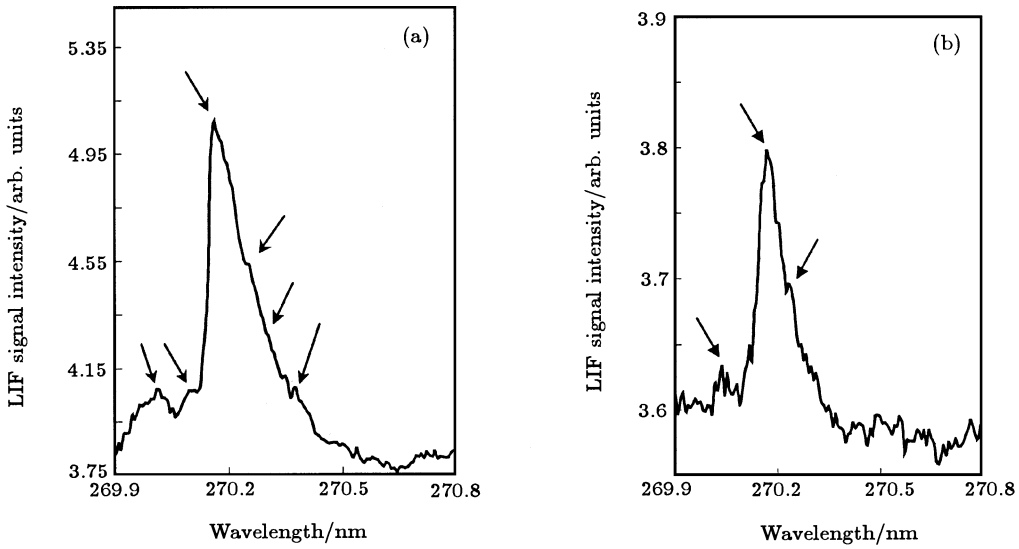


Fig.4. Stark spectrum of n=9 for 40 kPa pure helium discharge. Applied voltage 260 V, 25% duty ratio, 50 kHz. (a) Glow discharge, (b) afterglow discharge.

In order to increase the accuracy, the Stark broadening for the transition from the $2s^3S$ to $8p^3P$ level was also observed in our experiment. Because the He np^3P levels have a larger quantum defect (0.068),[10] exciting a higher n energy level is better to observe the linear Stark effect at a given field. At lower gas pressure (<13 kPa) the $2s^3S \rightarrow 9p^3P$ transition is the optimum one for the discharge used in this investigation. At higher pressure (>13 kPa), the signal of n=8 is larger than that of n=9. Comparing the Stark spectrum between n=9 and n=8, the error in the estimation of electric field should be less than 10%.

The typical temporal evolution of the plasma emission(λ=587.56 nm), electric field and wall voltage during one discharge period is shown in Fig.5. A square pulse of 260 V, 50 kHz and 25% duty ratio was used to produce the plasma. The working gas was pure helium and gas pressure was 40 kPa. Here, the maximum electric field strength $|E_{//}|$ between two coplanar electrodes has been measured, and the wall voltage was estimated from it. From the measured curve, we can describe the basic operation process of the ac PDP cell. At the start of the pulse-on, the external voltage increases from zero to 260 V in 300 ns which initiates glow discharge. The plasma emission appears and the polarity of wall voltage changes from positive 68 V to negative 210 V within about 600 ns. The electric field increases during the initial discharge, because the wall charge from the previous discharge generates an electric field in the same direction as the applied voltage. Until the plasma current reaches the peak, the plasma radiation rises sharply, and the electric field increases.

As the discharge continues, the charges of opposite polarity continue to accumulate on the dielectric surface of two electrodes, electric field decreases and the magnitude of reversed wall voltage increases. When the electric field in the gap is reduced below the threshold of sustaining discharge, the discharge is quenched and begins the afterglow period. The electric field keeps on decreasing and wall voltage increasing because of the continuous charged particle deposition on dielectric surface from the afterglow plasma, but at a much decreased rate. When the external voltage was turned off (pulse-off phase), the opposing field is removed and the potential difference in the cell gap increases, which initiates a second (self-erasing) discharge, albeit less intense, and erases the wall voltage from 250 to 90 V. After the second discharge stops, the electric field and wall voltage decrease until the end of the cycle due to the diffusion-induced charge recombination or leakage through dielectric. At t=10 μs, the wall voltage was about 68 V.

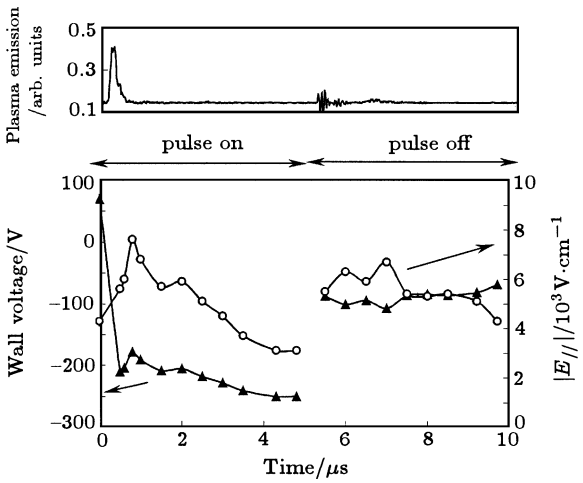


Fig.5. Measured plasma emission (λ=587.56 nm), electric field (circle) and estimated wall voltage (triangle) behaviour during one discharge period. The discharge condition: pure He, 40 kPa, 300 V, 50 kHz, 25% duty ratio.

The electric field behaviour of discharge in different gases (pure helium and He/Xe (0.1%)) has been investigated in our experiments. Figure 6 shows the comparison of the temporal electric field for the case of pure helium and He/Xe (0.1%) under the same discharge conditions. During the main glow discharge, the electric field of He/Xe (0.1%) mixed gas was higher than that of pure He. As soon as the glow discharge stops, the slope of decrease with He/Xe gas was faster than that with pure helium gas. During the voltage pulse-off period, the He/Xe mixed gas shows an electric field somewhat higher than that of pure He gas throughout the whole off phase. Since the ionization energy of xenon is smaller than that of helium, the He and Xe mixed gas should have more charged particles than the pure helium gas under the same discharge conditions. So there will be more ions and electrons drifting towards the opposite dielectric surfaces and makes the electric field decrease faster in He/Xe glow discharge.

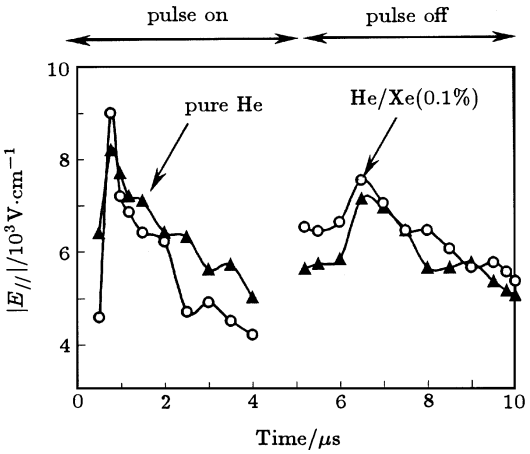


Fig.6. Measured electric field for pure He and He/Xe (0.1%) under the same conditions: 13 kPa, 260 V, 50 kHz, 25% duty ratio.

Generally, the wall voltage at the end of pulse-off period plays an important role in the re-ignition of the next pulse. Figure 7 shows the measured electric field and wall voltage at the end of pulse-off period (t=10 μs). The electric field and wall voltage decrease as the gas pressure increases. This is because the ambipolar diffusion increases with pressure, and thus the wall charge should decay faster on the dielectric surface at higher pressure.

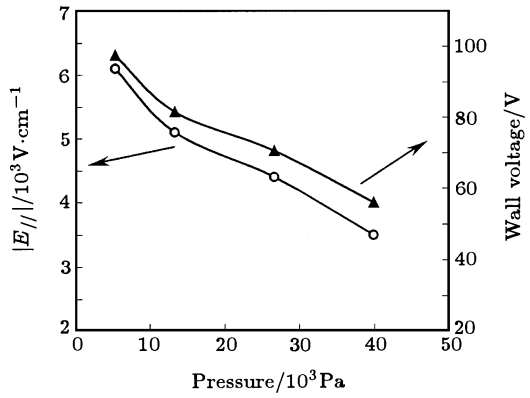


Fig.7. Final voltage and electric field as a function of gas pressure at t=10 μs. Discharge conditions: applied voltage 260 V, 50 kHz, 25% duty ratio, working gas is pure He.

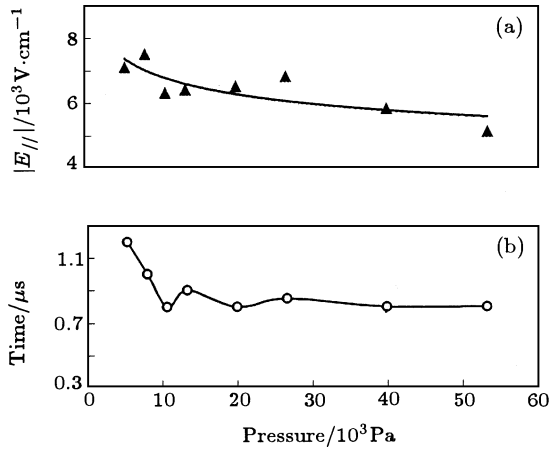


Fig.8. Maximum $E_{//}$ value (a) and corresponding time (b) vs pressure during pulse-on discharge. Discharge conditions: 240 V, 50 kHz, 25% duty ratio, He/Xe (0.1%).

The measurement showed that the electric field has a peak value during the main glow discharge. This maximum electric field has been measured under different gas pressures and is shown in Fig.8. The maximum electric field decreases with the increase of pressure. This is due to the fact that the electric field peak value depends on the wall voltage from the previous discharge, because the polarity of wall voltage is the same as that of the applied voltage during the early stage of discharge. In Fig.7, we showed that the wall voltage (t=10μs) at the end of one period decreases with increase of pressure. Fig.8(b) shows that the occurring time for peak electric field shortens with the increase of pressure.

4. Conclusion

The triplet atomic helium Rydberg state ($2s^3S$) Stark spectrum provides a means to measure the electric field in Xe mixed high pressure discharge in the PDP cell, and consequently the wall voltage. The temporal evolution of electric field and wall voltage during one discharge period gives a clear picture of the very dynamic basic discharge process in PDP cell. The maximum electric field during glow discharge and the wall voltage at the end of pulse-off decrease with the increase of pressure.

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