Striations in Plasma Display Panel *

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The phenomenon of striation has been investigated experimentally in a macroscopic ac-plasma display panel (PDP). The relationship between the characteristics of striation and the operation conditions including voltage, frequency, rib, and electrode configuration, etc is obtained experimentally. The origin of the striations is considered to be the ionization waves in the transient positive column near the dielectric surface in the anode area during the discharge, and the perturbation is caused by resonance kinetic effects in inert gas.

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Striations are well known in positive column of a dc-discharge in inert gas[1] or ionosphere plasma,[2] which are identified as the manifestations of ionization oscillations and waves. Recently, this phenomenon of stratification has been observed in inert gas discharge in ac-plasma display panels (PDPs). At both low pressure (in macrocells[3−6]) and high pressure (in microcells[7,8]), the duration of discharge is much shorter (several μs in macro-cells and several tens of ns in micro-cells). One of the proposed explanations is that the striation occurs in PDP due to the ion wall charge fluctuation on the cathode dielectric surfaces from the previous pulse. The ion wall charge fluctuation caused by the applied potential and the accumulated electron wall charge on the anode dielectric makes the striations of ion density hump at the next pulse.[7] Another explanation proposes that the striation occurs in some special channels between some points on the dielectric surface where the electrons have accumulated and form an "electric field valley".[8,9] In both cases, the pre-accumulated wall charge on the dielectric surface plays an important role and is absolutely necessary to form the striations. Unfortunately, it is difficult, with these models, to explain the phenomenon of striation in matrix geometry[3] or large-gap coplanar geometry of PDP cells,[5] where the surface state changes during the discharge. In fact, because of the small size of the real PDP cell, it is difficult to diagnose experimentally the characteristics of the discharge and the striation in such a system. The information about the striations in PDP is limited and the mechanism of generation and propagation is hence unclear as yet.

In this Letter, we have investigated the phenomenon of striation in a coplanar macroscopic PDP experimentally for various electrode arrangements. The macroscopic cell is a sealed macro-cell filling with gas of 4% Xe in Ne–He at 5 Torr, as described in Ref. [5]. All the electrodes are put outside the cell and can be varied conveniently. Two pieces of glass supporting the cell act as dielectric ribs. The gas gap (rib height) is of $h = 1$ cm. A square-wave driving voltage is applied between the two sustaining electrodes. The data (address) electrode made of transparent ITO, is placed on the opposite to the sustaining electrodes and grounded. The space and time resolved light emission from the discharge has been measured by using an intensified charge coupled device (ICCD) camera in order to understand the spatio-temporal characteristics of the striations. The time-resolved ICCD images were recorded by integrating the light emitted by the discharge over a large number of cycles during a time interval (gate), which was moved over the entire duration of the current pulse. The gate was 200 ns for the images in this study, much lower than the duration of the discharge pulse (e.g. a few μs in macro-cell). We tested different electrode geometries. The aim is to investigate the occurrence conditions and the basic characteristics of striation in PDPs, and to explore the possible mechanism for the origin of striations.

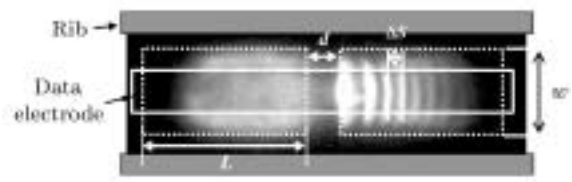


Fig. 1. Striations in standard configuration with $L \times w = 4\,\text{cm} \times 2\,\text{cm}$, $d = 0.8\,\text{cm}$ at $180\,\text{V}/100\,\text{Hz}$. $\Delta S \sim 0.33^{\pm 0.02}\,\text{cm}$.

We firstly investigate the striations in standard geometry: that is, the coplanar gap length is small so that the discharge will sustain directly between the two coplanar electrodes. It is observed that the striations are formed clearly during the discharge. A typical configuration is shown in Fig. 1 with sustain elec-

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trode length $L = 4\,\mathrm{cm}$, width $w = 2\,\mathrm{cm}$, and gap $d = 0.8\,\mathrm{cm}$. The separation of striations is $\sim 0.33\,\mathrm{cm}$ at minimum operation voltage (i.e. $\sim 10\,\mathrm{V}$ above the lowest voltage which can just sustain a stable discharge). The main results are summarized as follows.

(1) The striations of light emission appear only above the dielectric surface of the anode. (2) The first one or two striations move slowly towards the cathode during the rising of the current pulse, then all the striations become stationary when the discharge current reaches peak value. (3) The dielectric ribs may cause a change of the striation shapes from straight lines to curves (e.g. changing w from 2 cm to 3 cm, as shown in Fig. 2). (4) At low frequency (less than 150 Hz), the pitch of the standing striations ΔS decreases as the sustaining voltage increasing, as seen in Fig. 3. However, ΔS does not change with gap d if operating at the minimum operation voltage. (5) Increasing frequency (e.g. higher than 500 Hz) results in a change of striation's shape and positions. (6) Removing the data electrode causes a change in position and pitch of the striations under the same operation conditions. (7) The striations will disappear (i.e. immerse in the surrounding light emission of high intensity) at a very high voltage and frequency.

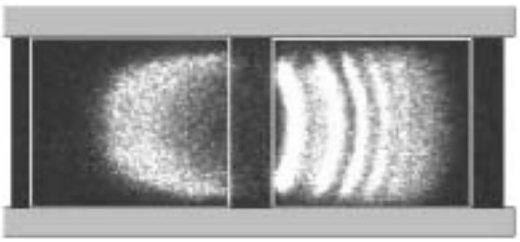


Fig. 2. Curved striations with electrode dimension of 3 cm×3 cm and gap of 0.8 cm at 190 V/100 Hz.

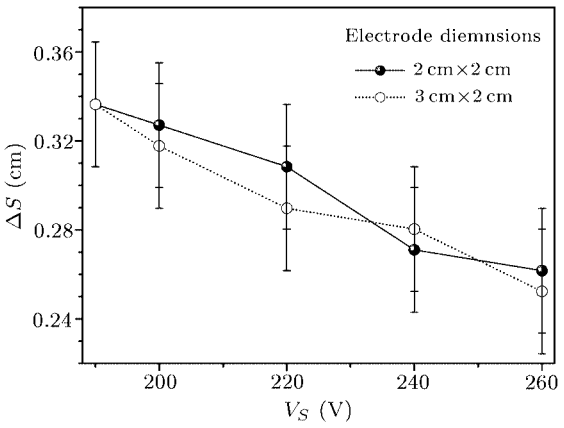


Fig. 3. The striation spacing as a function of the sustaining voltage at 100 Hz, with gap of 0.8 cm and different electrode dimensions.

Results (1) and (3) are consistent with the previous reports.[4,7,8] It has also been proven that the pitch decreases with the increasing xenon percentage and the pressure in both macro- or micro-cells.[4,7] By using the scaling laws, the space separations of striations in macro- and micro-cells agree well with each other. We therefore suppose that the striations in PDP cells are similar at low and/or high pressure. Result (2) shows that the striations near the cathode region (sheath) shift during the discharge development, similar to the manifestation of striation in dc-discharge.[1] Result (5) has also been observed in previous research, which shows that the high-density plasma from the former pulse distorts the electric field along the electrode surface from straight to curved lines.[6] Results (3)–(6) show that the change of the electric field along the anode surface results in a change on the positions and shapes of striations. The striations seem to follow the equipotential lines above the anode.

We then tested a configuration of large gap ($d_1 = 5\,\mathrm{cm}$) with two auxiliary electrodes (i.e. X_2 and Y_2 separated by $d_2 = 0.4\,\mathrm{cm}$). An additional glass layer (with thickness of $e_2 = 2\,\mathrm{mm}$ and relative permittivity $\varepsilon_{r2} = 3$) was inserted between the electrodes and the cell. The voltages on X_2 and Y_2 are the same as those on the main electrodes X_1 and Y_1 respectively. The operation voltage is $V_S = 240\,\mathrm{V}$ at 100 Hz.

It has been observed experimentally that the discharge turns on between X_2-Y_2 firstly and then develops outwards. The striations appear when the discharge turns on between X_2 and Y_1 and the plasma spreads in the anode area (i.e. between Y_1 and Y_2). The striations become standing after the discharge between X_1 and Y_1 turning on, as seen in Fig. 4. The separation of striation is $\sim 0.34\,\mathrm{cm}$.

It should be noted from Fig. 4 that the striations appear and close to the lower side where there is no sustaining electrode covering the dielectric between Y_1 and Y_2. We therefore believe that the wall charge on the dielectric layer is not important for striation formation.

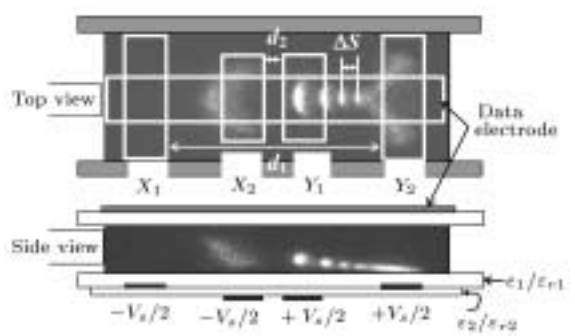


Fig. 4. Striations in configuration with auxiliary electrodes, with $d_1 = 5.0\,\mathrm{cm}$, $d_2 = 0.4\,\mathrm{cm}$ at $V_S = 240\,\mathrm{V}/100\,\mathrm{Hz}$. $\Delta S \sim 0.34^{\pm 0.02}\,\mathrm{cm}$.

Based on the above observations, it is confirmed

that it is the dielectric layer that plays an indispensable role for the striations forming in PDP cells. The state of the "anode" surface and the pre-accumulated wall charge, however, seem to be unimportant. Meanwhile the electric field should be weak in the discharge channel since the striations may only occur in the anode region. With the field changing, the striations change their positions, shapes and the spatial separation consequently. The change of the striations in shape and pitch reflects the change of the equipotential lines in the anode area.

It is noticed that the amplitude of current pulse in ac-PDP cells is weak, in the order of 1 mA. The discharge channel in the anode region is actually a transient positive column, with an electric field of a few $\mathrm{Vcm^{-1}Torr^{-1}}$ in Ne–Xe or Ne–He–Xe mixtures, very similar to that in the dc positive column at low pressure. The excitation frequency of xenon atoms in this low-field transient positive column is greater than direct ionization from the ground states because of the lower threshold. We therefore suppose that the formation of striation in PDP is similar to that in dc positive column in inert gas, which is related to the non-local effect of the electron energy distribution function formed by the striated potential profile,[10] or a weak ionization wave along the transient discharge channel. The energy spatial relaxation exceeds the striation length. The destabilizing mechanism is due to resonance kinetic effects in the weak field where the electron energy balance is controlled by the inelastic collisions. The dielectric layer in the anode area in PDP acts a similar role as the dielectric tube in dc discharge at low pressure, collecting the electrons as a disturbing source. In this case, the fluid model may be inapplicable for description of gas discharge stratification and therefore may not reproduce striations in PDP.[3–5]

In the stratified gas discharge in inert gas where the energy loss in elastic collisions is small and the electron energy balance is controlled by inelastic collisions, the electrons gain energy U^{ex} (excitation energy) in a length Λ which is slightly larger than $U^{ex}/e\boldsymbol{E}$ ($\boldsymbol{E}$ is mean electric field along the anode surface),[10] or

$$\Lambda \sim U^{ex}/e\boldsymbol{E}.$$

All the factors influencing the mean electric field, such as the gas mixture and pressure, the driving voltage and frequency, the dielectric ribs, the data electrode, etc., will affect the perturbation wavelength and hence result in a change of the striation positions and pitch. If this ionization wave is relatively weak enough, the striations will disappear. That is what we have seen in experiments. In typical PDP discharge in gas mixture of Ne–He–Xe4%, the electric field in the transient positive column is $\boldsymbol{E}/p = 1$–$10\,\mathrm{Vcm^{-1}Torr^{-1}}$, the excitation threshold of Xe is $U^{ex} \sim 8.44\,\mathrm{eV}$. Then the wavelength of perturbation should be $\Lambda \sim 0.844p^{-1}$–$8.44p^{-1}$ cm·Torr. This is on the same order of the striation pitch $\Delta S \sim 0.3\,\mathrm{cm}$ at 5 Torr in our experiments and $\sim 60\,\mu\mathrm{m}$ at 400 Torr in real PDP cells.[8]

In conclusion, we have investigated the striations in macroscopic PDP cell. The striations in PDP are the reflections of the ionization waves in the transient positive column near anode dielectric surface during the discharge. The perturbation mechanism is supposed to be caused by resonance kinetic effects in inert gas. The striation pitch relates to the relaxation length of electron energy in weak electric field along the transient positive column. It changes with the operation conditions including the driving voltage and frequency, the xenon concentration and the pressure of the gas mixture, the dielectric ribs and the data electrode, etc. A physical model should be developed based on this mechanism to reproduce the striations in PDP cells.

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