Imaging of plasma emission in a Macroscopic Plasma Display Panel Cell, in Xe-Ne mixtures

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Abstract
We have used a macroscopic discharge cell to study the space and time evolution of the plasma in plasma display panel cells with a scaling factor around 100 (dimensions 100 times larger, pressure 100 times smaller, i.e. 1 cm gap length, 5 torr pressure). Discharges in a xenon-neon mixture with 10% xenon have been investigated. The measurements have been compared with results from a 2D fluid model of the discharge. It appears that photoemission by resonant photons at 147nm could contribute, in a significant part, to the plasma formation time at 5 torr.

1. Introduction – Scaling laws
The similarity laws\(^1\) predict that glow discharges having the same size as real PDP cells because of the larger dimensions and the slower time evolution of the discharge, it is tempting to design “macroscopic” PDP cells (macro-cells) to study in details the physical mechanisms occurring in the cell.

In this paper we present some results obtained with macro-cells in a coplanar electrode configuration (see Fig. 1). The scaling factor is on the order of 100, i.e. the dimensions are 100 times larger than those of a real PDP cell, and the pressure is 100 times smaller. These are not true PDP cells because of the larger dimensions and the slower time evolution of the discharge, it is tempting to design “macroscopic” PDP cells (macro-cells) to study in details the physical mechanisms occurring in the cell.

In this paper we present some results obtained with macro-cells in a coplanar electrode configuration (see Fig. 1). The scaling factor is on the order of 100, i.e. the dimensions are 100 times larger than those of a real PDP cell, and the pressure is 100 times smaller. These experiments can help PDP cell optimization and are useful for model validation. Comparisons between experimental and simulation results obtained with 2D fluid models are also discussed.

There are however some limitations in the validity of the scaling laws because some of the discharge mechanisms do not follow these laws. This must be kept in mind when one wants to apply the macro-cell results to a real PDP cell. This aspect is carefully discussed in this paper.

We summarize below the classical scaling laws of discharge physics.

When the pressure \(p\) and the dimension \(d\) are changed while keeping the same \(pd\) (“similar” discharges), the following quantities are conserved when the same voltage \(V\) is applied between the electrodes\(^1\):
- \(J/p^2\) where \(J\) is the current density
- \(n_e/p^2\) where \(n_e\) and \(n_i\) are the electron and ion densities
- \(E/p\) where \(E\) is the electric field

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These properties are the same for similar discharges at locations corresponding to the same px (x is the position in the gap) and at times corresponding to the same pt. The scaling laws are valid when the dominant collisions are collisions between electrons and atoms in the ground state. This situation generally occurs when the reduced current $J/p^2$ density is relatively small. In AC PDP conditions collisions between charged particles and atoms in the ground state are dominant during the current pulse. After the current pulse the plasma slowly decays during the afterglow phase. The plasma decay is due to ambipolar diffusion but also to recombination between electrons and molecular ions. The recombination process is non-linear with respect to the charged particle density and does not follow the scaling laws. This means that using the scaling laws to extrapolate high pressure results to low pressure will lead to an overestimation of recombination in the macro-cell. The excited species kinetics during the afterglow does not follow the scaling laws either because of three body collisions. Three body collisions between a xenon excited state or a xenon ion and two atoms (Xe+Xe, or Xe+Ne) lead to the formation of xenon excited molecular states (excimer) $\text{Xe}_2^+$ or molecular ions such as $\text{Xe}_2^-$. The three body collision frequency of a xenon excited state scales as $p^2$. Therefore the difference between the production of molecular states at high pressure and at low pressure will be much larger than predicted by the scaling laws which assume linear increase of the collision frequencies with pressure. On the other hand only recombination between molecular ions and electrons is important (the recombination coefficient between electron and atomic ions is negligible). One can therefore expect that recombination will have an effect on the duration of the afterglow at high pressures but not at low pressures. For example, if the afterglow duration is 5 $\mu$s at 500 torr, the scaling laws would predict an afterglow duration of 500 $\mu$s at 5 torr, but since recombination does not follow the scaling laws and is practically negligible at 5 torr, one can expect an afterglow duration significantly larger than 500 $\mu$s at 5 torr.

These features must be kept in mind when applying the macro-cell results to a real PDP cell. We think however that the macro-cell can provide very useful results concerning the current pulse and energy deposition in the plasma during the current pulse and that these results can help improve the real PDP cells and validate the models.

2. Experimental set-up

![Experimental set-up](image)

Figure 1: experimental set-up for a coplanar electrode design (left figure). Macro-cell design for a coplanar electrode configuration. With a pressure of 5.6 torr and a scaling factor of 62.5, this design corresponds to a real cell with 80 $\mu$m coplanar electrode gap length and 350 torr pressure (right figure).
In this paper we consider a discharge cell with coplanar electrodes. The macro-cell is inserted in a discharge chamber represented in Fig. 1. The cell design is shown in Fig. 1 for coplanar electrodes. Two ceramic disks are used to hold the electrodes and dielectric layers. The disk holding the right electrode is actually a ring, to allow imaging of the discharge through the front view-port. The electrodes are cut in a transparent ITO polyester film. The ITO electrodes are covered with a 1 mm glass plate that plays the role of the dielectric layer. The thickness $e$ of the glass plate is such that $e/\varepsilon_r$ (where $\varepsilon_r$ is the relative permittivity) scales like the cell dimension. In other words, if the macro-cell is 100 smaller than the real cell, the capacitance per unit surface of the dielectric layer in the macro cell must be 100 times smaller than in the real cell.

3. ICCD imaging of Plasma formation

A square-wave voltage is applied between the electrodes of the macro-cell. In order to operate under conditions where successive pulses are independent from each other we chose an operating frequency around 100 Hz (this was close to the frequency limit below which current jitter could occur).

We present below some images of the time evolution of the light emission from the plasma obtained with an Intensified CCD camera (IMAX from Princeton Instruments). Figure 2 shows the light emission "seen" by the ICCD camera (i.e. integrated over all wavelengths) for a coplanar discharge in a mixture of 10% xenon filled with neon at 5.6 torr (geometry of Fig. 2). We can see on this figure that:

1) The influence of the address electrode can be seen during the first phase of the plasma spreading since the plasma first forms above anode and below the address electrode.
2) The plasma expansion and sheath contraction can be seen by looking at the motion of the negative glow above the cathode. Side view imaging of the negative glow indicates the shape of the plasma (and the sheath).
3) As the sheath contracts, the plasma on the anode side tends to spread along the dielectric surface.
4) The spreading of the plasma along the dielectric surface above the anode is accompanied by the formation of striations in the emitted light.

Figure 2: Front view and side view of the integrated light emission for a coplanar electrode configuration in a 10% Xe-Ne mixture. Gas pressure 5.6 torr, coplanar electrode gap 0.5 cm,
scaling factor 62.5 (i.e. 350 torr, 80 µm for a “similar” high pressure cell). The cathode voltage is −95 V, the anode voltage is +95 V and the address electrode voltage is 0 V. The light emission decays on the same time scale as the current. The results of the 2D fluid models of the discharge in a coplanar electrode configuration (see Ref. [2]) are in general qualitative agreement with the experimental results of Fig. 2 except for the following discrepancies:

- the spreading of the plasma above the electrodes is faster and more important in the experiment
- the model does not predict the formation of striations in the light emitted above the anode (this was expected since the model uses the local field approximation)

Figure 3: Spatio temporal evolution of neon emission at 640nm (a) and infra red emission from xenon at lines 823nm and 825nm. Measurements are made with a CCD camera through the side viewport of the macrocell. Electrodes are in a coplanar configurations and discharge conditions are the same as in Fig. 2.

Measurements with filters (centered around 825 nm and 640 nm, 10 nm half width) have also been performed. Figure 3(b) represents the time evolution of infrared lines of xenon viewing through the side viewport of the macrocell and fig. 3(a) corresponds to the orange line at 640nm from neon. The emission from the infrared lines (823 nm and 828 nm) of xenon obtained with the 825 nm filter is similar to the integrated light emission of Fig. 2. However the emission from the neon lines around 640 nm is quite different. This emission is important above the cathode, as in Fig. 2, but practically no emission is seen above the anode. This is coherent with measurements in real PDP cells and can be explained as follows3-7. The sheath electric field above cathode is large enough to heat some electrons above the neon energy thresholds so light emission from xenon and neon can be seen above cathode. The electric field parallel to the anode (see the simulations of Ref. [9]) due to the charging of the dielectric surface is sufficient to heat the electron above the xenon excitation energy thresholds but is too low to heat a significant number of electrons above the neon excitation thresholds. We see on fig 3(b) that a significant part of the total infrared emission from xenon occurs above the anode. This indicates that the plasma above anode is more efficient in term of xenon excitation and therefore of UV production than the plasma above cathode. The VUV
measurements\(^7\)\(^8\) in real PDP cells confirm that the plasma above anode also emits UV photons, which is coherent with the above discussion. The general features of the infrared and visible light emission in the macro-cell are in excellent qualitative agreement with the reported measurements in a real PDP cell (see e.g. Refs. [3]-[5] and references therein).

4. Comparison with models – Sheath velocity

We have compared the space and time variations of the measured light emission from xenon and neon lines with results from 2D fluid models\(^6\)\(^2\). The agreement is qualitatively good and the model reproduces well the features described above. The main noticeable difference between the macro-cell and model concerns the velocity of plasma spreading above cathode. This velocity is defined here as the velocity of the maximum of negative glow emission above the cathode in a direction parallel to the cathode. From Fig 3, it is easy to plot the position of the maximum light emission against time and to estimate a plasma expansion velocity. The uncertainty on time is about 50ns (CCD gate width) and the uncertainty on position depends on the reading (<0.5mm). We found that the plasma expansion velocity is about 10km/s for an applied voltage of 190V and 25km/s at 220V. The calculated velocities remains under 2km/s for both applied voltage.

One possible explanation of this discrepancy between model and experiments in the Xe-Ne mixture could be that photo-emission on the MgO surface, due to UV photons from Xe resonant states, which is not included in the model, plays an important role in the current rise and plasma expansion. The plasma expansion or sheath contraction is controlled by 1) ionization, 2) ion velocity (since the ions created in the cell volume must go back to the cathode surface to generate secondary electrons), and 3) secondary emission. If photoemission is important the ion velocity is no longer a relevant parameter and the plasma expansion can be much faster and larger.

Other experiments recently performed in the macro-cell\(^1\)\(^0\) confirm the fact that photoemission due to UV photons from xenon excited states can strongly affect the discharge properties. It was shown in these experiments that the jitter and time lag of the current pulse in a pure neon discharge in the macro-cell could be significantly reduced using an external xenon lamp (with a MgF\(_2\) window).

5. Conclusion

Diagnostics have been performed on a macroscopic matrix PDP cell and compared with simulation results for pure neon and a Xe(10\%)\textendash Ne mixture. The model reproduces qualitatively well the plasma formation, expansion and decay as seen with an intensified CCD camera. Hence measurements in the macrocell confirms the good efficiency of anode region in producing UV photons. One possible way to increase plasma display panel efficiency is to enlarge plasma spreading above anode (for example by changing electrodes geometry). The calculated velocity (~2km/s) is smaller than the velocity measured in the macro-cell by a factor more than 5 in the mixture. We think that this discrepancy can be attributed to the photoemission induced by UV photons from xenon hitting the MgO surfaces. Photoemission during the current growth is probably much less important at high pressure (in real PDP cells) because of the imprisonment of resonant radiation and the losses of resonant states by three body collisions. The apparent life time varies like the square root of the cell dimension and so the imprisonment of resonant radiation does not follow the scaling laws. We suspect that the UV photons reach the MgO surface after the end of the current rise in the high pressure case. In these conditions photoemission has no effect on the plasma spreading. This interpretation is
coherent with the fact that the calculated sheath contraction velocity is in agreement with the measurement in a real PDP cell (at high pressure).

Acknowledgments

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References