Plasma display panels: problems and their analysis via computer simulations

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Abstract

Computer simulations of a pdp discharges provide unique information necessary for their analysis, unavailable otherwise. Statistical instability of the ramp discharge and the role of exoemission, nature of striations during sustain discharge, physical mechanism responsible for the propagation of the cathode ionization wave, and line loading effects are just a few examples when simulations can be successfully used.

1. Introduction

Plasma display panels (PDPs) are leading the market in the area of a large size flat television displays. Though, the competition is becoming very tense with recent successes of liquid crystal and projection displays. Being of very high quality, PDPs still have a number of problems, which require investigation of the fundamental properties of a discharge in the conditions of PDP. Unfortunately there is only a handful of small research groups to do this work, compared to hundreds doing research in a liquid crystals field. With this in mind the progress of PDPs is nothing less than impressive.

In this paper we demonstrate the capabilities of numerical experiments, to "look" inside the discharge and find relations between discharge characteristics, which are hard or impossible to extract from experimental data. One feature that separates numerical experiments from any other kind of experiments, (which we widely use in order to uncover some "hidden" relationships) is the freedom of changing the value of any physical parameter in the simulation. On the other hand when using simulations for deciding on or optimizing the panel parameters one has to use real data obtained from basic physical measurements.

We will show that some questions are not obvious, initial assessment may be very far from the truth, which require serious investigations, to uncover. Specifically, we have chosen three very different topics – ramp discharges (used during the set-up of the PDP cells), the strong sustain discharges, and the line loading effects (which take place at synchronous operation of many cells in the same sustain line).. .

2. Stability of the Ramp Discharge

Ramp discharge is currently widely used in plasma displays during the setup period. The idea of the ramp [1] came from a simple 1-D consideration, that if one has two separated electrodes (covered with dielectric) and applies ramping voltage to one of them then when the voltage across the gap reaches the breakdown magnitude, the cell becomes active (i.e., the discharge between electrodes ignites), plasma density quickly reaches a certain (high) level, and the voltage across the gap stays constant, and equal to the breakdown one. Later we developed a theory of the ramp discharge [2], based on the hydrodynamic approximation. This theory shows that the voltage across the gap stays constant only if conditions in the gap (when this voltage reaches the breakdown value), are exactly as they should be during the ramp to provide the necessary current

$$I = CdV/dt, \qquad (1)$$

otherwise (in most cases) the voltage oscillates around the breakdown voltage. Numerical simulations supported this conclusion. After creating 3D PIC/Monte-Carlo kinetic code we reexamined our theory. The result of our simulations was quite shocking. We did

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not observe any steady oscillations. Instead, the very first or second pulse ended up in the discharge disruption. One reason was quite obvious – since the volume of a cell is only about, $10^{-5} cm^3$ then if the particle density during oscillations falls below $10^5 cm^{-3}$, discharge may die. We observed, however,

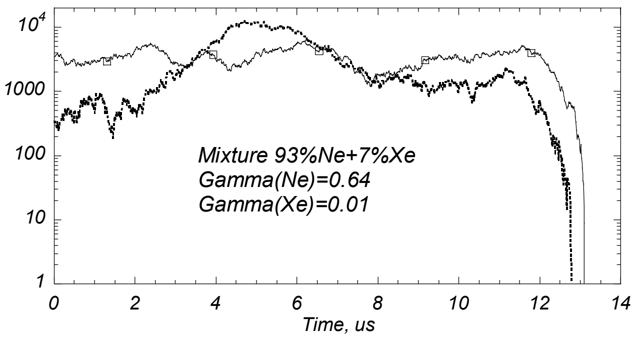

Figure 1. Number of ions in the gap from 3D kinetic simulations of a ramp discharge. Different initial conditions lead to essentially the same result – the disruption of the discharge.

the disruption of the ramp discharge, even when it was started from almost ideal conditions, and when fluid simulations (started with worth conditions) showed stable oscillations, that never fall too low as shown in Fig.2.

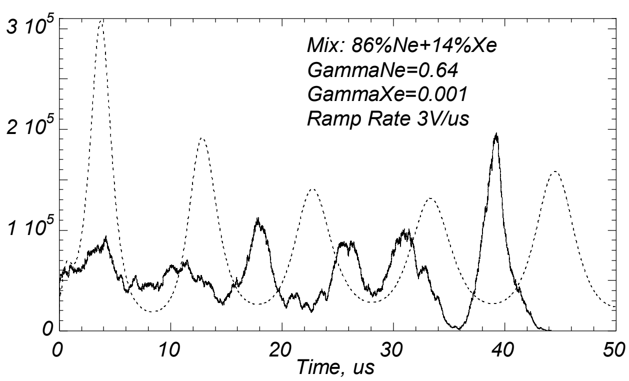

Figure 2. Number of ions in the cell calculated for identical ramps in identical cells. While fluid simulations show regular decaying oscillations, kinetic simulations show also irregular behavior and finally the disruption of the discharge.

After thorough investigation we realized that we encountered the new feature of a micro-discharge, never discussed before, when the number of particles by itself play an important role. It turned out that the number of particles in the gap during the ramp is not large enough to neglect fluctuations, so the discharge exhibits dual behavior. It shows fluid oscillations of the current, affected by large statistical fluctuation, which often initiate these oscillations. The magnitude of fluctuations δN_i of the number of ions N_i in just one ion transit time (τ_i) is of the order of $\sqrt{N_i / \gamma}$, so that the relative fluctuation of this number may be very large $\delta N_i / N_i \sim 1/\sqrt{N_i \gamma}$, especially in the mixtures with large xenon component, where effective γ is small (assuming that $\gamma_{Xe} <<< 1$). The smaller the γ or N_i the stronger the influence of statistical effects, the larger these numbers, the longer it takes for these effects to develop, and competing fluid effects may overwhelm them. The average number of ions in the gap is related to the ramp rate, and cell parameters as $\langle N_i \rangle = \tau_i (I/2e) = (\tau_i / 2e) C dV/dt$, so the lower ramp rate, and smaller capacitance of the cell result in stronger statistical fluctuations.

For typical cell parameters $C \sim 0.02 pF$, $\tau_i \sim 150 ns$, $dV/dt \sim (1-3) V/\mu s$, the average number of ions in the gap is about 20000-60000. This number would seem large if not for γ, which can be of the order of 10^{-3} in mixtures with large Xe component, and not for the current oscillations, when the number of ions in the gap can easily drop by one or two orders of magnitude. As the number of ions in the gap becomes small, they may not produce even a single electron, or too few of them, so that discharge dies.

The described ramp instability is quite powerful, as it has built-in source, and works even when both N_i and γ are large. The average lifetime may become long, but as long as discharge dies in some cells, the panel will not operate properly. The only way discharge may restart again is the presence of an independent source of electrons, like electron exoemission from MgO surface [3-6]. Obviously, if exoemission is weak, then discharge may die, then start again, then die, etc., but if exoemission is strong enough, then the ramp becomes stable, as shown in the Figure 3. One should remember though, that if exoemission is too high, then the voltage across the gap is stabilized at the level below the breakdown, and then after the ramp exoemission continue to "work", so one has to take special measures to protect the wall charge.

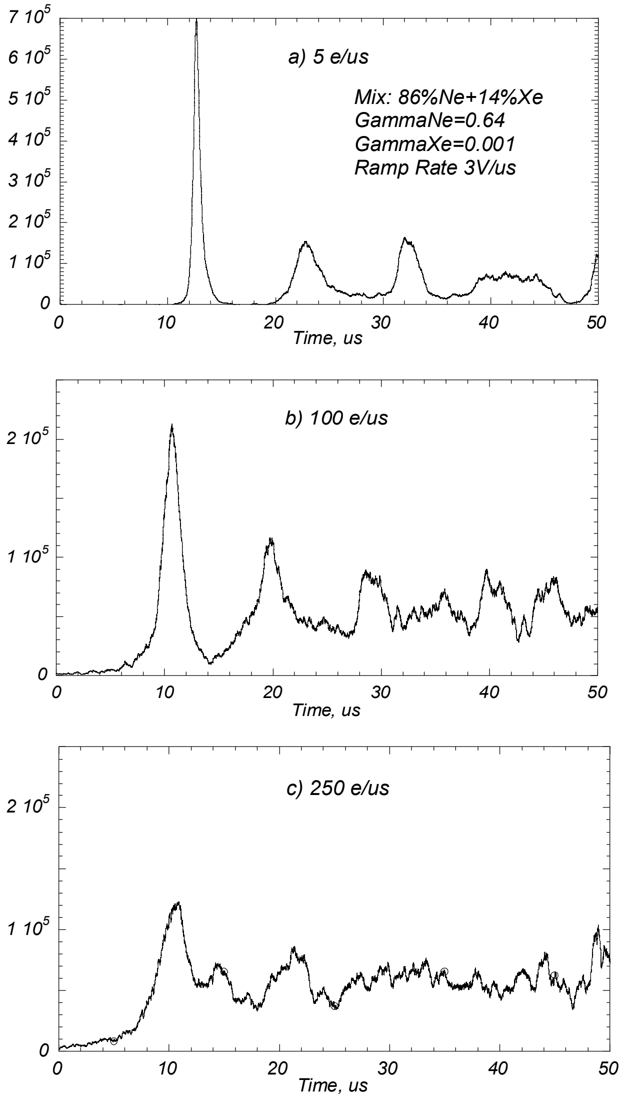

Figure 3. 3D PIC/Monte-Carlo simulation of the ramp discharge in a pdp cell with different levels of exo-emission. Weak exoemission results in separate peaks. Strong exoemission provides stable discharge. All discharges started in an empty cell.

3. Sustain discharge

3.1 Striations

Striations in barrier discharges is a mesmerizing physical phenomenon which still awaits a complete explanation of its underlying mechanisms. They appear during each sustain discharge pulse near the dielectric surface above the anode sustain electrode or the address electrode (when the latter performs a function of the anode in a PDP cell). Experiments performed using high-speed CCD cameras show that they form anew each cycle of the external AC voltage in the gas volume in the immediate vicinity of the dielectric surface [7].

Our simulations of the sustain discharge performed using 3D PIC/Monte-Carlo method reproduced the spatial structure and the dynamics of the striations [8]. The follow-up numerical experiments [9], which involved manipulations with physical parameters, like the ones shown in the Figs.4-5 brought some light to this phenomenon. Briefly, the main process in the anode area is a deposition of the negative charge on the dielectric surface. The deposited charge reverses the vertical (normal to the surface) component of the electric field and creates its horizontal component, which pulls electrons to new surface areas. As the charged area increases, electrons accelerated by the horizontal field may gain enough energy to ionize atoms of the background gas.

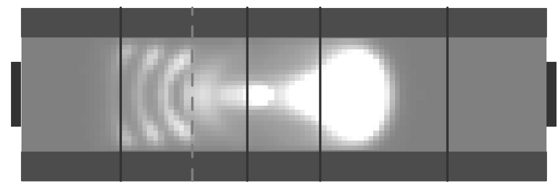

Figure 4. Distribution of the ion density (top view) when ions are immobilized above the anode (to the left from the dashed line) of the PDP cell. Striations are more pronounced and do not disintegrate later.

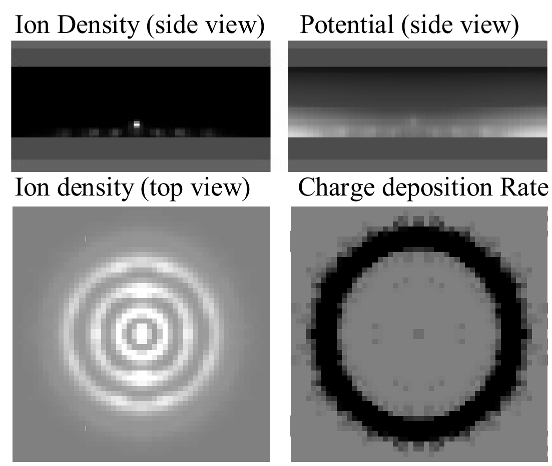

Figure 5. Spatial distribution of the ion density, potential and charge deposition rate on the dielectric surface above the anode in the system composed of two parallel electrodes. Electron source is placed between plates. The velocity of the front is controlled by the current $I(t)$ to the surface.

The positive charge created in the volume prevents most of the electrons from immediate escape from the volume and facilitates the transport of electrons to uncharged areas of the dielectric. When the ion density exceeds a certain level, there forms a potential well, which traps some of the electrons. In this way the first plasma lump (striation) appears. As the process of charging the surface involves newer areas, more and more striations successively appear. One can say that the plasma is created in the course of formation of striations (rather than striations emerge from a plasma background, like in DC discharge). The potential wells and striations evolve with time and eventually become disintegrated largely due to the motion of ions.

Although evolving, the striation structure (where strong and weak electric field regions alternate with each other) is quite stable. Electrons quickly cross the region with strong electric field, gaining there energy, but produce almost all ionizations and excitations within striations, where they spent most of the time.

As a result, the plasma density in striations grows, but the positive charge and electric field remain almost unchanged (if the ion motion is neglected). The depth of the potential wells inside striations is controlled by the following mechanism: if after ionization both primary and secondary electrons leave the well, it becomes deeper; if, on the other hand, both electrons get trapped in the well, it becomes shallower. The well becomes shallower also if an electron gets trapped in the well after loosing its energy due to excitation.

Potential difference between striations changes with time. At the moment of formation it is greater than the ionization potential of xenon I_0, but then it decreases and becomes smaller than I_0.

3.2 Cathode Ionization Wave

The other important phenomenon observed during sustain discharge is a cathode wave - the bright area spreading over the cathode. Our first kinetic simulations revealed that the cathode wave is, in essence, an extension of the cathode fall (CF) where the ionization rather than charging the surface is a main factor. The study of the cathode wave is important, because a large portion of power consumed by the discharge from the external circuit is utilized in the cathode region.

Using 3D PIC/Monte-Carlo method, we perform simulations of the CF expansion over the dielectric in 90%Ne-10%Xe mixture at a pressure of 500 Torr. In order to separate the CF expansion from other effects and keep the plasma potential close to a constant we intentionally simplified geometry by introducing the bare anode electrode (the side electrode in Fig. 6) right above the dielectric surface. The cathode wave in such a system propagates under almost unchanging conditions. We choose the dielectric thickness d=40μm, the dielectric constant ε=11, and the secondary electron coefficients γ_{Ne} =0.5 and γ_{Xe} =0.01.

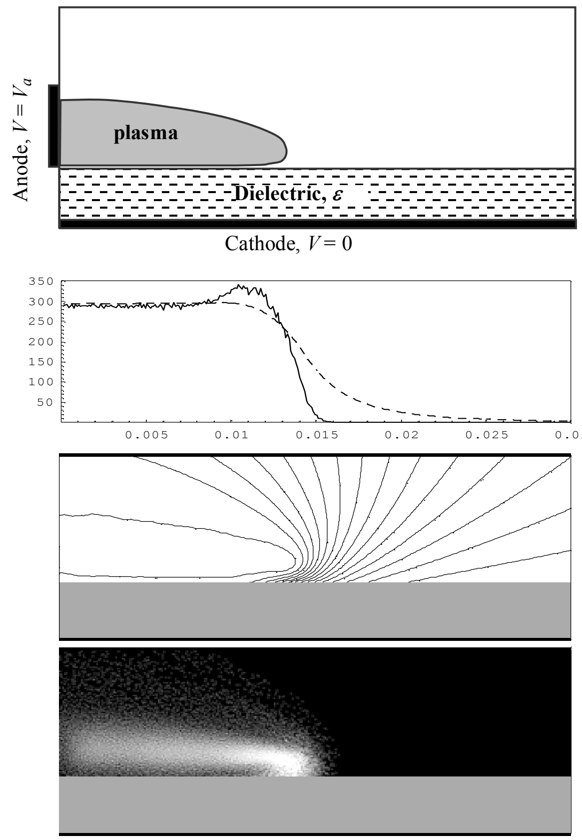

Figure 6. Expansion of the CF above the dielectric layer. Sketch of the simplified system (top panel) in which the CF expansion is studied; Electric potential (second panel) at the dielectric surface φ_s (dashed curve) and the renormalized surface charge σ/C (solid curve), where $C=\varepsilon\varepsilon_0/d$. The other panels show the spatial distribution of the electric potential φ (with 20V separation between the contour lines) and the ion density n_i (max n_i =1.85×10^{14} cm^{-3}) at the moment t=110ns.

As it follows from the simulations, the velocity of the cathode ionization wave is almost constant and about 1.2km/s (V_a=300V). With advancing the plasma region above the dielectric surface, the positive anode potential protrudes forward and the electric field lines reconfigure. Detailed analysis of the trajectories of the electrons and ions near the tip of the CF shows that the charged particles appears on the new electric field lines due to their diffusion which significantly influences all parameters of the cathode wave.

4. Line Loading Effects

Computer simulations of plasma displays usually ignore that the voltage from the voltage generator is not the one applied to a cell. In a real PDP several thousand individual cells are connected to a single pair of sustain electrodes. These cells do not operate independently, but react with each other through distributed as well as discrete resistance, capacitance, and inductivity of the electrodes.

The effect that line imposes on the work of any cell can be very large. Just a simple voltage drop in the line if all cells fired together can easily be about 100V. As the voltage applied to a cell may differ from cell to cell, their operating regimes, currents, brightness, etc., can be different as well.

In order to analyze these kinds of effects we have developed a computer model which can perform an arbitrary number of PDP discharges along a given line. We found that when certain symmetry exists (e.g. all lines are lit together, which we assume here) the circuit can be represented as a repeating series of discharge cells distributed along a sustain electrode pair, where each cell contains a plasma simulation element $S_{k=1...N}$, two resistors R_0, capacitors C_1, C_2, and C_3, and transformers of types A and B, as shown in the Figure 7. In the absence of such symmetry the number of elements in each cell is much larger, and the task is much more complicated, as one may have to consider many lines simultaneously.

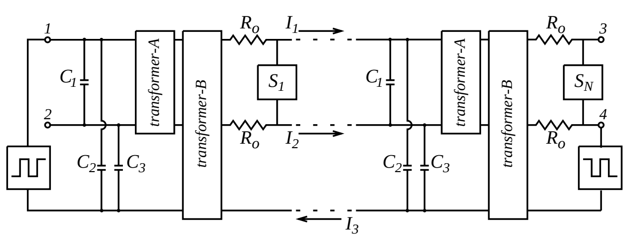

Figure 7. Two-sided driving configuration shown here has one sustain electrode driven from the left, and the mate electrode is driven from the right side. Arrows indicate the current flow, and positive direction is from the left to the right for all wires.

Details of the model are quite complicated and will be published somewhere else, but roughly $R_0 \times N$, $C_1 \times N$, $C_2 \times N$ and $C_3 \times N$ are the total resistance of the sustain wire, the total capacitance between two sustain wires, and the total capacitances between sustain wires and the return wire, respectively.

The type-A and B transformers reflect mutual inductances between sustain wires (A), and between sustain wires and the return wire (B), which is described by the formulas,

$$\Delta V_A = L_A\, d/dt(I_1 - I_2),$$

$$\Delta V_B = L_B\, d/dt(I_1 + I_2 - I_3).$$

One should keep in mind though, that all elements $C's$ and $L's$ are calculated for the boundary conditions related to the specific configuration of the discharge in the panel.

For a standard panel configuration, $R_0 \times N \sim 100\Omega$, $C_1{\times}N{\sim}(25\text{–}100)\,pF$, $L_A{\times}N{\sim}(0.5-1)\mu H$, and $L_B{\times}N \sim (1-5)\mu H$. Capacitances C_2 and C_3 are about $(0.1-0.3)C_1$.

We drove our circuit by applying a series of 0 to V_0 square wave potentials, with half-cycle periods of 5μs and a 180 degree phase shift between the left and right ends (see Fig.7). We found that even if one starts with identical initial conditions in all cells, they all experience different voltage and behave differently. Depending on the circuit parameters, line load, and on parameters of a cell one could observe a regular or irregular mode of the discharge. In the figures below we show results of the simulation of the line with 2000 cells, where we used fifty (2D) macro-cells, (each containing 40 cells working as one macro-cell). In the regular mode there is a small time shift between discharges in close cells, and the overall width of the discharge is close the width of any single cell. There is a small spatial non-uniformity of the amplitude with the largest ones near the edges of the line (See Fig.8). In the irregular mode, (Fig.9) the time shift between close cells is large, and the total current width is significantly larger than the pulse width in any pixel. The order in which cells fire changes from pulse to pulse. Individual current peaks may differ significantly in this mode.

The two modes reflect the difference in the interaction between cells as they work together in the line. If parameters of the line (or the load) are such that this interaction is weak, the regular mode is being realized, if interaction is strong then one observes the irregular mode of the discharge, where the power input varies

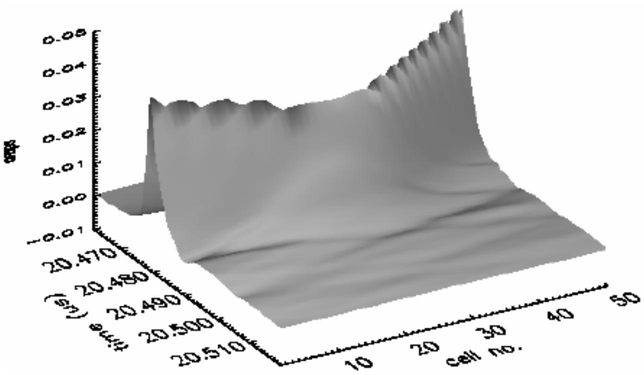

Figure 8. Regular mode of the discharge. There is only small time shift between close pixels. The width of the total current through the wire is only about twice as big as the current width through an individual pixel.

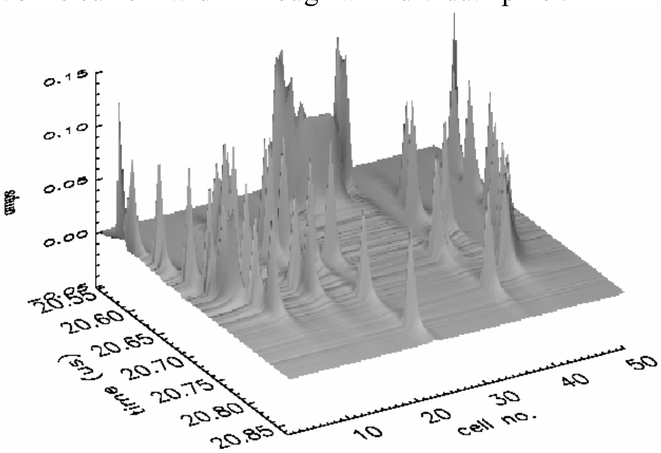

Figure 9. Irregular mode of the discharge. Every cell had exactly the same initial conditions, and during the first discharge all fired synchronously. Shown is the fifth pulse. The width of the current envelope is about 200ns, while current in any individual cell is only about 15ns wide.

from cell to cell significantly. These results show that one has to be careful when extrapolating results obtained on a small test panel (where interaction between cells is weak) to a full size panel (where such interaction may be large).

5. Summary

The specifics of plasma displays with their small size of a cell and very large number of cells, with their low current quasi-stationary ramp discharges and large current pulse discharges, with different mechanisms of electron emission from the surface and crucial role of the exoemission, with importance of operation of individual cell alone and collectively with other cells, brings many new elements to the physics of gas discharge, some of which has never been investigated. It also brings new challenges for the pdp industry to overcome, which is very difficult if one takes into account that tools available for investigation (and even observation) of the pdp discharge are very limited and simply not adequate for the task. Low signal to noise ratio for individual cell discharge, delayed optical (IR) signal, inability of making electrical measurements directly on a single cell are just a few obstacles for a real time, spatially resolved direct measurements. Currently used integrated optical (IR) observations of a cell, or electrical measurements of the whole line (often without analysis of the power supply, and matching it to the line), as well as investigation of a macro-cell do not provide necessary information about the discharge, the lack of which is often being substituted with speculations and guesses, which cannot make a good basis for improvements. In this situation carefully designed numerical and physical experiments combined with theoretical analysis that can produce a quantitative information and analysis of the discharge is absolutely necessary for the progress of PDPs.

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