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Effects of pulsed potential on address electrode in a surface-discharge alternating-current plasma display panel

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The influence of pulsed potential application onto the address electrode of an ac-type plasma display panel was investigated from the observation of front and side views of Xe atom densities in the metastable \(1s_5\) and excited \(2p\) states in a unit discharge cell by using microscopic laser absorption spectroscopy and optical emission spectroscopy. It was seen that a predischarge occurs between the address electrode and one of the sustain electrode worked as a preceding anode, which is a similar effect found previously by applying a higher sustain voltage. The predischarge partially erases the surface charge accumulated in the preceding pulse, but it induces a faster main sustain discharge, bowing towards the address electrode, and enhances the production efficiency of Xe\((1s_5)\) atoms, if the applied potential is within an optimal range. © 2003 American Institute of Physics. [DOI: 10.1063/1.1580638]

One of the most important issues of the present alternating-current plasma display panels (ac-PDPs) is to improve luminous efficiency, which is dependent on the composition of rare gases, total pressure, cell structure, and driving wave forms. Various driving techniques using address pulses in sustain periods have been suggested to improve the luminous efficiency.\(^1\sim5\) However, real phenomena occurring in the discharge by applying address pulses have not been experimentally investigated as yet. In this work, we examine the behavior of metastable Xe atoms in the \(1s_5\) state, Xe\(^*\)(\(1s_5\)), under this condition by using the microscopic laser absorption spectroscopy (LAS) technique, which we have developed previously.\(^6\sim9\) The near-infrared emission from excited Xe atoms in the \(2p\) state, Xe\(^*\)(\(2p\)), is also examined, which is composed mostly of the 823- and 828-nm lines and correlates with the vacuum ultraviolet emission at 173 and 147 nm through the cascade transitions to the metastable \(1s_5\) and resonance \(1s_4\) states.\(^10\sim11\) As the total gas pressure or the Xe concentration increases, the emission intensity at 173 nm from Xe\(^*\)(\(2p\)) excimers increases through the enhanced production efficiency via three-body collisions of Xe\(^*\)(\(1s_5\)) atoms with Ne and Xe atoms in the ground states.\(^12\sim13\) It is, therefore, of great importance to investigate the total number of Xe\(^*\)(\(1s_5\)) atoms for the estimation of the luminous efficiency in ac-PDPs.

The structure of an ac-PDP unit cell shown in Fig. 1(a) was specially designed for the three dimensional (3D) observation of spatiotemporal behaviors.\(^8\sim9\) The sustain electrodes of 200 \(\mu\)m width made of indium tin oxide (ITO) film were successively covered with a dielectric layer and a MgO protective layer, and set in parallel to each other on the front glass plate with a gap of 75 \(\mu\)m. By using transparent glass prisms of 150-\(\mu\)m thickness as barrier ribs, we could observe the front and side views of the discharge at the same time. On the rear glass plate, the address electrode also made of ITO was located perpendicularly to the sustain electrodes. A mixture of Ne and Xe (5%) was filled at a pressure of 500 Torr. The width, frequency, and voltage of the sustain voltage pulses \((V_x \text{ and } V_y)\) employed in this experiment were 9.2 \(\mu\)s, 50 kHz, and 200 V, respectively. The width of the address voltage pulses \((V_a)\) was fixed at 800 ns. The timing of \(V_a\) at the center was adjusted to the rising edge of \(V_x\), as shown in Fig. 1(b). Hereafter, the time origin \((t=0)\) is defined at the rising edge of \(V_x\). The values of \(V_a\) was varied from 0 to 90 V. The LAS measurement of the Xe\(^*\)(\(1s_5\)) atom density was performed by tuning the laser wavelength to the 823.1 nm \((2p\sim1s_5)\) transition. The IR emission from Xe\(^*\)(\(2p\)) atoms

\(\text{FIG. 1. (a) Structure of the 3D observation cell and (b) wave forms of sustain voltage pulses (}V_x \text{ and } V_y\text{) and address voltage pulses (}V_a\text{).}\)
was observed by an intensified CCD camera at a gate width of 10 ns. The CCD camera was equipped with a band-pass filter centered at 820 nm with a full width at half maximum of 20 nm to observe mostly the 823 nm (2p-1s) and 828 nm (2p-1s) lines.

Figures 2(a) and 2(b) show the images of IR emission from Xe*(2p) atoms observed by the CCD camera from t = 150 to 400 ns and t = -80 to 120 ns at (a) V_a = 0 V and (b) V_a = 60 V, respectively. It is noted that the cathode and the anode in these figures are right and left sides, respectively, with respect to the central gap. Front and side views of the discharge image are shown on the upper and lower parts of each frame, respectively. It is seen that the discharge starts faster as the address voltage is applied. The discharge spreads to each end of sustain electrodes but the appearance is different on each side. The emission intensity above cathode is stronger and it expands outward according to the ion mobility, while it becomes weaker and shrinks inward due to charge accumulation on the electrode surface. The occurrence of a predischarge between the previous anode and the address electrode is clearly seen at V_a = 60 V. The predischarge may partially erase the surface charge accumulated on the previous anode, but it induces the main discharge between the sustain electrodes as soon as the address pulse is applied. In this discharge mode, the main discharge tends to take a path bowed towards the address electrode. This is apparently quite similar to the case which we observed previously by applying a higher sustain voltage of 250 V, where the charge accumulated on the address electrode due to the stronger discharge causes a similar predischarge after the falling edge of the preceding sustain pulse.

Figure 3 shows the measured spatiotemporal behaviors of the Xe*(1s) atom density at the address voltage of V_a = 60 V. The graphs on the left side are the distribution of Xe*(1s) atoms in the front view. In each graph, the left-side electrode is working as anode. In a usual operation mode without the application of V_a, Xe*(1s) atoms begin to be observed at the anode side of the gap and a striated pattern is formed. In this case, however, the excited Xe atoms appear first at the cathode side. From the side view, it is found that the predischarge occurs between address electrode and the previous anode (therefore, the succeeding cathode) at t < 0, where the address electrode works as the anode, and stimulates the main discharge between the new anode and cathode at t > 0. The maximum density of Xe*(1s) atoms reaches 5.5 x 10^13 cm^-3 on the cathode side.

The discharge current at the sustain electrode I_s and address electrode I_a were measured by a differential probe through a small resistor of 680 Ω. Figures 4(a) and 4(b) show the current wave forms of I_s and I_a, respectively, which were measured at V_a = 0, 30, 60, and 90 V. Here, we define the response (or delay) time τ as the time difference between the rising edge of the sustain pulse (t = 0) and the peak of the sustain current. At a given sustain voltage of 200 V, τ was measured to be 360, 135, 100, and 95 ns at V_a = 0, 30, 60, and 90 V, respectively, showing a tendency of shortening with the increase of V_a. The occurrence of predischarge is also seen in the wave forms of I_a at V_a = 60 and 90 V, where the address electrode is working as the anode. However, it is noticed that in each wave form of I_a, a smaller negative peak follows the positive peak just after the start of the main sustain current. It suggests that the address...
function of time. The peak number of Xe* (1\textsuperscript{s}s) atoms in the whole cell volume, as a function of time, increases from 1.3\times10\textsuperscript{8} to 2.1\times10\textsuperscript{8} as \( V_a \) increases from 0 to 60 V, but it decreases as \( V_a \) increases further to 90 V. At \( V_a = 90 \) V, it is suggested that too much surface charge is lost from the sustain electrode in the predischarge, and as the result the main discharge is weakened. At the optimal condition with \( V_a = 60 \) V, the total input power estimated from the current wave form and the applied voltage increases by about 50% as compared to the case without \( V_a \). However, the density of Xe\textsuperscript{8}(1\textsuperscript{s}s) atoms increases by about 70% and, then, the production efficiency increases by about 25% with the power expense at the address electrode of only 6% of the sustain discharge power consumption.

In conclusion, by the application of address pulse potential with a moderate amplitude, say 60 V in our case, the spatiotemporal distribution of the electric field caused by both the surface charges and the external applied voltages becomes optimal across the whole electrode area, leading to an expanded discharge scheme with higher luminance and luminous efficiency. At higher values of \( V_a \), however, the predischarge becomes too strong to disturb the optimum balance of the electric field.

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