Spatiotemporal Behaviors of Excited Xenon Atoms in a Three-Dimensional Diagnosable Microplasma Unit Cell with High Sustain Frequency for Plasma Display Panels

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Abstract

With the high sustain frequency at 250 kHz, a three-dimensional diagnostics of excited xenon atoms was investigated by the emission and absorption microscopic spectroscopy for plasma display panels, spatiotemporally. As a typical feature of the emissions, a broad discharge peak was observed on the temporal cathode and a sharp one was monitored on the anode, at the high frequency. However, the discharge starts from the cathode edge, actually, that is a discharge space on the floated address (or data) electrode. Spatially, the dense emission and absorption peak were observed in the discharge space between the sustain electrodes gap. Overall, the microdischarge at high sustain frequency showed priming dominant characteristics.

1. Introduction

For the improvement of luminous efficiency of plasma display panels (PDPs), a sustain frequency has been investigated as one of solutions [1][2]. However, the basic researches [3] of the discharge phenomena have not been studied sufficiently. Here, we investigated them using by the state of the art of the three-dimensional (3-D) microdischarge unit cell [4][5]. It had been developed for the observation of the side viewing performances for plasma display panels (PDPs). The 3-D observations of the front and side view were realized by the transparent glass prisms as barrier ribs.

Employing the higher sustain frequency, it means increasing the emission intensities and the realization of the natural colors as through the expending gray scales, and contrast ratios. With the time spent in sustaining, it is only about 5 milliseconds (ms) for giving short period in a part of one TV-field or frame, 16.7 ms, totally [4]. To overcome of the restriction, it is necessary to investigate the discharge characteristics, spartiotemporally, with the high driving frequencies.

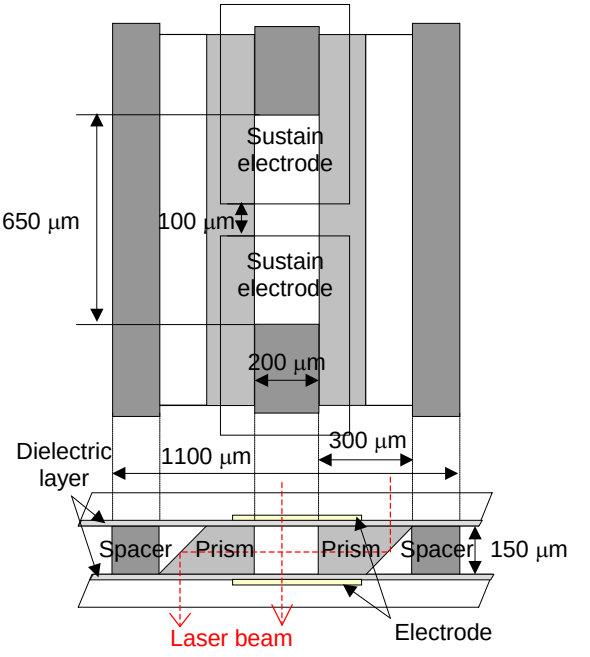

Fig. 1 Structure and dimensions of the three-dimensional microdischarge cell.

2. Experimental Details

The three-dimensional (3-D) microdisharge cell was prepared. The panel structure and cell dimensions are given in Fig.1 and the details wew introduced in our previous paper [4]. A slight difference is the total electrode length (including the sustain electrode gap: 100 μm) as 650 μm only. The gas condition is the Xe(5%)-Ne binary mixture at 500 Torr. The operating sustain waveforms were prepared by an arbitrary waveform generator combined with the high-speed voltage amplifiers. The duty ratio, rising, and falling

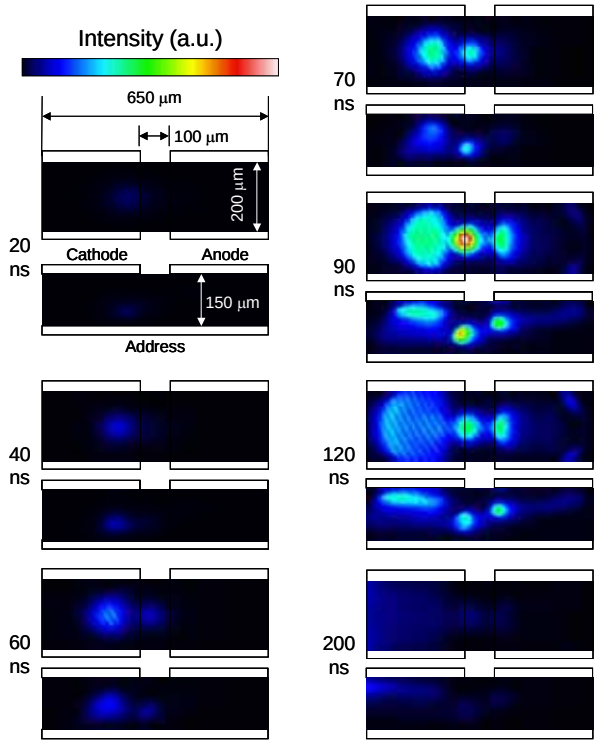

Fig. 2 Spatiotemporal behavior of near-IR emissions were measured by ICCD camera at the sustain frequency of 250 kHz. V_s = 210 V.

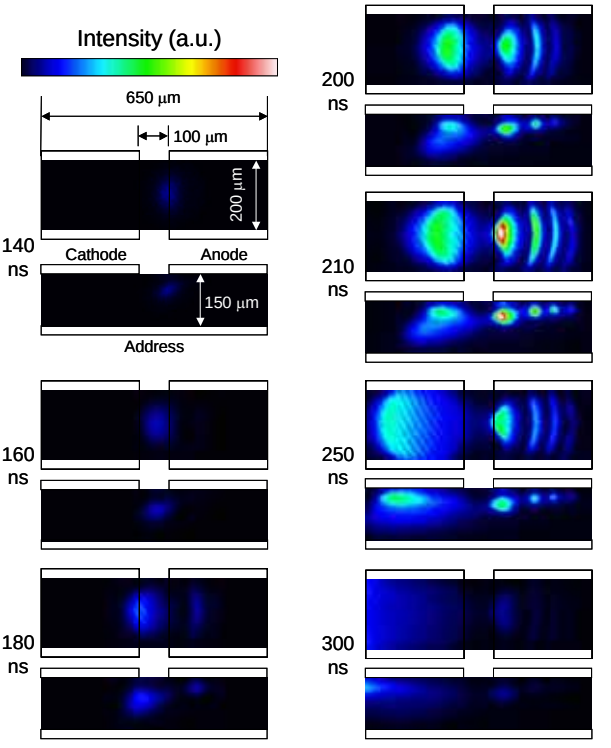

Fig. 3 Spatiotemporal behavior of near-IR emissions were measured by ICCD camera at the sustain frequency of 50 kHz. V_s = 210 V.

time were fixed at 40 % and 300 ns, respectively, for the both of 250 kHz and 50 kHz in this work. The sustain voltage V_s was fixed at 210V for all of measurements of the emission and absorption.

The experimental measurement techniques are the same as our previous works [4][5][7]-[11]. The spatiotemporal images of the near-IR emissions were observed by an intensified charged couple device (ICCD) camera with a narrow band pass filter centered at 820 nm. The transition range is comprised in the near-IR from higher excited $Xe^{**}(2p)$ to $Xe^{*}(1s)$ atoms at 823.1 and 828.0 nm. Corresponding results of the spatiotemporal behaviors of the excited $Xe^{*}(1s_5$ in Paschen notation) atoms in the metastable state were measured by an advanced technique of a microscopic laser absorption spectroscopy (μ-LAS) [7].

3. Near-IR emissions

Figure 2 shows the spatiotemporal behavior of near-IR emissions from the excited $Xe^{**}(2p)$ atoms at the sustain frequency of 250 kHz. The side and the front emission images are shown in time sequence. In the 250 kHz at 20 ns, the beginning of discharge, a weak emission appeared on the temporal cathode edge near electrode gap in the front view. (It can be clearly distinguished in the colored figure of electric material.) However, in the side view, the emission begins in the discharge space above the floated address electrode. In the mean time, the discharge propagates to the temporal cathode region and the anode side along the address electrode on the back plate. The most intense emission peak is shown in the space near the electrode gap at 90 ns after the beginning. It is 120 ns faster than the case of 50 kHz, reaching the peak. (The results of 50 kHz are shown in the Fig. 3.) At the late time after the emission peak, the cathode peak diffused to the whole cathode electrode region and the anode peak connected two tails on the end of anode electrode.

In Fig. 3 for the lower sustain frequency of the 50 kHz, the discharge begins on the temporal anode edge at 140 ns and propagates to the cathode region along the sustain electrode gap on the front plate. The most intense emission peak and the striation peaks appear

on the anode side. The differences of the spatio-temporal IR emissions are the beginning of the discharge and the striations formations on the anode at the 50 kHz. It is similar to our previous observations of the IR emissions from Xe-Ne binary mixtures [9]. In the both of the higher and lower cases, however, the total emission time of the near-IR is almost same around 200 ns. It is correspond to the discharge current width (FWHM) [12].

4. Spatiotemporal behavior of $Xe^*(1s_5)$ atoms

The corresponding results of the spatiotemporal behaviors of the excited $Xe^*(1s_5)$ atoms are shown in Fig. 4(a) 250 kHz and (b) 50 kHz, respectively. The beginning conditions are presented for the both frequencies at the 0.0 μs. In the case of (a) 250 kHz, the long-lived metastable Xe atoms remain at the between the sustain electrodes (electrode gap) in the discharge cell and the peak density is 2.21×10^{13} cm^{-3}. On the other hands, the case of (b) 50 kHz shows the scattered values of the density in the order of between 10^{11} cm^{-3} and 10^{12} cm^{-3} on the sustain electrodes regions at the beginning of discharge (0.0 μs). In the peak density, it is noticed that the value of 3.50×10^{13} cm^{-3} measured for the 250 kHz at 0.5 μs and that of 2.15×10^{13} cm^{-3} measured for the 50 kHz at 0.8 μs. Similar to the result of the IR emissions, the higher sustain frequency leads to the faster production of the $Xe^*(1s_5)$ atoms and the concentrated distributions at the middle of the discharge cell. The details will be given in the presentation on the conference.

5. Discussion

Here, we discuss the microplasmas with the realistic PDP unit cell at the higher sustain frequency of 250 kHz and at the lower that of 50 kHz.

Firstly, the main peak of IR emission was observed between the sustain electrodes in front view and on the address electrode in side view. This position is very closed to the visible phosphors in real PDPs. It may become one of reasons for the phosphor degradation of the recent key issue of image quality (image sticking) in the sustain-mode discharge. Only with our results, we cannot discuss to that effect in the address mode discharge. However, there are very frequent interactions between the U-shaped plasma channel and the phosphors. According to our works [4][12], the U-shape (plasma shape in side view) is developed well under the higher sustain voltage and frequency conditions like recent operating conditions.

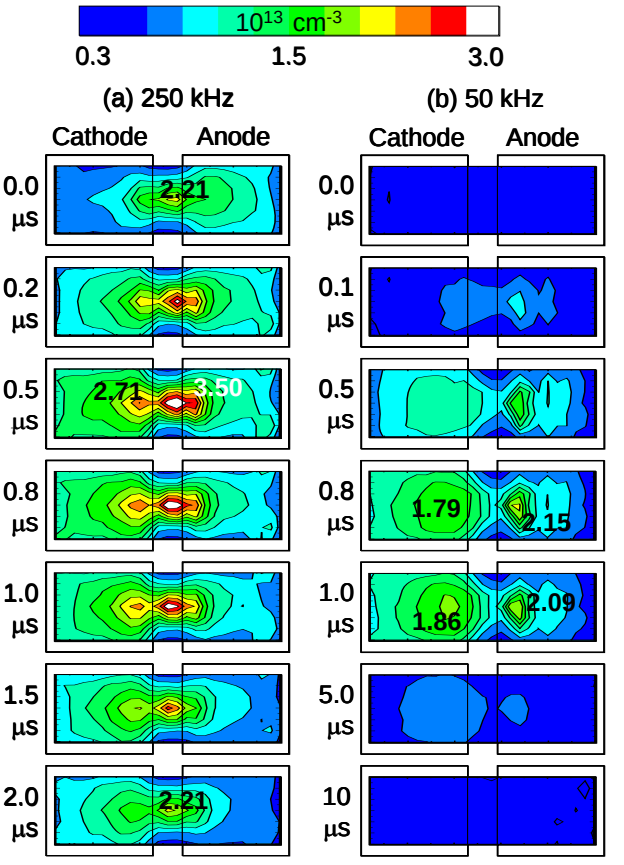

Fig. 4 Spatiotemporal behaviors of the excited $Xe^*(1s_5)$ atom densities (in unit of 10^{13} cm^{-3}) were measured by μLAS at (a) 250 kHz (2 μs in half period) and (b) 50 kHz (10 μs), respectively, during a half cycle.

Secondly, in general, the discharge starts on the anode side (or near anode) caused by the fast moving electrons from the cathode. In higher frequency, however, the beginning of the emissions was monitored on the floated address electrode and slightly shifted to the temporal cathode. The different phenomena can explain well with the given model in Fig. 5. The model of higher frequency (250 kHz) contains plenty of the long-lived Xe metastable atoms in the discharge space as the priming particles. The lower level excited $Xe^*(1s)$ atom is easier to (1) the ionization (Xe^+) or (2) the excitation to the higher levels (Xe^{**} or Xe^{***}) by the electron collisions. At that moment, the electrons need lower kinetic energy and/or they have the shorter mean free paths. Moreover, this priming dominant-conditions lead to the faster response time (time lag) in the discharge.

$$Xe^* + e \rightarrow Xe^+ + 2e \quad (1)$$

$$Xe^* + e \rightarrow Xe^{**} \text{ (or } Xe^{***}) + e \quad (2)$$

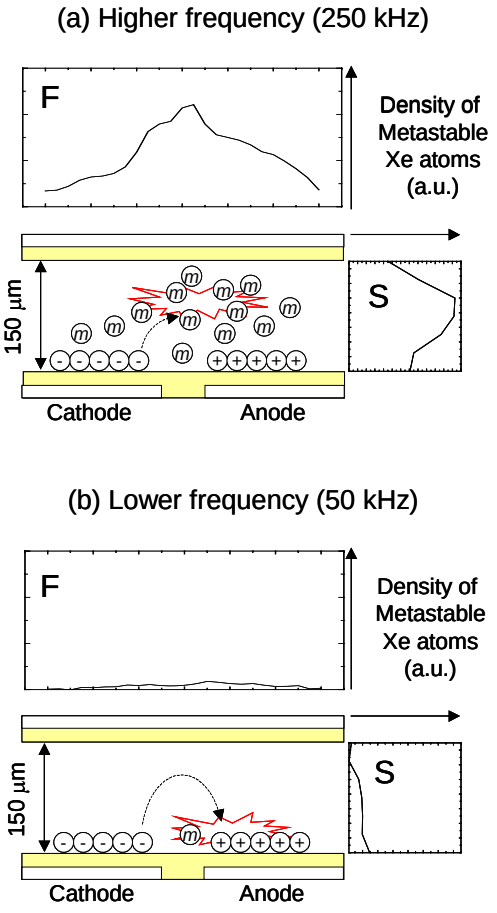

Fig. 5 The discharge models are given in the sustain frequencies at 250 kHz for (a) higher case and at 50 kHz for (b) lower case. The distributions of the long-lived Xe metastable atoms are shown in the graphs S (side view) and F (front view) at the cross section of the center.

Finally, we consider the higher sustain frequency conditions over the 250 kHz. As our previous states, the high frequency leads to the plenty of the excited $Xe^*(1s_5)$ atoms and the fast response time. In the production of the vacuum ultraviolet (VUV) photons, however, the remaining of the excited Xe atoms plays a bad effect. Because, the VUV photons are generated by the decays of the collisional process [9] and the trapping effect [13] of the excited $Xe^*(1s_5,1s_4)$ atoms in PDPs [6]. Therefore, the overabundance of the Xe atoms plays the energy loss part in the high frequency for the production of the VUV photon emissions. The valuable discussions of the various frequencies will be reported in the other paper with the viewpoint of the luminous efficiency [12].

6. Conclusions

The spatiotemporal behaviors of excited xenon atoms were measured by spectroscopic diagnostics of an emission and an absorption spectroscopy technique at the high sustaining frequency of 250 kHz. The spatiotemporal behaviors of the excited $Xe^*(1s_5)$ atoms showed the similar features of the IR results: the main peak on the center and the two tails on the temporal anode region. The higher sustain frequency mode induced the fast response time and the plenty of the excited metastable $Xe^*(1s_5)$ atoms at the beginning of the discharges. The long-lived metastable Xe atoms as the priming particles exercised their influence over the discharge of the next half cycle at the high frequency condition. Moreover, the disadvantage of the high-frequency mode discharge should be considered in the viewpoints of the production and the luminous efficiency.

Acknowledgements

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