

Spatiotemporal Behavior of the Excited Xe Atom Density in the $1s_5$ Metastable State According to the Hoof-type Electrode Structure in an Alternating-current Plasma Display Panel

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Abstract

To improve the luminescence characteristics of high-efficiency alternating-current plasma display panels (AC-PDPs), we developed a new hoof-type electrode structure, and we studied the spatiotemporal behavior of the density of the excited Xenon atom in the $1s_5$ metastable state via laser absorption spectroscopy. Using this structure, the maximum density of the excited Xenon atom per cell was improved by 2.4 times that when the conventional electrode structure was used.

Keywords: Excited Xe-atom density, Laser absorption spectroscopy, Metastable state

1. Introduction

To realize high-efficiency alternating-current plasma display panels (AC-PDPs), further improvements are needed in their low luminous efficiency, which is inherently due to the use of the negative glow region that is produced by the conventional electrode structure of the AC-PDPs. If the conventional electrode gains a new structure, however, its luminous efficiency will improve. In this study, a new hoof-type electrode structure was developed. Bus electrodes with a longer gap size are proposed in which a high-efficiency positive-column region can be developed. The vacuum ultraviolet (VUV) light that is generated between a sustained electrode and a common electrode in the reference electrode structure was distributed in the cathode part, with which only some parts of the phosphor in the discharge cell were excited. Thus, they have low overall luminous efficiency. In the VUV light of the hoof-type electrode, however, via the density distribution of the excited Xe, each phosphor in the discharge cell is excited to improve the luminous efficiency of the hoof-type electrode.

Therefore, we propose a new hoof-type electrode structure to improve the luminescence characteristics of high-efficiency alternating-current plasma display panels (AC-PDPs). To enhance the luminous efficiency, one can research on the VUV light and the excited Xe atom density in the microdischarge cell. The surface discharged AC-PDP utilizes the photoluminescence phenomena of the phosphors excited by the VUV rays from the mixture gas, which include Xe. The Xe atoms in the $1s_4$ resonance state and the $1s_5$ metastable state generate a 147 nm and 173 nm VUV light in the Xe plasma, respectively [1]. The intensity of the 147 nm VUV emission is proportional to that of the 828 nm infrared (IR) emission, and the 173 nm VUV emission is roughly proportional to that of the 823 nm IR emission [2]. Due to this close relationship of the IR and VUV emissions from Xe gas, it is important to understand the behavior of the excited Xe atoms in the $1s_4$ resonance state and the $1s_5$ metastable state. Laser absorption spectroscopy enables measurement of the density of the excited Xe atoms in the AC-PDP. To tune the excited Xe atoms, we used a reference tube with 0.7 Torr pure Xe gas. Such reference tube with pure Xe gas makes it possible to resolve the hyperfine structure. To determine the maximum absorption signal for the excited Xe atoms, a fixed wavelength of 823.1 nm of the tunable laser diode with an external cavity was used. In this paper, we report the luminescence characteristics of the test panel and our analysis of the discharge characteristics

Manuscript Received November 12, 2010; Revised December 16, 2010; Accepted for publication December 24, 2010.
This research was supported by the Ministry of Knowledge Economy of Korea under the ITRC(Information Technolgy Research Center) Support Program supervised by the National IT Industry Promotion Agency (NIPA-2009-C1090-0902-0018)
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and the excited Xeon density via laser absorption spectroscopy.

2. Experimental Setup

Fig. 1 shows the experimental schematic of the laser absorption spectroscopy that was performed for the spatio-temporal measurement of the excited xenon atoms in the $1s_5$ metastable state [3]. The IR probe beam was split into two directions with a beam splitter. The first beam was sent into an Xe reference tube made of an external electrode fluorescent lamp (EEFL) [4], which was used to monitor the maximum absorption wavelength during the absorption process. The EEFL Xe reference tube was filled with 0.7 Torr pure Xe gas. The PZT controller with a resolution of 0.02 pm was used to finetune the wavelength. In addition, we used the Littman-Metcalf type, which was tuned with a rotation mirror with high reflectivity, along with fixed diffraction grating in the external cavity. The external-cavity tunable laser diode ensures fast-mode hop-free tuning over the entire wavelength range as well as superior wavelength repeatability and precision. The second IR probe beam was transmitted through a PDP cell, and the absorbed signal was fed into a photomultiplier tube (PMT). To eliminate the emission lines from a PDP cell, a bandpass filter was installed on the PMT, the wavelength of which was centered at 820 nm (FB820-10 Thorlabs), and the full width at half maximum (FWHM) was 10 nm.

Moreover, the PMT was covered with the shielding box. The PMT output was connected to the current-voltage (I-V) converter with a high gain and an ultralow noise. A motorized stage with two axes in the X-Z directions can travel with a resolution of 1 um to scan the PDP panel. The spatial resolution for this measurement was 30 um, wherein 18x7 points were scanned over a unit discharge cell. The IR probe beam diameter was about 30 um, as measured with the knife-edge method, wherein a 90um-wide nontransparent bus electrode was used as the knife. To monitor the 823.1 nm that entered the PDP cell, an IR charge-coupled device (IR-CCD) camera was installed in front of the PDP panel. The bandpass filter was also installed on the CCD camera. Each panel was operated with a driving frequency of 35 kHz and with a duty ratio of 25% in an He (35%)-Ne (bal)-Xe (15%) mixture gas at a pressure of 400 Torr.

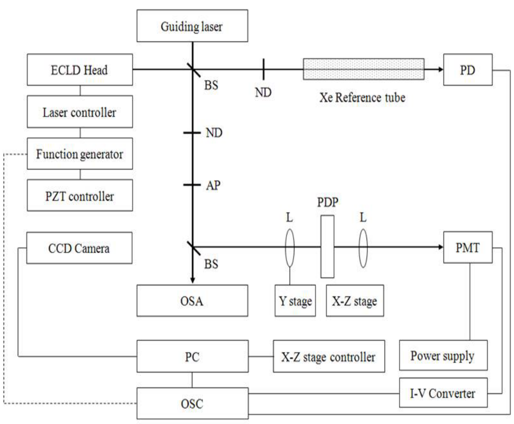

Fig. 1. Experimental schematic.

The measurement of the absorption signal was based on the determination of the absorption coefficient k_v from the spectral intensity, which was transmitted through the absorption path length x, wherein I_0, and I_v are the incident and the transmitted IR probe beam intensity, respectively.

$$I_v = I_0 \exp(-k_v x) \quad (1)$$

x with a 120 um discharge space was used as the absorption path length through a PDP cell in this experiment, wherein the k_v, that was obtained from $-(1/x)$ in $((I_V) / (I_0)) = k_v$, is the absorption coefficient per unit length over the scanning frequency. When the IR probe beam with I_v was incident on a PDP cell, absorption occurred in the $1s_5$ metastable state and the $1s_4$ resonance state.

3. Results and Discussion

The temporal density N_1 of the excited Xe atoms in the $1s_5$ metastable state was expressed by Eqs. [5] and [6] for a given discharge point, wherein $k(t)$ is the temporal absorption coefficient, H is the correction factor, $\Delta\nu_v$ is the Doppler width, λ_0 is the wavelength at the maximum absorption, and g_1 and g_2 are the statistical weights of the lower and upper levels of the transition [7, 8]. A21 is the transition probability of a spontaneous jump from the upper level to the lower level per second.

$$N_1(t) = \frac{k(t)}{H}\frac{\Delta\nu_v}{2}\sqrt{\frac{\pi}{\ln 2}}\frac{8\pi}{\lambda_0^2}\frac{g_1}{g_2}\frac{1}{A_{21}}. \quad (2)$$

In this paper, the inverse of the correction factors $1 / H$ in the $1s_5$ in the discharge cell with the Hoof-type electrode structure and the conventional elec-

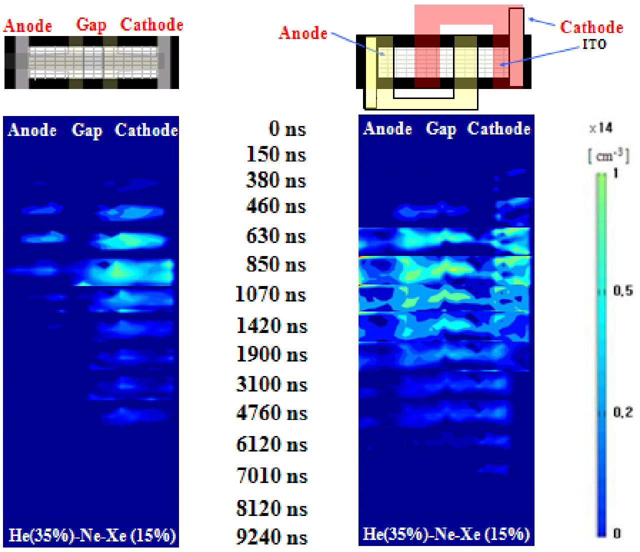

Fig. 2. Spatiotemporal behavior of the excited Xe-atom density in the $1s_5$ metastable state in the conventional electrode structure and the Hoof-type electrode structure.

trode structure were measured as 51 and 52, respectively. Fig. 2 shows the spatiotemporal behavior of the excited Xenon atoms in the $1s_5$ metastable state in the conventional electrode structure and the hoof-type electrode structure, which were obtained via laser absorption spectroscopy. Fig. 2 shows that the region of the excited Xenon atoms in the hoof-type electrode structure is much longer than that in the conventional electrode structure, and this is assumed to be partially related to the electrode structure. It is noted that the lifetimes of the excited Xenon atoms were the same in the two cases.

Fig. 3 shows the high-speed gated ICCD IR (750-900 nm wavelength) camera image. It is similar to that in Fig. 2 for the excited Xe atom density in the $1s_5$ image. It shows that the hoof-type electrode structure had a broader distribution especially in the discharge space. Moroever, the discharge emission intensity of the hoof-type electrode structure was higher, as shown in Figs. 2 and 3.

Fig. 4 shows that the spatial averaged peak densities of the excited Xenon atoms differed significantly between the conventional electrode structure and the hoof-type electrode structure. The maximum densities of the excited Xenon atoms in the $1s_5$ state in the discharge cell in the conventional electrode structure and the hoof-type electrode structure were measured as 5.2×10^{13} cm^{-3} and 1.4×10^{14} cm^{-3}, respectively.

Fig. 5 shows the spatial behavior of the averaged productive efficiency for the excited Xe atoms per cell versus the time for several electrode structures. The spatial aver-

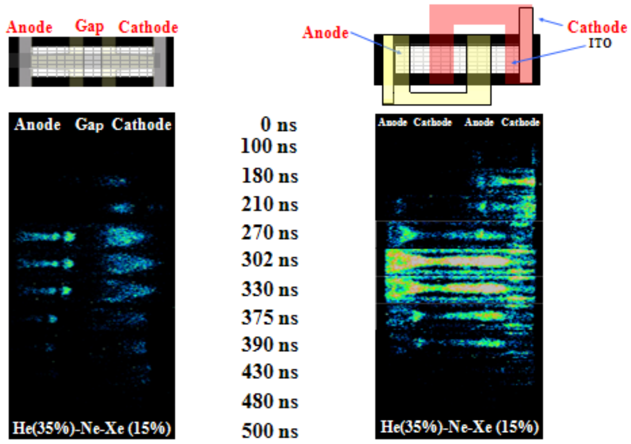

Fig. 3. High-speed gated ICCD image for several electrode structures.

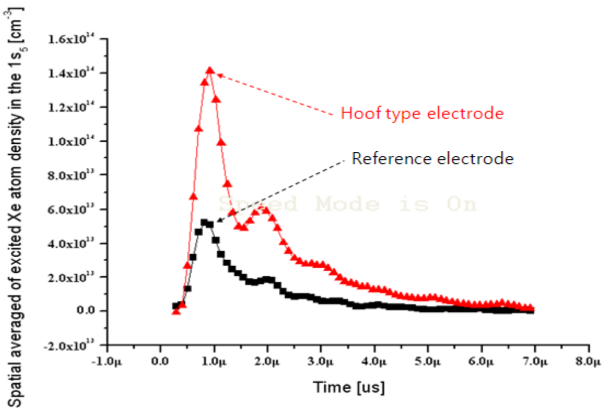

Fig. 4. Spatial-averaged peak densities of the excited Xe atoms in the $1s_5$ metastable state per cell in the conventional electrode structure and the hoof-type electrode structure.

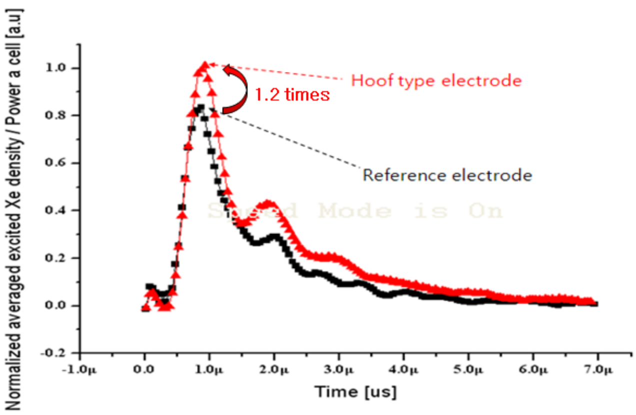

Fig. 5. Spatial behavior of the averaged productive efficiency for the excited Xe atom density per cell

aged productive efficiency for the excited Xe atoms means that its values were divided by the sum of the productive efficiency of the cells and the total cell number for each time. The maximum productive efficiency of the hoof-type electrode structure was higher than that of the conventional electrode structure.

Fig. 6 shows the luminance of the reference-type and hoof-type electrodes with a functional layer (sprayed MgO nano-sized powders on MgO). Each test panel was operated with a driving frequency of 35 kHz and with a duty ratio of 25% in an He (35%)-Ne (bal)-Xe (15%) mixture gas at a pressure of 400 Torr. As shown in Fig. 6, the luminance of the reference-type and hoof-type electrodes was lower than that of the FL (sprayed MgO nano-sized powders on MgO) + hoof-type electrode. It was further noted that the differences in the luminance among the three kinds of test panels increased as the sustaining voltage increased. The efficacy showed the same tendency–i.e., as the sustaining voltage increased, the efficacy of the reference-type, hoof-type, and FL (sprayed MgO nano-sized powders on MgO) + hoof-type electrodes decreased.

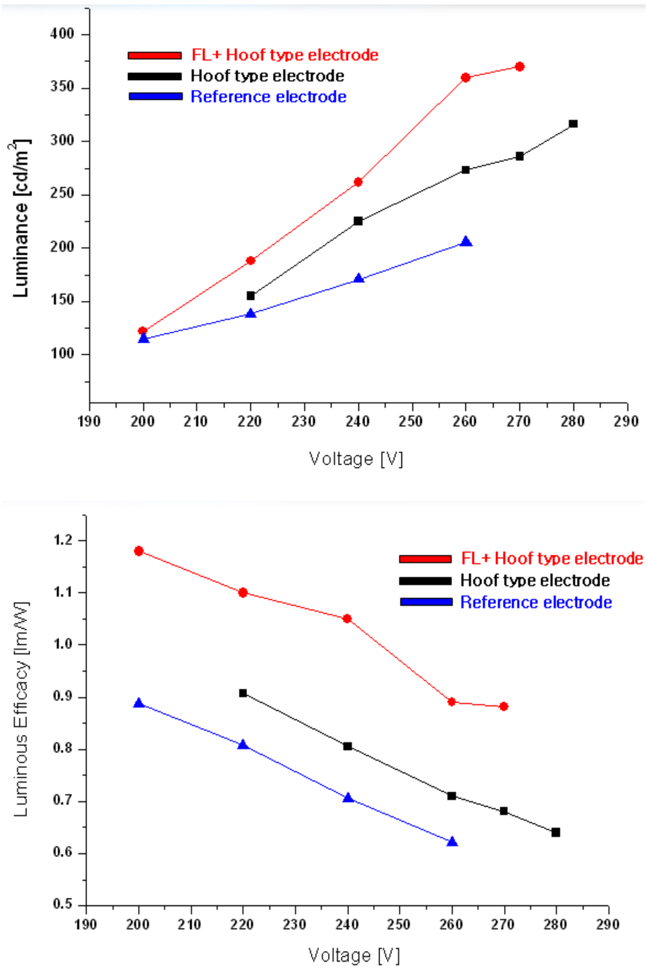

Fig. 6. Luminance and efficacy of the functional layer (FA, sprayed MgO nano-sized powders on MgO) + the hoof-type and reference-type electrodes at various sustaining voltages.

4. Conclusions

In this research, we investigated the spatiotemporal behavior of the density of the excited Xenon atoms in the $1s_5$ metastable states via laser absorption spectroscopy. The maximum densities of the excited Xe atoms in the $1s_5$ state in the discharge cell with the conventional coplanar electrode structure and the hoof-type electrode structure were measured as 5.2×10^{13} cm^{-3} and 1.4×10^{14}, respectively. In these results, the density of the hoof-type electrode structure increased by about 2.4 times compared to the maximum density of the excited Xe atoms in the $1s_5$ state in the discharge cell in the conventional electrode structure. Also, the efficiency of the hoof-type electrode structure was about 1.2 times greater than the maximum productive efficiency in the discharge cell in the conventional electrode structure. The FL (sprayed MgO nano-sized powders on MgO) + hoof-type electrode structure efficiency improved more than the 30% improvement in the conventional structure. New structures were developed, such as the hoof-type electrode structure. Bus electrodes with a longer gap size were proposed, in which a high-efficiency positive-column region can be developed. The hoof-type electrode gained VUV light via the density distribution of the excited Xe, and each phosphor in the discharge cell was excited to improve the luminous efficiency of the hoof-type electrode and to make the electric field strength of the hoof-type electrode stronger than that of the conventional type. It was shown that the new panel structure with a functional layer has a significant potential for use in applications with high-efficiency AC-PDP.

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[Parts of this work were presented in Proceedings of IMID 2010.]