Can Diagnostics and Simulations of Microplasmas Give Suggestions for New Generation PDPs ?

Kunihide Tachibana

Department of Electronic Science and Engineering, Kyoto University
Yoshida-honmachi, Sakyo-ku, Kyoto 606-8501, Japan
E-mail: tatibana@kuee.kyoto-u.ac.jp

Abstract

Present status of diagnostics and simulations on microplasmas for understandings of the discharge and VUV emission characteristics in a unit cell of plasma display panel is overviewed and their future perspective will be argued towards potential improvement of the characteristics.

1. Introduction

Plasma display panels (PDPs) are getting popular as a wall-hanging flat panel display of large diagonal sizes. However, the improvement of efficacy from a current typical value of 1-2 lm/W to 5 lm/W is a crucial problem for PDPs to open a wide market for home use. Various cell designs and operating conditions have been proposed and tested towards the goal., but the approaches are mostly performed in try-and-error manners. In order to construct firm guiding principles for the performance improvements, we have to understand physics of the discharge and photoemission processes from the microplasma in a unit cell of PDP. For the purpose, various diagnostics and simulation techniques have been developed up to present. In this review talk, I would like to overview how those techniques have been contributed to the developments of present PDPs, and what is required for them to be able to predict the proper direction for the future developments.

2. Simulations

2.1 Historical developments

The basic model for the PDP discharge was established at IBM in seventies for ac-type monochromatic PDPs operated with a Penning mixture of Ne and small amount of Ar [1-3]. The final model by Sahni *et al* was a one-dimensional one, but most of the fundamental atomic and molecular processes were taken into account including the secondary electron emission (γ) effects and the imprisonment of resonance transitions. The spatiotemporal profiles of the electric field, charged and excited species concentrations as well as the discharge characteristics such as the gap voltage, the current density, and the maximum and minimum sustain voltages were successfully calculated by the model.

Although the PDP market for rap-top computers was declined after the rapid rise of color LCDs, the effort to apply PDPs to wall-hanging large area displays has been continued at NHK and Fujitsu Corp. From early eighties a feasibility study was started at NHK to develop a simulation for color PDPs with Xe and other rare gas mixtures in one and, more hopefully, in multi-dimensional codes [4]. Unfortunately, at that time a satisfactory basic data were not available, so that we started to compile the data in addition to the experimental investigation on the excitation and ionization coefficients [5] and diffusion of metastable atoms in the mixture of Xe with He or Ne [6]. With those data we developed a one-dimensional model of a DC-type PDP discharge [7-9] based on the method of Sahni *et al*, and extended it to a two-dimensional (2D) model [10,11].

In the mean time, a one-dimensional model for an AC-type PDP was established by Boeuf *et al* [12], although the treatment of resonance trapping effect was approximated by using an effective lifetime. This model has become a standard for basic understandings of the microdischarge phenomena in a mixture of Xe and Ne. Shortly, this was extended to 2D models in order to analyze various practical problems such as cross-talk between adjacent cells and other geometric effects [13-15].

2.2 Present status

Models developed in the mid nineties have been improved recently in many respects [16-24]. The treatment for the imprisonment effect of resonance radiations has also been improved [25,26]. Those new generation models were used to understand the physical aspects of microdischarges, i.e., energy deposition and loss mechanisms [12,20], characteristics of the addressing discharge [17,18], and appearance of striations [23,24]. Those were also applied to parametric studies on the operating parameters such as the gas pressure, composition and the mixing ratio of Xe as well as the cell dimensions for the efficacy improvement [16,19,21,22]. A driving scheme using RF frequency range was also studied numerically [27-29].

3. Diagnostics

3.1 Historical developments

At panel manufacturing companies, the efficacy used to be estimated by the measurement of visible emissions from phosphors on the time-averaged base. The first measurement of VUV emissions from Xe* atoms and Xe_2* dimmers was done at NHK using a demountable DC-type cell placed in a vacuum chamber [30]. In order to perform the measurement on a realistic cell, we manufactured a panel with a sapphire front glass plate, which was transparent up to 140 nm ranges. The panel was placed onto the entrance slit of a VUV monochromator, and the temporal behavior and the intensity ratio of the 147 nm atomic line and the 173 nm excimer band were successfully measured as a function of Xe concentration [31]. In accordance with the development of a suitable CCD camera for the VUV measurement, spatiotemporal observations of the VUV emissions have become possible [32,33].

On the other hand, we have been doing the measurement of excited Xe atoms in the metastable ($1s_5$) and resonance ($1s_4$) states. Those can be accessed by a near infrared diode laser by tuning the wavelength with temperature and injection current to the appropriate transitions, i.e., 823 nm ($2p_6 - 1s_5$) and 828 nm ($2p_5 - 1s_4$). From the measured line absorption the absolute densities of those states can be derived, and then the intensities of VUV emissions at 147 and 173 nm can be estimated accurately. The first experiment based on this principle was performed on a DC-type PDP cell [34]. From the extended work with several different values of electrode gap, it was suggested that the efficacy increases with the gap length due to the appearance of the positive-column- like glow region [35].

3.2 Present status

The microscopic laser absorption technique, which has a spatial resolution of 20 μm and temporal resolution of 5 ns, was utilized in the measurement of an AC-type PDP cell [36]. As a characteristic features of the dynamic behaviors of excited atoms, it was revealed that the discharge start from the temporal anode edge, stretching towards the cathode, and then a striated pattern of excited atoms appears on the anode side while a single broader peak distributes on the cathode side, traveling to its far end. In the next step, in order to make comparisons possible with the 2D simulations, which are mostly done in the cross sectional plane perpendicular to the glass plates, we constructed a special panel for the side view of the excited atoms [37]. A preliminary comparison of the result with a simulation is going to be done with the collaboration of Prof. Lee's group at POSTECH.

In order to get a three-dimensional (3D) image of the dynamic behaviors of excited atoms, we have recently designed and manufactured a special cell for the simultaneous observation from front and side views [38]. The results on the observation of near IR emission from Xe(2p) atoms at different applied pulse voltages, i.e., 200 and 250 V, are shown in Fig. 1 (a) and (b), respectively. The corresponding data for the density of Xe($1s_5$) atoms are also shown in Fig. 2 (a) and (b). The typical front view feature is similar to our previous results [36]. However, in the side view, a noticeable difference is seen between the low-voltage (200 V) and high-voltage (250 V) operation modes due to the different influence of the accumulated charges on the address (data) electrode surface. It is suggested that a kind of self-erasing discharge occurred at the high-voltage mode between the preceding temporal anode and the data electrode, which drove the main discharge towards the data electrode in the successive pulse.

Recently, several other diagnostic methods have been developed for the measurement of plasma parameters such as the electron density and temperature (or, more precisely, electron energy distribution function). For the measurement, an electric probe method [39] and Thomson scattering method [40] were tried, although both of the experiments were performed on panel structures similar to but slightly larger than a realistic panel at lower pressure ranges. The electric field strength caused by wall charges was also measured by a laser-induced fluorescence (LIF) technique using the Stark splitting effect of a Rydberg level of He atoms [41]. This experiment was also done at a lower pressure and lower Xe concentration condition, but the change of the wall charges due to the self-erasing discharge was clearly seen at a certain condition.

4. Future Perspectives

The simulation technique is going to be extended to a three-dimensional scheme [42-44]. It is suited to study the effects of sophisticated cell structures and electrode patterns, which are tried experimentally at several institutions in recent years. In our 3D observation cell, we can check the validity of the simulations. However, it is necessary for us to develop a proper algorithm for the 3D image reconstruction from our experimental data that provide two sets of 2D data projected on the planes perpendicular and parallel to the panel surface.

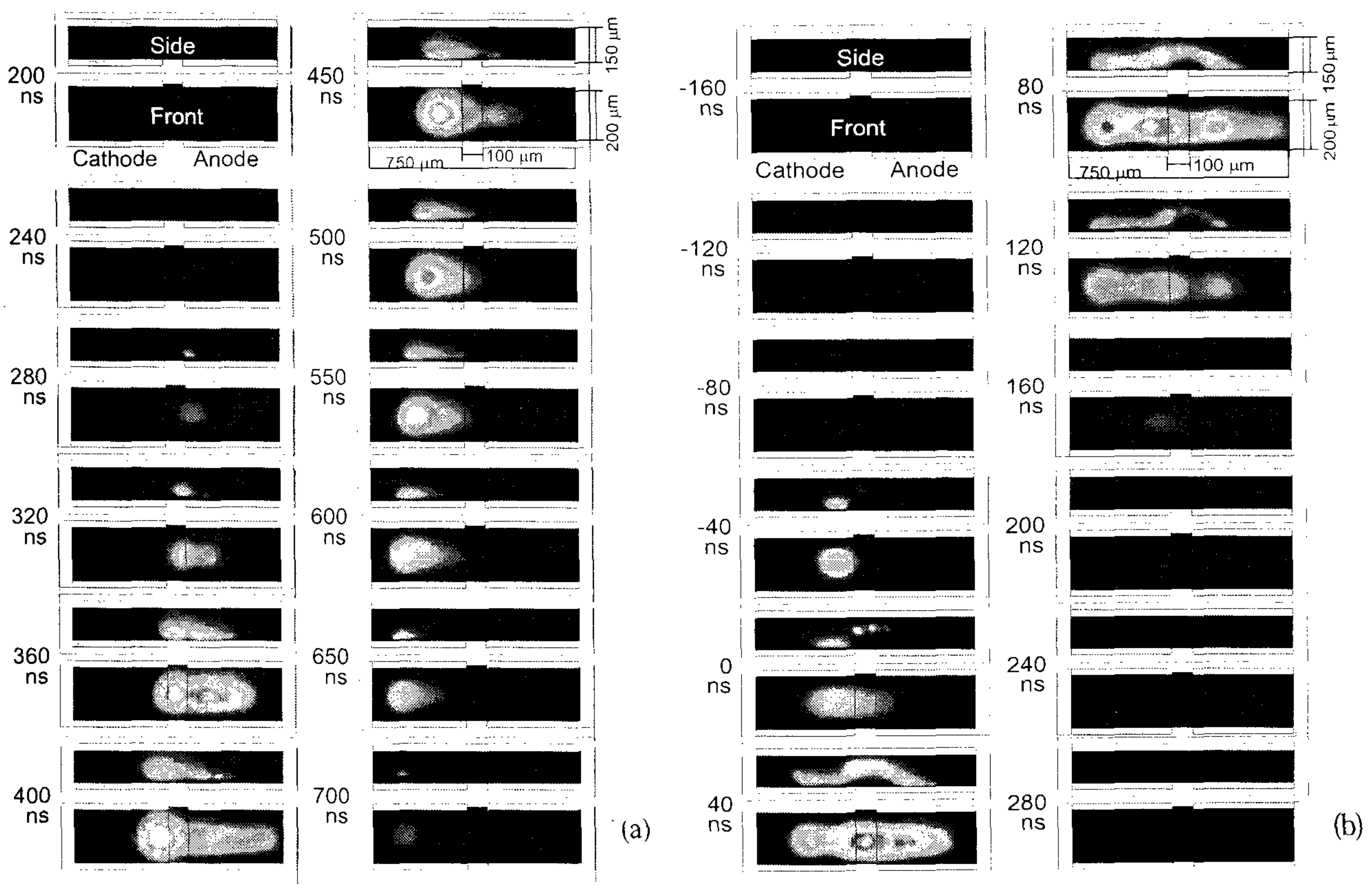

Fig.1 Spatiotemporal behavior of near IR emission from Xe(2p) atoms measured by gated CCD camera at (a) low-voltage (200 V) and (b) high-voltage (250 V) mode operations.

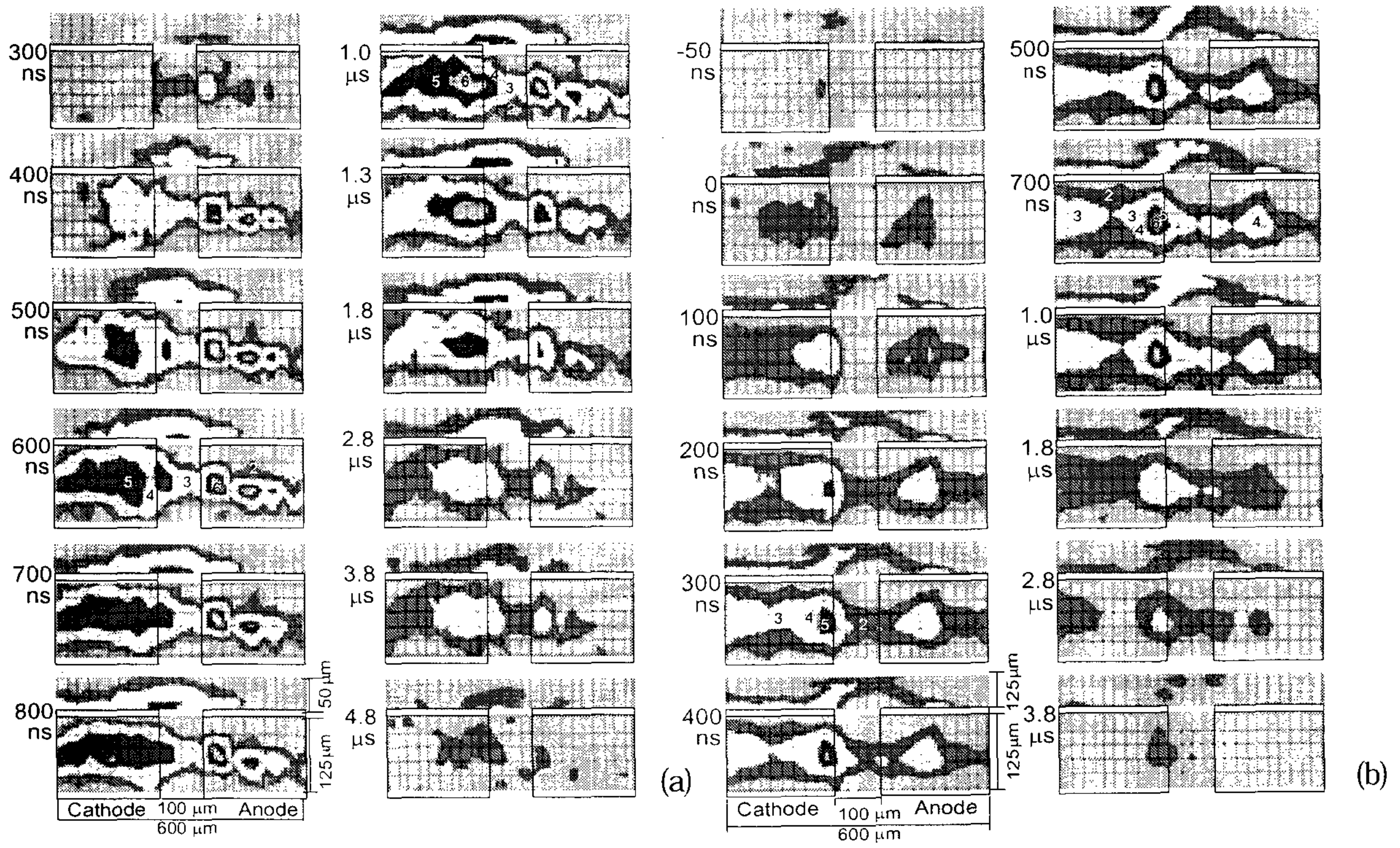

Fig.2 Spatiotemporal behavior of Xe(1s$_5$) atoms measured by laser absorption spectroscopy at (a) low-voltage (200 V) and (b) high-voltage (250 V) mode operations (maximum densities are 2.2x10^{13} and 5.5x10^{13} cm^{-3}, respectively)

In other experimental directions, there are seen several new developments. For an example, a new technique was developed for the measurement of wall charges by using the Pockels effect through a thin BSO crystal [45]. As for the laser Stark spectroscopic technique, it was made applicable to Rydberg levels of Xe atoms, by which the experimental condition can be extended to more realistic Xe concentration ranges [46]. The effort to increase the sensitivity of the Thomson scattering method has also been continued [40]. On the other hand, a LIF method using Evanescent waves has been developed to measure the excited atoms at the vicinity of glass surfaces [47]. It is interesting to apply this technique to measure the quenching rate of rare gas atoms in the metastable states at the surface.

In conclusion, both the simulation and diagnostic techniques have been developed and improved continuously. By using those techniques we can understand more deeply the behavior of microplasmas in PDP cells, and establish the guiding principles towards the performance omprovements.

References

[1] C. Lanza, IBM Res. Develop. **18**, 232 (1974).

[2] F. M. Lay, C. K. Chu and P. H. Haberland, IBM Res. Develop. **18**, 244 (1974).

[3] O Sahni, C. Lanza and W. E. Howard, J. Appl. Phys. **49**, 2365 (1978).

[4] Matsuzaki et al, IEIC Tech. Rep. EID87-19, 1987.

[5] K. Takahashi and K. Tachibana, Trans. IEE Japan, **111-A**, 182, (1991).

[6] K. Tachibana et al, Jpn. J. Appl. Phys. **33**, 6716 (1994).

[7] K. Takahashi et al, ITEJ Tech. Rep. IDY90-21 (1990).

[8] S. Hashiguchi et al, Proc. 21th ICPIG, p.383 (1993).

[9] K. Takahashi, S. Hashiguchi, Y. Murakami, M. Takei, K. Itoh, K. Tachibana and T. Sakai, Jpn. J. Appl. Phys. **35**, 251 (1996).

[10] Y. Murakami et al, IEIJ/JSAP Tech. Rep. LS-95-10/PE-95-5 (1995).

[11] Y. Murakami, H. Matsuzaki, H. Murakami and K. Tachibana, Jpn. J. Appl. Phys. **39**, 590 (2000).

[12] J. Meunier, Ph. Belenguer and J.-P. Boeuf, J. Appl. Phys. **78**, 731 (1995).

[13] K.-C. Choi and K.-W. Whang, IEEE Trans. Plasma Sci. **23**, 399 (1995).

[14] R. Veerasingam, R. B. Campbell, R. T. McGrath, IEEE Trans. Plasma Sci. **24**, 1411 (1996).

[15] C. Punset, J.-P. Boeuf and L. C. Pitchford, J. Appl. Phys. **83**, 1884 (1998).

[16] S. Rauf and M. J. Kushner, J. Appl. Phys. **85**, 3460, 3470 (1999).

[17] C. Punset, S. Cany and J.-P. Boeuf, J. Appl. Phys. **86**, 124 (1999).

[18] J.-H. Seo, W.-J. Chung, C.-K. Yoon, J.-K. Kim and K.-W. Whang, IEEE Trans. Plasma Sci. **29**, 824 (2001).

[19] Y. Ikeda, J. P. Verboncoeur, P. J. Christenson and C. K. Birdsall, J. Appl. Phys. **86**, 2431 (1999).

[20] G. J. M. Hagelaar, M. H. Klein, R. J. M. M. Snijkers and G. M. W. Kroesen, J. Appl. Phys. **89**, 2033 (2001).

[21] B.-K. Min, S.-H. Lee and H.-B. Park, J. Vac. Sci. Technol. A, **18**, 349 (2000).

[22] G. Oversluizen et al, J. Aool. Phys. **91**, 2403 (2002).

[23] G. Cho, E.-H. Choi, Y.-G. Kim et al, J. Appl. Phys. **82**, 4113 (2000).

[24] C.-H. Shon and J.-K. Lee, Phys. Plasmas, **8**, 1070 (2001).

[25] T. van der Straaten and M. J. Kushuner, J. Appl. Phys. **87**, 2700 (2000).

[26] H.-J. Lee, H.-C. Kim and J.-K. Lee, Phys. Plasmas, **9**, 2822 (2002).

[27] S. Hashiguchi and K. Tachibana, Proc. 13th ICPIG, Toulouse, p.76 (1997).

[28] M. Kurihara and T. Makabe, IEEE Trans. Plasma Sci. **27**, 21372 (1999).

[29] J. Kang et al, Proc. IDW'00, Kobe, p.643 (2000).

[30] M. Yokozawa and T. Kamegaya, ITEJ Tech. Rep. ED245/IPD18-12 (1975).

[31] T. Sakai, Y. Murakami, K. Takahashi and K. Tachibana, ITEJ Tech. Rep. **14**(67), 49 (1990).

[32] M. Sawa, H. Uchiike, S. Zhang, K. Yoshida, SID 98, Digest, p.361 (1998).

[33] C.-K. Yoon, J.-H. Seo and K.-W. Whang, IEEE Trans. Plasma Sci. **28**, 1029 (2000).

[34] K. Tachibana, N. Kosugi and T. Sakai, Appl. Phys. Lett. **65**, 935 (1994).

[35] N. Kosugi, K. Tachibana, M. Seki and T. Sakai, Proc. IDW'99, Sendai, p.687 (1999).

[36] K. Tachibana, S. Feng and T. Sakai, J. Appl. Phys. **88**, 4967 (2000).

[37] F. Katafuchi, K. Tachibana and T. sakai, Proc. IDW'99, Sendai, p.1115 (1999).

[38] K. Mizokami, K. Tachibana, N. Kosugi, T. sakai and Y. Wakabayashi, Proc. IDW'01, Nagoya, p.1755 (2001).

[39] J.-G. Kim, E.-H. Choi et al, Proc. IDW'99, Sendai, p.675 (1999).

[40] Y. Noguchi, A. Matsuoka, K. Uchino and K. Muraoka, J. Appl. Phys. **91**, 6123 (2002).

[41] J.-H. Kim, J.-H. Lee, K.-W. Whang and Y.-W. Choi, J. Appl. Phys. **89**, 2539 (2001).

[42] P. J. Drallos, V. N. Khudik and V. P. Nagorny, SID 98, Digest, p.632 (1998).

[43] H.-S. Jeong, Y. Murakami, M. Seki and H. Murakami, IEEE Trans. Plasma Sci. **29**, 559 (2001).

[44] H.-C. Kim, M.-S. Hur, S.-S. Yang, S.-W. Shin and J.-K. Lee, J. Appl. Phys. **91**, 9513 (2002).

[45] D. C. Jeong, W. J. Chung and K.-W. Whang, Abs. 6th APCPST/15th SPSM, Jeju, p.210 (2002).

[46] M. D. Bowden, B. Visser and G. M. W. Kroesen, Proc. ESCAMPIG-16/ICRP-5, Grenoble, p.283 (22002).

[47] T. Sakurai, S. Matsuzawa and Y. Kamo, J. Appl. Phys. **91**, 4806 (2002).