Numerical analysis of the striation phenomena in an ac Plasma Display Panel using energy fluid model

Hyun Sook Bae and Ki-Woong Whang
Plasma Laboratory, School of Electrical Engineering, Seoul National University, San 56-1, Shinlim-dong, Kwanak-gu, Seoul 151-744, KOREA
TEL:82-2-880-9554, e-mail: kitty01@snu.ac.kr.
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Abstract

We performed a discharge analysis on ac plasma display panel through the numerical simulation of the EF (Energy Fluid) model using the electron's energy equation. When it is compared to the results of commonly used LFA (Local Field Approximation) model, there is a clear difference in the spatio-temporal distribution of Xe excited species. In particular, the experimentally observed striation phenomena in the anode region could be observed in EF model and the occurrence of the striation was attributed to the ionization and excitation instability due to the streaming electrons in the anode region plasma.

1. Introduction

In order to enhance the display characteristics of PDP (Plasma Display Panel), it is essential to have a thorough understanding of the discharge characteristics. Generally, the LFA (Local Field Approximation) model has been used because of its simplicity and speed. In this study, we investigated the discharge characteristics of an ac PDP through the numerical simulation of the EF (Energy Fluid) model, in which the electron's energy equation was added to the governing continuity and drift-diffusion equations to obtain the electron temperature directly and its consequences were compared with those obtained from the LFA model.

2. Results and discussion

The governing equations of EF model are consisted of the continuity equation, the drift-diffusion equation and the electron's energy equation. The detailed descriptions can be found elsewhere [1]. Equation (1) represents the electron's energy equation.

$$\frac{3}{2} n_e k_B \left(\frac{\partial T_e}{\partial t} + \overrightarrow{\upsilon_e} \cdot \nabla T_e\right) = -\nabla \cdot (n_e k_B T_e \overrightarrow{\upsilon_e}) + \nabla \cdot (\lambda \nabla T_e) + Q_e \qquad (1)$$

$$Q_e = -e n_e \overrightarrow{\upsilon_e} \cdot \vec{E} - \frac{3}{2} n_e k_B (T_e - T_n) \nu_{en} - \left(\sum_k q_k I_k + \frac{3}{2} k_B T_e S_e\right) \qquad (2)$$

$$\lambda = \frac{5}{2} k_B n_e D_e \qquad (3)$$

In equation (1), the left hand side describes the total derivative of electron temperature with respect to time, and the first two terms in the right hand side are related to the hydrodynamic flux of enthalpy and the heat conduction flux. The last term denotes the energy transmission by electrons. The first term in equation (2) denotes the Joule heating, and the second term describes the elastic collisional loss with neutral species and the last term is the energy used for creating new electrons and excited species and passing thermal energy to the created electron [2]. Equation (3) shows the thermal conductivity.

Fig. 1 shows the applied voltage waveform and obtained discharge current for the gas condition of Ne-Xe [5%] at 300 torr. During the initial 2 μsec, 250 V is applied to the address electrode and ground level to the scan electrode in order to ignite the opposing-electrode discharge between two electrodes. During the sustaining period beginning at 4 μsec, the voltage of sustain electrode is set to 200 V.

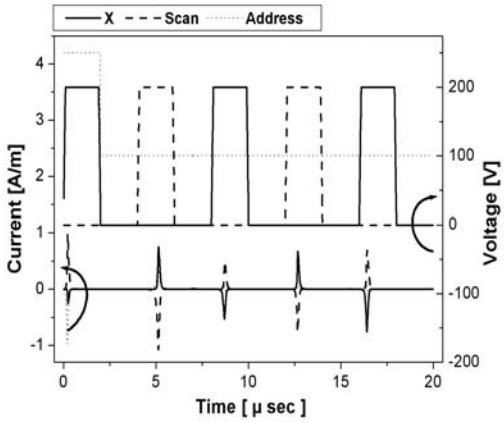


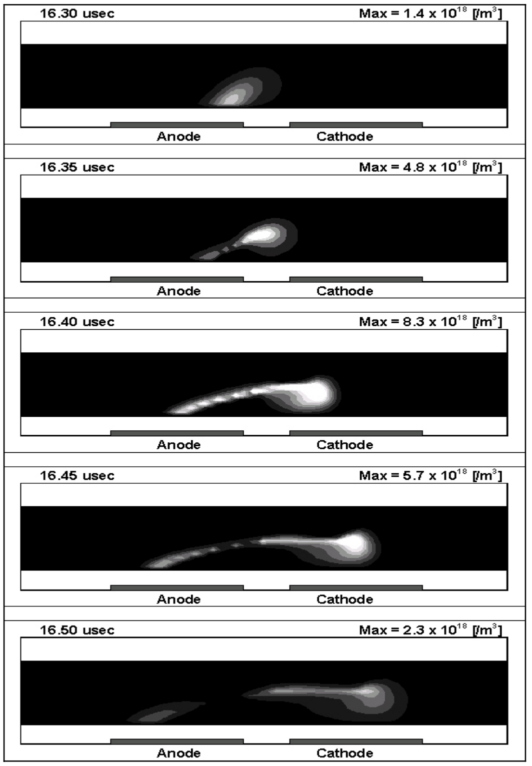
Fig. 1. Applied voltage waveform and discharge current in Ne-Xe[5%], 300torr

Fig. 2 shows the spatio-temporal distributions of Xe excited species. In the early discharge stage, the secondary emitted electrons pass through the cathode sheath, and the ionization and excitation reactions become active in the vicinity of the cathode sheath due to the strong electric field of sheath.

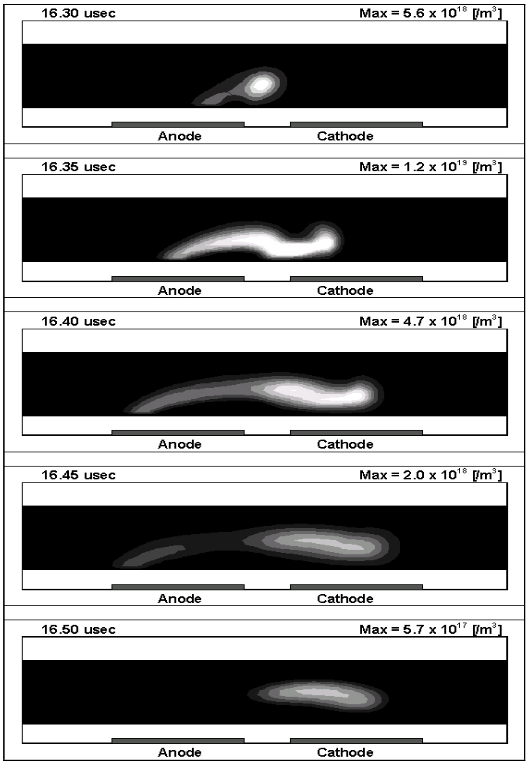
A major difference between the two models for the Xe excited species distribution is that the striation over the anode appears with the EF model, which has been observed experimentally. A numerical simulation with kinetic model showed that a non-uniform accumulation of surface charges and then the plasma density fluctuations change the potential, which form the striation [3]. Fig. 3 shows the surface charge density distributions for two fluid models, which do not show the fluctuated surface charge profile of kinetic model.

Because equation (1) includes the convective term related with the spatial energy change, the EF model produces a dynamic space charge density profile. The self-consistently computed electron temperature in connection with the drift-diffusion equation and continuity equation would result in the plasma ionization instability.

The ionization wave instability has influence on the accumulation of space charge near the anode electrode, and then the variation of space charge locally deforms the potential distribution near the anode region which makes electrons to be energetic, and results in the ionization to occur over the anode surface. Therefore, the origin of striation phenomena is thought to be the ionization and excitation wave instability caused by the streaming electrons toward the anode.

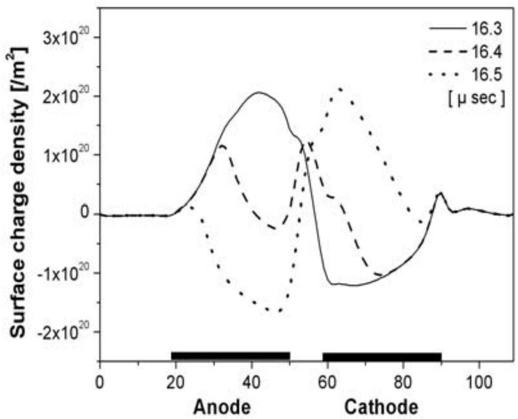


(a)

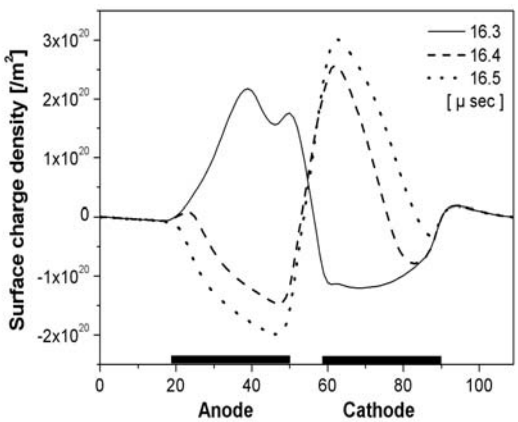


(b)

Fig. 2. Xe^{**} density profile (a) EF model (b) LFA model



(a)



(b)

Fig. 3. Surface charge density distribution (a) EF model (b) LFA model

The dispersion relation which describes the perturbed propagating wave is given in equation (5). Such a wave can be physically identified as an ionization wave, and the dispersion relation shows the transition from damping to growth of ionization waves with the variation of frequency and wave number. This ionization instability is thought to be originated from the drifting electrons near the anode which provides energy for the unstable ionization wave.

$$\omega = -i(\frac{\nu_d^* k_i^* N^{*2}}{\nu^* n_e}) + (i\frac{2}{5k^2\Lambda_u^2} + \frac{2}{5k\Lambda_u}) \times \left(\hat{\nu}_i \nu_i + \hat{\nu}^* k_i^* N^*\right) + iD_a k^2 \qquad (5)$$

where ν_i, ν^*, ν_d^* describe the ionization frequency, the excitation frequency of atom from ground state, the frequency of diffusion and recombination, respectively. And k_i^*, N^*, Λ_u denote the ionization rate of excited meta-stable atom, the density of excited species, the energy relaxation length, respectively [2].

Considering that the destabilizing effect of the stepwise ionization reaches its maxima, the dispersion relation can be rewritten as shown in equation (6) where the dimensionless wave number K is defined by $K = k\Lambda_u$, and the frequency $W = \omega / \nu_i$.

$$W = -i(\frac{1}{2}) + (i\frac{2}{5(K)^2} + \frac{2}{5K}) \times A + iB(K)^2 \qquad (6)$$

where A and B are defined by $A = \hat{\nu}_i + \hat{\nu}^*$ and $B = D_a / (\nu_i \times \Lambda_u{}^2)$.

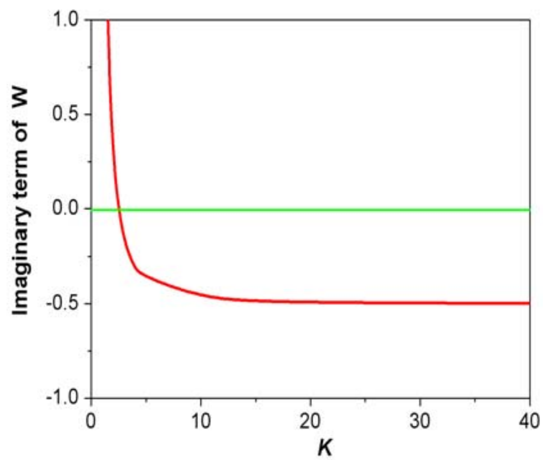


Fig. 4. Dispersion relation for ionization wave for K and $\mathrm{Im}(W)$

Fig. 4 shows the dispersion relation of ionization wave for the real K and imaginary W. Since we consider perturbations that grow exponentially as $\exp(i\omega t)$, the ionization wave is unstable under what conditions $\mathrm{Im}(W) < 0$ for almost values of K, in Fig. 4. For the PDP discharges at 67 kPa, the striation phenomena should be observable since the wave number K is about 28.

3. Summary

In this work, we developed a two-dimensional EF model by incorporating the electron's energy equation to study the discharge dynamics of ac PDP.

Because the EF model contains the convective term unlike the LFA model, the appearance of striation in the anode region could be observed, which is thought to be an ionization wave instability caused by the streaming electrons with respect to the relatively immobile background ions in the anode region. The numerical analysis in EF model might shed more lights on the understanding of the mechanism of striation phenomena.

4. References

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