TITLE: Gas Discharge and Experiments for Plasma Display Panel

# Gas discharge and experiments for plasma display panel

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## ABSTRACT

Physical phenomena which take place in an AC Plasma Display Panel(PDP) cells are discussed in this paper.

Basic principles for gas discharge in PDP are presented. According to experiments in this paper, we can see PDP changes behaviors including memory margin, luminance, luminous efficiency, Penning effect and Paschen curve with varying gas composition and pressure. For pure helium and neon gas, helium has higher breakdown voltage than neon below 350Torr. Pure neon has higher memory margin than helium. The memory margins of both pure neon and helium decrease when their pressures are increased. In Ne-Xe gas mixture, the minimum breakdown voltage is located on Xe = 0.1~0.2% due to Penning effect and then the voltage increases when Xe content is increased. The maximum memory margin for Ne-Xe gas mixture is located on Xe = 4~5%. The luminous efficiency increases when the gas pressure is increased. The spectrum of PDP with Ne-4%Xe at 500Torr from 400nm to 850nm is presented. Ne-Xe(up to 10%Xe) has lower luminous efficiency than pure Ne and the minimum value is located on 2~3%Xe. By SIPDP simulation model, we can see electrical and optical properties of PDP change with varying gas compositions.

**Keywords :** Gas Discharge, Plasma Display Panel.

## 1. INTRODUCTION

The gas discharge, that still suffers from a comprehensive understanding, is the predominant factor limiting the performance of the system.

PDP is a promising large size flat panel display for the next century. For the development of color plasma display panels, improvement of luminance and luminous efficiency is important. In color PDPs, vacuum ultraviolet(VUV) rays are produced by electrical discharges in a micro-cell which contain a mixture of gases including Xe. The VUV rays excite phosphors in each picture element and visible light is emitted from them.

An understanding of the discharge volume holds the key to improve VUV efficiency. Various discharge gas experiments and simulation are presented and discussed in this paper. We can also see how gas composition influence on electrical and optical behavior. From the simulation shown here, higher luminous efficiency can be achievable by increasing the xenon content in Ne-Xe gas mixture. Other ways to elevate the luminous efficiency are increasing the gas pressure and helium addition. But increasing the xenon content cause higher operation voltage and smaller margin. To increase the gas pressure limits the use of PDP at higher altitude area and has also the drawback of higher operation voltage. Helium addition pays for decreasing the luminance .



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# 2. GAS DISCHARGE REACTIONS

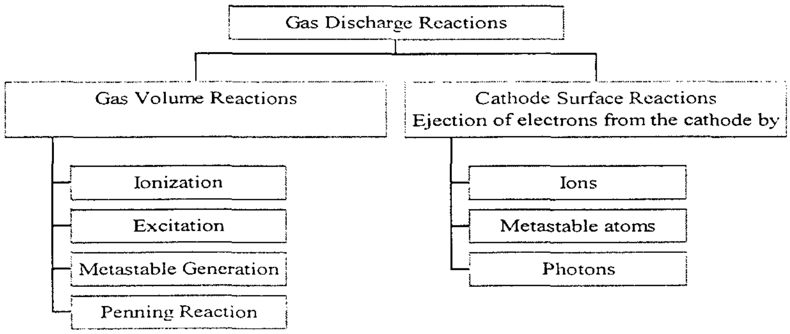


**Table 1** Gas discharge reactions.

## 2.1. Gas Volume Reactions

*Ionization* : electron energy > 21.6eV

$$Ne + e^- = Ne^+ + 2e^- , \tag{1}$$

(The most important reaction of a gas discharge)

*Excitation* : 16.6eV < electron energy ≦ 21.6eV

$$Ne + e^- = Ne^* + e^- , \tag{2}$$

$$Ne^* = Ne \text{ (or } Ne^*\text{, or } Ne^m) + \nu \text{ (visible or deep UV photons)} , \tag{3}$$

(The excited atom can only remain exited for a relatively short time(~$10^{-8}$ s) before it radiates a photon and returns to the ground state.

*Metastable generation* :

$$Ne + e^- = Ne^m + e^- \quad \text{electron energy} > 16.6\text{eV} , \tag{4}$$

$$Ne + e^- = Ne^* + e^- \quad \text{electron energy} \geqq 18.5\text{eV} , \tag{5}$$

$$Ne^* = Ne^m + \nu , \tag{6}$$

(Metastable atoms are simply excited atoms that do not radiate a photon and are not charged. In PDP, metastable lifetime's decay time constants are usually in the 1-to-10 microseconds range. Metastables usually do not decay naturally but are de-excited by a reaction with some other body, such as discharge chamber walls and by the Penning ionization process.)

*Penning reaction* :

$$Ne^m + Ar = Ne + Ar^+ + e^- \; (Ne^m + Xe = Ne + Xe^+ + e^-) , \tag{7}$$

(This reaction is of great importance to PDP because it generates additional ionization and allows PDP to operate at a lower voltage.)

| Discharge Gas | Ionization Energy(eV) | Metastable Energy(eV) |
|---|---|---|
| He | 24.6 | 19.8 |
| Ne | 21.6 | 16.6 |
| Ar | 15.8 | 11.53 |
| Xe | 12.1 | 8.28 |

**Table 2** Ionization and metastable energy of various discharge gases.[1]

### 2.2. Cathode Surface Reactions

The ejection of electrons is of critical importance to a gas discharge because these cathode electrons initiate the volume reactions and thus determines the firing voltage of the discharge.

The most important cathode surface reaction for PDP is the electron ejection due to positive *ions*. The neon ion has 21.6eV, and the argon ion has 15.8eV. During collision with the cathode, these ions capture an electron from the surface and they become neutralized. This energy is more than enough to allow an electron to escape the work-function energy of the cathode surface, which is usually in the 3-to-10eV range. This large amount of excess energy means that there is a high probability that an ion hitting the cathode will cause an electron ejection.

Since the work function of the cathode is generally greater than 3eV, only *UV photons* will have significant photoemission. But these photons have random directions and only a small fraction will be directed toward the cathode.

Although the *metastable* has about the same probability of ejecting an electron as an ion, the metastable is not nearly as important as the ion since the metastable diffuse in random direction at a very slow rate compared to the drift of the ions toward the cathode.[2]

## 3. CHARACTERISTIC VACUUM ULTRAVIOLET(VUV) WAVELENGTH AND XENON BEHAVIOR

### 3.1. VUV Wavelength

| Gas | He | Ne | Ar | Kr | Xe |
|---|---|---|---|---|---|
| Characterized VUV Wavelength(nm) | 58.4 | 74.4 | 107 | 124 | 147 |

**Table 3** Characteristic vacuum ultraviolet wavelength of various discharge gases.

The discharge energy of a Xenon atom is easily eliminated by activated gases such as hydrogen.

Xenon has been the predominant noble gas dopant that has been used in generating vacuum UV raditation. Ar and Kr emit at much shorter wavelengths in the VUV(shadow penetration of the phosphor) and their lines are not as intense as those of Xe.

### 3.2. Xenon Behavior

*Xe* : Xe ($^3P1$ or $^1S4$) resonance line(at 147nm)*

The vacuum lifetime of a $^3$P1 is naturally very short(3.7ns), but in dense gases, the emitted photons are quickly re-absorbed by ground state xenon atoms. These atoms are excited to a $^3$P1 state, and re-emit 147nm photons. This resonant emission therefore occurs repeatedly through absorption and re-emission, and the effective lifetime become longer as photons "diffuse" relatively slowly toward the gas boundaries. This is called radiation trapping effect.[3]

$$Xe^* = Xe + \nu \text{ (at 147nm)} , \tag{8}$$

Due to the self-absorbing phenomenon, the time when xenon atom becomes excited state is extended, so that the probability of collision between excited Xe* and electrons becomes larger. Once the collision occurs, Xe* is ionized and

VUV photon is distinguished as :

$$Xe^* + e^- = Xe^+ + 2e^- , \quad (9)$$

It shows that the probability of collision between Xe* and free electron becomes larger as the discharge current increases. This cause the lowering of luminance and luminous efficiency.[4]

*Xe2* : Xe molecular emission(at 173nm)(dimer or excimer radiation)*

The molecular excited states are produces by collisional interaction between the atoms of Xe($^3$P1) excited state and other neutral atoms :

$$A + Xe + Xe^* = Xe_2^* + A(\text{Dimer formation, A : neutral atom or photon}) , \quad (10)$$

$$Xe_2^* = 2Xe + \nu(\text{at 173nm}) , \quad (11)$$

Since dimer radiative dissociation is a three body process involving two atoms and a photon, there are multiple solutions to the energy and momentum conservation equations. Consequently, each of these lines has rather broad spectra width, on the order of 40nm for the principal emission centered at 173nm.[5]

Figure 1 shows the memory margin with xenon percentage in Ne-Xe gas at 500Torr. As shown in the figure, the maximum memory margin appears at around 4~5%Xe and then decreases with higher xenon content. The luminous efficiency with xenon content in Ne-Xe gas at 500Torr is shown in figure 2. When the content of xenon in Ne-Xe mixture is increased, the xenon resonance line(147nm) decreased and the xenon excimer (173nm) increase. The response of phosphors to 173nm VUV is stronger than 147nm. From this, the luminous efficiency improves as the xenon content is increased.[6] Although higher Xenon content has higher luminous efficiency, it's a flaw with higher operation voltage as shown in figure 3.

## 4. DISCHARGE GAS MIXTURE

Although xenon is an efficient UV emitter, the breakdown voltage in pure xenon is impractically large and mixtures of xenon with neon or helium are generally used in PDP.

Adding neon or helium to xenon decreases the breakdown voltage for two reasons

1) neon and helium ions are much more efficient than xenon at extracting secondary electrons from a MgO surface, and
2) the total ionization coefficient in some xenon-neon mixtures for example, can be larger than the ionization coefficient in pure xenon and in pure neon (this is because the momentum cross-section for electron-neutral collisions is much larger in xenon than in neon so that in a mixture containing a large concentration of neon, the electrons can gain energy more easily and reach the excitation and ionization thresholds of xenon for lower values of the reduced electric field).[7]

Figure 4 is the spectra emission from PDP cells with Ne-4%Xe gas at 500Torr. The intensity of the Xe 828nm emission is roughly proportional to that of the Xe 147nm vacuum ultraviolet. Figure 5 is the luminous efficiency with Ne-4%Xe gas pressure. Higher gas pressure has better luminous efficiency. It is because low electron temperature leads to high efficiency, in which the Xe($^3$P1) excitation rate is larger than the ionization rate. The UV-light emission efficiency is determined by the ratio of dissipation energy due to Xe($^3$P1) excited state to the Joule consumption energy of discharge current. As pressure increases, the ratio of Xe($^3$P1) excitation rate to ionization rate increases, which results in highly efficient light emission.[8] Figure 6 is the luminous efficiency in (Hex, Ne1-x)-4%Xe gas at 500Torr. He addition in Ne-4%Xe gas is helpful for luminous efficiency improvement. In He-Ne-Xe gas mixture, XeI resonance line increases with Ne content and $Xe_2^*$ molecular emission increases with He content. The electron temperature decreases as He content increases. Thus the density of $Xe^*$ decreases and that of $Xe_2^*$ increases as the He content increases due to the decreased electron impact reaction.

He-Xe mixture has a good color purity and fast response time, but its driving voltage is high and the lifetime of panel is short due to the high mobility of Xe ion in He gas.[9]

## 5. PENNING EFFECT

Penning effect does not play a significant role in mixtures of neon with more than a few percent of xenon because most of the electron energy in these mixtures is spent into xenon excitation and ionization. Penning effect starts to become much more important when the concentration of xenon is less than 1%. This is because for very low concentrations of xenon, most of the electron energy is deposited in excitation and ionization of neon. A lot of energy is stored in neon excited states and the ionization of a xenon atom by an excited neon atom becomes very probable. (Mixtures of neon with typically 0.1% argon have been used to lower the operating voltage in monochrome PDP.)[9]

Figure 7 is the breakdown voltage in Ne-Xe gas with Xe content. As shown in the figure, the breakdown voltage is minimun around 0.1~0.2%Xe due to Penning effect and then increases with higher xenon content.

Penning reaction is as follows for Ne-Xe gas :

$$Ne^m + Xe = Ne + Xe^+ + e^- , \qquad (12)$$

## 6. BREAKDOWN VOLTAGE

In a coplanar geometry the breakdown voltage no longer depends on the pd product alone(p : gas pressure, d : discharge gap), because the electric field distribution in the cell also depends on the position of the address electrode. The breakdown curves can still be plotted as a function of pd, but different curves are found for different d and different h where d is the distance between the coplanar electrodes and h is the distance between the dielectric surface.

Figure 8 is the breakdown voltage for helium and neon at different gas pressure. We can see that Ne has lower breakdown voltage below about 350Torr but higher above it than helium. Figure 9 is the memory margins with pressures in helium, neon, and Ne-4%Xe gas. As shown in the figure, the memory margins increase with the gas pressure after the minimum around 200~300Torr.

## 7. TWO-DIMENSIONAL SIMULATIONS OF GAS DISCHARGE CHARACTERISTICS

The light-generating region starts close to the anode and rapidly moves towards the cathode. After the light generating region covers the whole cathode, the distribution remains unchanged but the intensity decreases fast.[10]

Luminance of the PDP is dominated by the intense N-type emission, which originates from the negative glow.[11] In the Ne-Xe gas, Ne-4%Xe gas has more Ne atoms and generates more secondary electrons. Its higher ionization rate(electron density) and lower excitation rate lead to lower efficiency than Ne-10%Xe gas because the UV-light emission efficiency is determined by the ratio of dissipation energy due to Xe($^3$P1) excited state to the Joule consumption energy of discharge current. Figure 10(a)~(d) are electron density, ion rate, excitation rate, and electric potential respectively for Ne-4%Xe and Ne-10%Xe.

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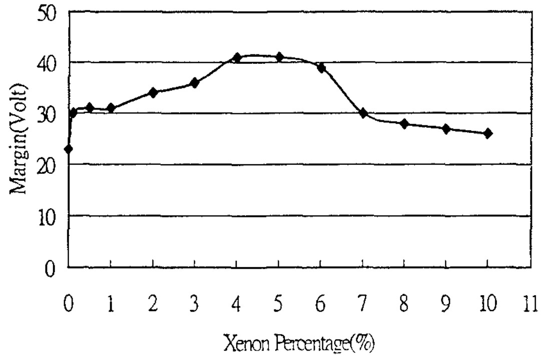


**Fig. 1** The memory margin with Xenon percentage in Ne-Xe gas at 500Torr..

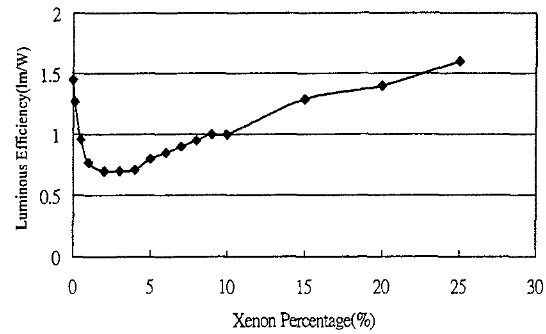


**Fig. 2** The luminous efficiency with Xenon content in Ne-Xe gas at 500Torr.

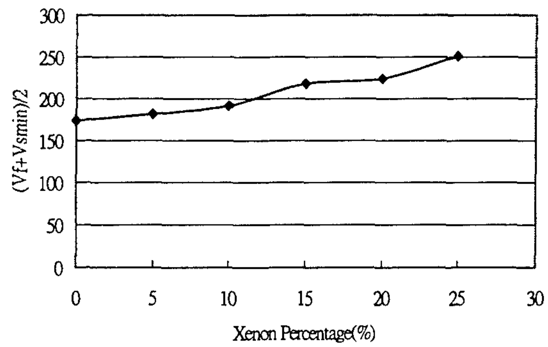


**Fig. 3** The operation voltage with different Xenon content in Ne-Xe gas at 500Torr.

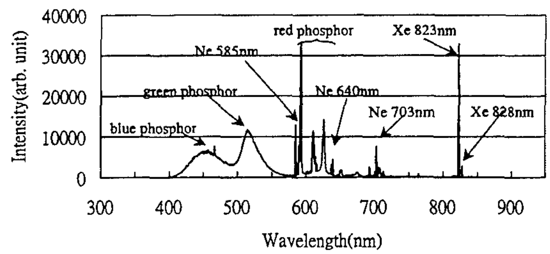


**Fig. 4** The spectra emission fron PDP cells with Ne-4%Xe gas at 500Torr.

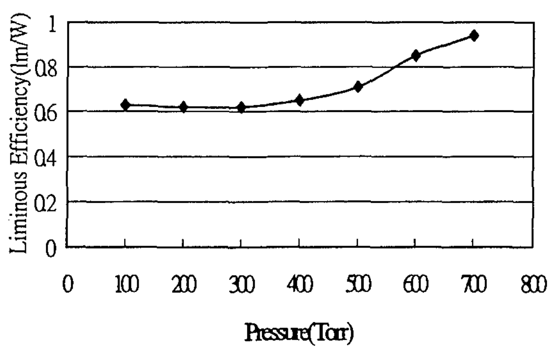


**Fig. 5** The luminous efficiency with Ne-4%Xe gas pressure.

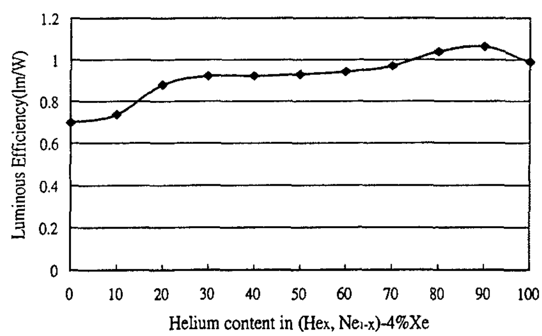


**Fig. 6** The luminous efficiency in (Hex, Ne1-x)-4%Xe gas at 500Torr.

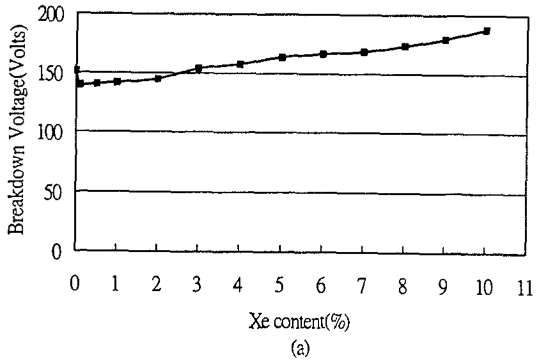


**Fig.7(a)** The breakdown voltage with Xenon percentage.

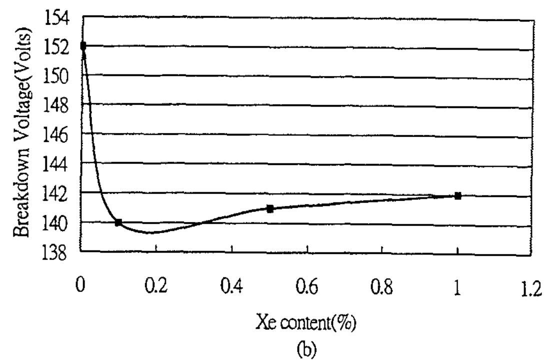


**Fig. 7(b)** The breakdown voltage with Xenon percentage.

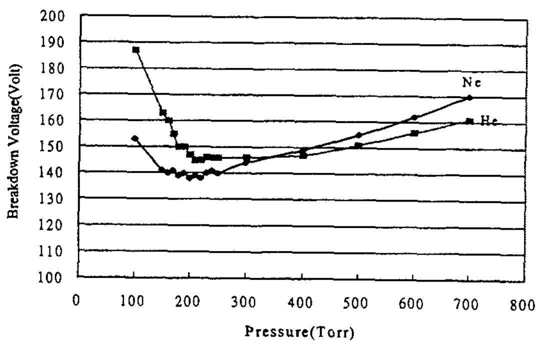


**Fig. 8** The breakdown voltages for Helium and Neon at different gas pressure.

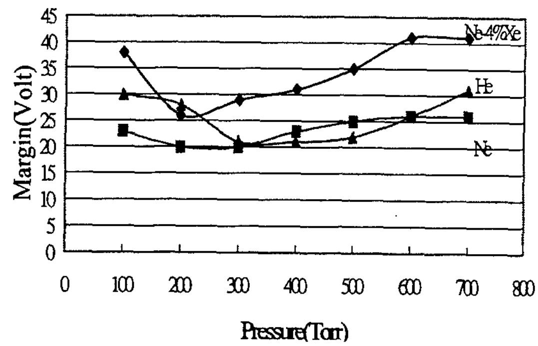


**Fig. 9** The memory margins with pressures in different gas.

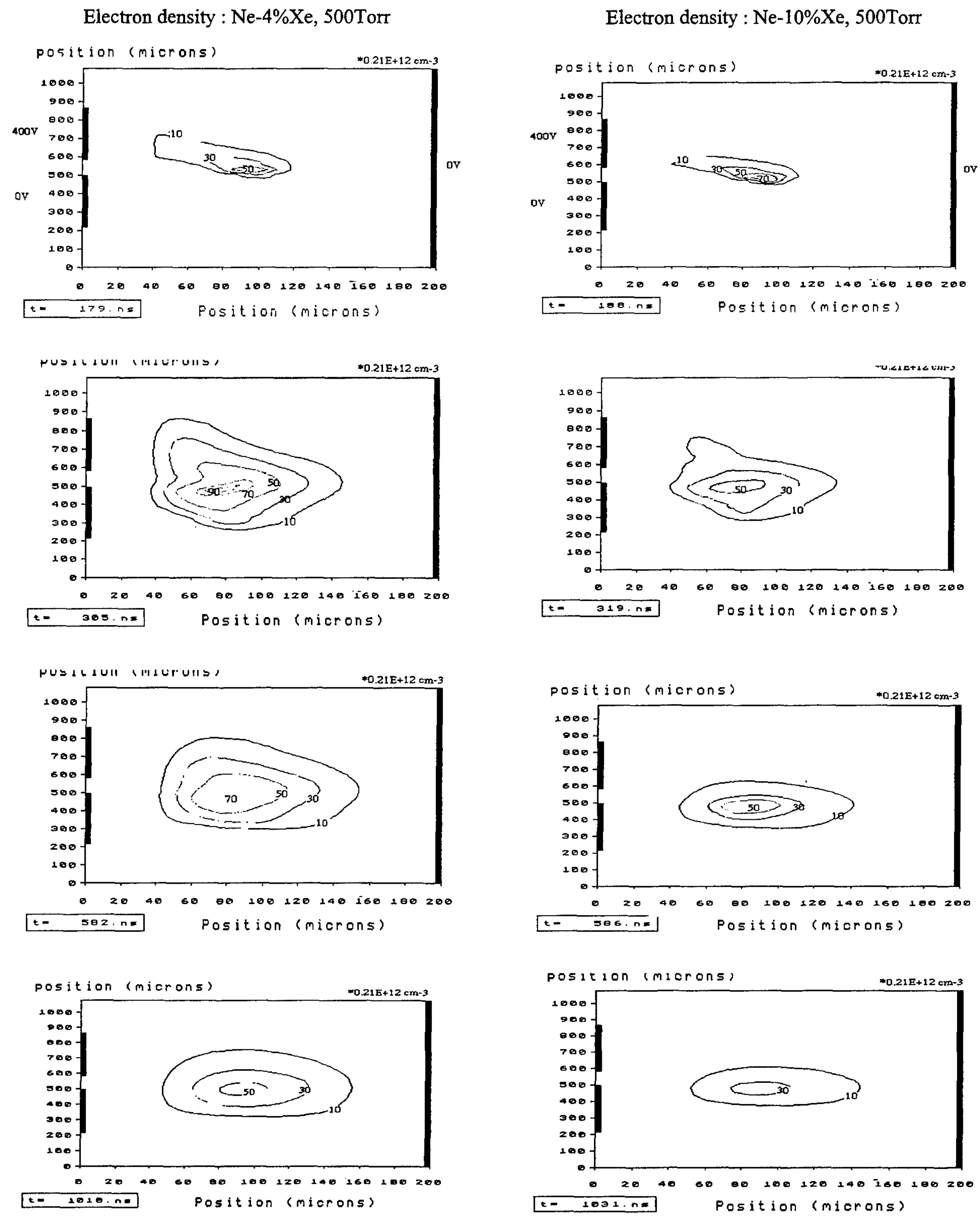


**Fig. 10(a)~(d)** Two-dimensional simulation of Ne4%Xe and Ne-10%Xe gas. Profiles of (a) electron density, (b) ion density, (c) excitation rate, (d) electric potential.

Ion density : Ne-4%Xe, 500Torr

Ion density : Ne-10%Xe, 500Torr

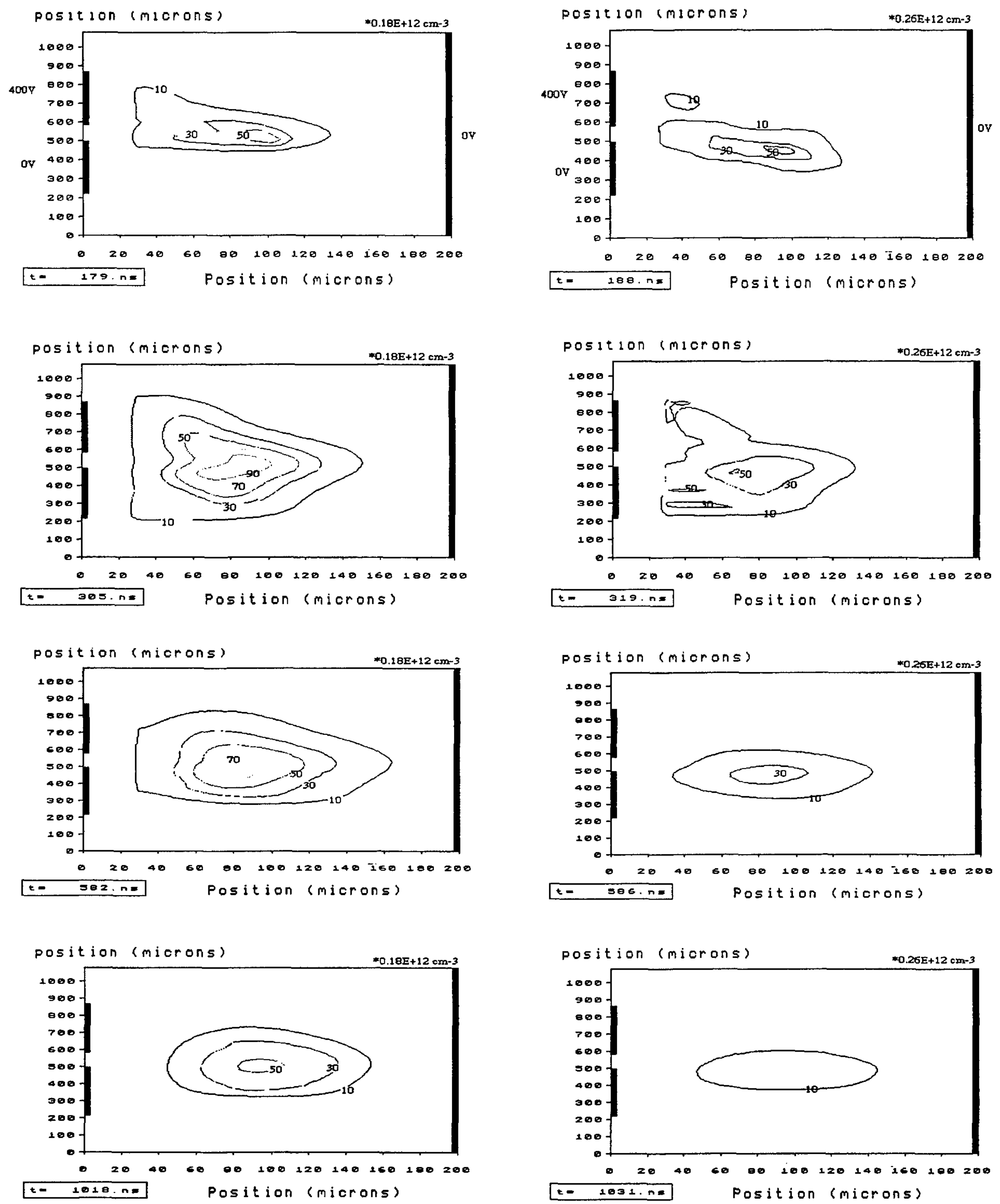


Fig. 10(b)

Excitation rate : Ne-4%Xe, 500Torr

Excitation rate : Ne-10%Xe, 500Torr

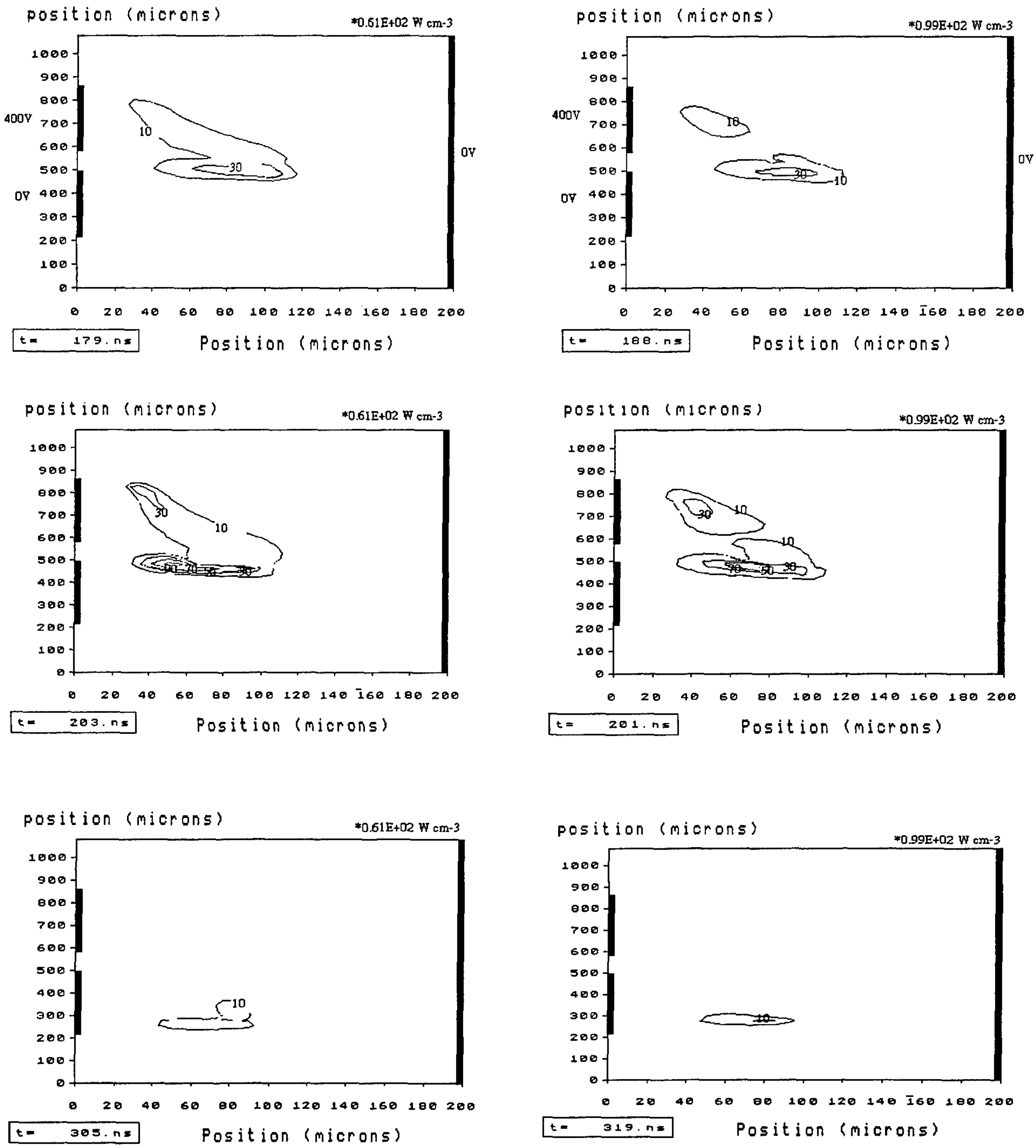


**Fig. 10(c)**

Electric potential : Ne-4%Xe, 500Tor

Electric potential : Ne-10%Xe, 500Tor

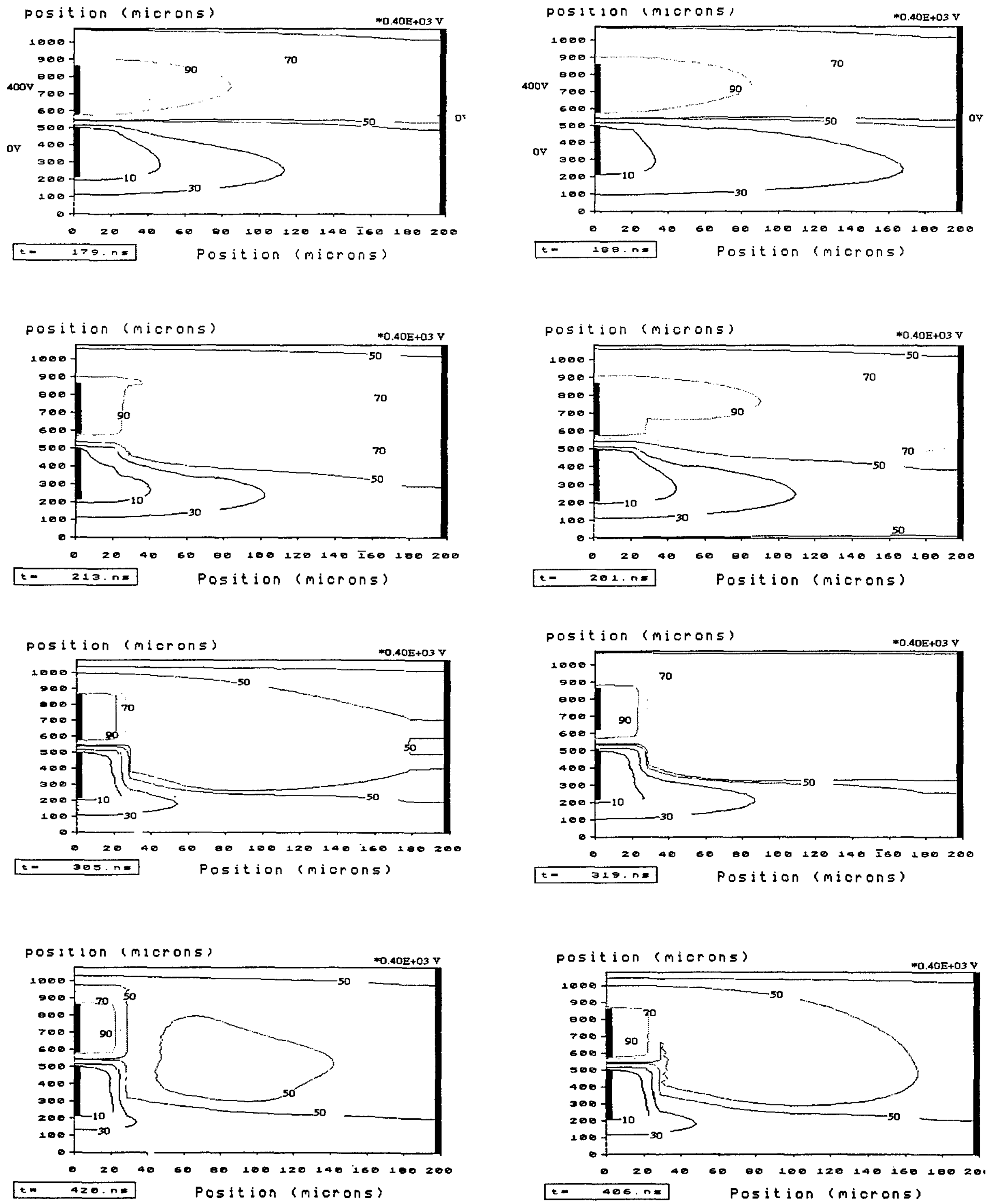


**Fig. 10(d)**