ABSTRACT

MODELING AND NUMERICAL ANALYSIS OF BEAM MATRIX PLASMA DISPLAY SYSTEM

by
Jingwu Zhang

This research investigates a new display device - Beam Matrix Plasma Display Panel (BM PDP). The scan of a PDP in such a system is accomplished through two electrical-beam guns instead of semiconductor switches.

The BM-PDP eliminates the expensive semiconductor switches in the current plasma display device systems. Its drive circuit has only three parts: electron beam guns, resistors and capacitors. During the operation of BM PDP, first a switch cell is turned on by a selection gun (X gun). Then another electron gun (Y gun) emits electrons onto column electrodes and capacitors. When the voltage over the corresponding luminous cell reaches its breakdown point, gas discharges and generates light. Drive circuit design and analysis for BM-PDP is an important research topic. This work derives the formulae describing the operation of the drive circuit. With these formulae all the cases in which the drive circuit may work are discussed theoretically and numerically. Two equations are also given to determine the time of cell breakdown in these cases. The results of numerical simulation show that the current of an electron beam gun can be employed to carry the signal of image, the capacitance of a display cell is not sensitive to the initial current of gas discharge. The later property can be used to reduce the difficulties of manufacturing. The process of gas discharge in a display cell is also discussed and a multi-particle physical model is given to simulate the plasma cell.

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MODELING AND NUMERICAL ANALYSIS OF BEAM MATRIX PLASMA DISPLAY SYSTEM

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CHAPTER 1

INTRODUCTION

1.1 Background

In recent years, plasma display panels have attracted more and more attention since some major companies such as the SONY, NHK and FUJI brought much clearer and brighter color pictures to large-size screens. With great enhancement of display technology, Much research work aiming at improving the electrode design, picture quality, lifetime and efficiency of devices is also on progress.

The basic principles of PDP were demonstrated three decades ago. As a very possible substitution for the CRT, PDP makes it predictable that a new display era is coming. PDP has many display cells which are used to replace pixels on the screen of CRT. A display cell is the basic element of lighting on the PDP screen. It contains some kind of gas. When a high voltage is placed across the display cell, a process called gas discharge happens. This emits light. Gas discharge happens inside the display cell that is relatively small in size. Thus the PDP device does not need the space for accelerating the electrons to get high speed to impact the phosphor on the screen. This elimination of the acceleration space makes it possible that PDP can be made in a "thin" form. If a large screen is needed the larger space is needed to accelerate and bend electrons in CRT. On contrast, no matter how larger a screen is built, it is not necessary to increase the thickness of PDP because we can keep the display cell in the same size and increase the number of the cells. On the other hand, the display cell is not easy to be made in very small size. It contains gas mixture and every cell may have their own built-in drive circuit.

There are two major problems for current PDP devices. 1) As we have mentioned above, every display cell in the PDP device has its own built-in circuit. The present PDP devices are all using semiconductor switches and some auxiliary elements to control the gas discharge in display cells. The semiconductor switches containing high voltage element are expensive. The larger screen to be built, the more display cells employed. The cost in this case is very high. 2) The semiconductor switches have a limited capability to undertake a high voltage. We can not apply a high voltage over a display cell if semiconductor switches are used. This is one of the main reasons why PDP device currently couldn't get very high brightness compared with CRT's.

In a Beam Matrix - Plasmas Display Panel, a new kind of drive circuit is introduced. It employs two electron guns and two charge receiving target matrices (called target matrices below). Each column of electrodes has one resistor and one capacitor in its simplest implementation. One of the tow electron guns scans target matrix and functions like a semiconductor switch in a conventional PDP. It is called a selection gun. Only one selection gun is needed for a row of electrodes and another for a column of electrodes. Thus all semiconductor switch are taken over by two selection guns. This implies that the cost of the display device can be reduced tremendously. Note that one of two electron guns carries the display signal. We can control the value of the electron beam current to get different color or different brightness. The details will be discussed later in Chapter 5.

As in the current product PDP, the quality of the image in BM-PDP device is decided by the gas discharge processes in display cells. The behavior of plasma in display cells is mainly determined by 1) the number of the electrons emitted on target or beam current, 2) the energy released from the capacitor in a drive circuit, and 3) the composition of the gas mixture and its pressure. For these reasons this thesis work is important in making high quality BM-PDP devices: study of the behavior of plasma in a display cell, analysis and numerical simulation of its drive circuit.

1.2 Objectives

The goal of this thesis is to present a new kind of display device: Beam Matrix Plasma Display Panel (BM PDP) and our preliminary modeling and analysis work on the device. The specific objectives of this thesis include:

1) Introducing basic gas discharge processes and physics useful for the BM-PDP.
2) Describing the structure and scanning principles of a simplified BM-PDP.
3) Introducing partial differential equations that describe the behavior of multiple kinds of particles in a display cell. These equations include mass equation, energy equation and momentum equations.
4) Conducting numerical design and simulation of BM-PDP. The focus is on its drive circuit. Different cases of the process are presented, including: cell breakdown during the scanning and breakdown after the scanning. A criterion on working condition is given. Two formulas for the breakdown point are also derived.

CHAPTER 2

GAS DISCHARGE AND GAS DISCARGE PHYSCIS

This chapter briefly reviews some fundamental concepts and characteristics in gas discharge and plasma physics. In a display cell or called pixel, gas discharge is the process that causes the cell to glow. The theory of plasma physics is employed to study the procedure of the gas discharge. There are two major parts in the chapter: 1) basic electro-optical characteristics of the gas discharge, mainly the phenomena in the gas discharge, and 2) gas discharge physics that briefly explains why the gas discharge exhibits such characteristics.

2.1 Basic Characteristics of the Gas Discharge

I-V Characteristic

A typical I-V characteristic of a gas discharge used in plasma displays is shown in Fig. 2.1. Note that the current is plotted on a log scale which spans nine orders of magnitude. For each current range different physical phenomena become dominant. This accounts for the various labeled regions of the curve as shown in Fig. 2.1. A more detailed discussion of these regions and their physical mechanisms appears in the next section.

Gas discharge is observed to exhibit the extreme nonlinearity. As shown in Fig. 2.1 for voltages near the firing voltage of 250 volts, the current can change by more than 3 orders of magnitude for a very small incremental voltage change. Since the light output of the display is roughly proportional to the current, this extreme nonlinearity is very useful for making matrix displays with a large number of display electrodes. This strong nonlinearity is one of the major reasons why plasma displays are successful in flat-panel matrix displays.

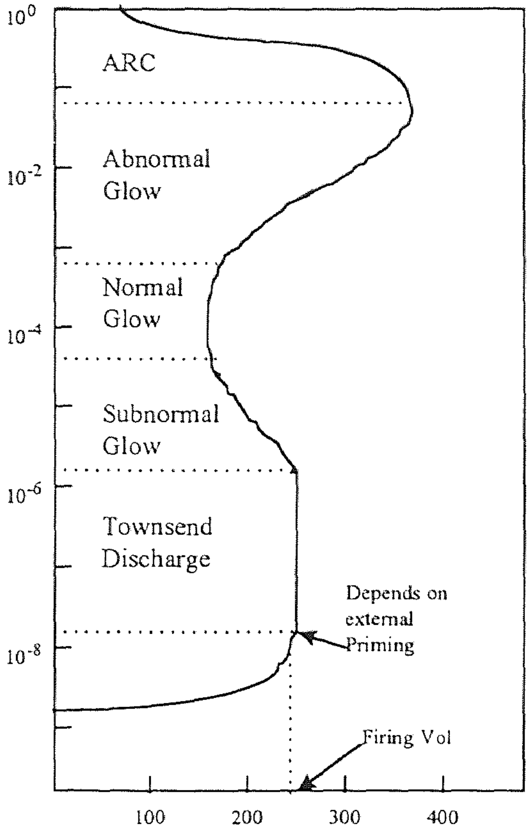

Fig 2.1 The Current-Voltage Characteristics of Gas Discharge

The very-low-current regions of the discharge characteristic depend on external priming. Gas discharge needs some energetic particles to get them started, and the generation of these particles is called priming. Electrons, ions, photons, or other excited species can be priming particles. The external priming is necessary to make a gas discharge occur. Otherwise there is no gas discharge even with very high voltage. This phenomenon is used to great advantage in plasma displays to perform integral gas-discharge switching operations. We can find that the negative resistance exists which can be used to make memory devices if the proper external resistance and power supply voltage are used as discussed next.

2.2 Gas Discharge Physics

Gas-Discharge Reactions

During a gas discharge process many reactions happen. We use gas neon as an example. Figure 2.2 shows a view of the most important reactions. Even this simplified view is rather complex.

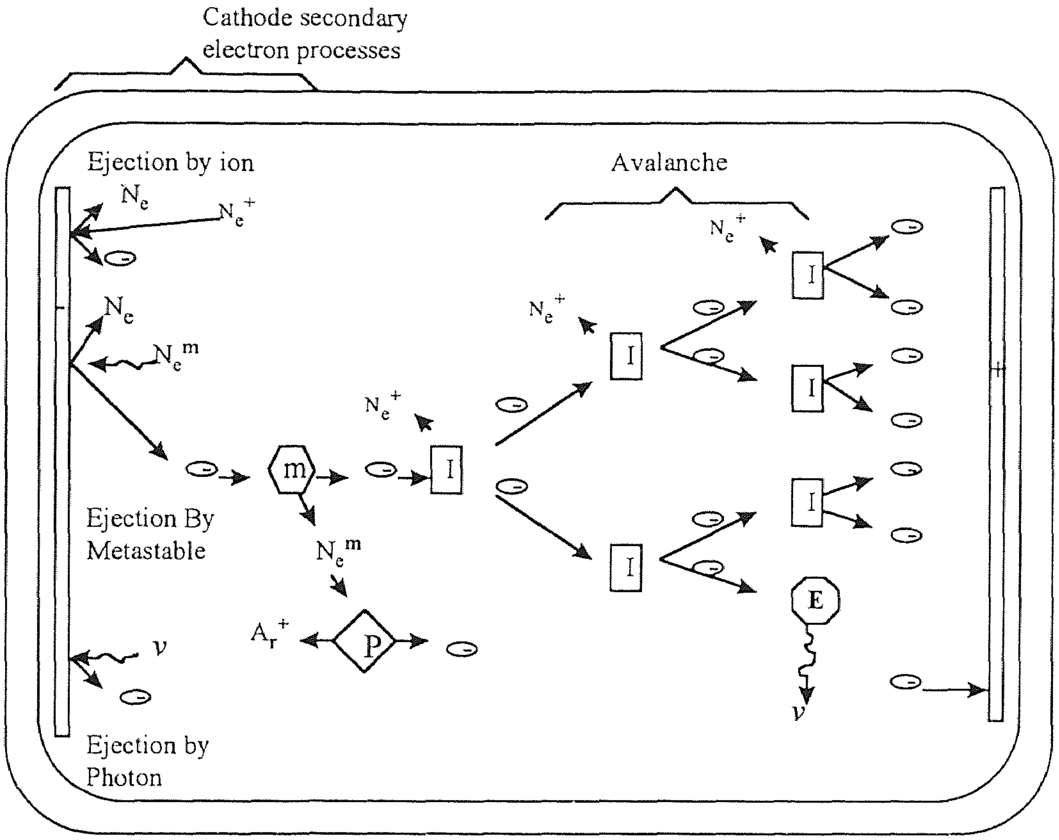

Fig. 2.2 Scheme of gas discharge reactions in display cell

Generally speaking there are two kinds of reactions: gas volume reactions and cathode surface reactions. The cathode surface reactions include ejection of electrons from the cathode by ions, metastable atoms, or photons. The ionization (I), excitation (E), metastable generation (M), and Penning ionization (P) are gas volume reactions. The details of each of these reactions are discussed below.

Each of the species of particles found in this discharge example is listed in the lower left corner of Fig. 2.2. They are transported by different mechanisms during the gas discharge. There are three categories of these mechanisms: 1) the field-induced drift, with diffusion transport of secondary importance; 2) diffusion; and 3) electromagnetic radiation law. They are for charged particles like ions and electrons, neutral particles and photons.

Ionization

When an electric field is placed across the gas, it accelerates the electrons that may be in the gas volume. The movement of these electrons causes continually colliding with the neutral gas atoms. Most of these collisions are elastic. Some of these electrons, when they are accelerated by the electric field and reach to the energy level greater than ionization limit of a neon atom. The collisions between these energetic electrons and the neon atoms can cause an electron to be ejected from the atom. In other words, such a collision leads to positive neon ion and a new free electron created. As seen in Fig. 2.2 the ionization reaction can be written as:

$$\mathrm{Ne} + e^- \rightarrow \mathrm{N}e^+ + 2\,e^-$$

Excitation

If the energy of an electron is lower than 16.6 electron volts, it only causes elastic collision while it moves toward the positive pole. The electrons which have energy in the range of

16.6 to 21.6 electron volts are able to excite a neutral neon atom during a collision. The excited atom can only remain excited for a relatively short time (roughly 10^{-8} seconds) before it radiates a photon and returns to the ground state. Thus the excitation reaction seen in Fig. 2.2 can be written as:

$$\mathrm{Ne} + e^- \rightarrow \mathrm{N}e^* + e^-$$

$$\mathrm{N}e^* \rightarrow \mathrm{Ne}\ (\text{or } \mathrm{N}e^*, \text{or } \mathrm{N}e^m) + \upsilon$$

Metastable Generation

When a neon atom is excited it may not be allowed to emit a photon. This happens when long neon atom is excited at some energy level of the neon atom. These states are called metastable levels. These metastable atoms can be generated by an electron with greater than 16.6 electron volts colliding with a neutral neon atom, as shown in Fig. 2.2. The reaction is:

$$\mathrm{Ne} + e^- \rightarrow \mathrm{N}e^m + e^-$$

A reaction called a by-product of the excitation reaction can also generate metastable. This reaction is written as:

$$\mathrm{Ne} + e^- \rightarrow \mathrm{N}e^* + e^-$$

$$\mathrm{N}e^* \rightarrow \mathrm{N}e^m + \upsilon$$

Metastable atoms do not radiate a photon and are not charged. Their transport is done only through the slow process of diffusion. The metastable atoms survive in the discharge for relatively longer time. In plasma displays, metastable usually do not decay naturally but are de-excited by a reaction with some other body. Among other reactions, metastable can be de-excited by colliding with the discharge chamber walls and by the Penning ionization process discussed next.

Penning Ionization

The metastable atoms have about 16.6 electron volts of energy. Because of a relatively longer lifetime, these atoms can make a large number of collisions with other atoms in the gas discharge. When a collision happens between an argon atom and metastable, there is a high probability the argon atom is ionized. The reason is that the 16.6 electron-volt metastable energy is greater than the 15.8-electron-volt ionization energy of an argon atom. Thus the reaction is:

$$Ne^{m} + \mathrm{Ar} \rightarrow \mathrm{Ne} + Ar^{+} + e^{-}$$

This reaction generates additional ionization beyond that produced by the ionization reaction. This additional ionization makes it possible that plasma displays operate at a lower voltage. The amount of this additional ionization is strongly dependent on the argon atom concentration.

Cathode Surface Reactions

In the display cell the surface of the container plays an important part because a number of reactions happen there especially on the surface of cathode. Three reactions can eject electrons form the cathode surface. This ejection can be stimulated by cathode collisions from positive ions, metastables, and photons. The ejection of electrons is of critical importance to a gas discharge because these cathode electrons initiate the volume reactions and thus participate in the gas-discharge feedback equation which determines the firing voltage of the discharge.

For plasma display it is very important that the positive ions cause the electron ejection on the cathode surface, and the argon ion has 15.8 electron volts. During collision with the cathode, the ions with 21.6 electron volts capture an electron from the surface and they become neutralized. In this process the surface obtains the energy from ions. Since usual work-function energy for an electron to escape is in the 3-to-10-electron volt range, this energy is more than enough to cause an electron ejection from the surface and thus the ejection possibility is very high. The factor, coupled with the fact that all positive ions produced in the gas volume are directed by the field to drift toward the cathode, makes this ejection reaction dominant in plasma displays.

Photo-emission can also cause an electron ejection on surface of the cathode and it is also a significant mechanism. Only ultraviolet photons have significant photo-emission because the work function of the cathode is in the range 3-to-10-electron volts. Fig. 2.4 shows that the transitions between the lst levels and the ground state generate these photons. Although the number of the photons is large, they have random directions and only a small fraction is directed toward the cathode.

Metastable neon atoms have 16.6 electron volts of energy that can be given to the cathode surface to eject an electron and de-excite the metastable. Although the metastable have about the same probability of ejecting an electron as an ion, they are not nearly as important as ions since they diffuse in random directions at a very slow rate compared to the drift of the ions toward the cathode.

Avalanches

The ionization reaction is initiated by one electron and results in two free electrons and a positive ion. These two electrons can then go on to create two more ionizations and so on, resulting in an avalanche as shown in Fig. 2.2. The electron that initiates the avalanche can be one that is ejected from the cathode. As the avalanche progresses toward the anode, the number of ionizations increases exponentially in space and time. In plasma displays, the number of ionizations occurring in an avalanche is in the range of 10 to 300.

Paschen Curve

The display engineers frequently use the dependence of the firing voltage on the gas-discharge cell design. This is conveniently characterized with the Paschen curve shown in Fig. 5.3[52]. This curve gives the firing or breakdown voltage as a function of the product of the gas pressure and gap distance: $P \times d$. A different curve is obtained for different gas mixture or different cathodes.

The important fact seen from Paschen curve is that the firing voltage remains unchanged for differing cathode-anode distances as long as the pressure is changed so that the product $P \times d$ is constant. This fact is used to great advantage by display engineers. In order to reduce drive circuit costs it is frequently desirable to design the firing voltage to be as low as possible in the conventional PDP products. The value of d is usually determined by other constraints as the required resolution of the display. Thus the engineer has the freedom to choose p for a given d in order to minimize the firing voltage.

CHPATER 3

DISCRIPTION OF BM-PDP DEVICE

BM-PDP is a kind of display devices that adopt plasma display panels with an electron-beam gun-based scanning method. Its screen consists of two sets of transparent electrodes: horizontal electrodes and vertical electrodes as shown in Fig. 31.

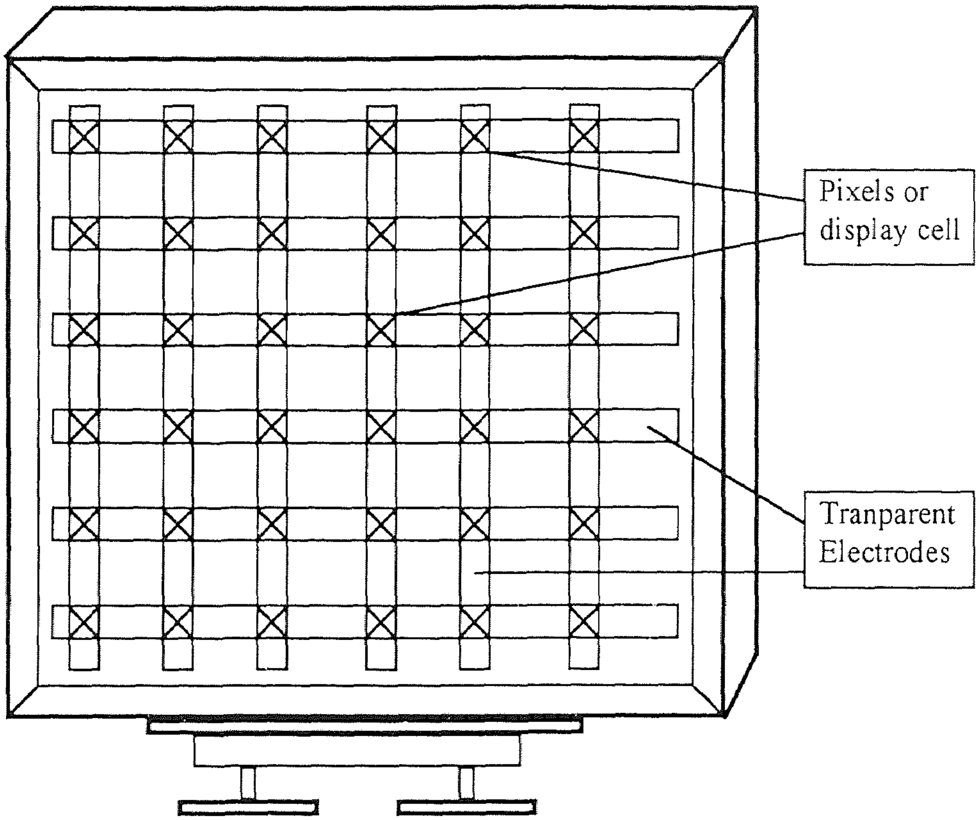

Fig. 3.1 The structure of the BM-PDP device

Each intersection between horizontal and vertical electrodes forms a display cell, also known as luminance cell. The *horizontal* electrodes are anodes. The vertical electrodes are cathodes. Between the anodes and cathodes there are some gas mixture filled. When a certain voltage is placed across the anode and cathode, the process of gas discharge happens. The point at which the gas discharge starts is called the breakdown point. Gas discharge gives out light. This display cell is lighted. By using a certain method to control all the display cells, a image can be shown on the screen.

Fig. 3.2 shows more details of the BM-PDP structure with electron guns.

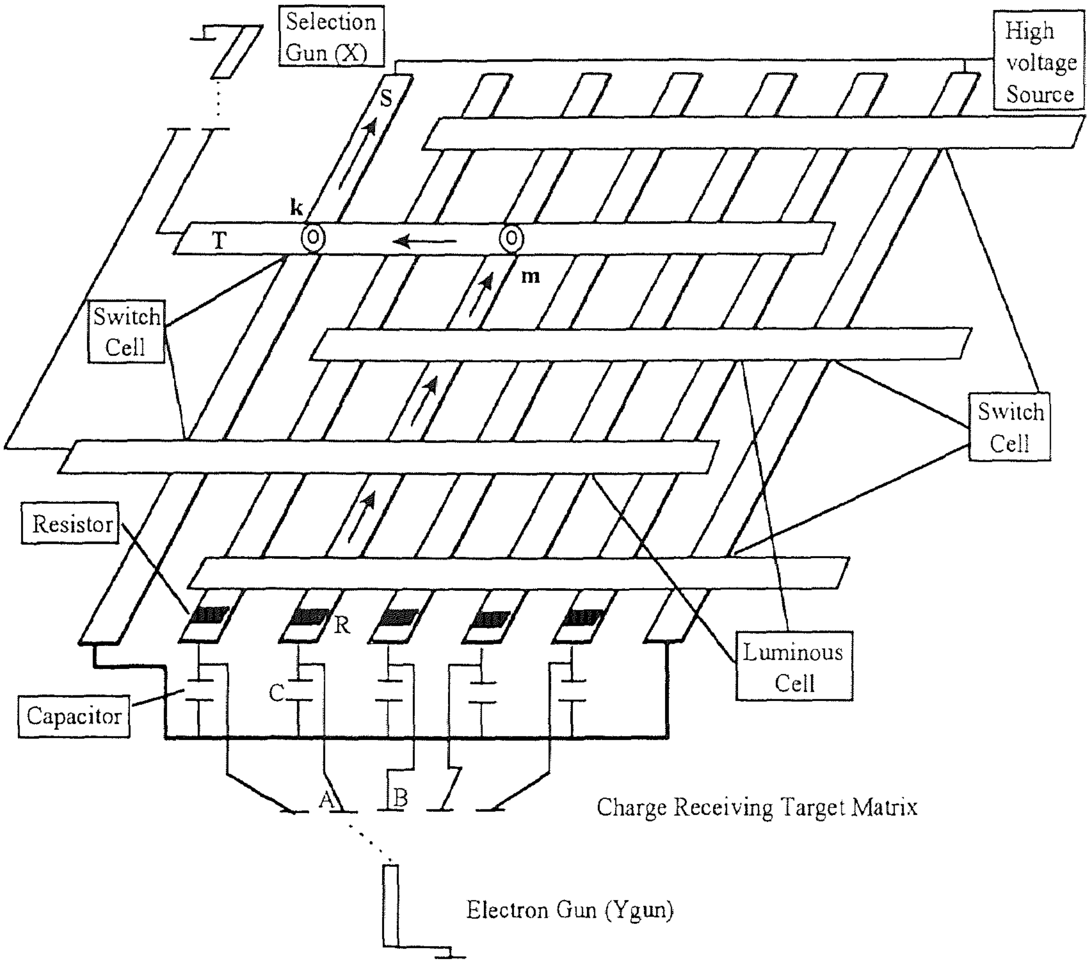

Fig. 3.2 The structure of display panel

To enlarge the screen of BM-PDP, more intersections or display cells are needed by enlarging two glass panels. There is no necessity to increase the thickness of the BM-PDP, which is different from the CRT.

BM-PDP display panel consists of two sets of electrodes arranged in an inter-crossing way. The upper electrodes are anodes, and the lower ones are cathodes. Each intersection of the rows (anodes) and the columns (cathodes) thus forms a discharge cell. There are two different categories of discharge cells in this device. One is called switch cells. The other is luminous cells. Switch cells, located in the leftmost and the rightmost columns, function as switches. When it is selected (in row, scanned by X-gun), it turns on the corresponding anode in the same row, which in turn sets all the luminous cells in this specific row ready to luminance. All the other cells falling in the category of luminous cells (also called display cells) function as pixels. Every luminous cell is connected to a charge receiver (a target). All the charge receivers are set in a matrix (or an array). An electron-gun (Y-gun) scans the targets (in column) one by one. The luminous cell in a row is turned on, if the connected target is scanned by the electron-gun (Y-gun).

First among all the selection guns X gun scans the horizontal electrode T as shown in Fig. 2.1. The switch cell k is turned on. The vertical electrode S under electrode T is connected to a high voltage source. Only switch cell k can be turned on when X-gun scans electrode T, because the voltage of all other horizontal electrodes is floating. The electron emission lowers the voltage of electrode T. Thus the voltage over the switch cell k increases. The gas mixture inside the switch cell k discharges when the voltage reaches its breakdown point. The switch k is turned on.

When Y-gun scans target A, a certain number of electrons are emitted onto the target. These electrons are accumulated on the capacitor C. The voltage of target A is lowered. The voltage of electrode T is fixed because it has been turned on. It is the voltage of source of minus the voltage of maintaining voltage of the switch cell k. When more and more electrons emitted onto the target A the voltage of the target A is decreased more and more. When the difference of the voltage between the electrodes T and A reaches breakdown point of display cell m, gas in cell m discharges.

The X-gun keeps scanning electrode T when Y-gun scans the target matrix from the leftmost target to a rightmost target. After scanning target A, Y-gun moves onto target B. The same process happens at target B as Y-gun scans target A. Thus the display cell next to the cell m is brokendown. All cells in the line of electrode T are brokendown one by one when Y-gun scans from the left to the right.

When Y-gun finishes scanning and goes back to the left most target, election gun X-gun moves to the next horizontal electrode. The gas in the cell in the next line starts to discharge one by one.

In BM-PDP device n capacitors and n resistors are employed where n is the number of the column electrodes used to form display cells. A capacitor collects the electrons coming from the Y electron gun. It has several functions. The energy stored in the capacitor is used to prolong the gas discharge. To avoid flicker problem the display is scanned at a fast enough rate to prolong the gas discharge process. In the BM-PDP device it is easy to meet these two requirements when a proper value of capacitance is chosen. Another function of capacitors is to help the luminance cell to establish a high voltage to breakdown. The resistor in the BM-PDP ensures the current or electron flow to the capacitor first in order to store energy and to quickly establish a voltage. When the display falls into a duration process a larger resistance value is preferred. But an improperly large value wastes much energy, which is not good for display. When a drive circuit is designed, the resistor helps to meet the criteria, which will be further discussed in Chapter 5.

Therefore, the usage of only capacitors and resistors can reduce the complexity and thus the manufacturing cost of display panel. Another advantage of this device is that the capacitor and resistor can both undertake relatively much higher voltage than current semiconductor switches. By using the drive circuit of the BM-PDP a high voltage can be placed across the display cell. Its working range may be quite wide. For example it is possible to choose different gas mixtures.

As a display device, BM-PDP takes many advantages of gas discharge in a luminance cell. The light emits while gas discharge is employed to display some images on the screen. As mentioned in Chapter 2, gas discharge is a very complex process. There are many reactions in a luminance cell. To achieve high luminance some proper gas mixtures has to be chosen, which further complicates the issue. Because the process of plasma in the cell is a non-linear process, it is inappropriate to use normal methods to analyze the drive circuit. Thus the study of the behavior of a plasma process inside a luminance cell becomes very important.

The equations to calculate the multi-particle plasma and its numerical calculation form are given in Chapter 4 as a prerequisite for future design. BM-PDP has both charge and discharge processes when it lights a display cell, which is different from the semiconductor switches. To ensure image quality, a longer discharge process is desired advantages, but a short and quick charging period is better for the capacitor charge because the scanning time is very short for every single cell. Actually if the charging period is too short there will not be enough energy accumulated in the capacitor, the whole display process may fail. In fact, the charge time and discharge time requirement are in a conflict. They are relate to each other through the drive circuit. To find out appropriate criteria, this work analyzes the drive circuit as discussed in Chapter 5. The capacitor is charged by Y electron gun. The energy obtained in the capacitor is released to breakdown as well as sustain the gas discharge.

As the value of the electron beam current varies with the image signals, the current in the drive circuit changes all the time. To calculate and control the discharge process is very important step to build a successful BM-PDP device. There may be several possible ways in which the drive circuit works. In order to specify a proper status, it is important to determine the breakdown time by the circuit parameters. Therefore to determine the breakdown point is another major part of this research work.

CHAPTER 4

A PROPOSED METHOD FOR ANALYSIS OF PLASMA IN A LUMINOUS CELL

Flat panel is based on the plasma behavior inside the luminous cell. The basic operation of all PDP is to select a right cell on the screen and trig the gas discharge in it. Currently the efficiency of luminance is one of the most important issues for the flat panels in the market. To achieve high brightness and enhance luminance, the plasma inside a luminous cell must be studied. We need a precise description of the behavior of plasma to design best-performance BM-PDP.

There are some publications about the analysis of the microdischarge in the plasma display numerically[2],[3],[4],[18],[20]. It is very difficult to diagnose the plasma generated in the one of the plasma display cell because of the tiny discharge volume. Some variables such as density, velocity, and temperature of the charged and uncharged particles in the plasma display cell could not be measured precisely. On the other hand the numerical analysis of the glow and afterglow in the plasma display cell can give detailed information on plasma variables. However, only a few 1-demesional and 2-demesional numerical analyses of the plasma display had been performance and published.

The structure of a display cell is also related to the behavior of the plasma. The structure of a display cell including the arrangement of electrodes, the deposition of phosphor etc.. Phosphor deposition must be placed within the confines of a three-dimensional barrier structure. Research show that color PDP's are theoretically more efficiently than monochrome PDP's; recently, this theoretical advantage has been realized in practical full color devices. The reason of using phosphor to get color plasma display is that it is not a practical approach for a full-color PDP with saturated colors. Thus we must use single gas mixture in conjunction with photo-luminescent phosphor. The plasma properties such as distribution of particles, velocity and velocity's distribution of particles and energy of particles must be investigated to obtain optimal design. The possible damage on the electrodes caused by the gas discharge is also an important issue. This is one of the key problems about the lifetime of commercial products of flat panels. The ion current density profile on the driven electrode is an important parameter in processing application, since the uniformity of the process, deposition or etching, is directly related to this parameter.

BM-PDP device has a possibility to operate under certain condition in which the voltage is high but current is low. This makes it possible that we can choose some kinds of gas mixture which have good properties in brightness and desired variables during the discharge but need high breakdown voltage.

As discussed above, two-dimensional or three-dimensional investigation on multi-particle plasma inside luminous cell is expected. Most of resent papers and mainly dealing with 1 or 2-dimensional numerical simulation. The methods include finite-difference, methods of characteristics, particle-in-cell/Monte Carlo and convective schemes. As Boltzmann solution, each of these methods must represent the kinetics of, typically, electrons in phase-space. As a result, these methods, depending on a problem, may require considerable computational time and their practicality is often questionable.

In this thesis we give out a possible method for numerical calculation of plasma in a luminous cell. These equations are derived from Boltzmann's equation. All the macro-parameters are considerated as averaged values of the corresponding micro-parameters.

Thus we think that during the gas discharge a transportation process happens. Parameters such as energy, momentum, pressure and densities of each kinds of particles are transported during the gas discharge. Three dimensional transportation equations are needed here. Based on the transportation equation, equation sets describing parameters which are the function of position, particle velocity and time can be derived.

Each kind of particles is described by their own equation sets including energy equation, momentum equation and mass equation. We list two mass equations for electrons and ions respectively below as an example. In each equation, there is an item called collision item which makes all particles related to each other.

To solve these equation sets, some other auxiliary equations are needed, such as Maxwell equation, state equation, momentum transfer equation, source equation for particles, heat source equations and thermal conductivity etc.

Here we list the mass equation, energy equation and momentum equations only. The details can be seen in Appendix A. These equation sets are useful for the real designation of BM-PDP device. They can be used for two or three dimensional numerical analysis depending on the requirement. The details can be seen in Appendix A

CHAPTER 5

THEORETICAL ANALYSIS ON MB PDP DEVICE

Figure 5.1 shows the effective driver circuit of a BM-PDP. A switch cell in Fig. 5.1 corresponds to the switch cell k in Fig. 3.2. A luminance cell in Fig. 5.1 corresponds to cell m in Fig. 3.2. The voltage across the switch cell is constant during the Y gun's scanning target A since it is supposed to be on. It's value equals is the maintaining voltage of the switch cell.

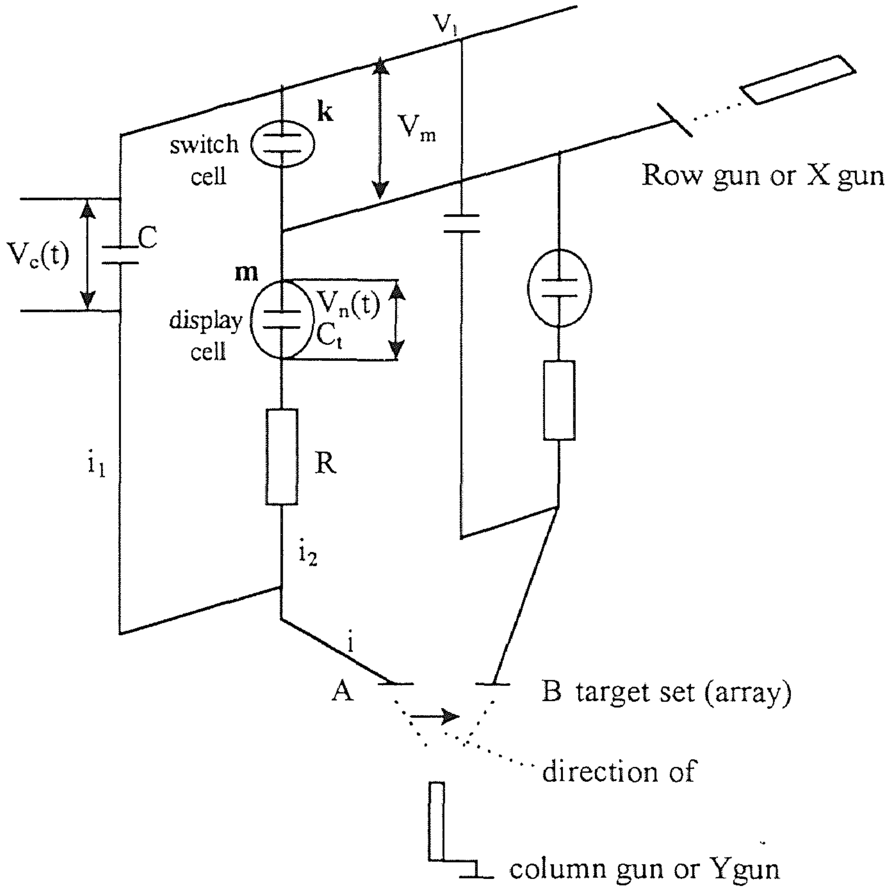

Fig. 5.1 The effective drive circuit

The current originated from Y electron gun flows into both capacitor C and cell m. The voltage of target A is lowered when more and more electrons are accumulated due to Y gun's scan. The voltage over the capacitor can be larger than the voltage over the luminous cell when the current i_2 is not zero. Once the scan is finished the capacitor can discharge to prolong the gas discharge in the cell. The resistor R here helps to establish the higher voltage over the capacitor and joins the process of prolonging the gas discharge. Y-gun scans the targets from left to the right. When it finishes scanning target A, it moves onto next target, i.e., B. The drive circuit similar to target A is connected to target B. Thus the same process happens in the next drive circuit.

When the electron-gun starts scanning target A (Fig. 5.1), a number of electrons emit onto target A. For each drive circuit the scan period of t_s is very short. For instance, $t_s=6*10^{-6}$ sec for a 50x50 pixels display panel. Thus the current i can be approximated a square-wave function applied to target A. The value of voltage Vc and V_n increases once electrons begin emitting onto the drive circuit. When voltage V_n reaches the breakdown point of the luminous cell, gas starts to discharge. The stored energy in capacitor C is then used to prolong the discharge process.

5.1 Conditions Required for BM-PDP

The parameters in a drive circuit, like capacitance C and resistance R, are not chosen arbitrarily. The capacitor is charged to make the voltage cross the luminous cell getting higher enough to breakdown and the capacitor discharge prolongs the gas discharge to make the image clear. When there are many luminous cells on the screen, the scanning time by the Y-gun to each target must be very short. A short time for charging the capacitor to reach the breakdown point is desired. This means the smaller capacitance of capacitor the better. But to hold more energy in the capacitor the larger the capacitance, the better. On the other hand, when a pixel lights, it must have a time period or interval to keep the luminance because we need to keep the light spot on the screen for a while to ensure it can be seen clearly. A simple calculation shows that in this case we need a relatively bigger product RC for prolonging the luminance where R is the resistance and C is the capacitance in the drive circuit. These two cases show that there is a conflict. Equations (5.1) and (5.2) below are the conditions which have to be satisfied when the drive circuit is designed and the gas mixture is chosen.

$$\mathrm{RC} \leq \frac{1}{|\ln(1-\frac{\Delta V_b}{iR})|m \cdot n \cdot j} \tag{5.1}$$

and

$$\mathrm{RC} \geq \frac{1}{n \cdot j} \tag{5.2}$$

where: R resistance of the resistor.

C capacitance of the capacitor.

n the number of the column electrodes on the screen.

m the number of the row electrode.

j the number of the images shown on the screen in a second.

ΔV_b the difference of breakdown voltage and maintaining voltage.

These conditions are obtained under the assumption that V_n is constant when the capacitor is being charged.

When the parameters are chosen for designing the drive circuit, equations (5.1) and (5.2) must be satisfied first. It is critical when the number of the luminous cells increases. According to two these conditions, increasing the value of the electron beam current is one way to make BM-PDP work properly. Increasing R is another way. In our designation, ΔV_b is around 10^2. Current i is around 10^{-3}. R is around 10^7. So ΔV_b/(R*I) is around 10^{-3}. This makes right side of equation (5.1) bigger. But increasing R consumes more energy to prolong the gas discharge. This can be seen in the second condition. Reducing the difference between the sustain voltage and the breakdown voltage is another consideration. But this results in the difficulty to choose right gas mixture and probably lowering the luminance.

Condition (5.2) is not such strict. It comes from the requirement to prolong the gas discharge. We may obtain compensation from phosphor's afterglow property.

5.2 Breakdown Point t_b

When Y-gun emits electrons onto the target and electrons are accumulated on the lower end of the capacitor and luminous cell, the voltage over the capacitor and luminous cell becomes higher. At some time point t_b gas in the cell discharges. t_b is related to the component of gas mixture, the pressure of gas, parameters of the drive circuit, beam current of Y electron gun and initial condition of voltage over the capacitor and luminance cell. t_b is a very important parameter that must be known to determine the work status of the drive circuit. In this thesis a method to calculate t_b is presented.

Obviously the breakdown voltage of gas and the initial value of the cell voltage are main factors affecting t_b. Given the same breakdown voltage if the initial voltage is different, t_b is different when other parameters are the same.

First we determine the relation between the breakdown voltage and other parameters. Figure 5.2 shows a model for that. In the luminance cell the status of gas is divided into two categories: molecular dynamics and plasma. Before the gas discharge it is molecular dynamics. Usually the gas pressure in the cell is relatively lower in current flat panel device (around 100 Torr). This value is a little higher than the bottom point of Paschen curve. The reason is the product of voltage and distance of the cell is small. The ideal gas status is assumed before breakdown. The model is one dimensional.

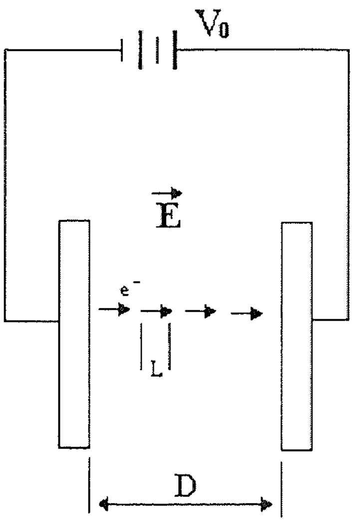

Fig.5.2 The Model Showing the Movement of Particles

Before breakdown there are some charged particles such as electrons in the gas. When a voltage is placed over the cell these charge particles are accelerated. They cause continuous collisions in the gas. The electrons here act as priming. They obtain kinetic energy from electrical field $\vec{E}$ during their free path. If this energy is large enough when they collide with a atom, the ionization happens. Based on this consideration, we have:

$$\vec{E} = \frac{V_0}{D};$$

$$L = \frac{1}{\sqrt{2}\pi \cdot n \cdot d^2}$$

$$n = \frac{N_0 \cdot P}{RT}$$

then we have:

$$V_0 = K \cdot E_i \cdot (\sqrt{2}\pi \cdot \frac{N_0}{R \cdot e})(d^2 \cdot T) \cdot D \cdot P \tag{5.3}$$

where:

K	a constant
E_i	the ionization energy of the gas in the cell
N_0	the Avogadro gas constant
R	gas constant
e	charge of electron
d	collision section of the gas
D	the height of luminous cell
P	pressure of the gas
V_0	breakdown voltage.

Formula (5.3) is not applicable everywhere. When the product PD is very small (lower then 10 Torr.cm), it is not correct. If D is too small, i.e. it is smaller than the free path of a particle, then the wall of a cell absorbs the energy which charges particles. If P is very small, the free path of a particle increases. There is a high possibility that a particle loses its energy to the wall before it hits another particle. The typical length of a free path is around 10^{-5} cm. Usually the height of the cell is greater than this. Thus formula (5.2) can be used after the bottom point of Paschen curve. There is another approximation. A particle does not lost its hole energy when it has a collision. The energy may be accumulated after that. The ideal gas model introduces another approximation. But usually the pressure of the gas in luminance cell is lower. The tendency shown by formula (5.3) matches well the Paschen Curve as shown in Fig. 5.3.

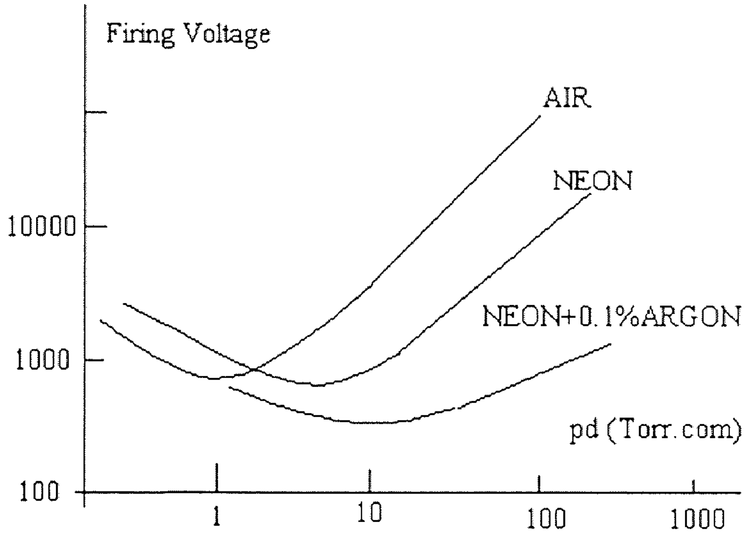

Fig.5.3 Paschen Curve

When the voltage over the cell increases from the initial value to the breakdown voltage gas discharge starts and this time period is denoted by t_b . Before the breakdown is reached there is a very small current flowing through the luminance cell. It is around 10^{-8}. Comparing to the electron gun current 10^{-3}, it can be neglected. The drive circuit is in capacitor charge process. Then we have:

$$t_b = \sqrt{\frac{1}{i}(2R \cdot c \cdot c_t \cdot \Delta V)} \qquad (5.4)$$

where:

i	the current of Y electron gun
ΔV	the difference between the breakdown voltage and its initial value.

c and c_t are capacitance of the capacitor and the effective capacitance of the luminous cell respectively.

Combining formulas (5.3) and (5.4), we obtain the relation between t_b and all parameters within the drive circuit, gas mixture and the initial condition. Note that ΔV is V_b minus the initial value of the voltage over the luminance cell.

If the gas inside the cell does not discharge during the scan, the energy or charges in the capacitor are transfered to the cell. The voltage over the cell increases further until it reaches the breakdown point. The time period plus the scan time is t_b:

$$t_b = t_p + RC_q \mathrm{Ln}\left[\frac{1}{1 - \frac{\Delta V - \Delta V_{tp}}{i_{2p} RC_q} c_t}\right]$$

where:

ΔV_{tp}	the increase of the voltage over the cell during the scan
i_{2p}	the value of current i_2 at the time the scan finishes

5.3 Analysis of the Drive Circuit

A luminous cell contains gas mixture. When the priming is introduced to it, the current flowing through the gas increases exponentially and a breakdown condition called Townsend condition is:

$$\mu=\gamma(e^{\alpha L} - 1) \quad \text{when} \quad \mu=1 \tag{5.5}$$

where α and γ are the first and second Townsend coefficients , L is the distance between electrodes and μ is the loop gain.

Experimental data shows that although there is current in the gas, it is very small before breakdown. It is around 10^{-8}-10^{-9} A. The proposed current i offered by the Y-gun is around 10^{-2} A. We can thus neglect the current in the gas. Hence, the values of V_n, V_c, i_1 and i_2 are mainly determined by the accumulation of the charges during the scanning period. V_m is constant because the switch cell is turned on before the row scanning starts. The X-gun scans the row in slight advance to ensure that switch cell is turned on before Y-gun scans the targets. Based on these considerations the following formulas which are used to determine the status of the drive circuit can be derived:

$$i_2=\frac{c_t i}{c+c_t}\left[\, 1 - \exp(-\frac{t}{RC_q})\,\right] \tag{5.6}$$

$$i_1=\frac{ci}{c+c_t}\left[\, 1 + \frac{c_t}{c}\exp(-\frac{t}{RC_q})\,\right].i \tag{5.7}$$

$$V_c=\frac{i}{c+c_t}t+\left[\, 1 - \exp(-\frac{t}{RC_q})\,\right]\frac{RC_q}{c+c_t}\frac{c_t}{c}i+V_{c0} \tag{5.8}$$

where

$$C_q = \frac{c \cdot c_t}{c + c_t} \tag{5.9}$$

c_t	the capacitance of the luminance cell.
R	resistance
V_{c0}	the voltage across the capacitor before Y-gun scans
c	the capacitance of the capacitor
i	the current of Y-gun's electron beam
t	time

The potential of the receiving target changes along with the emission of the electron beam gun. The voltage of the target is defined from target to the electron gun which is grounded: $V_1 - V_c$. When more and more electrons emitted onto the target, the voltage of the receiving target becomes lower. After gas discharges it becomes higher and ready to receive electrode during the next emission. This voltage change builds up the voltage needed to breakdown the gas in a luminous cell. A relatively higher voltage must be kept to get high efficiency of receiving the electrons from Y-gun. The voltage of the receiving target is determined by:

$$V_T = V_1 - \{ \frac{i}{c + c_t} t + [\ 1 - \exp(-\frac{t}{RC_q})\ ]\ \frac{RC_q}{c + c_t}\ \frac{c_t}{c}\ i + V_{c0} \} \tag{5.10}$$

These formulas are used to determine the status of the drive circuit during capacitor charge. When more and more electrons are emitted onto the target, V_n becomes bigger and the gas discharge in a luminous cell happens at some point ($V_n = V_{n0}$), where V_{n0} equals the breakdown voltage (which is denoted by V_b in Section 5.2). After the breakdown, the current-voltage relation changes into a different status depending on the external condition and parameters of the elements in the drive circuit. These statuses are Tonwsend discharge, subnormal glow and normal glow. In a luminous cell all parameters such as charge density distribution, ion and electron current, velocity distribution, and the ratio of charged particles to normal particles vary in a very short time.

The current of the electron beam can be regarded as a square-wave when Y-gun scans targets one by one as we mentioned before. When Y-gun scans the same target next time the current could be different from the first scanning. The electron beam carry the information of the image. The current has to change to match the image signal. This variation makes the drive circuit at different working statuses as shown in Fig. 5.4:

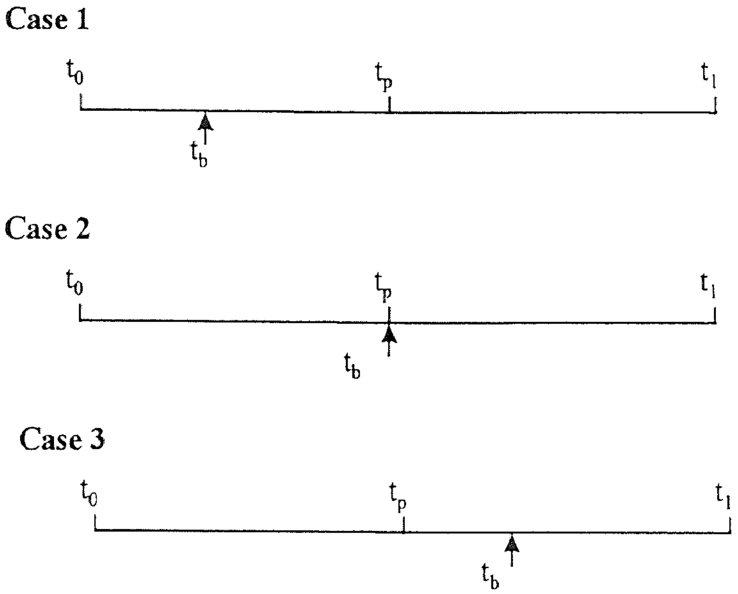

Fig. 5.4 The Illustration of Different Working Status

Case 1: Breakdown during the scan period.

Case 2: Breakdown when the scan is finished.

Case 3: Breakdown after the scan, i.e. V_c of the capacitor makes breakdown happen.

Case 4: No breakdown, a dark spot on the screen.

Case 1-3 are shown in Fig.5.4. an the horizontal axis represents the time. The total length of the line presents the whole time including the scan and gas discharge.

In Case 1, the voltage over the luminous cell reaches the breakdown point while Y-gun is still scanning. The voltage across the luminous cell is highly affected by the plasma inside the cell. After the breakdown, the capacitor could be still charged by Y gun or if its voltage is higher enough to discharge to the cell. In this case the current flowing through R and the cell is the sum of capacitor discharge current and electron beam current. The following are the formulas for Case 1:

$$0<t<t_b \qquad V_c = \frac{i}{c+c_t}t + [\ 1 - \exp(-\frac{t}{RC_q})\ ]\ \frac{RC_q}{c+c_t}\frac{c_t}{c}\text{i} + V_{c0} \qquad (5.11)$$

$$t_b<t<t_p \qquad V_c = \exp(-\frac{t}{RC_q})\{\frac{i}{c+c_t}t_b + [\ 1 - \exp(-\frac{t_b}{RC_q})\ ]\ \frac{RC_q}{c+c_t}\frac{c_t}{c}\text{i} + V_{c0}$$

$$+\frac{1}{RC}\sum_{j=0}^{n-1}\ \exp(\frac{t_j}{RC_q})(\text{V}+\text{V}(\tau_j)+\text{Ri})\,\delta\tau_j\,\} \qquad (5.12)$$

$$\tau_j = \text{j}\,\delta\tau \qquad\qquad \delta\tau = (\text{t} - \text{t}_b)\frac{1}{n}$$

$$t_p<t<t_1 \qquad V_c = \exp(-\frac{t}{RC_q})\{\exp(-\frac{t_p}{RC_q})\{\frac{i}{c+c_t}t_b + [\ 1 - \exp(-\frac{t_b}{RC_q})\ ]\ \frac{RC_q}{c+c_t}\frac{c_t}{c}\text{i}+$$

$$V_{c0} + \frac{1}{RC}\sum_{j=0}^{n-1}\ \exp(\frac{t_j}{RC_q})(\text{V}+\text{V}(\tau_j)+\text{Ri})\,\delta\tau_j\,\}$$

$$+\frac{1}{RC}\sum_{k=0}^{n-1} \exp\left(\frac{t_k}{RC_q}\right)(V+V(\tau_k))\,\delta\tau_k \} \qquad (5.13)$$

$$\tau_k = k\,\delta\tau \qquad \delta\tau = (t - t_p)\frac{1}{n}$$

$$\tau_j = j\,\delta\tau \qquad \delta\tau = (t - t_b)\frac{1}{n} \qquad t_b < t < t_p$$

Three parts in Case 1 are $0<t<t_b$, $t_b<t<t_p$ and $t_p<t<t_1$. The first part is the capacitor charge. The electron gun emits electrons onto the target. The voltage over the capacitor, cell and resistor is increased. The voltage of the capacitor is equal to the sum of the voltages of the switch cell, luminous cell and resistor. When the voltage of the cell reaches the breakdown voltage, gas discharges inside the cell. t_b is the moment of breakdown. At the end of the first part the voltage over the capacitor is expressed by equation (5.11) at time $t=t_b$. During the second part $t_b<t<t_p$ the luminous cell is brokendown and the Y-gun continues to emit electrons onto the target. The capacitor may continue to obtain the electrons from Y-gun. Then we have: $i_2 = i - i_1$. Probably there is another situation: the capacitor also discharges when the cell is brokendown. Then $i_2 = i + i_1$. When the scan is finished, $t=t_p$, the capacitor sustains the gas discharge inside the cell.

In Case 2 shown in Fig. 5.3, at the point $t=t_p$ the cell scan is complete. The voltage over the cell just reaches the breakdown value. Then let $t=t_p$ in the formula (5.8) and (5.7) we can obtain the voltage over the capacitor and the current flowing through resistor R. At this point the initial condition for the voltage of the capacitor is the last value of the formula (5.13). we then have:

$$0<t<t_p \qquad V_c = \frac{i}{c+c_t}t + [\,1 - \exp(-\frac{t}{RC_q})\,]\,\frac{RC_q}{c+c_t}\,\frac{c_t}{c}\,i + V_{c0} \tag{5.13}$$

$$t_p<t<t_1 \qquad V_c = \exp(-\frac{t}{RC_q})\{\frac{i}{c+c_t}t_b + [\,1 - \exp(-\frac{t_b}{RC_q})\,]\,\frac{RC_q}{c+c_t}\,\frac{c_t}{c}\,i + V_{c0}$$

$$+\frac{1}{RC}\sum_{j=0}^{n-1} \exp(\frac{t_j}{RC_q})(V+V(\tau_j))\,\delta\tau_j\,\} \tag{5.14}$$

$$\tau_j = j\,\delta\tau \qquad \delta\tau = (t - t_p)\frac{1}{n}$$

Case 3 is very similar to Case 2. t_b intends to be slightly larger than t_p. Actually, if the voltage over the capacitor is higher than the breakdown voltage of the luminous cell, once the cell scan is finished, it continues to charge the cell. The voltage of the cell increases until the gas discharges. if the current of the electron beam is not large enough to charge the capacitors to a certain voltage the gas discharge cannot happen. A black spot is on the display screen. Some measures need to be taken to get rid of the surplus charge both on the capacitor and the display cell. Otherwise the voltage of the receiving target would be lower than the one as usual. This probably causes a deformation to the image. The issue about this is beyond the scope of this thesis. After scanning, the formulas for calculating the current and the voltage of the drive circuit are:

$$i_2 = (\frac{V}{R}+i_{2p})\exp(-\frac{t}{RC_q}) \tag{5.16}$$

$$V_c = V_{cp} - \frac{1}{C}(\frac{V}{R}+i_{2p})RC_q[1-\exp(-\frac{t}{RC})] \tag{5.17}$$

where:

i_{2p} the value of i_2 at the time when the cell scan finishes.

V_{cp} the value of V_c at the time when the cell scan finishes.

When the voltage over the cell reaches the breakdown voltage, Eqs. (5.16) and (5.17) give the last value of the current and voltage. They are used by the Eqs. (5.14) and (5.15) as initial condition.

The analysis for Case 3 can use formulas (4.13) and (4.14).

CHAPTER 6

SIMULATION OF DRIVE CIRCUIT

6.1 Summary of Simulation

This chapter analyze the behavior of a drive circuit, investigates each element's effects on the I-V characteristics of the drive circuit, and makes suggestion on the design of the drive circuit.

For BM-PDP through numerical simulation method a typical working process of the drive circuit is shown in Fig. 6.1-2. As shown in Fig. 6.1 the voltage over a capacitor and a luminous cell change with time. Fig.6.2 shows the current through the capacitor and the luminous cell. There are four major periods as shown in Fig. 6.1: scan, capacitor discharge, breakdown and gas discharge sustainment. When the voltage of a cell reaches the breakdown voltage, the voltage over the capacitor and the current through the cell are the initial condition of breakdown. They determine the procedure of gas discharge. As shown in Fig. 2.1, different currents flowing through a cell determine the different statuses of gas discharge such as subnormal glow, normal glow and abnormal glow etc.. Thus choosing a proper parameter for each element in the drive circuit is important in controlling gas discharge process. The following parameters are used in the simulation:

i current of electron beam gun (Y-gun),

V_b breakdown voltage of gas,

C capacitance of capacitor,

C_t capacitance of luminous cell,

R resistance of resistor,

V_s sustaining voltage of gas discharge.

t_l line scanning time period of Y-gun. it is a time interval within it the Y gun scans all the column electrode.

It is assumed that the switch cell is turned on during the simulation. The selection gun (X gun) scans the switch cell in a little advance of the Y gun and keeps scanning the same switch cell till Y gun finishes scanning column electrode from the leftmost to the rightmost one. Thus the voltage over the switch cell is constant. Assuming that all the electrons emitted from Y gun are received by the target and the current of an electron gun is a square wavelike, as the scanning time is extremely short i.e., about 5 μsec., the following parameters can be calculated:

V_c voltage over the capacitor,

V_n voltage over the luminous cell,

i_1 current through the capacitor,

i_2 current through luminous cell,

These parameters indicate whether the gas in the cell can be broken down and in what status of the gas discharge is. Among all the parameters of a drive circuit, the voltage over the capacitor, the initial current of the breakdown (which is the current through the cell when gas discharge starts) and the length of time period of capacitor discharge are the three major parameters of a working process.

During the simulation the value of the resistor and capacitor are chosen to satisfy one cycle scanning delay, which means after breakdown the discharge process sustains to keep the brightness till the Y gun finishes scanning all the column electrodes. The calculation shows the working process of a currently designed drive circuit is Case 3, because a relatively large resistance of the resistor is chosen. All the simulation is based on this testing model. Case1 is the situation when a small capacitor and resistor are chosen.

The simulation results show that the final voltage over the capacitor when the cell scan finishes is mainly determined by i and C. The voltage over the capacitor is sensitive to i. This suggests a good possibility that i can be used to control the gas discharge at different statuses. Hence this current is used to carry the image signals. The relationship between i and V_c is almost linear, as the scanning time is so short. The linearity gets better if the number of pixels increases implying that the cell scan time becomes shorter. The final voltage increases when C is decreased. The effects on the final voltage by the resistor is not significant.

When the cell scan finishes, capacitor discharge starts. This process continues until V_t reaches the breakdown voltage and the gas discharge starts. It is critical that the final voltage over the capacitor should be high enough for the voltage over the cell to reach the breakdown voltage. This was discussed in the Chapter 5 section 5.1 as its working condition was required by the drive circuit. Another important issue is how long the capacitor discharge takes. The time period of the capacitor discharge is determined by R and C_t. Larger value of a cell's capacitance results in longer time period of the capacitor discharge. To avoid flick on the panel screen, the whole process including scan, capacitor discharge and sustaining gas discharge should finish within t_l.

The initial current of the gas discharge is also critical for the BM PDP. Basically if we lower the breakdown voltage and the sustaining voltage, the current of Y gun can also be reduced, then Eq. (5.1) can be satisfied. Therefore we can increase the initial current of gas discharge. Increasing the electron current increases the initial current. R is another factor to determine the initial current. Obviously a larger resistor results in smaller current, while it also brings longer capacitor discharge time. The capacitance of the luminous cell can affect the initial current too. The larger the capacitance is, the smaller the current is, and vice versa.

6.2 Results of Simulation

The parameters used in the simulation are listed as follows. When they are changed in each individual calculation, the data are marked in the Fig.

C=1.587000e-11 C_t=7.500000e-12

R=3.000000e+06 i=1.000000e-03

V_0=5.400000e+02 the initial value of the voltage over the capacitor.

V_d=1.300000e+02 breakdown voltage minus sustain voltage.

t_p=4.960000e-06 the cell scan time.

V_{c0}=2.700000e+02 the sustain voltage.

Fig.6.1 Shows a typical voltage curve of the capacitor and the cell in a working process. There are three ranges: scanning (from 0 to 10), capacitor discharge (from 11 to 133) and gas discharge (after 134). The unit of x axis is $4.96*10^{-1}$ μsec. During the sustaining period the unit of time changes into 4.762*10 μsec. The curve at the lower part shows the voltage over the luminous cell. The upper curve shows the voltage over the capacitor. After the cell scan the voltage over the luminous cell keeps increasing until it hits the horizontal line. Gas discharge happens at this point.

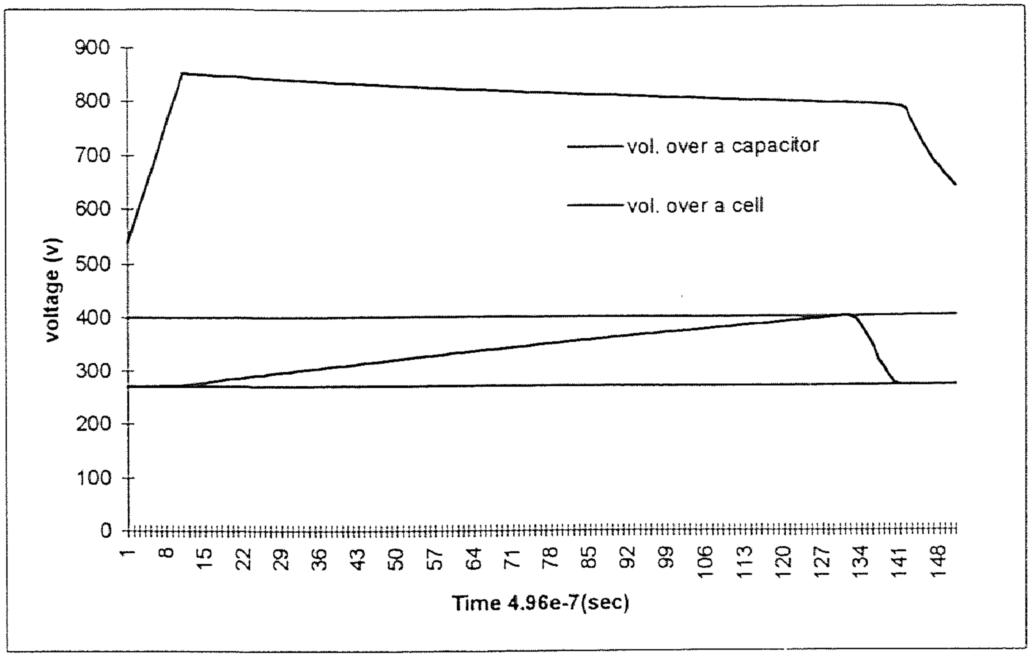

Fig. 6.1 A Typical Voltage Curve over a Capacitor and a Cell

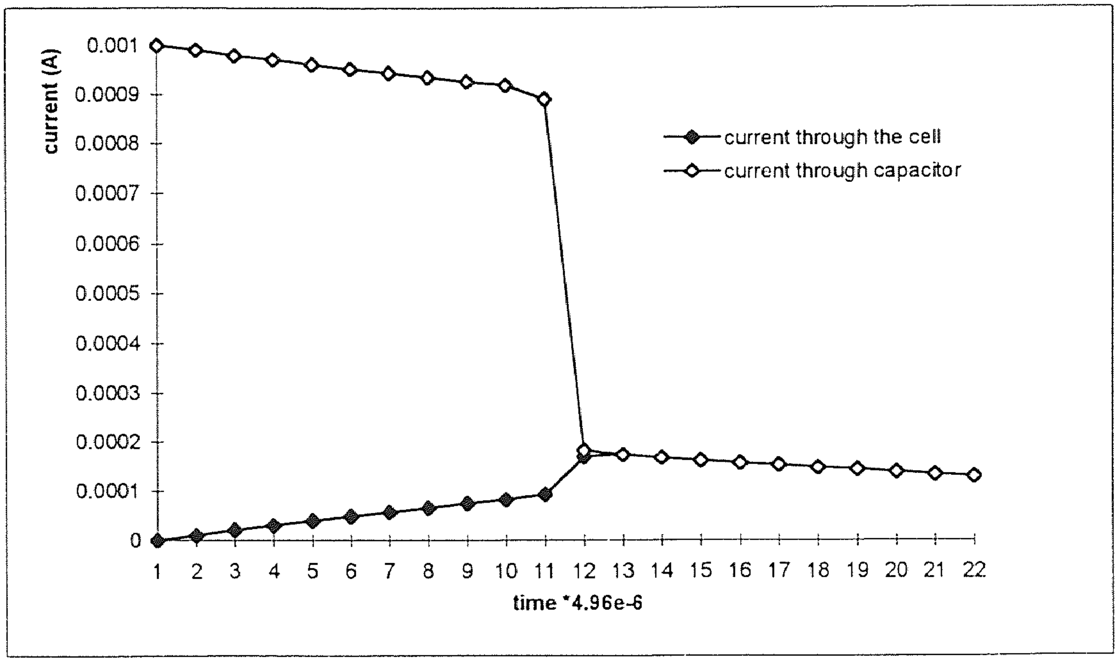

Fig. 6.2 A Typical Current Curve of Luminous Cell and a Capacitor

Fig.6.2 shows the current through the cell and the capacitor before the breakdown. During the scanning most current flow to the capacitor because R is large and there is no resistance in the part of capacitor.

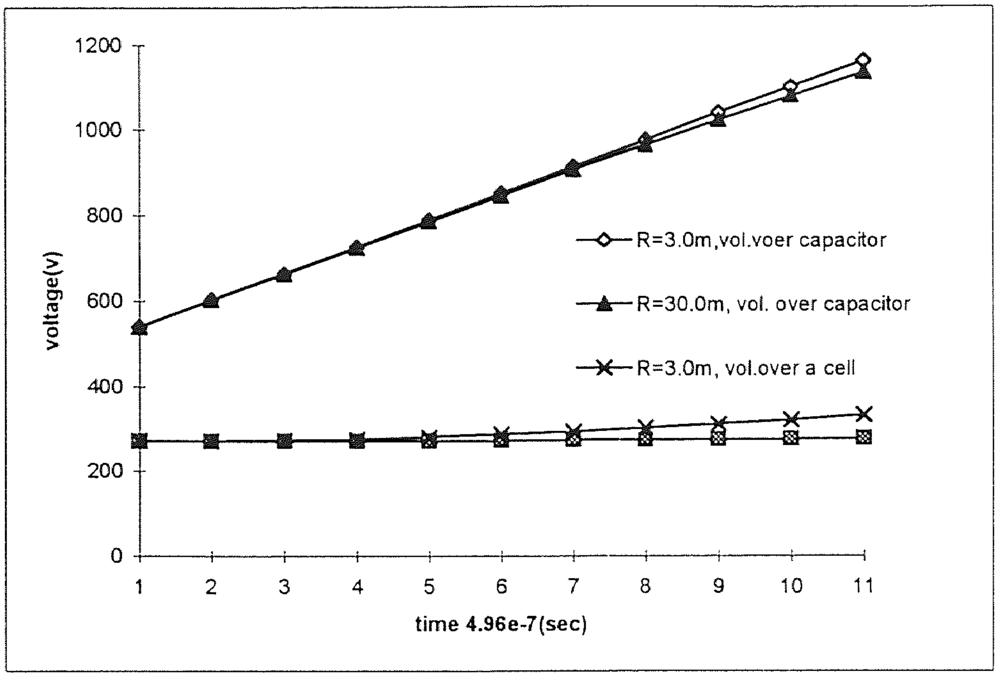

Fig. 6.3 The Voltages Affected by the Resistor

Fig.6.3 shows that R is not so sensitive to the final V_c and V_t when the cell scan finished. In Fig.6.2, two resistance value are 30.0 MΩ 3.0 MΩ. But the curve does not show a significant difference. Resistor R is not efficient to adjust the final voltage.

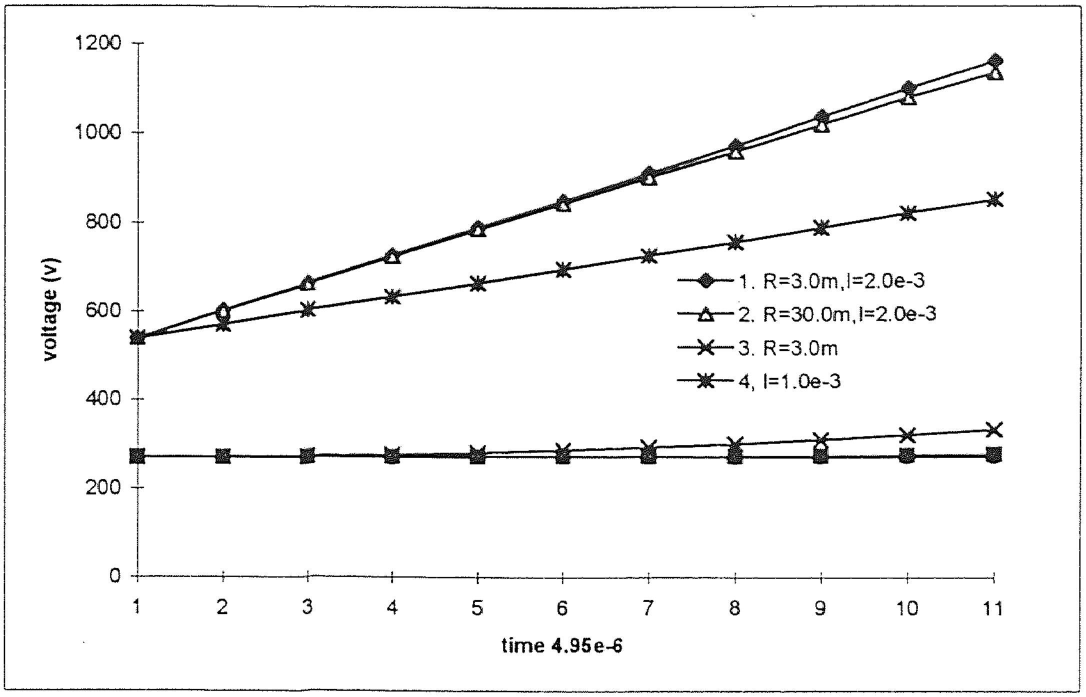

Fig. 6.4 The Voltage as Function of the Current of Y Gun

Fig. 6.4 shows the electron current affecting the voltages over the cell and the capacitor. Series 1 and series 2 are the voltage over the capacitor when the electron current is $2.0*10^{-3}$ (A). Series 4 is the voltage when the electron current is $1.0*10^{-3}$(A). The effect on the cell's voltage is weak, but strong for the voltage over the capacitor. As a contrast, the resistance corresponding to the series 1 is 30.0 MΩ. The resistance corresponding to the series 2 is 3.0 MΩ. The difference between series 4 and series 1 indicates that i is sensitive to the initial condition of gas discharge because the final voltage of the capacitor effects the initial condition. Thus we can use i to carry signals which are to be shown on the screen.

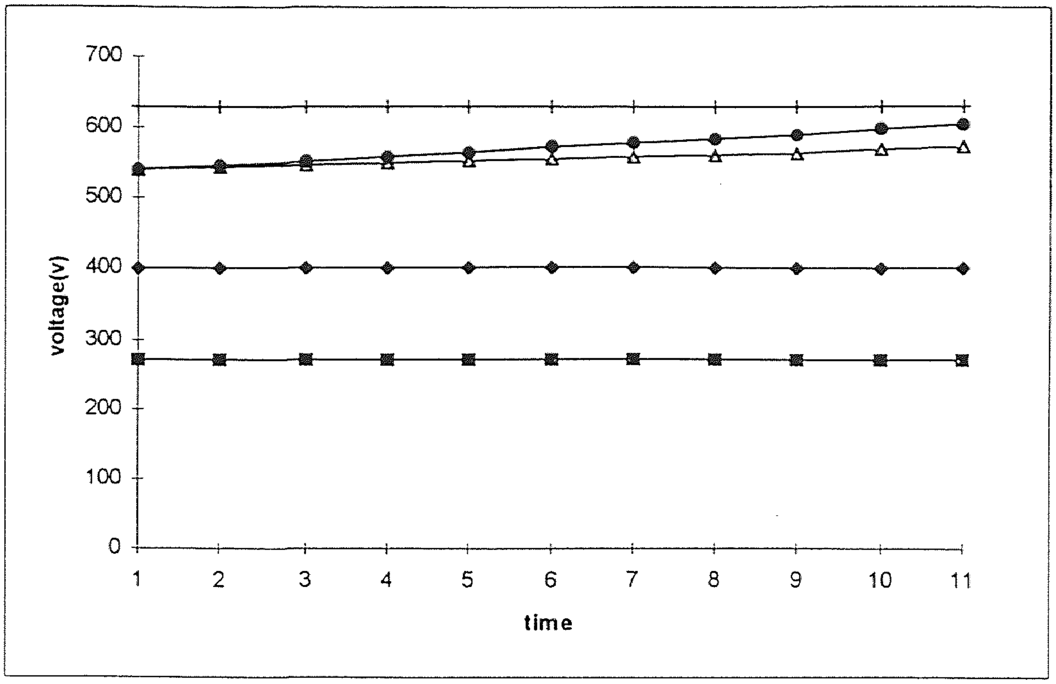

Fig.6.5 Some Failed Examples of Designation

Figure 6.5 Shows that some failed designs due to improper parameters of the drive circuit. When the cell scan finishes the voltages over the capacitor and cell are too low to reach the breakdown voltage.

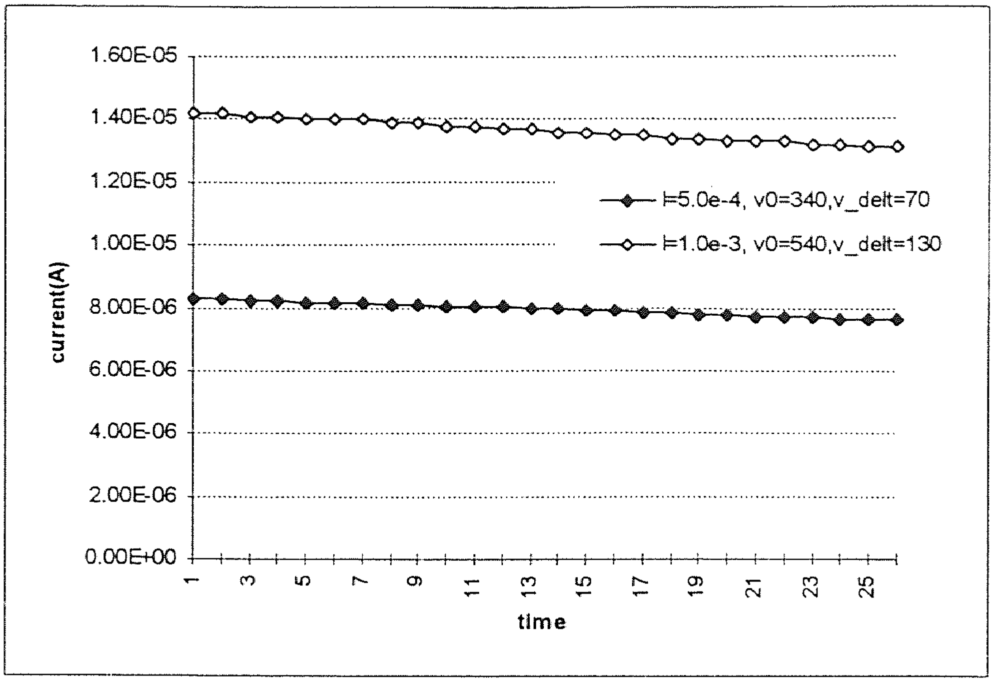

Fig.6.6(a) The Different Initial Current at Breakdown Point

According to Fig. 2.1 the gas discharge can work at different currents under same voltage or in a small range around the breakdown voltage. These different currents show different work ranges of gas discharge such as normal glow, Townsend discharge, subnormal glow and abnormal glow, etc. Fig. 6.6(a) and Fig. 6.6(B) suggest that by adjusting the value of the resistor and the breakdown voltage, different working currents can be reached. Between these two curve, the current is around the subnormal glow range.

Basically we can reduce the breakdown voltage and the electron gun current to reduce the current that flows through the cell. Or we can increase R to reduce the current.

The data of drive circuit are: for series1, the breakdown voltage and the sustain voltage are both 70 volts. For series 2 they are 130 and 270 volts. Resistance for both is 30 MΩ.

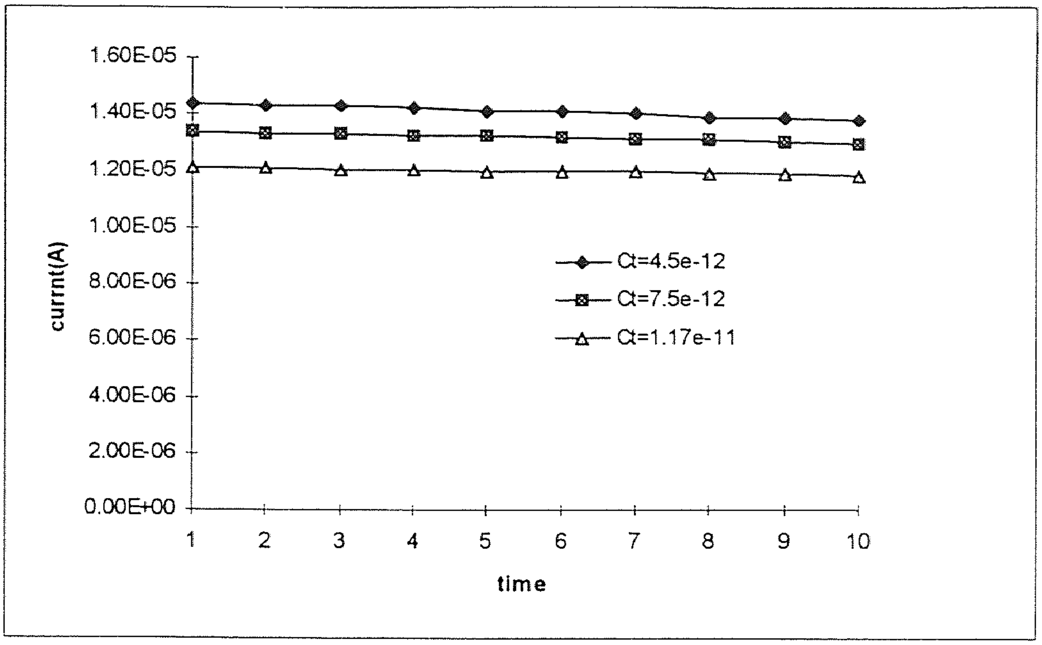

Fig. 6.6(b) Different Initial Current of Gas Discharge by the Capacitance of Luminous Cell

Figure. 6.6(b) indicates that the capacitance of the cell is not very sensitive to the current through the cell during the capacitor discharge and the process of the glow.

C_t corresponding to series 3 is $1.17*10^{-11}$ (F) and $7.5*10^{-12}$ (F), $4.5*10^{-12}$ (F)to series 2 and series 1 respectively. The larger the capacitance of the cell is, the smaller the current through the cell. This is because larger capacitance needs more electrons to accumulate the voltage to reach the breakdown point during the capacitor discharge, thus the final voltage of the capacitor is lower. But the capacitance of the luminance cell is very sensitive to the length of time during the capacitor discharge.

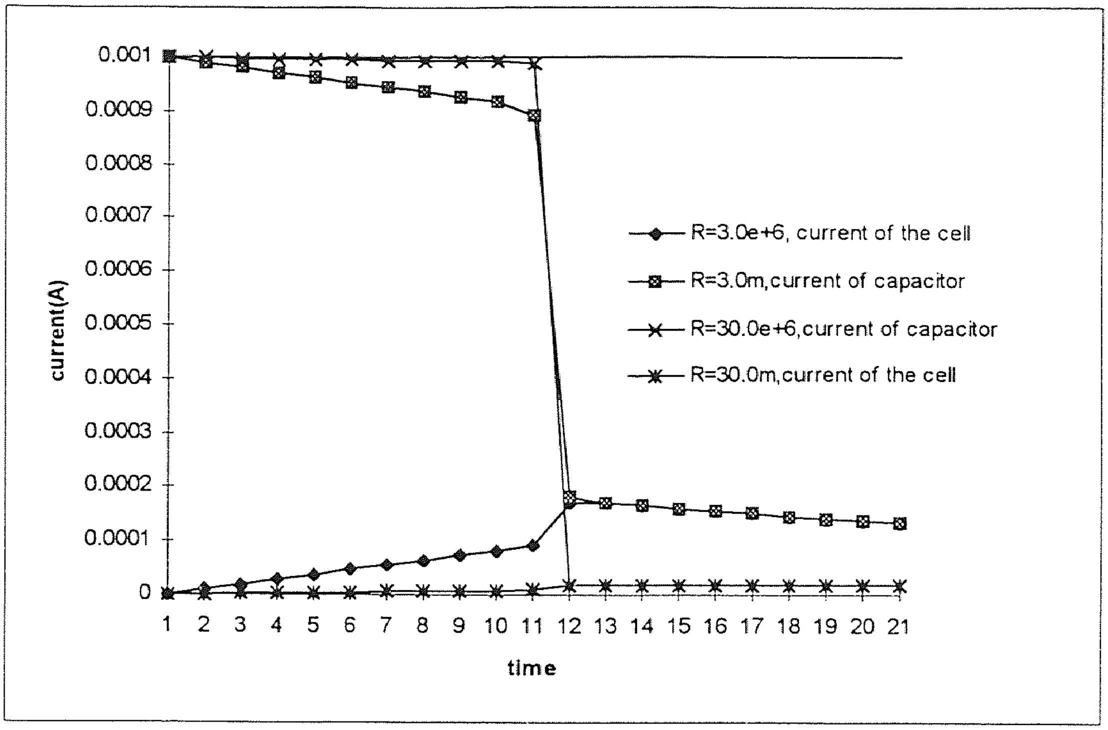

Fig.6.7 The Currents under Different Resistors

Figure.6.7 shows that the comparison of different resistance values affecting the current through i_1 and i_2. The resistance corresponding to series 3 is 30.00 MΩ and 3.00MΩ to series 2. The 10 times difference of resistance of resistors causes around 10% difference of the current during the cell scan. But the initial current of gas discharge have a relatively large difference by resistors. If the initial current is more important than the one during the cell scan, the different value of R can be used to adjust the initial current. When larger resistance is employed to reduce the initial current, it must be taken under consideration that it prolong the time period of the capacitor discharge.

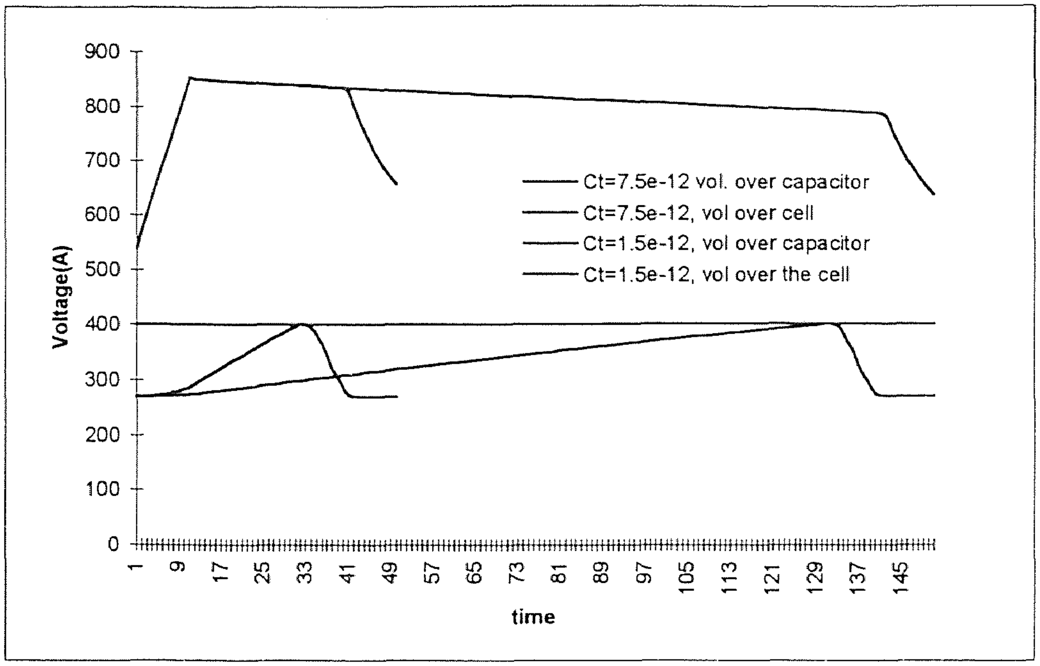

Fig. 6.8 The Different Length of Capacitor Discharge

Fig.6.8 Shows that the capacitance of the luminous effects the length of time of capacitor discharge. A larger capacitance of the cell results in a longer capacitor discharge.

In Fig. 6.8 the capacitance of luminous cell corresponding to the two longer curves is 7.5 $*10^{-12}$ F. The C_t corresponding to two shorter curves is 1.5 $*10^{-12}$ F. As shown in Fig. 6.6(b) the capacitance of luminous cell does not effects the initial current significantly. Thus we can adjust the length of time of capacitor discharge by the C_t. But there are no significant affection on the initial current.

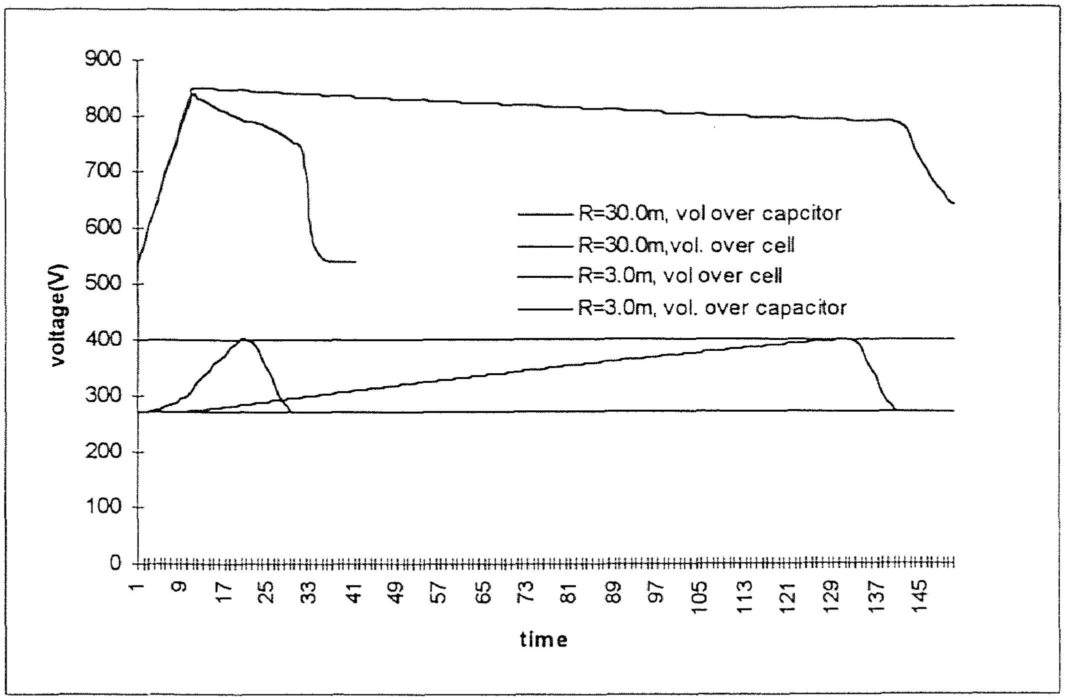

Fig. 6.9 Different Voltage Curve with Different Resistors

Fig. 6.9 shows that the resistance of the resistor affects the length of time during the capacitor discharge. The resistance corresponding to two short curves is R=3.0MΩ and to tow longer curves is 30.0MΩ.

In Fig. 6.9 two upper curves are the voltages over the capacitors. They have value at highest point 851 V and 837 respectively. This difference is not significant comparing to the 10 times difference of resistance. But the resistor effects the length of capacitor discharge tremendously. As shown in Fig.6.7 a small resistor results in relatively large initial current. If we take a consideration on the efficiency of electrons emission, reducing resistance of resistor is a possible way to obtain a desired initial current.

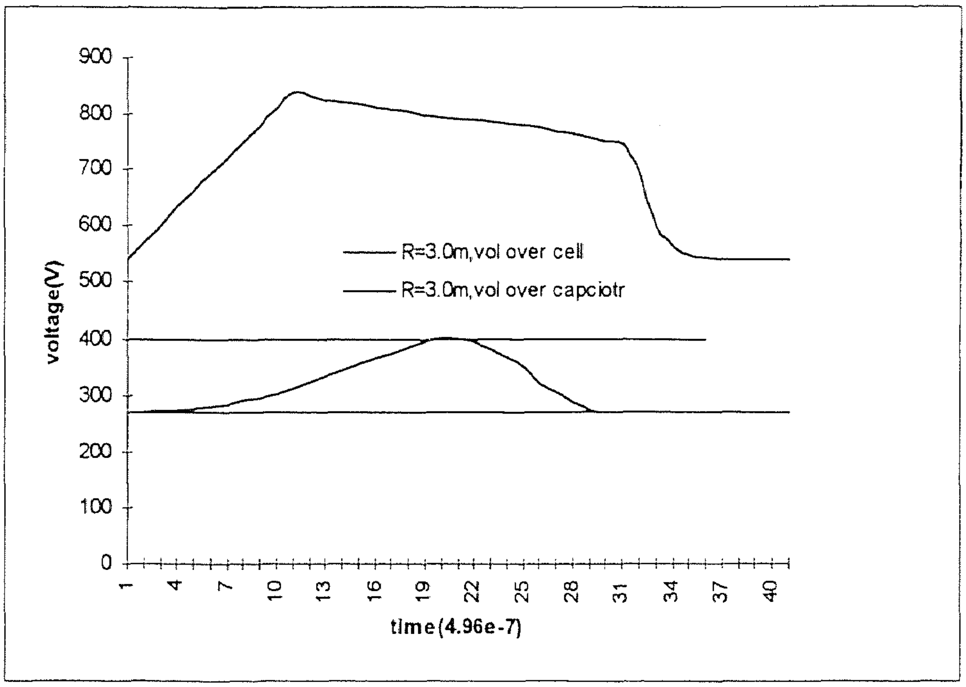

Fig. 6.10 A Proposal for Drive Circuit

Fig. 6.10 shows an operation of a proposed design of the drive circuit. The resistance of resistor in the drive circuit reduces to 3.0MΩ. It shorts the process of capacitor discharge a lot. It also shorts the prolong period of gas discharge. The prolonged gas discharge period functions to obtain a better vision. If the rate of the cell scan is fast enough the shortness of prolonged gas discharge period can be compensated. An obvious advantage of this proposal is that the voltage of the capacitor drops back to the initial condition around 540 when the whole process finishes. This make the BM PDP words repeatedly without any other extra measure.

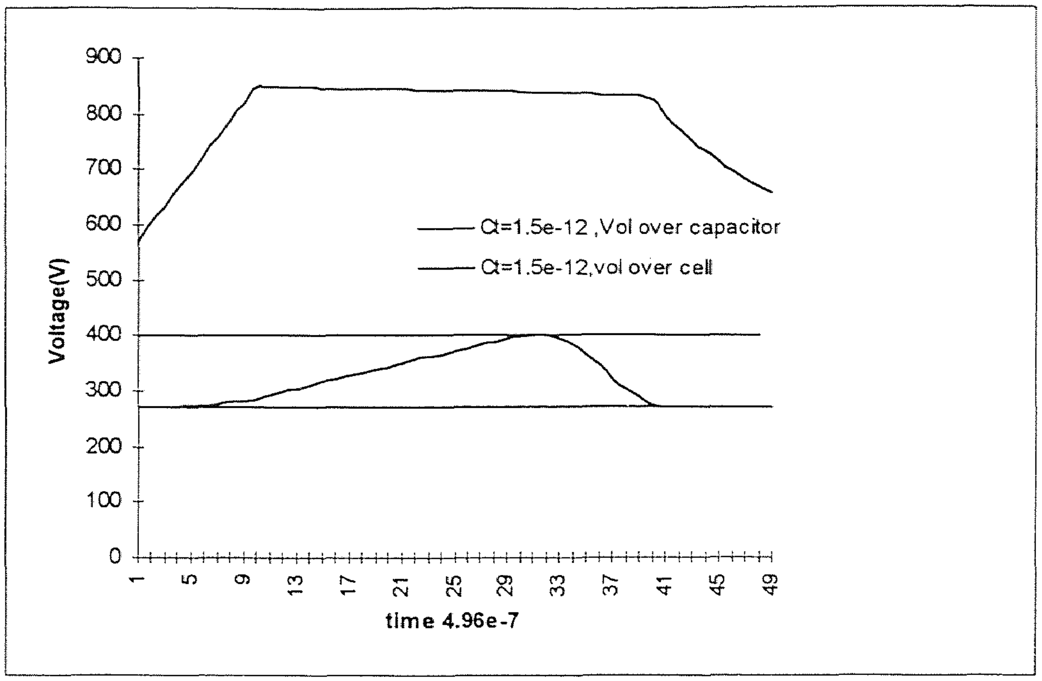

Fig. 6.11 A Proposal of Drive Circuit

Fig.6.11 is another proposed designation. In this proposal the capacitor discharge is around three times long as scanning period.

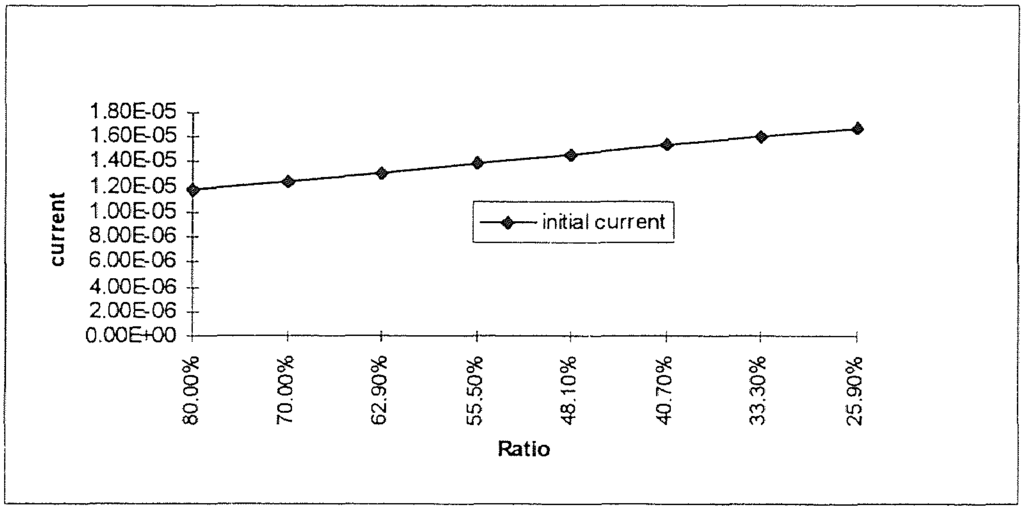

Fig.6.12 The Variation Initial Current by the Ration of V_d and V_s

Fig.6.12 shows the variation of initial current of breakdown with the ratio of V_d and V_s. The curve shows that when the Ratio decreases the initial current increases.

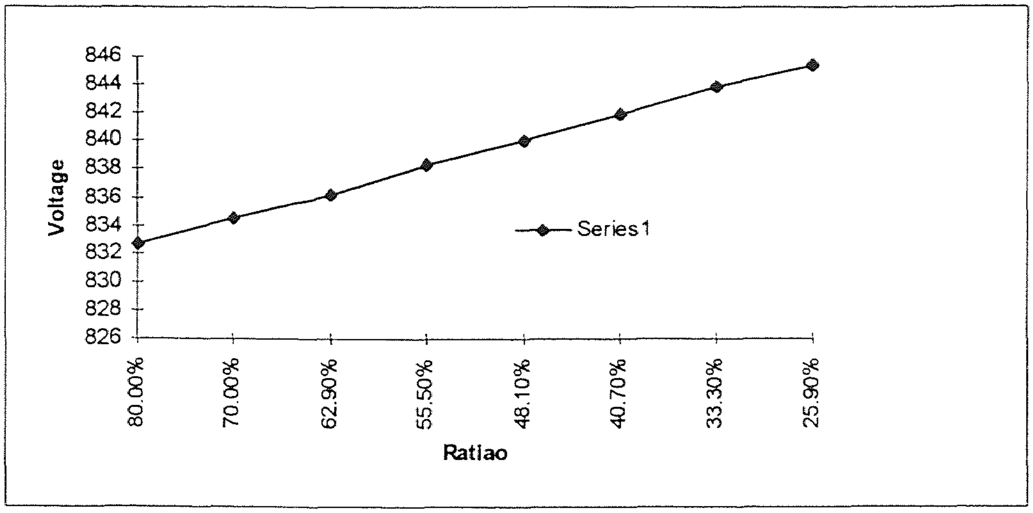

Fig. 6.13 The Variation of Initial Voltage with V_d and V_s

Fig.6.13 shows the variation of initial voltage of breakdown with the ratio of V_d and V_s. The curve shows that when the Ratio decreases the initial voltage increases.

CHAPTER 7

CONCLUSSON

7.1 Contributions

This thesis presents the idea of a BM PDP device. The device employs two electron guns instead of expensive semiconductor switches. It provides a shortcut to lower the current flat panels' manufacturing cost greatly. The contributions of the thesis are as follows:

1) To study the details of the plasma inside a luminous cell, a series of partial differential equations are given. These equations describe the theory of multi-particles gas discharge. BM-PDP is potentially capable of working at relatively high voltages, which makes it possible to choose the gas mixtures in a relatively wide range. These equations are useful tools to investigate the details of the gas mixtures.
2) The drive circuit of the BM PDP device is studied. A criterion on its working condition is given to design the drive circuit and the BM PDP. Two formulas are given to calculate its breakdown point of time. These two formulas are used in different situations: breakdown during and after the cell scan respectively. There are three cases under which the drive circuit may work. These three cases are determined by the parameters of the drive circuit, gas mixture and current of electron-guns. Formulas describing each different situation are also derived.
3) A numerical simulation of the BM PDP is presented. The following conclusions are drawn:
    a) The final voltage over the capacitor is mainly determined by the capacitance of the capacitor and the current of the electron gun. The

current of electron beam gun is sensitive to the final voltage. This shows the possibility that the signal of image can be carried by the electron beam gun;

b) The duration of the capacitor discharge is mainly determined by the resistance of the resistor and the capacitance of the luminous cell;

c) The initial current of gas discharge is mainly determined by the Y-gun, capacitance of the capacitor and resistance of resistor.

d) Also, two drive circuit designs are given based on the analysis results. One of them satisfy that the variables back to initial values when an operation finishes. Another has a shorter capacitor discharge process.

7.1Limitations and Future Research

Many research issues remain unsolved in order to put the BM PDP device into practical use. These includes:

1) The numerical calculation of the plasma's behavior inside the luminous cell during the gas discharge process. Several issues are to be studied with the numerical calculation. They are: a) The voltage over the luminous cell and the current inside it during the gas discharge; b) The radiation during the gas discharge and the deposition of a phosphor layer which is related to the luminance of the device; and c) The structure of luminous cell.

2) An investigation is needed if we choose very small resistance and large current of the electron beam gun. The operation of the drive circuit may be different in this

case. For example: gas discharge may happen during the scan, and the value of voltage over the capacitor, could be back to the original value more easily.

APPENDIX A

EQUATION SETS OF MULTY KINDS OF PARTICLES PLASMA

A.1 Boltzmann's Equation

Boltzmann's equation is used to describe the motion of the particles in plasma. In a wide variety of situations the rate of atomic processes depends strongly on the energy distribution of the interacting particles. This particularly so when there is a threshold for some inelastic process. One therefore needs to find the energy distribution function in a self-consistent way. This means that a more detailed description of the collision processes is required.

when a particle moves around in the plasma its energy, momentum, and some other characters are changed whenever it has a collision with other particles. In general, every particle has different value of these quantities from other particles. In order to describe the plasma, a function f($\vec{x},\vec{v},t$) called distribution function is introduced. We think each micro quantity like gas energy, pressure, temperature, is average over all the particles in the plasma. If a particle is focused on or traced, its energy, momentum is changed randomly. To determine the value of these quantities we use a distribution function. The energy and momentum are determined by seven parameters of particle which are $\vec{x},\vec{v},t$. The distribution function shows the number of the particles that fall into the range (x→x+dx,y→y+dy,z→z+dz, v_x→v_x+dv_x, v_y→v_y+dv_y, v_z→v_z+dv_z, t) is relatively fixed. This makes it possible to calculate the average value of the quantities.

According to the definition of the distribution function, we have:

$$f_a\left(\vec{x},\vec{v},t\right)=\frac{dN_a}{d^3xdv^3}$$

where, dN_α is the number of the particles of type α lying in the volume element dX^3 and whose velocities fall in the velocities ($v_x \to v_x + dv_x$, $v_y \to v_y + dv_y$, $v_z \to v_z + dv_z$) and position fall in: $((x \to x + dx)\vec{i} + (y \to y + dy)\vec{j} + (z \to z + dz)\vec{k})$.

Then:

$$N_\alpha(\vec{x},t) = \frac{\partial N_\alpha}{\partial V} = \frac{\partial N_\alpha}{dxdydz} = \iiint f(\vec{x},\vec{v},t)\, dv_x\, dv_y\, dv_z$$

and

$$dN_\alpha(\vec{x} + \vec{v}\,\Delta t,\ \vec{v} + \vec{a}\,\Delta t,\ t + \Delta t) - dN_\alpha(\vec{x},\vec{v},t)$$

$$= \Delta N_c$$ subscript c means collision.

For any function $G(x, y, z) \to G(x + \Delta x, y + \Delta y, z + \Delta z)$

$$G(x + \Delta x, y + \Delta y, z + \Delta z) = G(x, y, z) + \frac{\partial G}{\partial x}\Delta x + \frac{\partial G}{\partial y}\Delta y + \frac{\partial G}{\partial z}\Delta z + \ldots\ldots$$

Therefore, the following equation can be obtained:

$$\frac{\partial f_\alpha}{\partial t} + \vec{v}\,.\,(\nabla . f_\alpha) + \vec{a}\,.\,(\nabla_v . f_\alpha) = (\frac{\Delta f_\alpha}{\Delta t})_c$$

where c means collision. This is called Boltzmann's equation.

A.2 Multi-Kinds of Particles Plasma Transportation Equation Set

In plasma, the statuses of the particles are described by their positions, velocities at certain moment t. The inter-collision and force (e.g. electromegnatic force) put on each particle change the micro status of the plasma. At the micro scale, we use micro quantities to describe the plasma such as voltage, current in the plasma, pressure, temperature, energy of the gas and momentum of the gas.

The transportation equation is used to establish the relation between the micro phenomena and macro phenomena. It shows that the macro quantity is the average value over all the particles in the plasma. That means if we apply some action on the particle a relative change of macro quantities can be obtained. In other words, some change in macro quantity it means there are probably some force applied onto the particles.

If $f(\vec{x},\vec{v},t)$ is the distribution function, the number of the particles in a small volume dxdydz is:

$$\Delta \mathrm{N} = \mathrm{dxdydz}\ f_\alpha\left(\vec{x},\vec{v},t\right) \mathrm{d}\,v_x\, \mathrm{d}\,v_y\, \mathrm{d}\,v_z$$

For any quantity $\mathrm{Q}\left(\vec{x},\vec{v},t\right)$:

$$\mathrm{Q}\left(\vec{x},\vec{v},t\right) \Delta \mathrm{N} = \mathrm{dxdydz} \int \mathrm{Q}\left(\vec{x},\vec{v},t\right) f_\alpha\left(\vec{x},\vec{v},t\right)\ \mathrm{d}\,v_x\, \mathrm{d}\,v_y\, \mathrm{d}\,v_z$$

This describes the relation between the micro phenomena and macro phenomena. Combine with the Boltzmann's equation we can obtain:

$$\frac{\partial}{\partial t} [\mathrm{n}(\vec{x},\mathrm{t}) . <\mathrm{Q}>] - [\mathrm{n}(\vec{x},\mathrm{t}) . <\dot{Q}>] + \nabla . [\mathrm{n}(\vec{x},\mathrm{t}) . <\mathrm{Q}\vec{v}>] - \mathrm{n}(\vec{x},\mathrm{t}) . <\vec{v} . \nabla\ \mathrm{Q}>$$

$$- \mathrm{n}(\vec{x},\mathrm{t})\ <\vec{a} . \nabla_v\ \mathrm{Q}> = \partial Q_\alpha$$

When Q is a vector $\vec{Q} = Q_X \vec{i} + Q_Y \vec{j} + Q_Z \vec{k}$, we can get:

$$\frac{\partial}{\partial t} [\ n(\vec{x},\mathrm{t}) < Q_i >] - \mathrm{n}(\vec{x},\mathrm{t}) < \dot{Q}_i > + \nabla . [\ \mathrm{n}(\vec{x},\mathrm{t}) < Q_i\ \vec{v} >] - \mathrm{n}(\vec{x},\mathrm{t}) < \vec{v} . \nabla Q_i > - \mathrm{n}(\vec{x},\mathrm{t}) < \vec{a} . \nabla_v\ Q_i > = \delta Q_i$$

$$\frac{\partial}{\partial t} [\ n(\vec{x},\mathrm{t}) < Q_j >] - \mathrm{n}(\vec{x},\mathrm{t}) < \dot{Q}_i > + \nabla . [\ \mathrm{n}(\vec{x},\mathrm{t}) < Q_j\ \vec{v} >] - \mathrm{n}(\vec{x},\mathrm{t}) < \vec{v} . \nabla Q_j > - \mathrm{n}(\vec{x},\mathrm{t}) < \vec{a} . \nabla_v\ Q_j > = \delta Q_j$$

$$\frac{\partial}{\partial t} [\ n(\vec{x},\mathrm{t}) < Q_k >] - \mathrm{n}(\vec{x},\mathrm{t}) < \dot{Q}_i > + \nabla . [\ \mathrm{n}(\vec{x},\mathrm{t}) < Q_k\ \vec{v} >] - \mathrm{n}(\vec{x},\mathrm{t}) < \vec{v} . \nabla Q_k > - \mathrm{n}(\vec{x},\mathrm{t}) < \vec{a} . \nabla_v\ Q_k > = \delta Q_k$$

This is the set of transportation equations.

A.3 Conservation Equation Sets

Transportation equations give a general principle any quantity transported in the plasma follows some rules. The quantity Q in the transportation equation can be any one which is the function of $\vec{x}, \vec{v}, t$. The quantity finally we get from transportation equation is the result caused by the affection put onto the plasma. This means that if some force is applied onto the gas all the macro quantities change simultaneously. We can use different macro quantity to figure out the interaction in the plasma. Usually the mass, energy , and momentum are employed for this goal.

A.3.1 Mass Conservation Equation

In an enclosed area, for example, the display sell, the mass of the gas is conservative. The ion is the atom which loses the outside layer electron or electrons. Thus if Q = m, the average value of one kind of particles should be same as any single particle. The average of the mass is time independent. It is easy to image that for kind of particle there does not exist a source (this means the gradient of the mass is zero). According to these analysis and assuming Q = m in the transportation equation, we can obtain:

$$\frac{\partial}{\partial t}\rho + \nabla .(\rho \vec{u}) = m_\alpha \int \left(\frac{\partial f_\alpha}{\partial t}\right)_c d^3\mathrm{v}$$

where:

$\rho(\vec{x}, t) = n(\vec{x}, t) m_\alpha$ the mass density of α kind of particle

$n(\vec{x},t)$	the number density of α kind of particle
f_α	the distribution function
u	the velocity of particle in the gas

A.3.2 Energy Equation

General speaking, the energy of a particle is the sum of its kinetic energy and potential energy. There are two reasons here. We can ignore the potential energy: 1) The dimension of the display cell is very small and 2) The mass of the atom is very small. Thus we have Q $=\frac{1}{2}m_\alpha\bar{c}^2$ for the transportation equation.

We need to introduce a parameter: pressure, $p=\frac{1}{3}\rho_\alpha\bar{c}_\alpha{}^2$. We can find that the pressure is the mass effects of the micro particles.

Another thing to notice is that the actions in the plasma are collision and electromagnetic force. Based on these assumptions and definitions we can have:

$$\frac{\partial}{\partial t}\frac{3}{2}P_\alpha + \nabla\,.\,\vec{q} + \frac{3}{2}\nabla\,.\,(\vec{u}\,P_\alpha) + \sum_{i=1}^{3}\sum_{j=1}^{3}\overline{\overline{P}}_{ij}\frac{\partial}{\partial x_i}u_j - \rho < \vec{a}\,.\,\vec{c} > = \delta\,Q$$

where

$\vec{q}$	the flux of the energy
P_α	the pressure of α kind of particle
$\overline{\overline{P}}_{ij}$	the tensor of the pressure of α kind of particle.

There is an alternative form of energy equation form. If we define:

and

$$P=\frac{1}{3}\, m_{\alpha}\,(< c_x c_x > + < c_y c_y > + < c_z c_z >)$$

Then we can get:

$$\frac{3}{2} n_{\alpha} (\frac{\partial}{\partial t} + u_{\alpha} \nabla) T_{\alpha} + \frac{3}{2} \frac{T_{\alpha}}{m_{\partial}}\, \delta Q_m = -\nabla \bar{q} - T_{temp} + \delta Q_e$$

where:

T_{temp} the temperature of the plasma

T_{α} the temperature of α kind of particle

We can choose different energy equations to calculate the plasma. If the pressure is easy to get we can use the former one. And some times when temperature is easy to get then we can use the second energy equation.

A.3.3 Momentum Equation

The momentum of a particle equals its mass times its velocity. We must notice that the momentum is independent of t because we choose $\bar{x}, \bar{v}, t$ as the parameters of plasma. In the plasma particles move randomly. We can assume that any particle moves all directions equally likely. thus the integration of relative velocity, $\bar{C}_{\alpha} = \bar{v}_{\alpha} - \bar{u}_{\alpha}$ called flux vector, is zero.

Let the Q in the Boltzmann's equation be $m_{\alpha}\,(c_i \vec{i} + c_j \vec{j} + c_k \vec{k})$, we can obtain:

$$\rho_{\alpha} [\frac{\partial}{\partial t}\, \vec{u} + (\vec{u} \,.\, \nabla) \vec{u}\,] = \rho_{\alpha} < \vec{a} > - \nabla \,.\, \bar{\bar{P}} + \nabla\, \bar{Q}_{\alpha}$$

This is the momentum equation. In order to get the momentum equation, several basic concept and auxiliary parameters are introduced. The reason that we use the flux vector instead of the absolute velocity is: only micro momentum can be obtain if we use absolute velocity. We cannot figure out the effect caused by the external force put onto the particles by the micro momentum. Because the transportation equation is for any quantity related to the particles and internal and external force, we can choose the flux vector to obtain the momentum equation.

When gas is mix up with several kinds of the particles, the mass and momentum are defined as follows:

The number of molecules of species i

$$n_i = \int f_i(\vec{r}, \vec{v}, t)\, d^3 r \; d^3 v$$

Density: $\rho_i = m_i\, n_i$

Mass density: $\rho = \sum_{i=1}^{k} \rho_i = \sum_{i=1}^{k} n_i\, m_i$

$$n_i\, \varphi_i = \int f_i\, \varphi_i\, d^3 v$$

or. $$\varphi_i = \frac{1}{n_i} \int f_i\, \varphi_i\, d^3 v$$

Average velocity $\vec{a}$ of a mixture:

$$n\, \vec{v} = \sum_i n_i \bar{c}_i = \sum \int f_i\, v_i\, d^3 v$$

$$\rho\, \vec{v} = \sum_i \rho_i \bar{c}_i = \sum_i m_i \int f_i\, v_i\, d^3 v_i$$

A.4 The Equation Sets for the Finite Difference Method (FMD)

The mass equation , energy equation and momentum equation are used to calculate the plasma's behavior in the display cell. These are differential equation sets. A numerical calculation method is needed because it is too difficulty to get a theoretical solution. Here we list all the discrete equations for the mass equation energy equation and momentum equation.

A.4.1 The mass equation for FDM

$$\frac{1}{\Delta t}(n'_{ce} - n_{ce}) + n_{ce}\frac{1}{\Delta x}(v_{Rxe} - v_{cxe}) + v_{cxe}\frac{1}{\Delta x}(n_{\mathrm{Re}} - n_{ce})$$

$$+ n_{ce}\frac{1}{\Delta y}(v_{uye} - v_{cye}) + v_{cye}\frac{1}{\Delta y}(n_{ue} - n_{ce})$$

$$= n_{ce}\,\upsilon_I + <\sigma_I\,\upsilon_e> n_{ce}\mathrm{M} - \alpha_e\,n_{ce}\,n_{ci}$$

for ion's

$$\frac{1}{\Delta t}(n'_{ci} - n_{ci}) + n_{ci}\frac{1}{\Delta x}(v_{Rxi} - v_{cxi}) + v_{cxi}\frac{1}{\Delta x}(n_{Ri} - n_{ci})$$

$$+ n_{ci}\frac{1}{\Delta y}(v_{uyi} - v_{cyi}) + v_{cyi}\frac{1}{\Delta y}(n_{ui} - n_{ci})$$

$$= n_{ci}\,\upsilon_I + <\sigma_I\,\upsilon_e> n_{ci}\,\mathrm{M} - \alpha_i\,n_{ci}\,n_{ce}$$

A.4.2 Energy Equation for FDM

$$n_e\,T_e\,\nabla\,.\,\vec{v}_e = n_e\,T_e\,[\frac{1}{\Delta x}(v_{Rxe} - v_{cxe}) + \frac{1}{\Delta y}(v_{uye} - v_{cye})] + \frac{1}{\Delta z}$$

A.4.3 Momentum Equation for FDM

x coordinate:

$$\rho_{ce} \frac{1}{\Delta t} (v'_{cxe} - v_{cxe}) + \rho_{ce} \; [(v_{cxe} \frac{1}{\Delta x} (v_{Rxe} - v_{cxe}) + v_{cye} \frac{1}{\Delta y} (v_{uxe} - v_{cxe})]$$

$$= - e \, n_{ce} \, E_{cx} - \frac{1}{\Delta x} (P_{\mathrm{Re}} - P_{ce}) - m_{en} \, n_{ce} \, \upsilon_{en} (v_{cxe}) + m_{ei} \, n_{ce} (v_{cxe} - v_{cxi})$$

y coordinate:

$$\rho_{ce} \frac{1}{\Delta t} (v'_{cye} - v_{cye}) + \rho_{ce} \; [(v_{cxe} \frac{1}{\Delta x} (v_{Rye} - v_{cye}) + v_{cye} \frac{1}{\Delta y} (v_{uye} - v_{cye})]$$

$$= - e \, n_{ce} \, E_{cy} - \frac{1}{\Delta y} (P_{ue} - P_{ce}) - m_{en} \, n_{ce} \, \upsilon_{en} (v_{cxe}) + m_{ei} \, n_{ce} \, v_{ei} (v_{cxe} - v_{cyi})$$

APPENDIX B

PROGRAM LIST

```
// this code is used for calculating the first step of BM-PDp
// first step: when the Y-gun scanning the target.
// the current to the cpacitor:i_capacitor, the current to the
// luminance cell i_cell, and the voltage change over the
// capcitor v_capcitor and the voltage over the cell during the
// scanning by the y-gun
// note that the this step finishes once the the luminance cell
// breakdown, after that the calculation switch to another code:
// the date of drive circuit can be input in tow ways 1) write them
// as a initial data. 2) let the value of a spercific data to be
// zero in the initial input iterms, the code will ask you input
// a data during running.// other two parts are added following the charge1.cpp
// after scanning the voltage over the capacitor,cell, the current through
// the drive circuit, after it reaches the breakdown. the
#include<iostream.h>
#include<stdio.h>
#include<math.h>
#include <stdlib.h>
#include <conio.h>
FILE *fi1,*fi2,*fvc,*fvcel;

double capacitor   =1.587e-11;   //capacitance of the capacitor
double cell_capc        =0.15e-11;    //this is a estimation
double resistor   =30.0e6;    //value of resistor
double puls_width  =4.960e-6 ;  //time of scanning(96*84*25)
double e_current   =1.0e-3;   //current of Y-gun
double v0_capacitor=540.00;  //voltage over the capacitor before scanning
double v0_cell    =270.00;  //voltage over the switch cell before scanning
double v_cell_delt =150.0;       //maximum increasment of volt before breakdown
double v_switch    =270.00;  //voltage over the cell before scanning
double prolong                    =4.762e-4; //atfer discharge keep brightness
1/(RC)=4.762e-4.
double dschg_delay =10.0e-6;  //the gas discharge with 10e-6
//int      time_step3  =15;
int        time_step2  =10;
int    time_step =10;              //number of steps to calculate the parameters

void load()  // if data is ==0 then will be asked to input while running
           {      //by this function call.
         if(capacitor==0){
         cout<<"enter the value of capacitor)"<<endl;
```

```
                cin>>capacitor; }
        if(resistor==0){
        cout<<"enter the value of resistor;"<< endl;
                cin>>resistor; }
        if(cell_capc==0){
        cout<<"enter the value of cell'capacitance"<<endl;
                cin>>cell_capc;}
        if(puls_width==0){
        cout<<"enter the value of puls_width:"<<endl;
                cin>>puls_width; }
        if(e_current==0){
        cout<<"enter the value of e_current)"<< endl;
                cin>>e_current; }
        if(v0_capacitor==0){
        cout<<"enter the value of v0_capacitor)"<<endl;
                cin>>v0_capacitor; }
        if(v_cell_delt==0){
        cout<<"enter the value of V-cell_delt)"<<endl;
                cin>>v_cell_delt; }
        if(time_step==0){
        cout<<"enter the number of time step"<<endl;
                cin>>time_step; }
         };
double icell_tptb(double nt,double cq,double lastI2_tp){
return((v_switch/resistor+lastI2_tp)*exp(-(nt/(resistor*cq))));
}         //the current through the cell during the capacitor discharge

double vcapc_tptb(double nt,double cq,double lastvc_tp,double lastI2_tp){
return(lastvc_tp-(v_switch/resistor+lastI2_tp)/capacitor*cq*resistor*
                                        (1-exp(-(nt/(resistor*cq)))));
}        //the voltage over the capacitor during the capacitor discarge

double break_point(double cq,double lastvt_tp,double lastI2_tp) {
return(resistor*cq*log(1/(1-(v_cell_delt-lastvt_tp-v0_capacitor)*cell_capc
                /lastI2_tp/resistor/cq)));
}       // the time from the moment when scanning finish to breakdown

double vcell_tptb(double nt,double cq,double lastvt_tp,double lastI2_tp){
return(lastvt_tp+(v_switch/resistor+lastI2_tp)/cell_capc*cq*resistor*
                                (1-exp(-(nt/(resistor*cq)))));
}       // voltage over the cell during the capacitor discharge

double total_break(double tp, double tc){
return(tp+tc);
}       // the total time from the begining of scanning to the breakdonw
```

```
int break_check(double vcell_tptb, double vcapc_tptb){ //check if get breakdown
if(vcell_tptb-v0_cell<v_cell_delt && vcapc_tptb-v0_capacitor>
                v_cell_delt) return(1);          //continue
if(vcell_tptb-v0_cell>=v_cell_delt && vcapc_tptb-v0_capacitor>
                v_cell_delt) return(0);          //reaches the breakdown point
if(vcapc_tptb-v0_capacitor<=v_cell_delt && vcell_tptb-v0_cell<=
                v_cell_delt) return(2);                              //failed;
                // 0 reaches breakdown, 1 continue to calculte( not breakdown yet)
                // 2 failed.
return(3);
}

double vcapc_tbt1(double nt,double lastvc_tb,double integrate){
return(exp(-(nt/resistor/capacitor))*(lastvc_tb+integrate));
}                          //voltage over the capacitort duringthe gas discharge

long double prolg( int n, double data){
double nt=dschg_delay+n*prolong/time_step;
return(data +(v_switch+v0_cell)*(exp(nt/(resistor*capacitor))-exp(dschg_delay/
        (resistor*capacitor))));
        }

/*long double integ( int n, double data){
long double tt=0.0;
double ntt,t15;
if(n<time_step){
for(int i=0;i<n;i++)
ntt=i*dschg_delay/time_step;
tt=tt+exp(ntt/resistor/capacitor)*(v_switch+data)*dschg_delay/time_step/
        resistor/capacitor;
cout<<tt<<endl;
return(tt);
}
else {
return (tt);
//for(int i=0;i<time_step;i++){
//ntt=i*dschg_delay/time_step;
//tt=tt+exp(ntt/resistor/capacitor)*(v_switch+data)*dschg_delay/time_step/
 //     resistor/capacitor; }
//cout<<tt<<endl;
//ntt=dschg_delay+(n-time_step)*prolong/time_step;
//return(tt+(v_switch+v0_cell)*(exp(ntt/(resistor*capacitor))-
//                       exp(dschg_delay*(1-1/time_step)/(resistor+capacitor))));
                         }
```

```
}        //return the value of the integrated
 */

long double integ( int n, double data){
long double tt=0.0;
for(int i=0;i<n;i++){
double ntt=i*dschg_delay/time_step2;
tt=tt+exp(ntt/resistor/capacitor)*(v_switch+data)*dschg_delay/time_step2/
         resistor/capacitor;}
         cout<<tt<<endl;
return(tt);
//return(2.00);
}        //return the value of the integrated

double i_capacitor(double nt,double cq) {
return(capacitor/(cell_capc+capacitor)*(1+
cell_capc/capacitor*exp(-(nt/(resistor*cq))))*e_current);
}          // function i-capacitor calculte the current flowing to
                                    // the capacitor during the scanning by y-gun

double i_cell(double nt,double cq){
return(cell_capc/(cell_capc+capacitor)*(1-exp(-(nt/(resistor*cq))))*e_current);
}         // function i_cell calculate the current flowing to the cell
                                    // during the scanning bythe y-gun

double v_capacitor(double nt,double cq){
return(nt*e_current/(cell_capc+capacitor)+ v0_capacitor+
         resistor*cq/(cell_capc+capacitor)*cell_capc/capacitor*e_current*
         (1-exp(-(nt/(resistor*cq)))));
}        // function v_capacitor calculate the voltage over the capacitor
                                   // during the scanning bythe Y-gun

double v_cell(double nt,double cq){
return(nt*e_current/(capacitor+cell_capc)+v0_cell-e_current*resistor*cq/
         (capacitor+cell_capc)*(1-exp(-(nt/resistor/cq))));
}         //function v_cell calculates the voltage over the display cell
                                   // during the scanning.
print(FILE *filename ){
fprintf(filename,"\ncapacitor   =%e   cell_cap   =%e",capacitor,cell_capc);
fprintf(filename,"\nresistor    =%e   e_current  =%e",resistor,e_current);
fprintf(filename,"\nV0_capacitor=%e   V_cell_delt=%e",v0_capacitor,v_cell_delt);
fprintf(filename,"\npuls_wodth  =%e   time_step  =%d\n\n",puls_width,time_step);
return 0;}

void main(){
```

```
double  i_cap0tp,i_cel0tp,v_cap0tp,v_cel0tp,v_captptb,i_captptb;
double  v_celtptb,i_celtptb,i_captbt1,v_captbt1,i_celtbt1,v_celtbt1;
double data[15]={400,395,382,365,347,321,305,288,275,270};
double time_record,integ_dschg,lastv_t1,v_capt1t2;
fi1=fopen("\\azjw\\cpp\\icapct","w");   //current through capacitor
print(fi1);
fi2=fopen("\\azjw\\cpp\\icell","w");  // current through the cell
print(fi2);
fvc=fopen("\\azjw\\cpp\\volcap","w");  // voltage over the capacitor
print(fvc);
fvcel=fopen("\\azjw\\cpp\\volcel","w"); // voltage over the cell
print(fvcel);

load();
double  t_step=puls_width/time_step;
double cq=cell_capc*capacitor/(cell_capc+capacitor);
int check=1;
double nt=0;
while(check==1 && nt<=puls_width){
i_cap0tp=i_capacitor(nt,cq);                    //current to capacitor
fprintf(fi1,"\ntime=%e  i_capacitor=%e",nt,i_cap0tp);
i_cel0tp=i_cell(nt,cq);                         //current to cell
fprintf(fi2,"\ntime=%e  i_cell =%e",nt,i_cel0tp);
v_cap0tp=v_capacitor(nt,cq);                    //voltage over the capacitor
fprintf(fvc,"\ntime=%e  v_capacitor=%e",nt,v_cap0tp);
v_cel0tp=v_cell(nt,cq);                     //voltage over the cell
fprintf(fvcel,"\ntime=%e  v_cell    =%e",nt,v_cel0tp);
nt=nt+t_step;
//check=break_check(v_cel0tp,v_cap0tp);
//cout<<"check="<<check<<endl;
//cout<<"vcap0tp="<<v_cap0tp<<endl;
//cout<<"v_cel0tp="<<v_cel0tp<<endl;
}
i_captptb=i_cap0tp;
i_celtptb=i_cel0tp;
v_captptb=v_cap0tp;
v_celtptb=v_cel0tp;
fprintf(fvc,"\n------------------------------------");
fprintf(fvcel,"\n--------------------------------------");
check=break_check(v_celtptb,v_captptb);
nt=0;//puls_width;
while(check==1){
i_celtptb=icell_tptb(nt,cq,i_cel0tp);  //current through the cell during

          // capacitor discharge tp-tb
```

```
fprintf(fi2,"\ntime=%e  i_cell =%e",nt+puls_width,i_celtptb);
fprintf(fi1,"\ntime=%e  i_capacitor=%e",nt+puls_width,i_celtptb);
v_captptb=vcapc_tptb(nt,cq,v_cap0tp,i_cel0tp);      //voltage over the capacitor

        //during the capacitor discharge tp-tb
fprintf(fvc,"\ntime=%e  v_capacitor=%e",nt+puls_width,v_captptb);
v_celtptb=vcell_tptb(nt,cq,v_cel0tp,i_cel0tp);        // the voltage over the cell

        //during the capacitro discharge tp-tb
fprintf(fvcel,"\ntime=%e  v_cell    =%e",nt+puls_width,v_celtptb);
check=break_check(v_celtptb,v_captptb);
nt=nt+t_step;
}
time_record=nt+puls_width;
i_captbt1=i_captptb;
i_celtbt1=i_celtptb;
v_captbt1=v_captptb;
v_celtbt1=v_celtptb;
if(check==2){
cout<<"failed="<<check<<endl;
exit('0');
}
fprintf(fvc,"\n-----------------------------------");
fprintf(fvcel,"\n-----------------------------------");
int n=0;
nt=0;
double data1=270.00;
while(check==0 && n<time_step){
long double third_item=integ(n,data[n]);
v_captbt1=vcapc_tbt1(nt,v_captptb,third_item);
                                          //voltage over the capacitort during the gas
discharge
fprintf(fvc,"\ntime=%e  v_capacitor=%e",nt+time_record,v_captbt1);
fprintf(fvcel,"\ntime=%e  v_cell    =%e",nt+time_record,data[n]);
nt=nt+dschg_delay/time_step;
n++;
integ_dschg=third_item;
lastv_t1=v_captbt1;
cout<<"integ_dschg"<<integ_dschg<<endl;
                                         // there are no break_check here. check is 0 or 2
along with
                                         // the gas discharge
}
fprintf(fvc,"\n-----------------------------------");
fprintf(fvcel,"\n-----------------------------------");
```

```
n=0;
while(n<time_step){
double fourth_item=prolg(n,integ_dschg);       // integ_dschg+t15
nt=dschg_delay+n*prolong/time_step;
v_capt1t2=vcapc_tbt1(nt,lastv_t1,fourth_item);
n++;
fprintf(fvc,"\ntime=%e  v_capacitor=%e",nt+time_record,v_capt1t2);
fprintf(fvcel,"\ntime=%e  v_cell    =%e",nt+time_record,data1);
}
fclose(fi1);fclose(fi2);fclose(fvc);fclose(fvcel);
return ;
}

/*long double prolg( int n, double data){
long double tt=0.0;
for(int i=0;i<n;i++){
double ntt=i*prolong/time_step;
tt=tt+exp(ntt/resistor/capacitor)*(v_switch+data)*prolong/time_step/
          resistor/capacitor;}
return(tt);
}         //return the value of the integrated

long double prolg( int n, double data){
double nt=dschg_delay+n*prolong/time_step;
return(data +(v_switch+v0_cell)*(exp(nt/(resistor*capacitor))-exp(dschg_delay/
          (resistor*capacitor))));
          }  */

/*while(n<time_step){
double fourth_item=prolg(n,integ_dschg);       // integ_dschg+t15
nt=dschg_delay+n*prolong/time_step;
v_captbt1=vcapc_tbt1(nt,lastv_t1,fourth_item);
}
double vcapc_tbt1(double nt,double lastvc_tb,double integrate){
return(exp(-(nt/resistor/capacitor))*(lastvc_tb+integrate));
}                          //voltage over the capacitort duringthe gas discharge
*/
```

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