Development of new Structure AC-PDP using Thick Film Ceramic Sheet Technology

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Abstract
New planar discharge structured AC-PDP has been developed by using TFCS (Thick Film Ceramic Sheet) technology. By applying TFCS to AC-PDP, a sustaining electrode and scanning electrodes are embedded in the TFCS. It is shown that panel performances such as electrical and optical characteristics are superior to commercialized coplanar AC-PDP as well as cost reduction. Moreover the experimental result shows panel performances can be improved drastically by continuous development.

1. Introduction
Commercialized PDPs have several issues to improve higher luminous efficiency and achieve lower manufacturing cost. For cost reduction, several additive methods have been suggested to take place a photo-lithography process such as a sand-blasting method and photo-sensitive materials [1,2,3,4]. And equipment actualizing higher productivity and energy saving has been studied [5]. For efficiency improvement, several papers has been reported such as higher Xe content, wider discharge gap, and so on [6,7,8]. However no proposal for panel structure, which satisfy both a higher productivity and an improved performance, has been reported yet. The possibility of improving luminous efficiency with planar discharge structured panel was reported [9]. But the color panels were not commercialized because of short lifetime of phosphor and complexity of its structure. We developed a planar discharge structured AC-PDP having parallel electrodes by using a new TFCS technology [10]. As a result, we confirmed the possibility of a luminous efficiency improvement as well as a cost reduction.

2. TFCS (Thick Film Ceramic Sheet) for PDP
2.1 TFCS Technology
Figure 1 shows an example of the TFCS process. Unlike a conventional thick film process, TFCS can be separated from the substrate after a baking. Basically the film formation materials and process are the same as those used for the conventional thick film process. Only a special material for a separating is required. As a substrate, ceramics plate and glass substrate a having high strain point can be selected for the continuous use. Thermal expansion coefficient matching between the substrate and the TFCS is not necessary because of week adhesion. By optimizing the materials, particle size distribution and film thickness, the size accuracy and warp of the TFCS can be controlled.

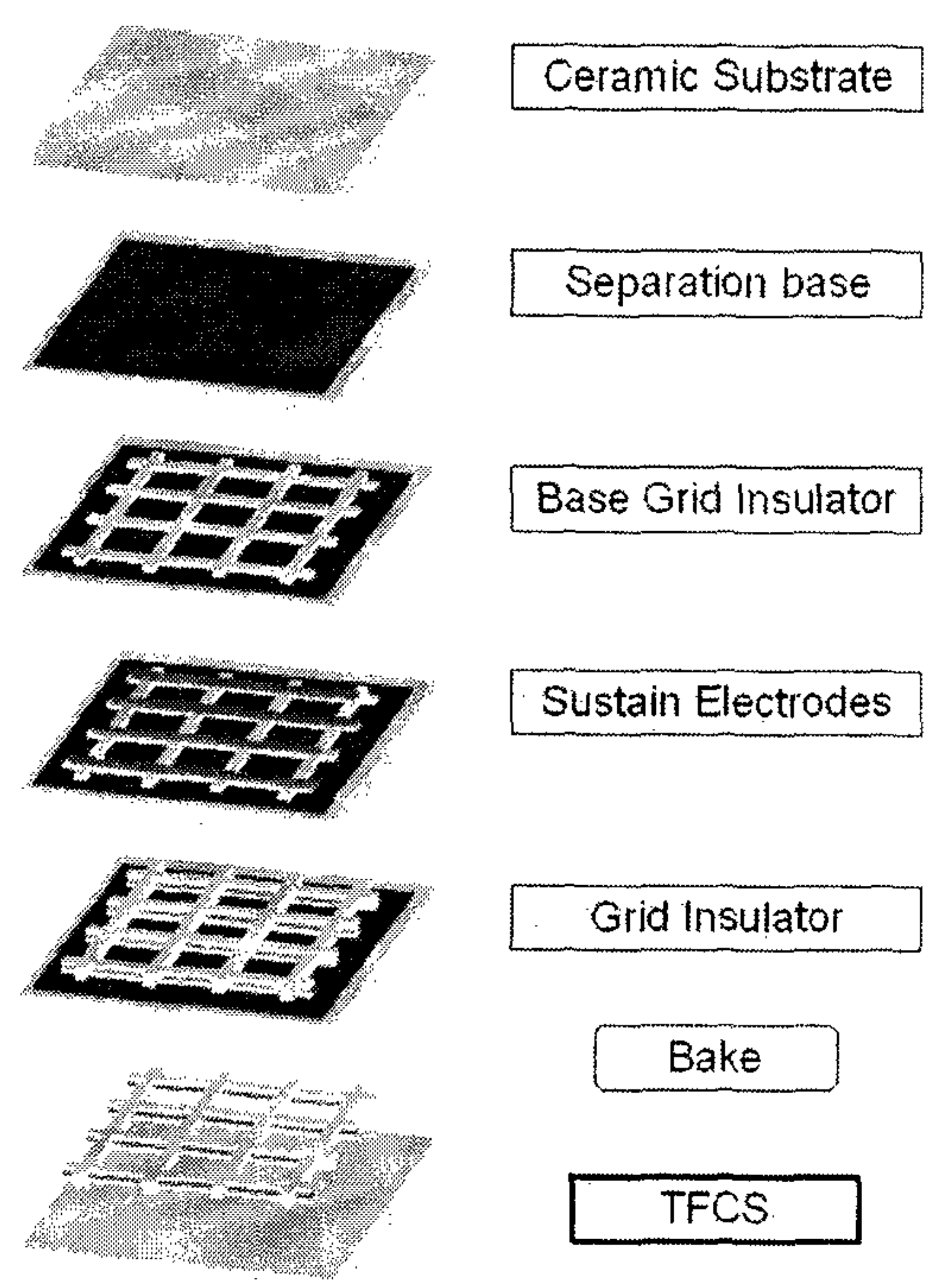


Figure 1. An example of TFCS Process
[1st.Generation TFCS-PDP]

2.2 Structure of TFCS- PDP
Within a TFCS, more than 1 pairs of electrode can be formed. It is at a distinct advantage compare with the metal partition sheet PDP [12,13].
Figure 3 shows the schematic structures of the first-generation TFCS-PDP. By forming two pairs of

electrode, sustaining electrode and scanning electrodes, in the TFCS, a planar electrode structure is successfully realized. Regardless of a cell pitch, an electrode area can be widened by thickening the electrode thickness. Unlike the conventional PDP, the front plate doesn't need ITO and dielectric layer, which decrease the luminance. In addition to the reflective phosphor structure on the rear plate, a formation of the phosphor layer on the front plate also improves luminance. In this case, the phosphor layer on the front plate side should be controlled about 5 micrometer thickness for its transmissible structure. The rear plate is composed almost the same as that of the conventional structure.

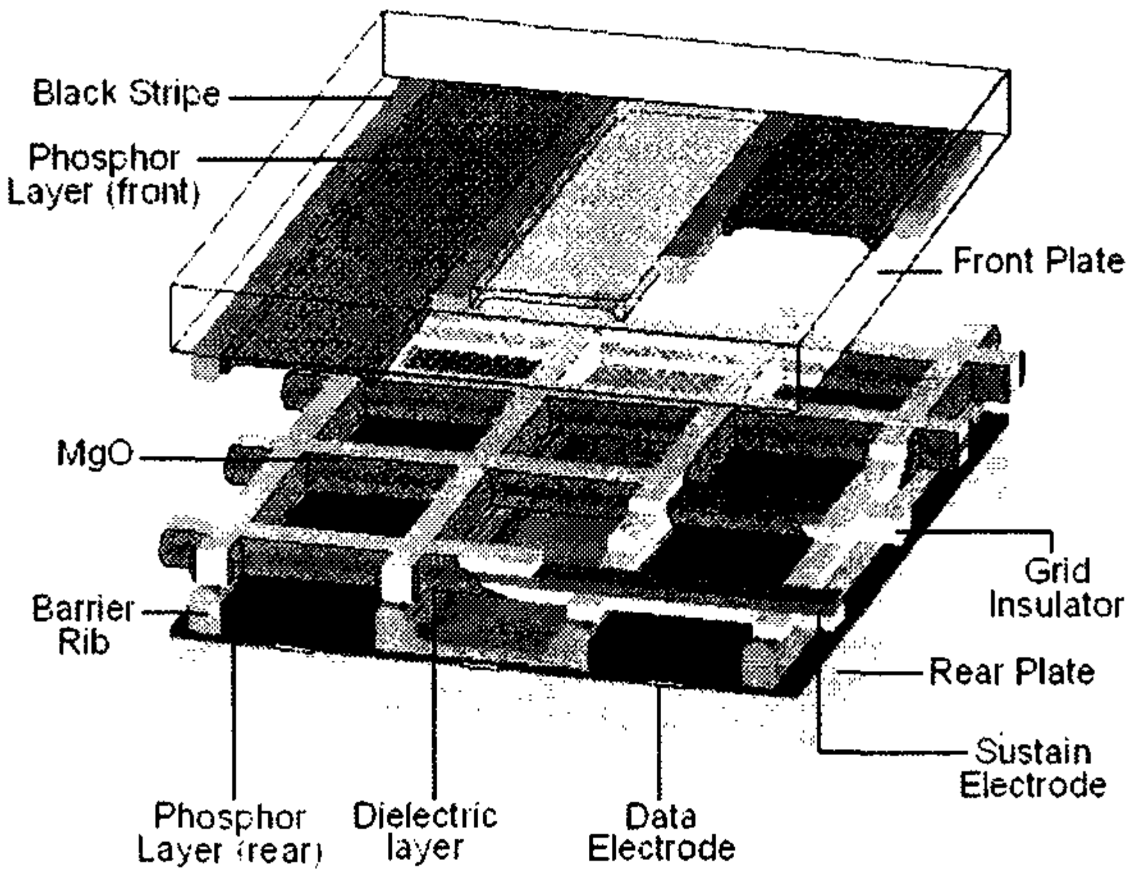


Figure 3. Schematic structure of TFCS-PDP
[Data Electrodes are formed on Rear Plate]

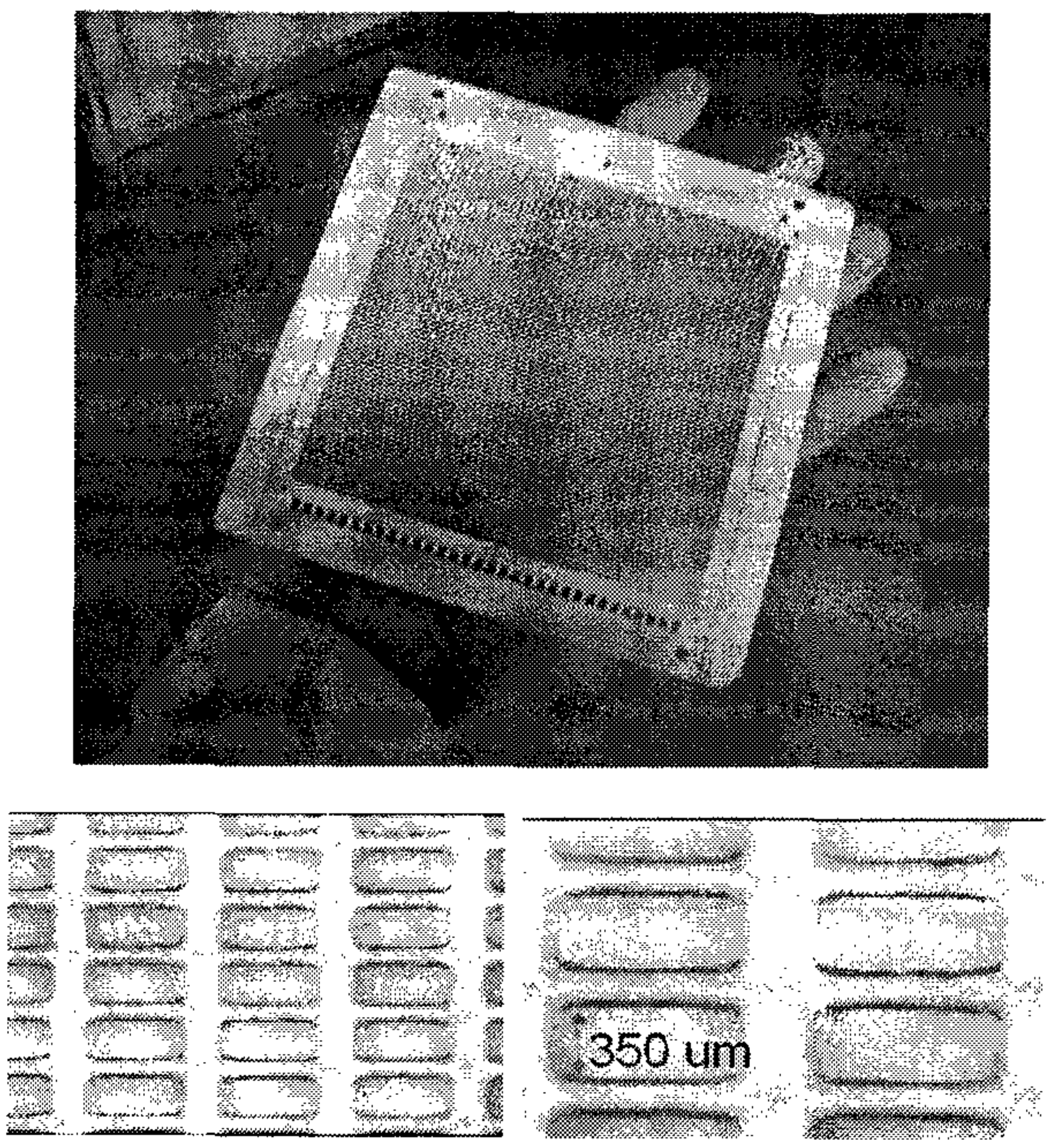
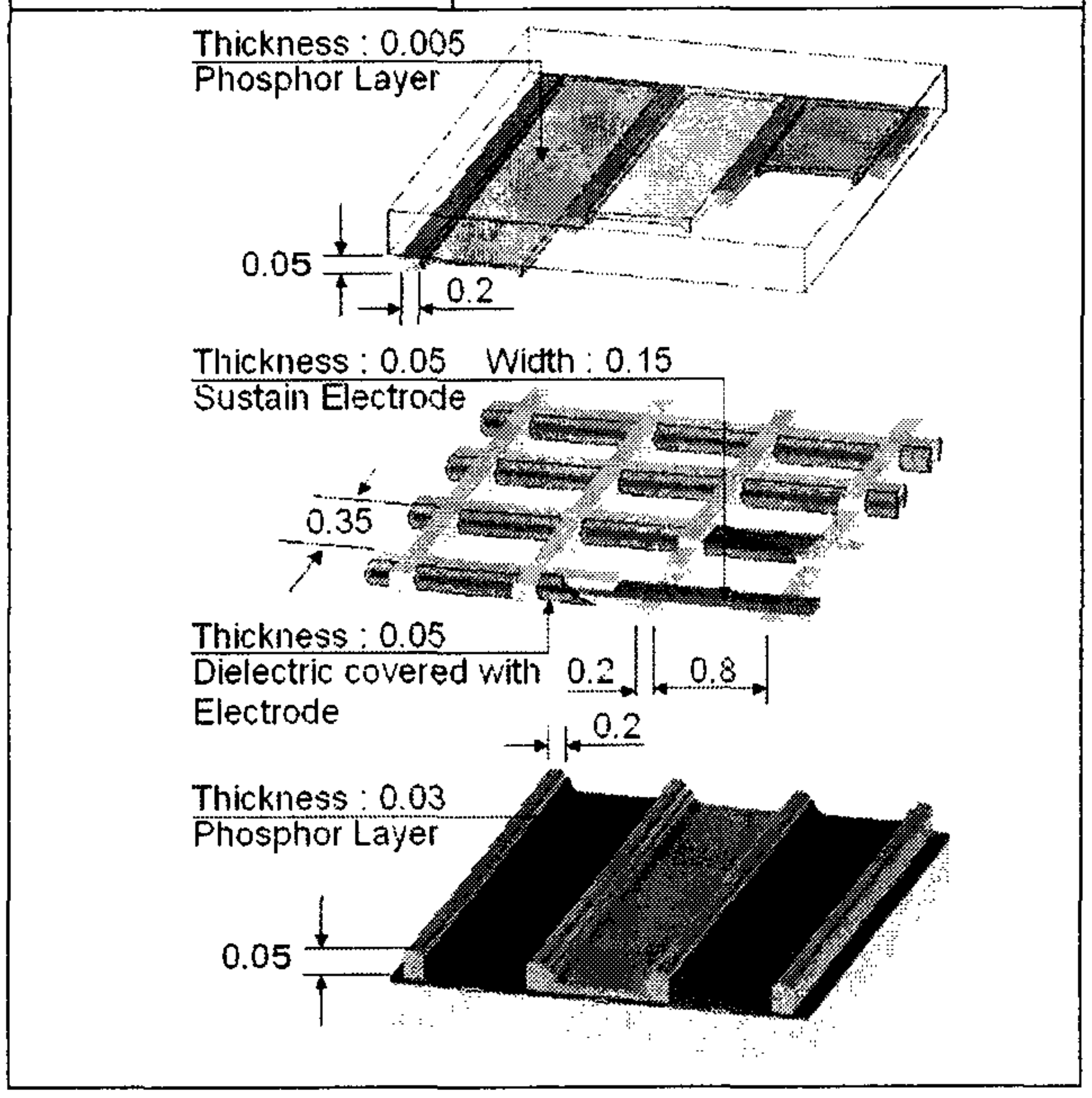


Figure 4. TFCS of Test panel with dipped Dielectric

Table 1. Specification of experimental panel

Diagonal size	5.35 inch (96 X 96 mm)
Display capacity	32 X RGB X 32
Pixel size	3 X 3 mm
Discharge Gap	0.35 mm (0.55 mm)
Phosphors Red	(Y, Gd)BO_3 : Eu
Green	$Zn2SiO_4$: Mn
Blue	$BaMgAl_{14}O_{23}$: Eu
Gas Xe content	Xe (10, 15, 20 %) + Ne
Pressure	350, 450, 550, 650 torr
Sustain Frequency	30 KHz
Sustain Pulse	8 micro-sec.



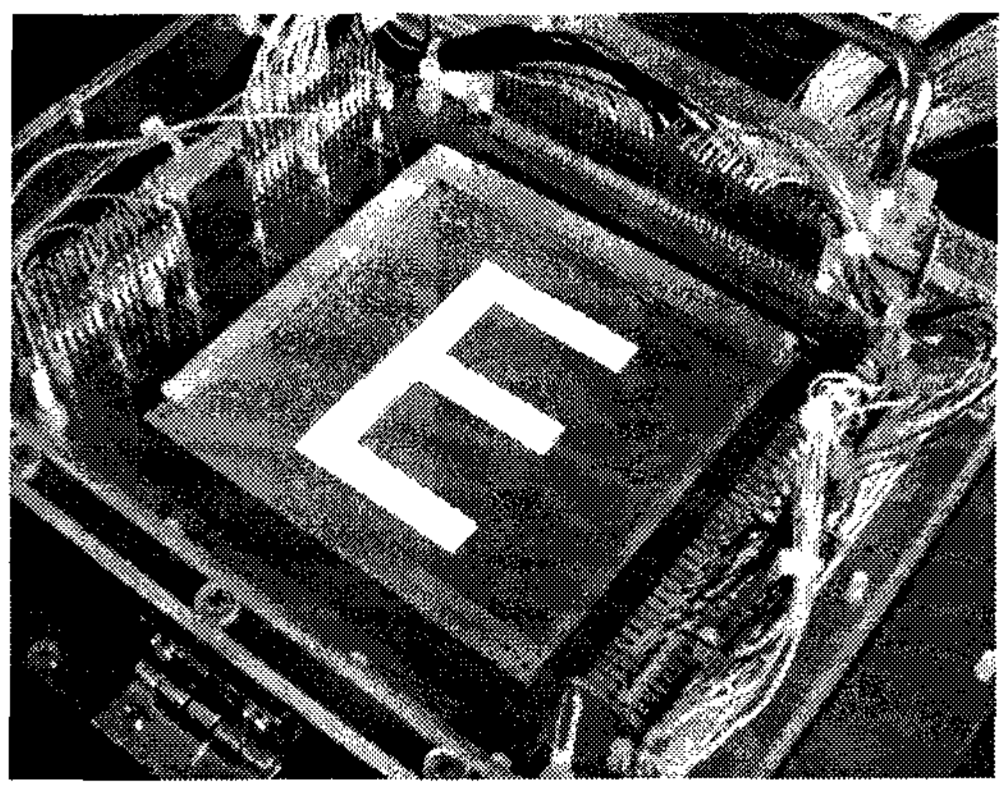


Figure 5. Test panel

3. Experiments

Table 1 shows the specifications of 1st generation structure, shown in fig.3. As shown in the table, all materials are conventional standard items. The front and rear plate is manufactured by the screen-printing method. The dielectric layer covering electrodes is formed by the dipping method, and MgO is formed by the vacuum deposition method. Figure 4 and figure 5 are photographs of a TFCS and a test panel, respectively. After fabrication of panel, the electrical and optical performance has been investigated.

4. Results and Discussion

4.1 Xe partial pressure

Figure 6-A and figure 6-B show the discharge voltage in term of the gas pressure. Data in fig. 6-A is taken from three panels with Xe10%-Ne and in fig. 6-B from two panels with Xe10%-Ne and Xe15%-Ne.

Figure 7 shows the dependence of Xe content on the discharge voltage. It should be emphasized that the sustaining discharge voltage is not changed even if the gas pressure or Xe content is increased. With these results, we confirmed the superiority of the planar discharge structure.

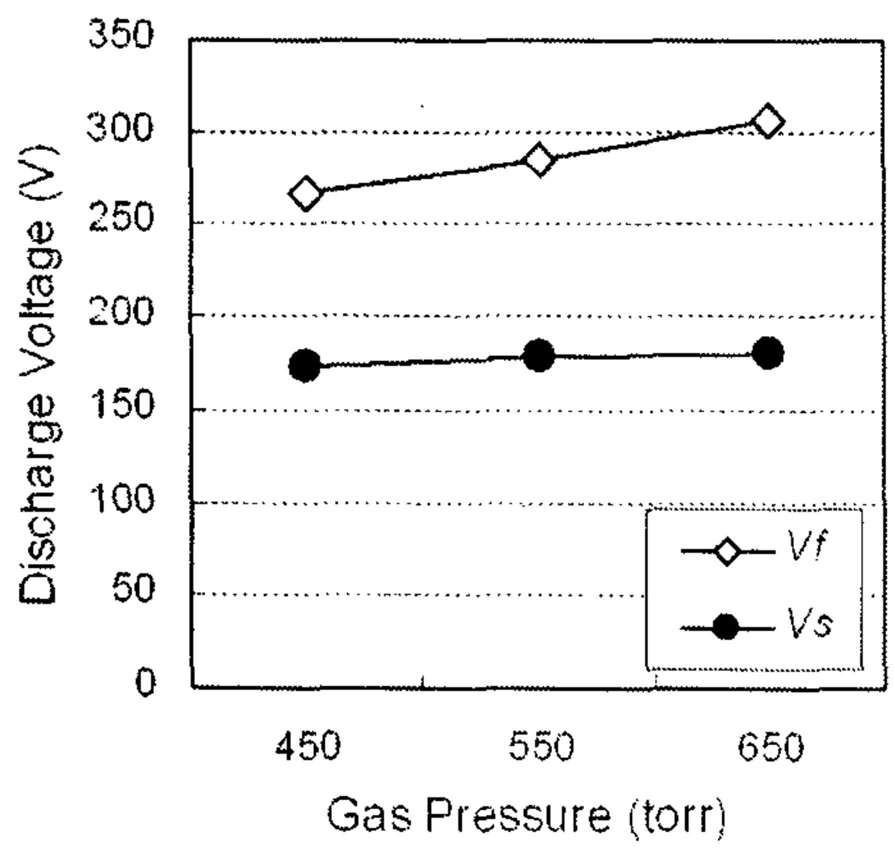


Figure 6-A. Relationship between gas pressure and discharge voltage (Xe10%-Ne)
[Vf: Firing voltage, Vs: Sustaining voltage]

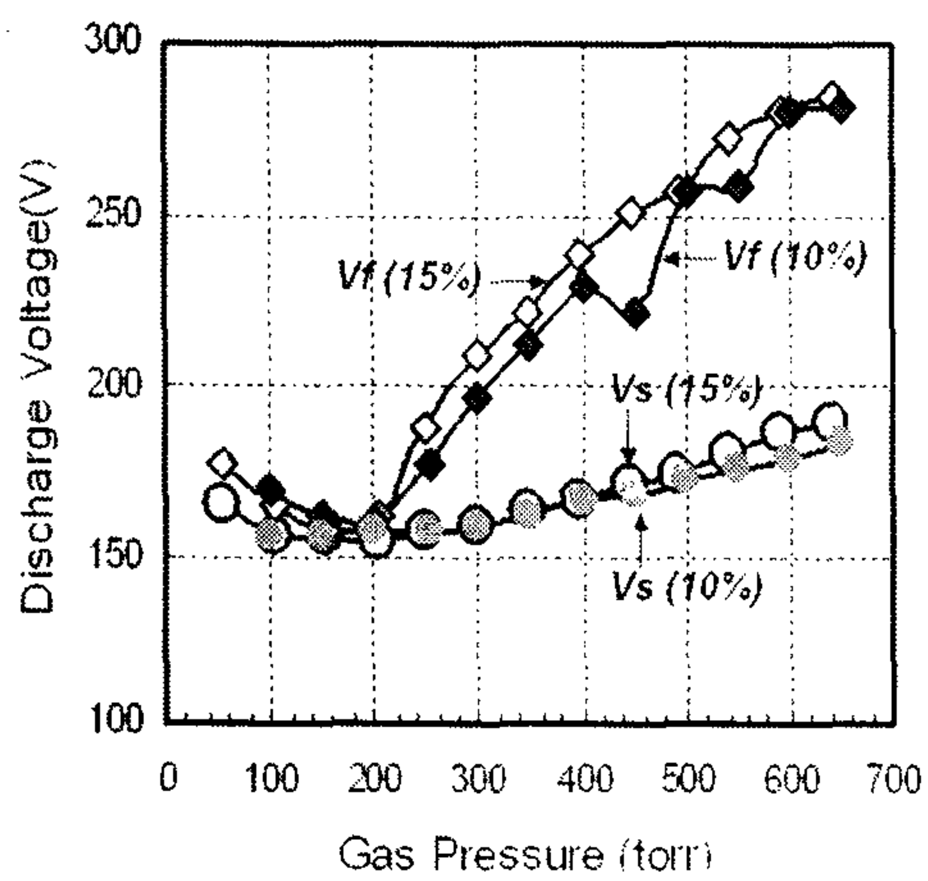


Figure 6-B. Relationship between gas pressure and discharge voltage in various Xe%
[Vf: Firing voltage, Vs: Sustaining voltage]

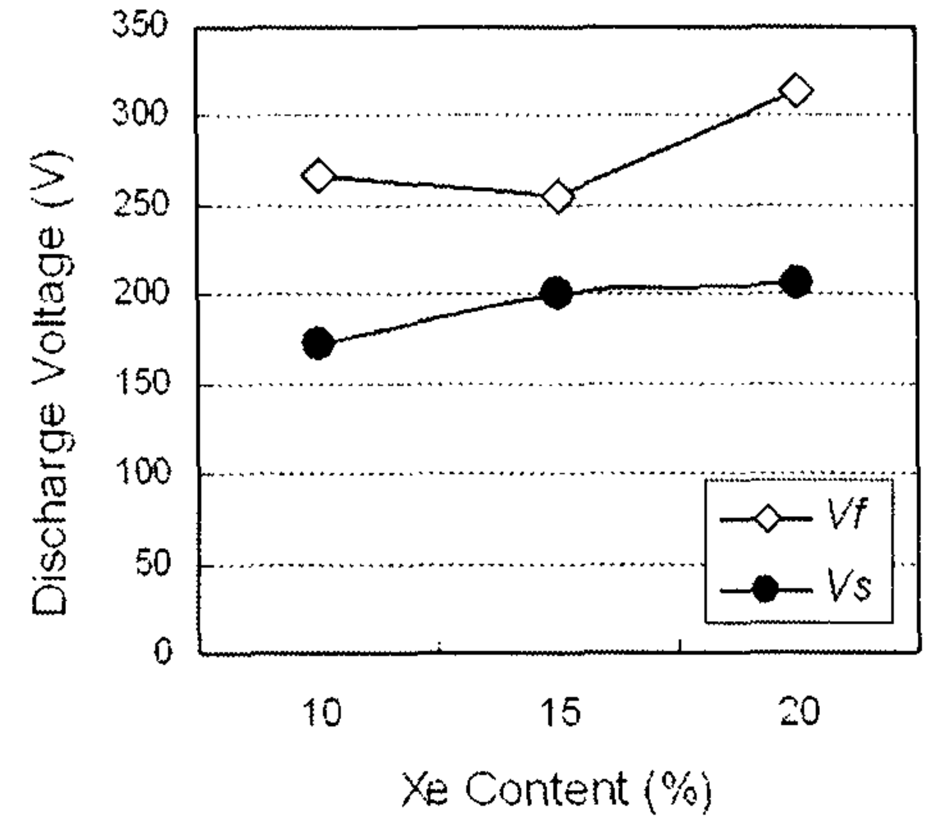


Figure 7. Dependence of Xe content on the discharge voltage (450 torr)

4.2 Electrode Structure

To investigate the dependence of the sustain electrodes area on the luminous efficiency, two different types of panel are made as shown in figure 8. As shown in figure 9, a panel having a wider electrode with 2 layer electrodes shows improved luminance efficiency. Also a widening of electrode contributes to a response characteristic. As can be seen from in figure 10, the panel having 2 layer electrodes have a fast response characteristics. It is known that a fast response characteristic is necessary for the driving.

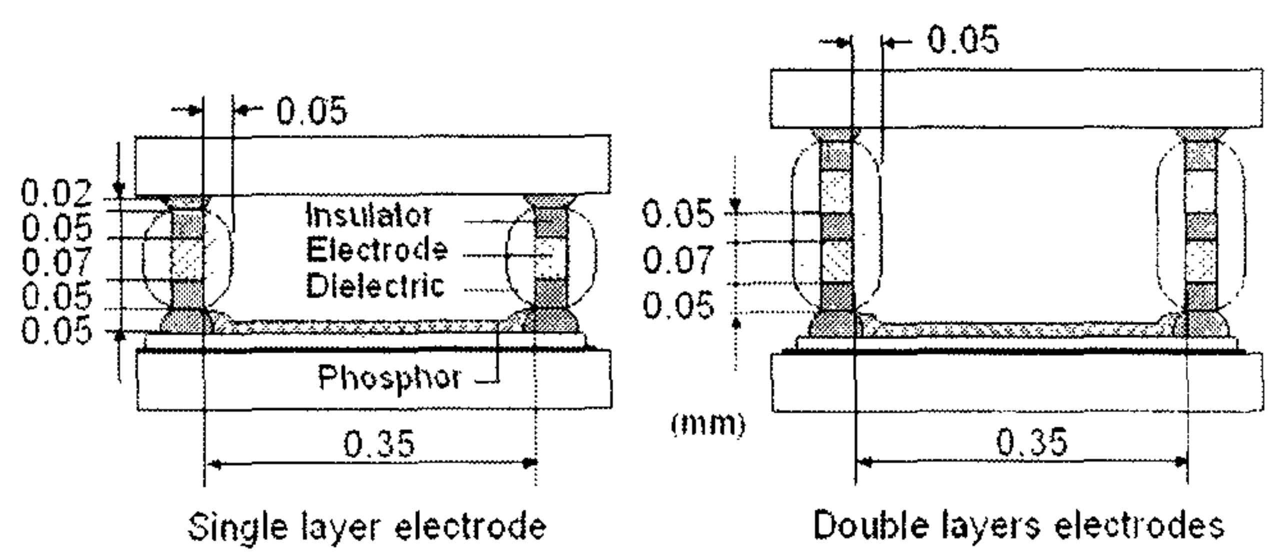


Figure 8. Dimensions of 2 panels with different types sustain electrodes

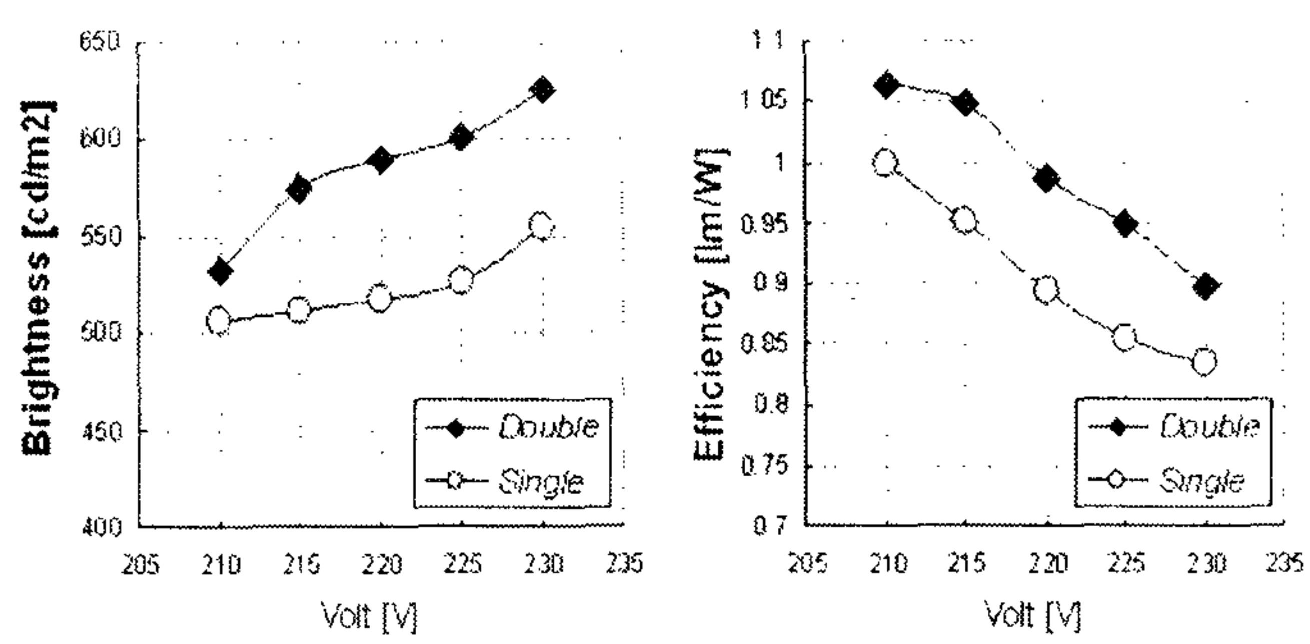


Figure 9. Effect of electrode area on the brightness and efficiency, respectively.

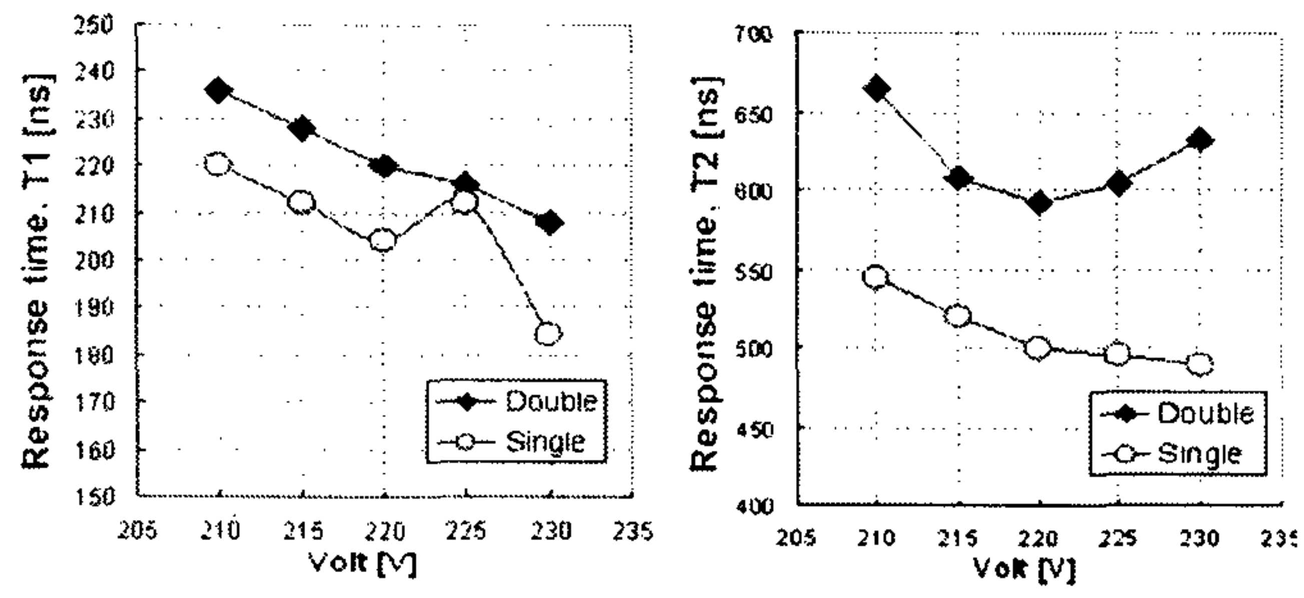
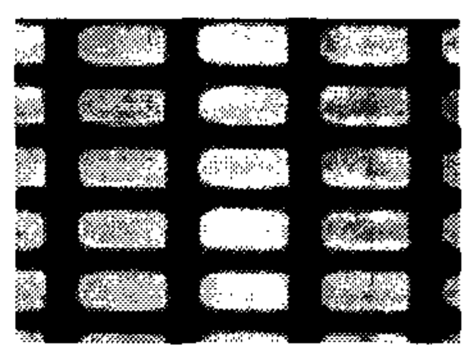
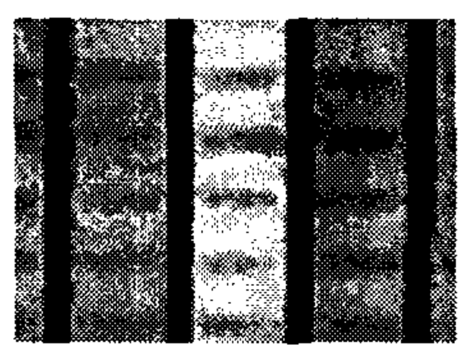


Figure 10. Response time for different electrode design

4.3 Phosphor Layer coated on Front Plate

Table 2 shows the luminance of two different panels with and without phosphor layer on front plate. By adopting a phosphor layer on front plate, the luminance was improved.

Table 2. Luminance of panels with and without phosphor layer on front plate (450 torr)

	Without phosphor	With phosphor [5um]
Xe15%-Ne	680 cd/m2	850 cd/m2 (+25%)
Xe10%-Ne	425 cd/m2	580 cd/m2 (+37%)
		

4.4 Discharge Imaging

To understand the discharge mechanism of TFCS-PDP, visible light image was taken by a high speed camera as shown figure 11 [14,15,16]. In the beginning, the discharge initiates from the anode side due to fast electron and move to the cathode side. And then a strong discharge occurs on the cathode side also. After all both electrode area become dark as a net potential applied on the gas apace is decreased by an accumulation wall charges. This phenomenon is just an exemplary planar discharge as reported [17,18].

Figure 12 shows a comparison of infrared and visible light output in a discharge cell. Generally, the negative glow region shows strong visible light emission because its electron energy is high enough to excite Ne atoms. But the mean electron energy in positive column is not enough to excite Ne atoms. On the contrary, the positive column produces an ultraviolet (UV) wavelength and infrared since the mean energy is well match with the collision cross section of UV production. TFCS-PDP has electrode on its wall. Therefore negative glow can see a vicinity of electrode. The negative glow region is marked a picture as a dotted area, the glow in rest of area attributed to the positive column. It should be emphasized that TFCS-PDP can generate a positive column discharge region, which can improve the discharge efficiency. Thus, from that point of view, we believe more strong positive column like discharge mode can be generated by optimizing the panel structure.

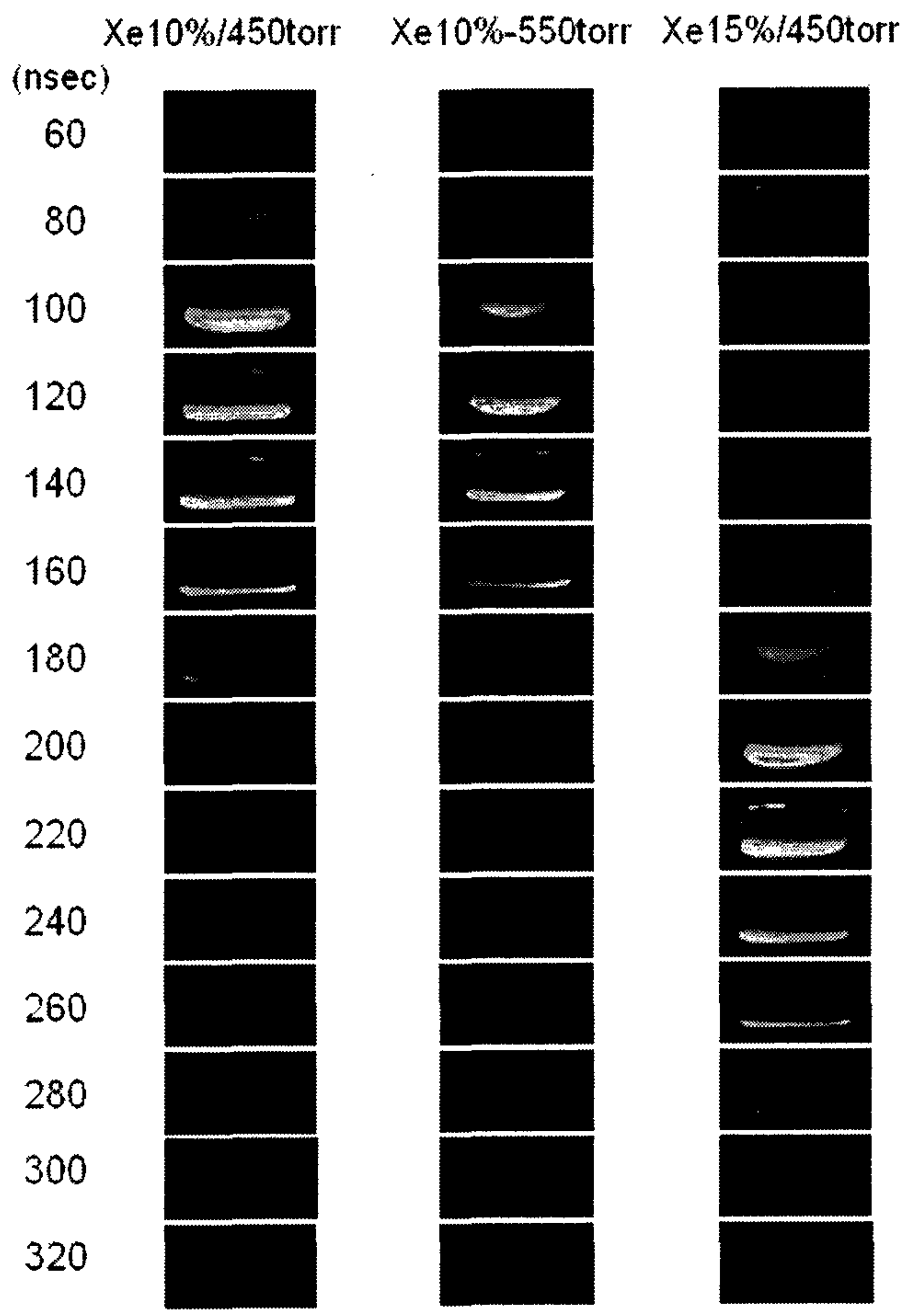


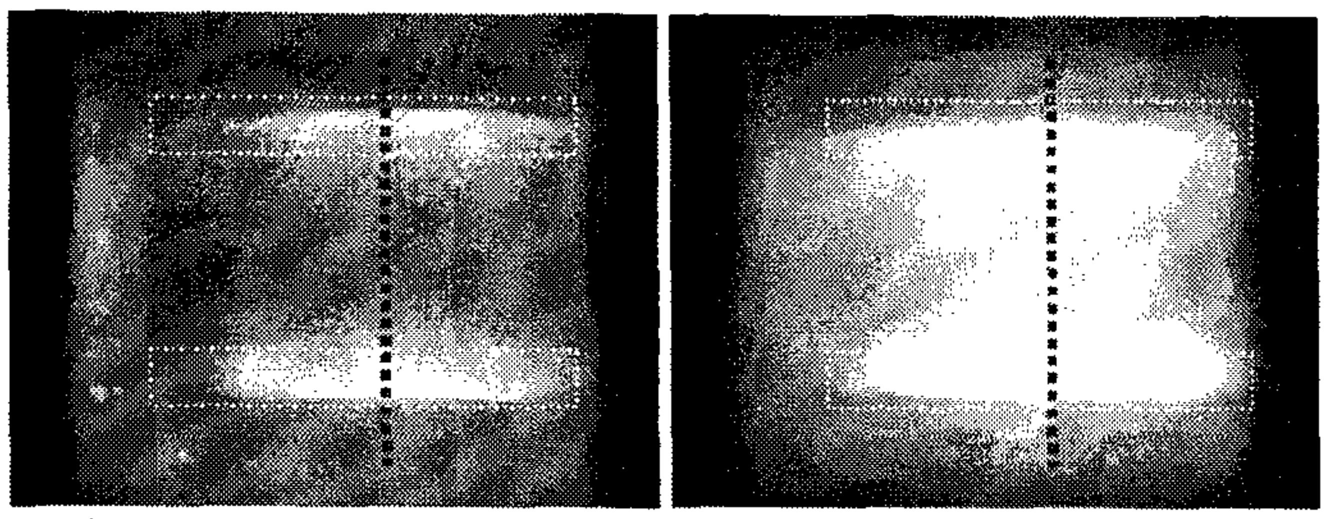
Figure 11. Discharge Observation of TFCS-PDP
Anode : upper side, Cathode : lower side
TFCS Insulator : both sides, Electrodes Gap : 0.35 mm

5. Conclusions

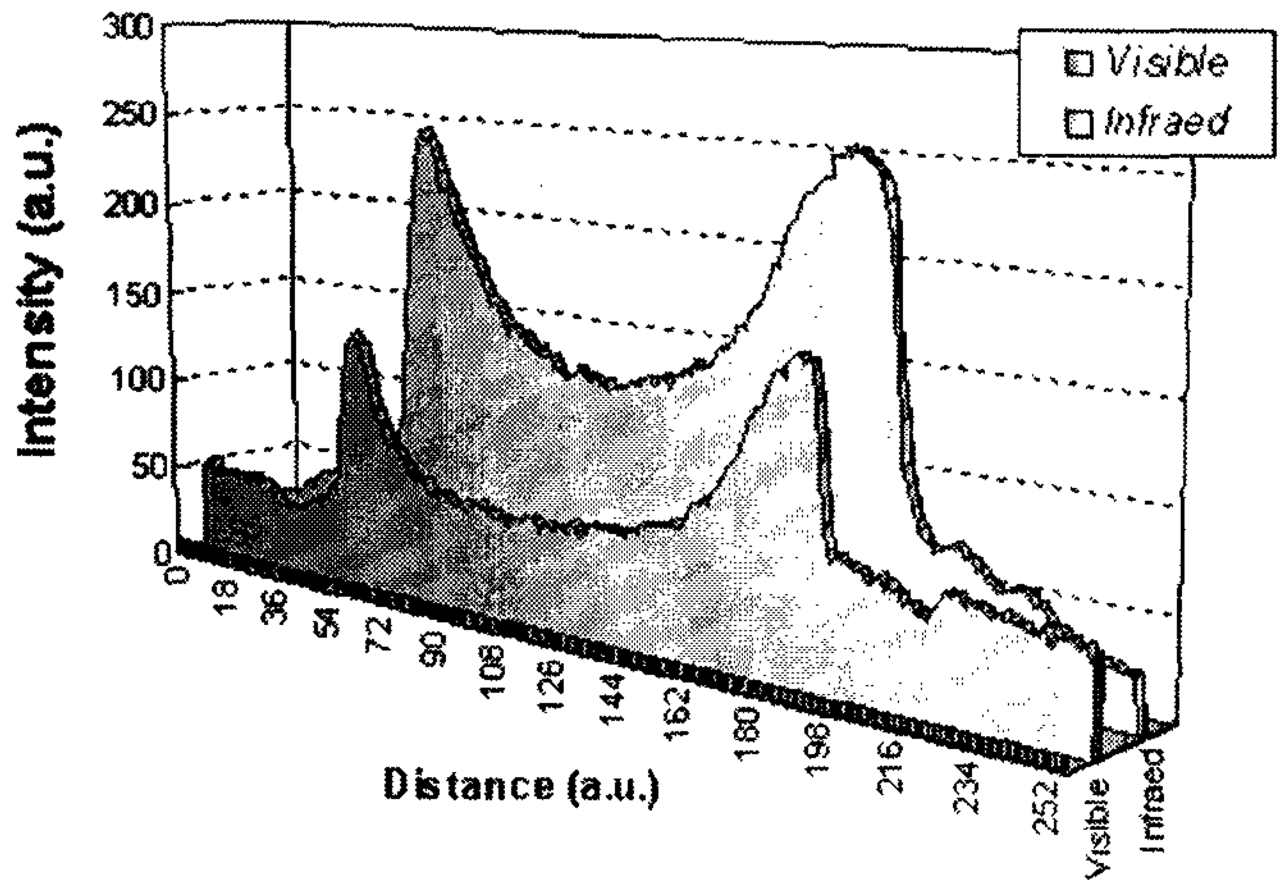
We developed AC-PDP with a planar discharge structure by using TFCS technology and evaluated its characteristics.

(1) Exemplary planar discharge has been realized.
(2) Discharge in a high Xe% and a high gas pressure has been realized by adopting planar structure. Discharge voltage with a high Xe content (10, 15, 20%; 450 torr) shows acceptable range as similar as conventional surface-discharge panel.

(3) Luminous efficiency has been improved by sustain electrodes design such as electrode area. An analytical study has been investigated to verify a high efficiency operating mechanism.
(4) Phosphor layer on front plate side improve the luminance.



(a) Visible light image (b) IR image



(c) Intensity profile

Figure 12(c). Comparison of visible and IR image
[Circled area: Negative glow region]

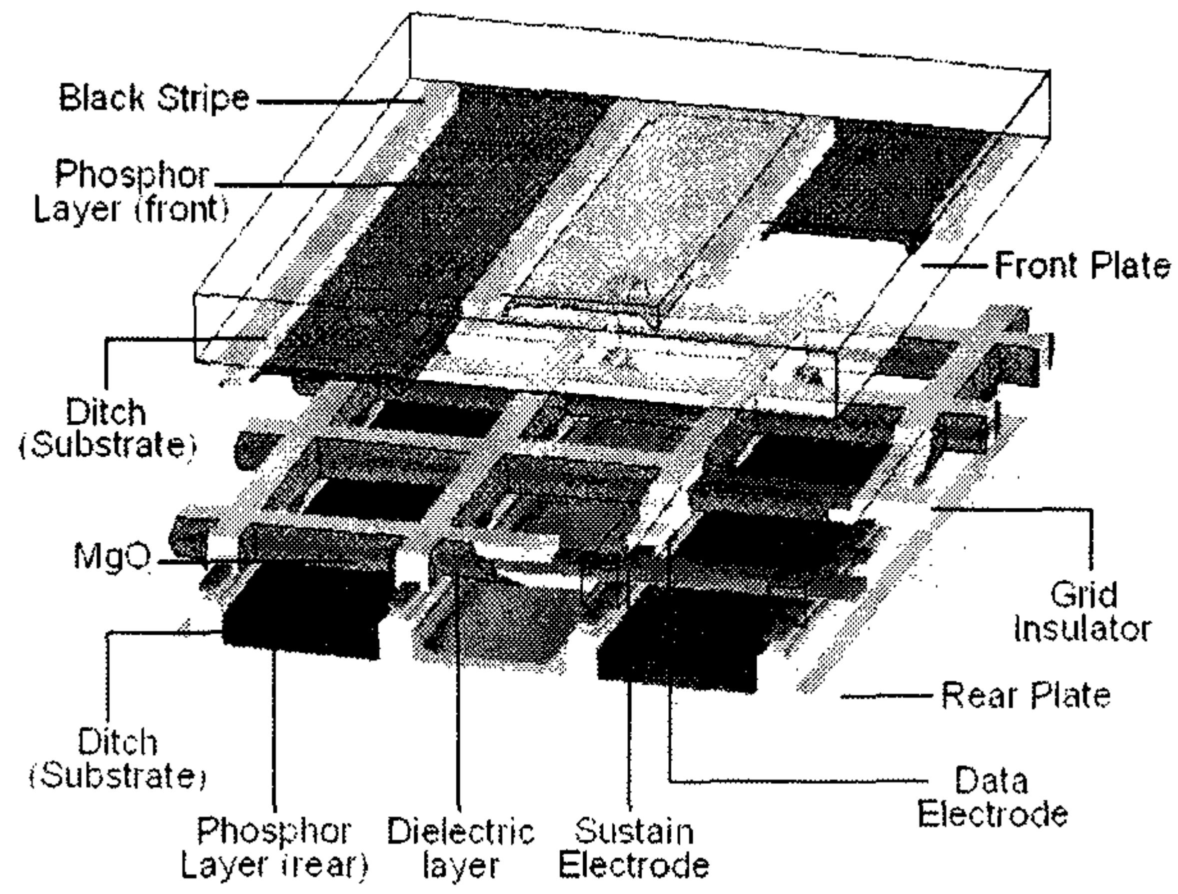


Figure 13. 2^{nd} Generation TFCS-PDP
[Data Electrodes are formed in TFCS]

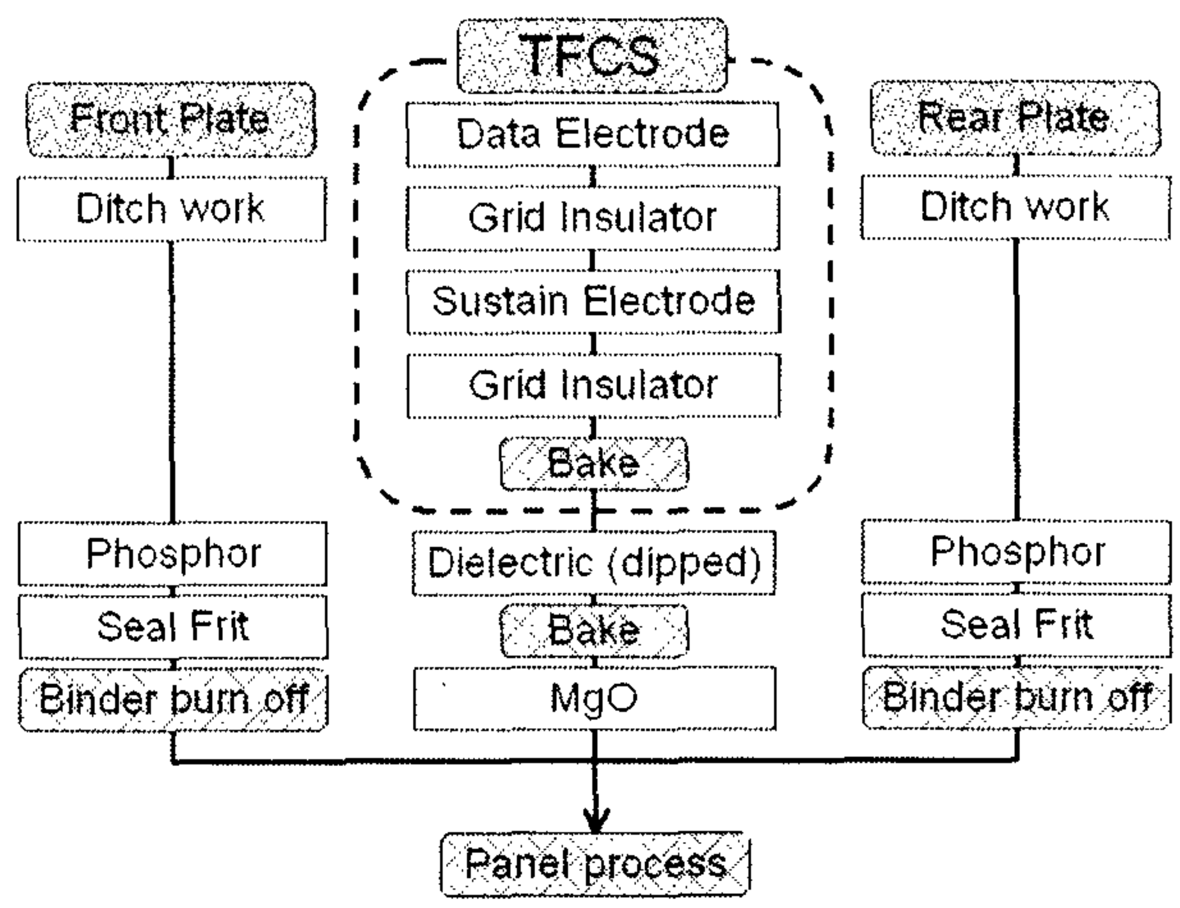


Figure 14. Process chart of 2^{nd} generation TFCS-PDP

6. TFCS Applications

6.1 2^{nd} generation TFCS-PDP

Figure 13 shows the 2^{nd} generation TFCS-PDP structure. In this panel, the data electrode is incorporated in the TFCS. As shown in the figure, electrodes from the front and the rear panel are eliminated. Formation of the barrier rib by the direct processing of the glass substrate dissolves the out-gassing problem of the thick film barrier rib as well as a cost reduction.

Figure 14 shows the basic process chart of the second-generation TFCS-PDP with a planar electrode discharge structure. Higher luminous efficiency and lower manufacturing cost are expected by taking the following advantages.

(1) Sustaining, scanning and data electrode can be designed considerably freely: the discharge gap, electrode space, data electrode location, and so on.
(2) All the electrodes are formed within the TFCS and co-fired. Control of the warp and shrinkage of the glass substrate are not required. The process capability of alignment is drastically improved.
(3) Photolithography processes such as ITO and barrier rib can be skipped. All films are formed by additive methods except vacuum deposited MgO.
(4) Only TFCS has to be backed twice. The front and rear plate doesn't need to bake at higher temperature (>500 degree C). A soda-lime window glass is usable.

(5) Since the film is not formed on the glass substrate in TFCS, baking at higher temperatures is possible. Thus a reduction of out gas and adoption of lead-free materials are also possible.
(6) The dielectric materials on the TFCS should not be necessarily transparent. It is possible to form it by a simplified process such as the dipping method. Low content binder and low viscosity paste are usable.
(7) Phosphor layer can also be formed on the front plate. It is possible to increase the area of phosphor layer contributing to luminance by deepening the grooves of the front and rear plates.

6.2 TFCS for FED with CNT cathode

Figure 15 shows a gate electrode for CNT-FED as another application the TFCS [11]. The gap between gate electrode and CNT cathode surface can be controlled by the insulator thickness.

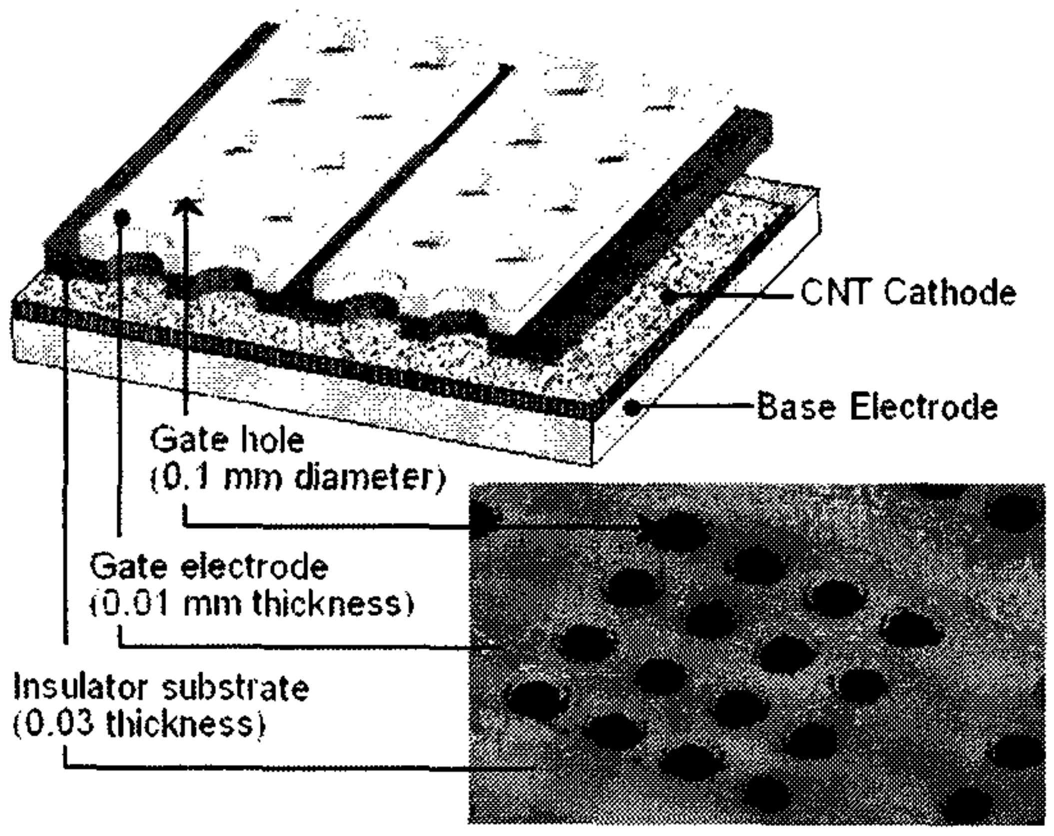


Figure 15. Schematic structure and photograph of TFCS gate electrode for a CNT-FED

7. Acknowledgement

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