Characteristics of Carbon Nanotube FED

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Abstract

Field emission display(FED) using carbon nanotubes (CNT) as field emitters is expected to large-area panels with high luminance and low power consumption.

In order to perform the uniform luminance with low driving voltage, we introduced a new electrode to apply higher electric potential over the CNT cathode in 2003.[1]

In the study, we described the luminance uniformity of the panel and the improvement of emission uniformity by increasing the emission-site density. The luminance uniformity of the several ideal dots which were selected over the display area in the panel was 2.8%. [2]

The CNT cathode was irradiated by excimer-laser, which was effective to improve emission uniformity and lower driving voltage.

A prototype of CNT-FED character display was performed for middle size message displays. The prototype panel had 48 x 480-dots and the resolution was 1-mm. The panel realized high luminance at low power consumption. It will be important characteristics for legible and ubiquitous displays. [3]

1. Introduction

The first practical high-luminance CNTs-FED was realized in 1999 using a triode-structure.[4] In 2000, electron-emission uniformity was improved with the development of the round-edged smooth-surface cathode electrode on which the CNT-network structure was formed by thermal Chemical Vapor Deposition(CVD) technology.[5] After that, we developed a new structure that opened the way to large-area uniform displays in IDRC'01 and SID'02. [6,7]

In 2003, for the uniform luminance with low driving voltage, a new electrode was introduced to perform higher electric potential over the CNT layer and low driving voltage, which is called "electric-potential-control-electrode". At the same time, we proposed a laser irradiation over the CNT-layer for low voltage driving. A part of the result was reported in IDW'03.[2]

A prototype of CNT-FED character display was performed for middle size message displays. The display was constructed by metal-frame-cathodes, gate substrate and anode substrate with 3mm-tall glass spacers. The technology had advantages at the size-flexibility, deposition temperature and manufacturing yield. The prototype panel had 48 x 480-dots and the resolution was 1-mm. The panel realized high luminance at low power consumption. It will be important characteristics for legible and ubiquitous displays. [3]

2. Panel Structure and Resolution

Fig.1 shows the structure in order to realize an uniform luminance all over the large display area in 2001.

Anode electrode is operated at a high-positive potential. They are consisted of lines of RGB(red, green, blue)color-phosphor backed with thin aluminum film. A parallel array of ribs is formed on the black-matrix areas between each phosphor line. These ribs prevent miss addressing of the color phosphor stripes by stray electrons.

The gate electrode was formed on the insulator substrate with through holes on the anode electrode side. The gate electrode on the insulator substrate (the gate-insulator composite substrate) was sandwiched between ribs on the anode substrate and cathode electrodes. That is, the gate-insulator composite substrate was not adhered on the cathode electrode but compressed to it by atmospheric pressure during the evacuating process. A distortion by difference of heat expansion among an insulator substrate and other substrates will be restrained by sliding of the gate-insulator substrate.

The cathode electrodes consist of metal electrodes with CNT-layers. The electrical isolation is performed by many ribs which are formed as almost same height with the cathode electrode. Cathode lines are arranged crossly to the ribs on anode electrode and gate electrode lines.

Among manufacturing processes of CNT emitters, we prepared it produced by thermal CVD which were expected the desired surface morphology of electron emitter and most uniform of emission distribution up to the date. The CVD-CNTs were making a network structure for each other, then the surface conductivity and electric potential would be thought as uniform. Fig.2 shows the SEM-images of a CNT electrode. Fig.3 shows the TEM-image of the CVD-CNT. Most of the CNTs had opened edge at the end of tubes. These edges were observed around the small-mesh network-like structure. It will be considered that the small-mesh networked CNT structure provides a uniform electrical field for the CNT-edges. These CNT edges, which are existing exactly in same electric potential, were observed to be randomly distributed over the electrode, thus emission uniformity would be realized.

In this paper, the resolution was considered to display characters and graphics, so that we concluded the dot-pitch as 1.0mm, for color display, the pixel size was 1.0 x 3.0mm or 3.0 x 3.0mm.

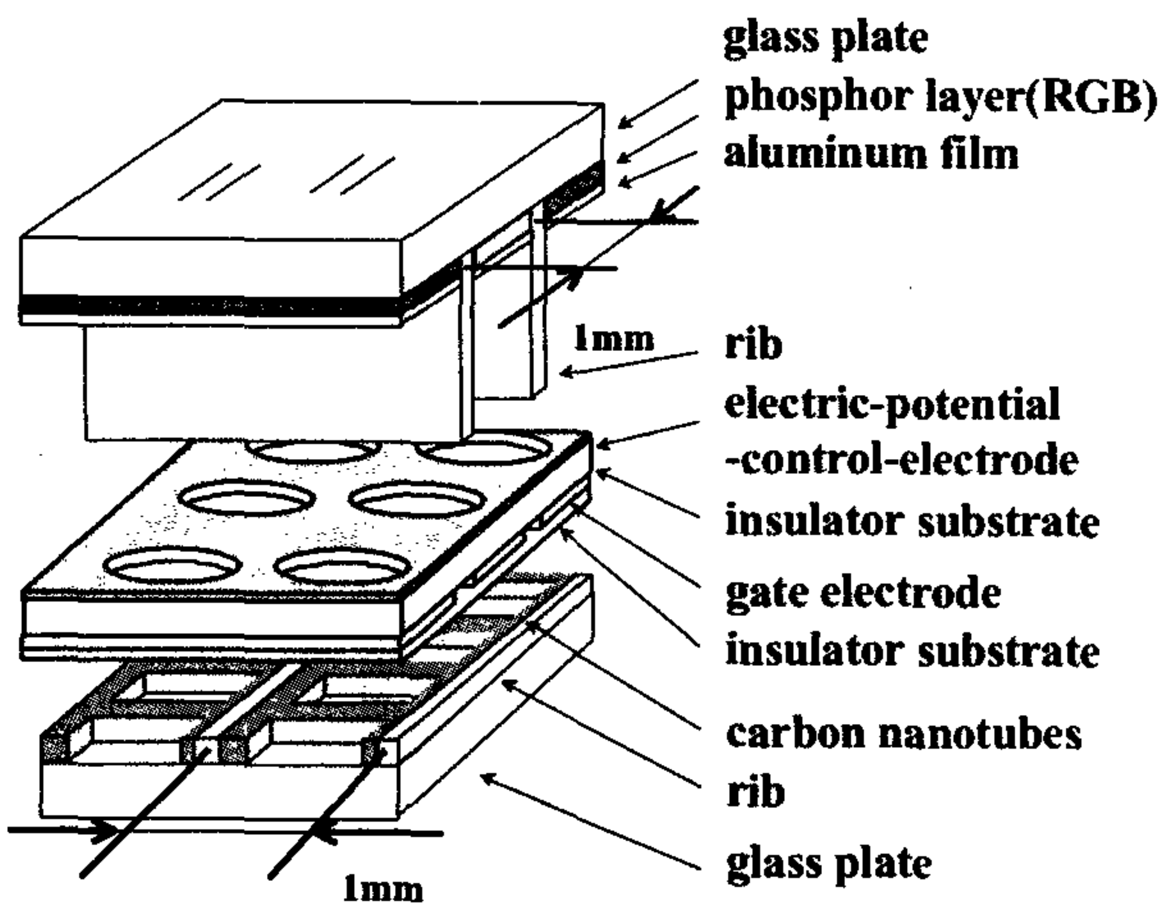

Fig.1 Schematic structure of the CNT-FED.

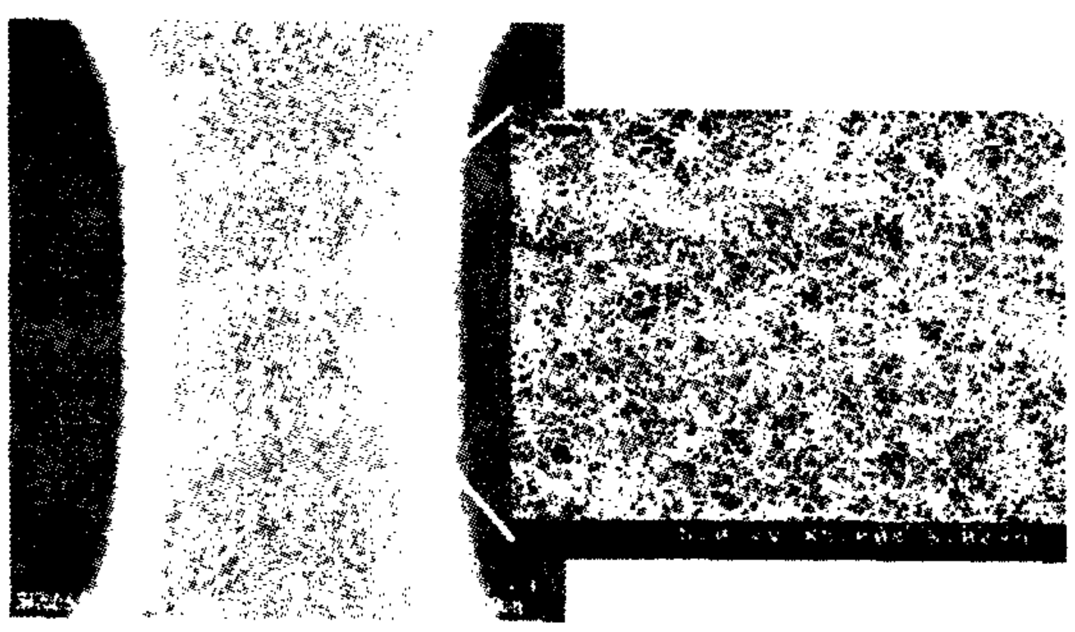

Fig.2 SEM images of a CNT electrode.

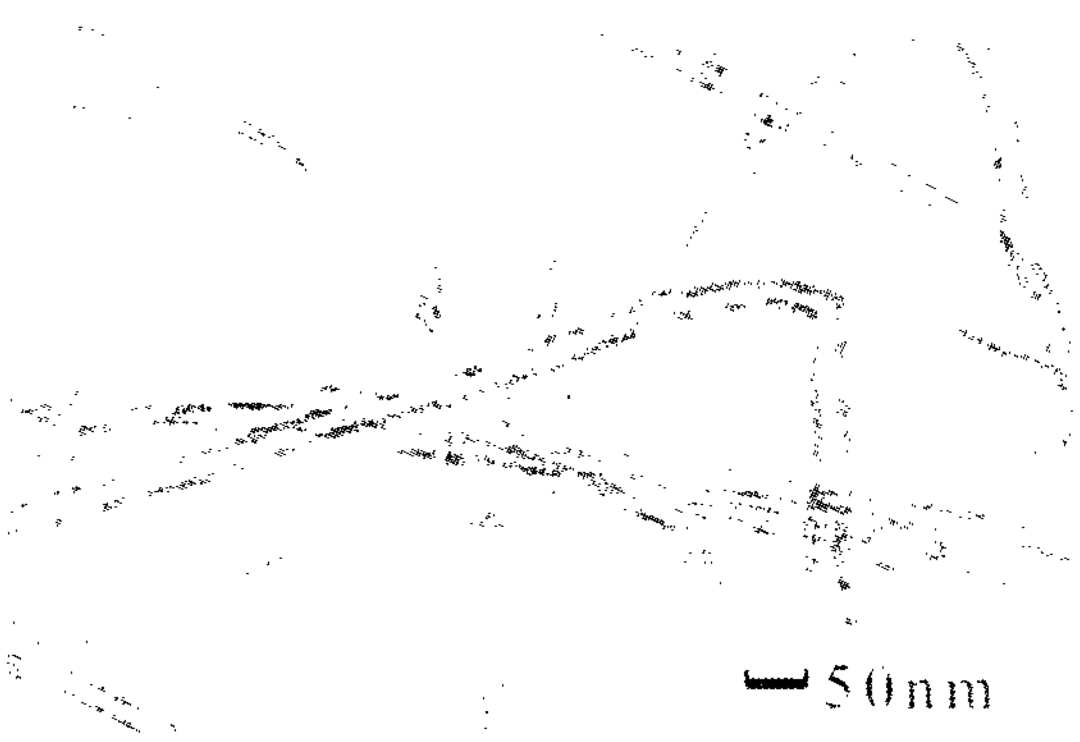

Fig.3 TEM image of individual CNTs

3. Gate Structure withstanding Low-driving voltage and Uniform-emission

Luminance uniformity was also examined at different gate voltages. Fig.4 shows luminance distribution over a single pixel at two different gate voltages. A CA-1000(Minolta) instrument was employed to measure the data. In Fig.4, different levels of luminance are shown in different colors. Peak luminance increased as a function of increasing gate voltage over an increasing fraction of the pixel area. The luminance profiles obtained were due to the emission distribution profiles from the CNT cathode and due to the electrical field created by the gate electrode. The lighted area was slightly enlarged as a function of increasing gate voltage corresponding to the size of the hole in the gate electrode. The results described above show that high-luminance levels obtained at higher gate voltages will also provide the best luminance distribution. This suggests that the number of emission site is increased at higher gate voltage.

On the other hand, low driving voltage is required to apply low cost driver circuits.

A new electrode was introduced to perform higher electric potential over the CNT layer and low driving voltage, which is called "electric-potential-control-electrode". The new structure is shown in Fig.5. The electric-potential-control-electrode should apply a uniform and high electric potential over the CNT layer with a several hundreds voltage. And the gate electrodes perform switching and addressing with a low driving voltage.

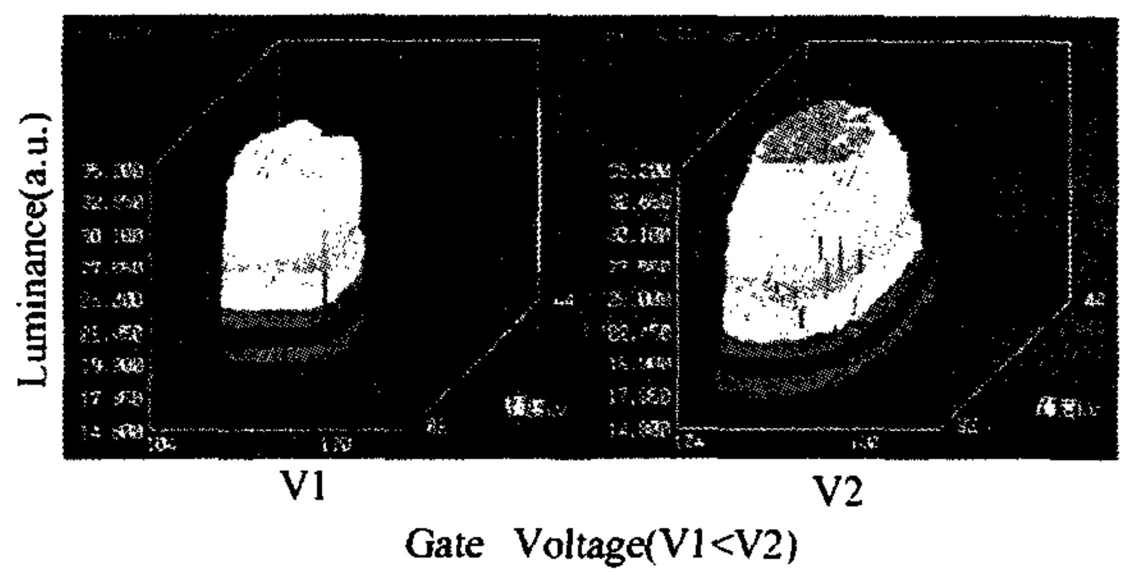

Fig.4 Luminance distribution profiles of one pixel at different gate voltages.

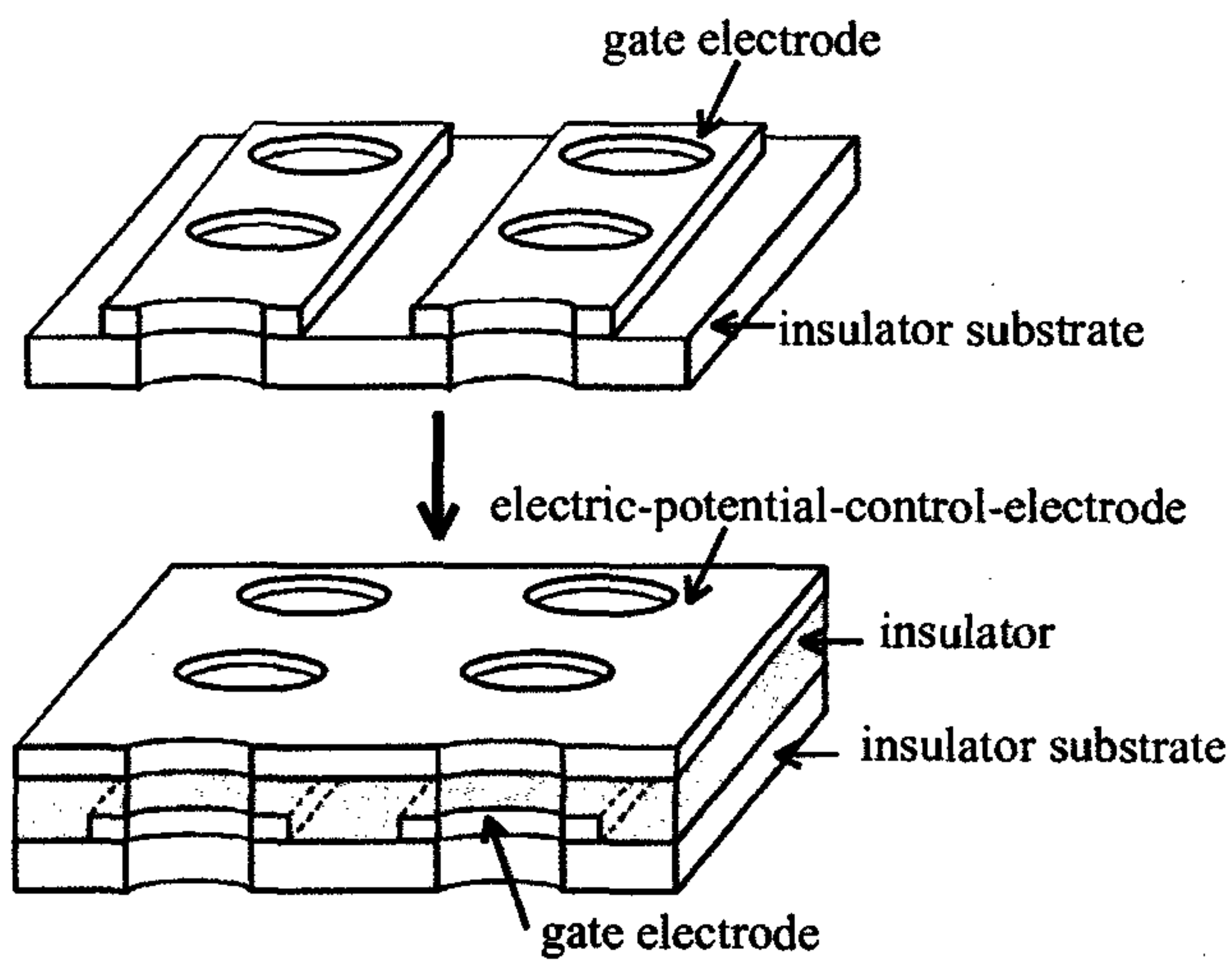

Fig.5 Schematic structure of the improved gate-insulator composite substrate.

4. Luminance Uniformity

The luminance of each dot was measured over the half of display area. Green-luminance distribution data under the driving condition of ca.3kV anode voltage is shown in Fig.6. It was measured the average-luminance of each sub-pixel under a fixed measuring area. An uniformity was estimated as the ratio of the standard deviation to average-luminance.

The luminance uniformity of the several ideal dots which were selected over the display area was 2.8%. And the luminance uniformity over a quarter display area of the panel was 9.7%.

In this panel, no high resistive layer was used, and the thin aluminum film disturbed a part of electron irradiation. As a result, the luminance uniformity of the panel will be expected up to ca.2-4% under well aligned panels. And the experimentally manufactured panels will be expected up to ca.6-9% luminance uniformity.

In order to perform more uniform luminance, emission uniformity was improved by increasing the emission-site density. The surface of CNT cathode was treated by laser irradiation, which was performed by KrF laser at 248nm and XeCl laser at 308nm. In case of KrF laser, an energy density was tested from $20mJ/cm^2$ to $120mJ/cm^2$.

Fig.7 shows the SEM-image of the CNT surface after irradiation. CNT tips were increased up to ca.$10^8/cm^2$ at $50mJ/cm^2$ irradiation. Fig.8 shows TEM-image of the produced open edge. Fig.9 shows the improved emission distribution profile after laser irradiation at $30mJ/cm^2$.

Fig.10 shows I-V characteristics of CNT cathodes before and after laser irradiation with energy density of $50mJ/cm^2$. Emission measurement was performed with an anode-emitter spacing of 0.3mm. Fig.11 shows the Fowler-Nordheim(F-N) plots of I-V characteristics, before and after laser irradiation. These results suggest that the emission and the uniformity was improved by appropriate laser irradiation, which would be thought as the effect of increased emission-site density.

Fig.12 shows the electric field required to obtain a constant emission current as a function of laser energy density. It was measured at emission current density of $29.5mA/cm^2$ and the spacing between anode and cathode was 0.3-mm. The required electric field decreased down to the minimum value at 50-60 mJ/cm^2. The laser irradiation was effective to improve emission uniformity and lower driving voltage.

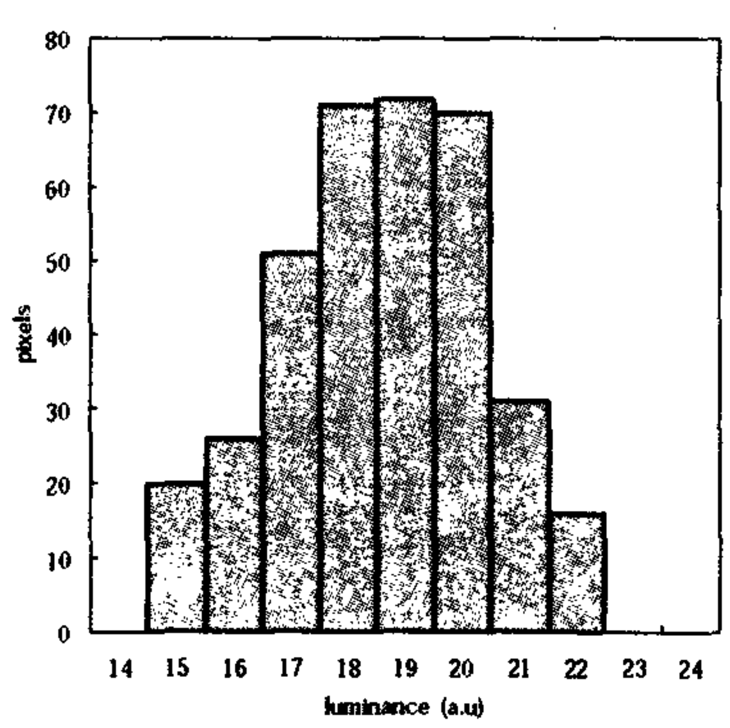

Fig.6Luminance distribution of green pixels.

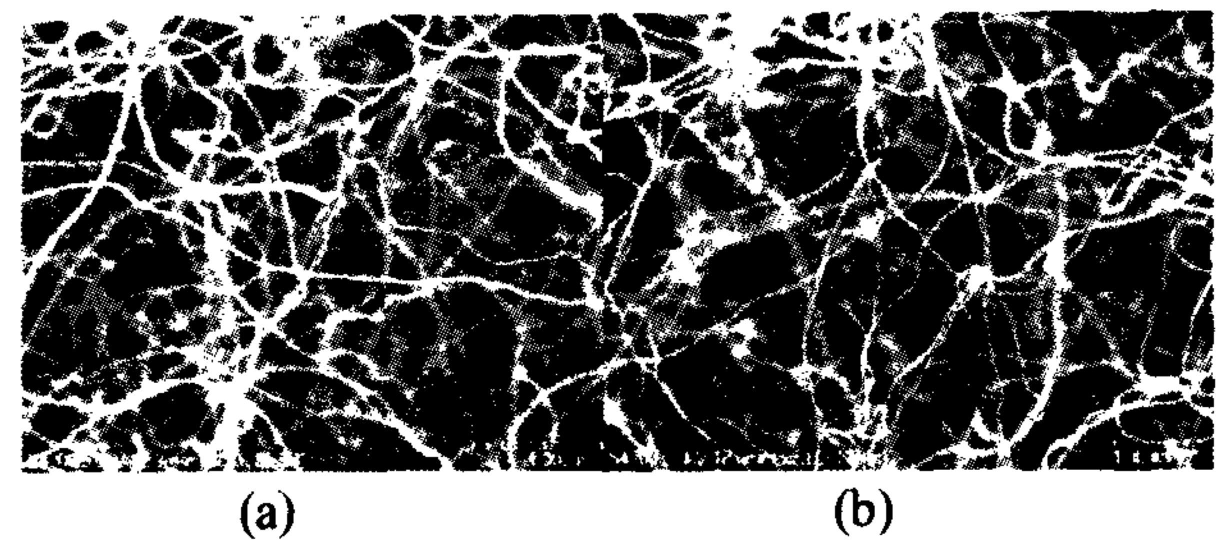

Fig.7 SEM images of a surface of CNT electrode.(a) before. (b)after laser irradiation.

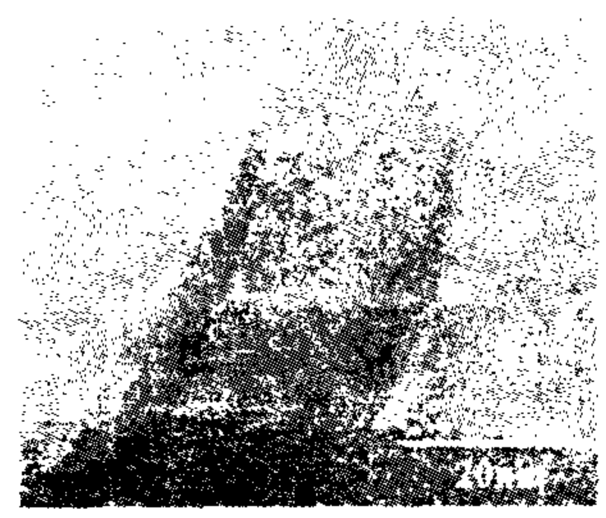

Fig.8 TEM image of the produced open edge.

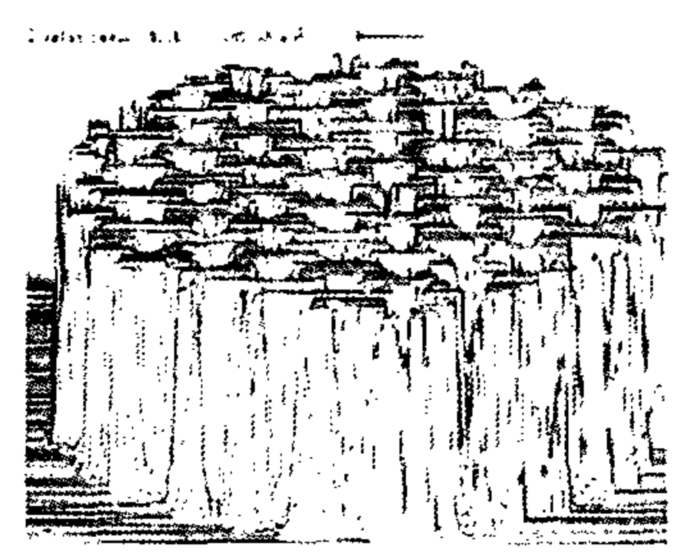

Fig.9 Emission distribution profiles(0-1.0mA/cm^2) over a 4mm-diameter section of the cathode irradiated by KrF laser with $30mJ/cm^2$.

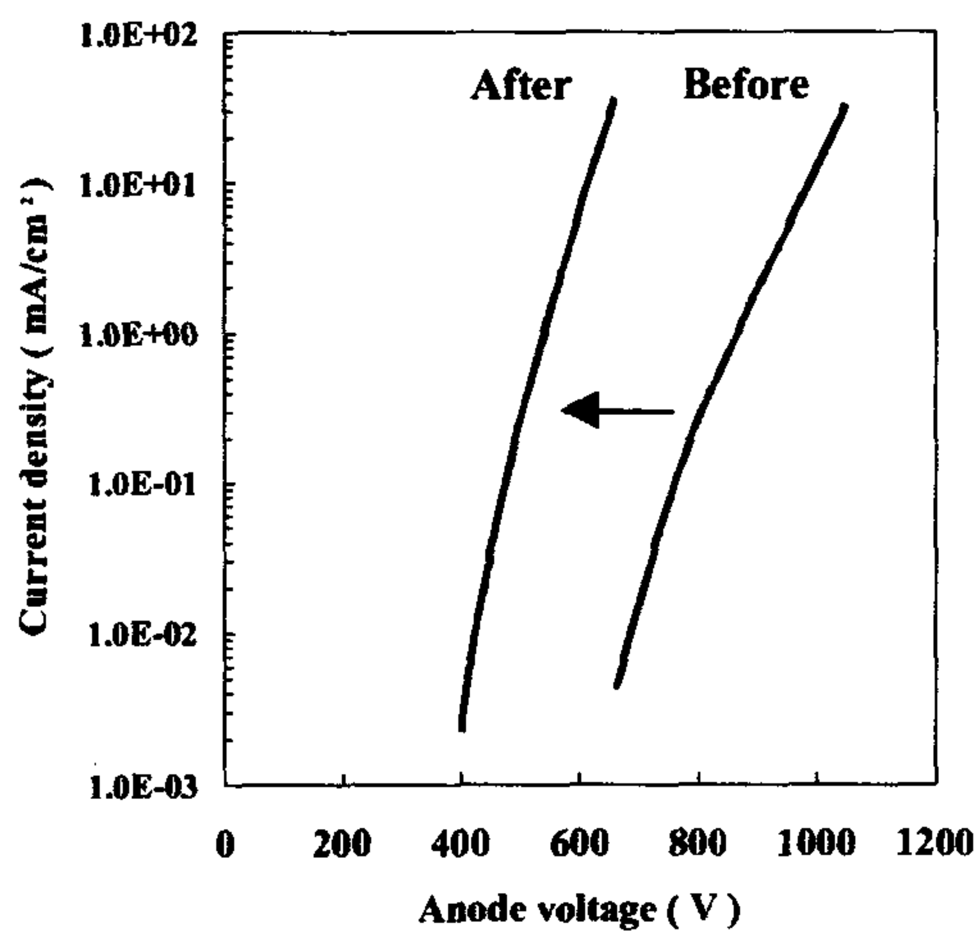

Fig.10 I-V characteristics.

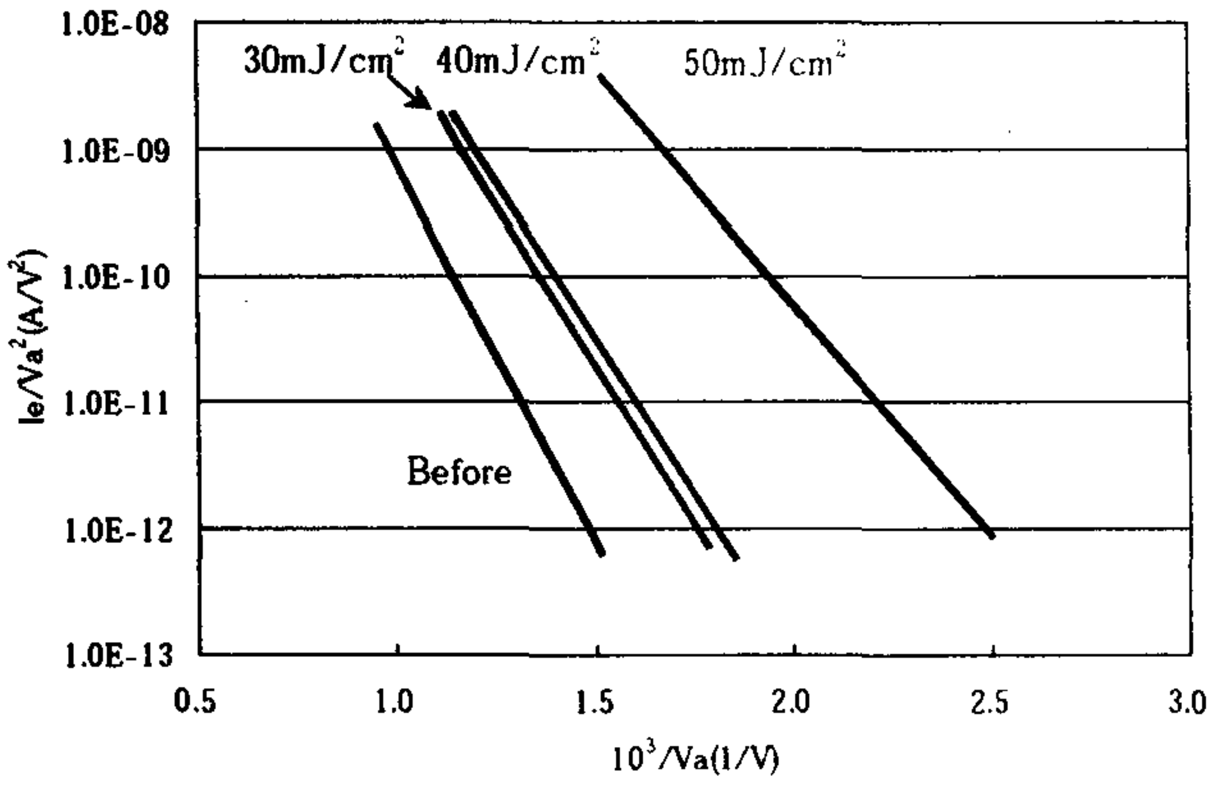

Fig.11 F-N plots of each emission. (before laser irradiation and after laser irradiation with $30mJ/cm^2$, $40mJ/cm^2$ and $50mJ/cm^2$).

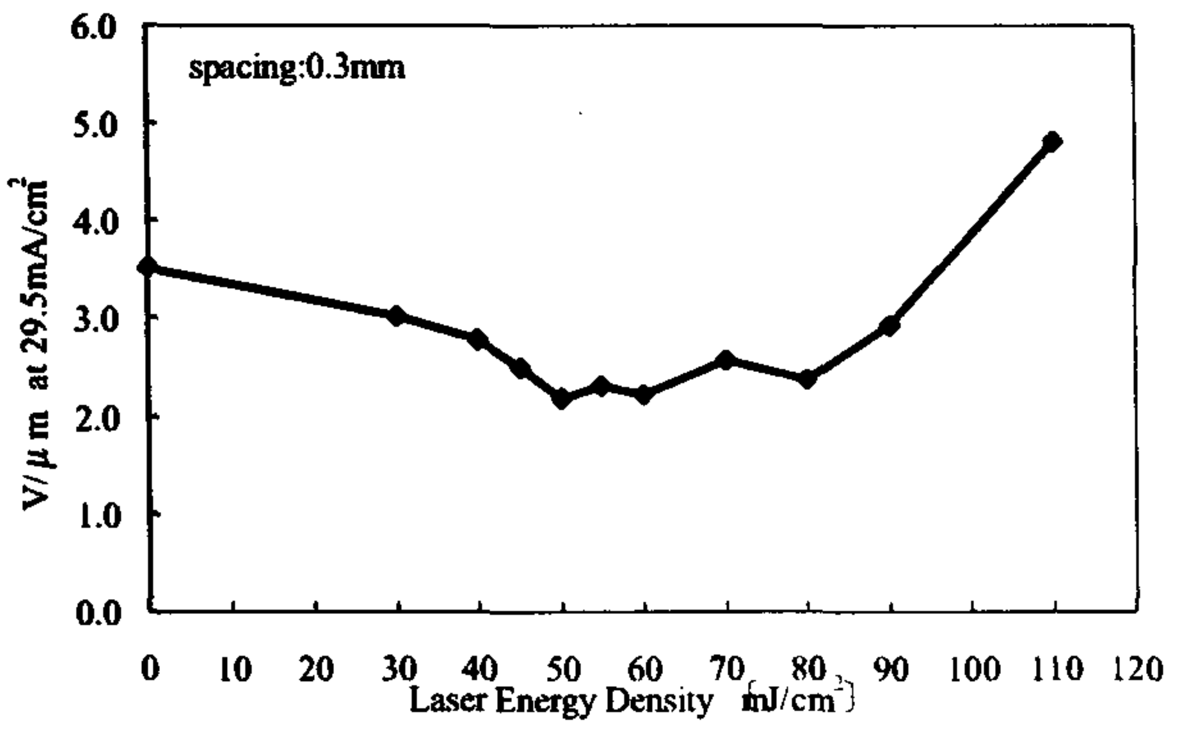

Fig.12 Applied electric field to obtain a constant emission as a function of laser energy density. Current density, $29.5mA/cm^2$.

5. Spacer and the Construction

A high anode voltage is required for the high luminance and long life characteristics for FEDs. We intended to increase the voltage up to more than 7kV, which required 2-3mm tall spacers to keep the distance between anode and cathode. The spacers should have a shape of high aspect ratios because the spacers must be hidden by the black matrix of the phosphor layer. Moreover, the cost of the spacing function has to be kept at a reasonable level.

At first, we tried to use an array of ceramic-spacers such as Fig.13[13]. The spacer was manufactured by screen printing technology[10]. The size was 64.0 x 492.0 x 3.0 mm, and the thickness of ribs was 0.15mm. The surface was coated with special material to avoid the charging up. It was successful but the cost was too expensive.

As a result, we selected the glass-spacer whose height was 3mm and the thickness was o.15mm. They were prepared by some different manufacturing methods to examine the cost. The thin spacers were required to be arranged vertically with parallel sides at a spacing of 1mm. The total number of glass spacers is 485-leaves. The schematic structure was shown in Fig.14 with some sizes.

The problem was how to keep vertical arrangement and parallel distance, with low cost. We tried to sustain the spacers at the end by accurate slit which was made by metal with chemical-etching technology. The spacers could be manipulated and placed by automatic placement machines. We used one spacer for one phosphor line so that the total number of spacer was many enough to sustain the required mechanical strength. It is a robust design but it should be less spacers in near future for cost reduction.

The surface of spacers were coated with special material to avoid the charging up as same as the ceramic-spacer. The protective effect against charging phenomena was examined by experimentally,

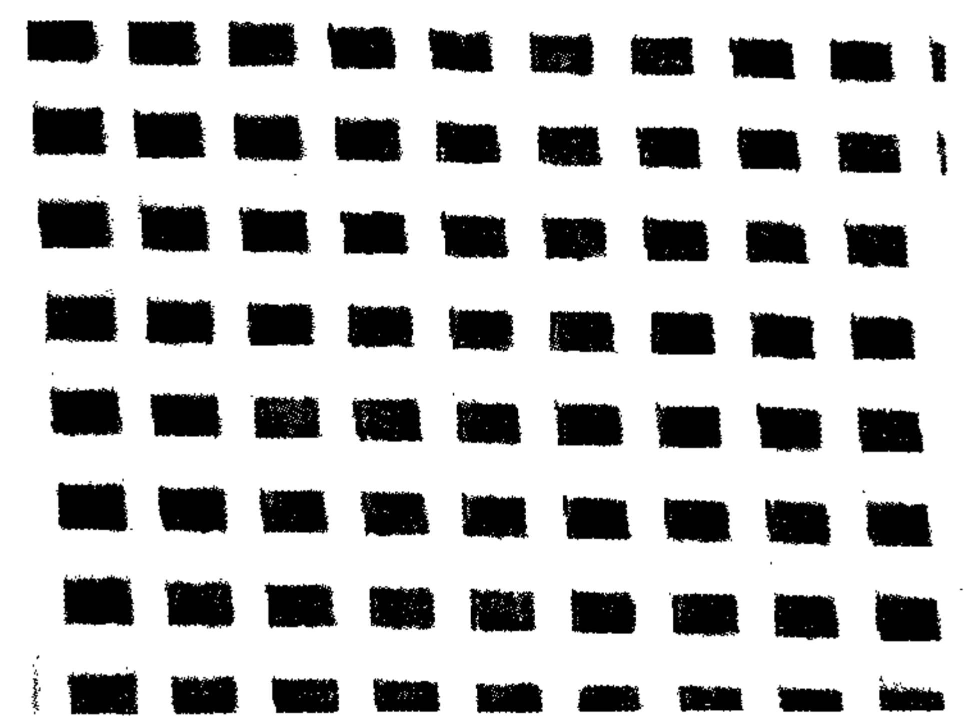

Fig.13 Photograph of a portion of ceramic spacer array.

6. Results

Experimentally, a 3.7-in. panel was built and tested. The screen size is 66mmx66mm. A pixel size was 1mmx1mm for monochrome and 3mmx1-3mm [3(RGB)x1or2or3mm] for color message display.

Fig.15 shows the detail of luminance distribution over a single pixel at two different electric-potential-control voltage. The luminance profiles obtained were due to the emission distribution profiles from the CNT cathode and due to electrical field created by electric-potential-control electrode. The top of lighting area was slightly enlarged according to the increasing electric-potential-control voltage.

Fig.16(a) shows moving picture of a graphic image, which was displayed over the 3.7-in experimental panel. A portion of the displayed pattern is shown in Fig.16(b). The photograph shows the moving image and the luminous uniformity of each pixel.

The green-color luminance was ca.$2.0x10^3 cd/m^2$ under 1/32 duty cycle driving at 3.5kV anode voltage, the height of spacer was 1.5mm.

The distance between the top of nanotube tips and the gate electrode was tested 0.06, 0.04 and 0.02mm respectively, the driving voltage was decreased almost linearly.

The colors displayed by the panel depend on the phosphors printed on the anode, ZnS:Cu,Al for green, Y_2O_3:Eu for red and ZnS:Ag for blue.

Under the above-mentioned consideration, a CNT-FED of middle size panel for character displays was built and tested. The screen size is 48 x 480-mm. A pixel size was 1 x 1-mm for monochrome and 3 x 1-3mm [3(RGB) x 1or 2 or 3-mm] for color message display, the pixel size could be selectable by gate-lines.

Fig.17 shows the photograph of the experimental panel compared to a conventional vacuum fluorescent character display, which has monochrome 16 x 256-dots.

In the figure, the periphery of cathode-metal-frames can be observed at both sides of the device. One frame has 80-electrodes so that 6 frames were required to construct the experimental panel.

7. Conclusion

Luminance uniformity was measured about an experimentally manufactured CNT-FED. The prospect for well aligned panels will be ca.2-4%. The uniformity and driving voltage was improved by appropriate laser irradiation over CNT-layer. The results were thought as an effect of increased emission-site density.

A prototype of CNT-FED character display was performed for middle size message displays. The display was constructed by metal-frame-cathodes, gate substrate and anode substrate with 3mm-tall glass spacers. The technology had advantages at the size-flexibility, deposition temperature and manufacturing yield. The prototype panel had 48 x 480-dots and the resolution was 1-mm. The panel realized high luminance at low power consumption. It will be important characteristics for legible and ubiquitous displays.

8. Acknowledgements

We thank to Dr. H.Murakami of ULVAC for the development catalytic CNT material by CVD and also Mr. T.Ishida of THE JAPAN STEEL WORKS, LTD for laser irradiation. We thank to Mie Prefectural Industrial Technology Advancement Center, Japan Science & Technology Corporation and New Energy and Industrial Technology Development Organization of Japan for their financial support.

9. References

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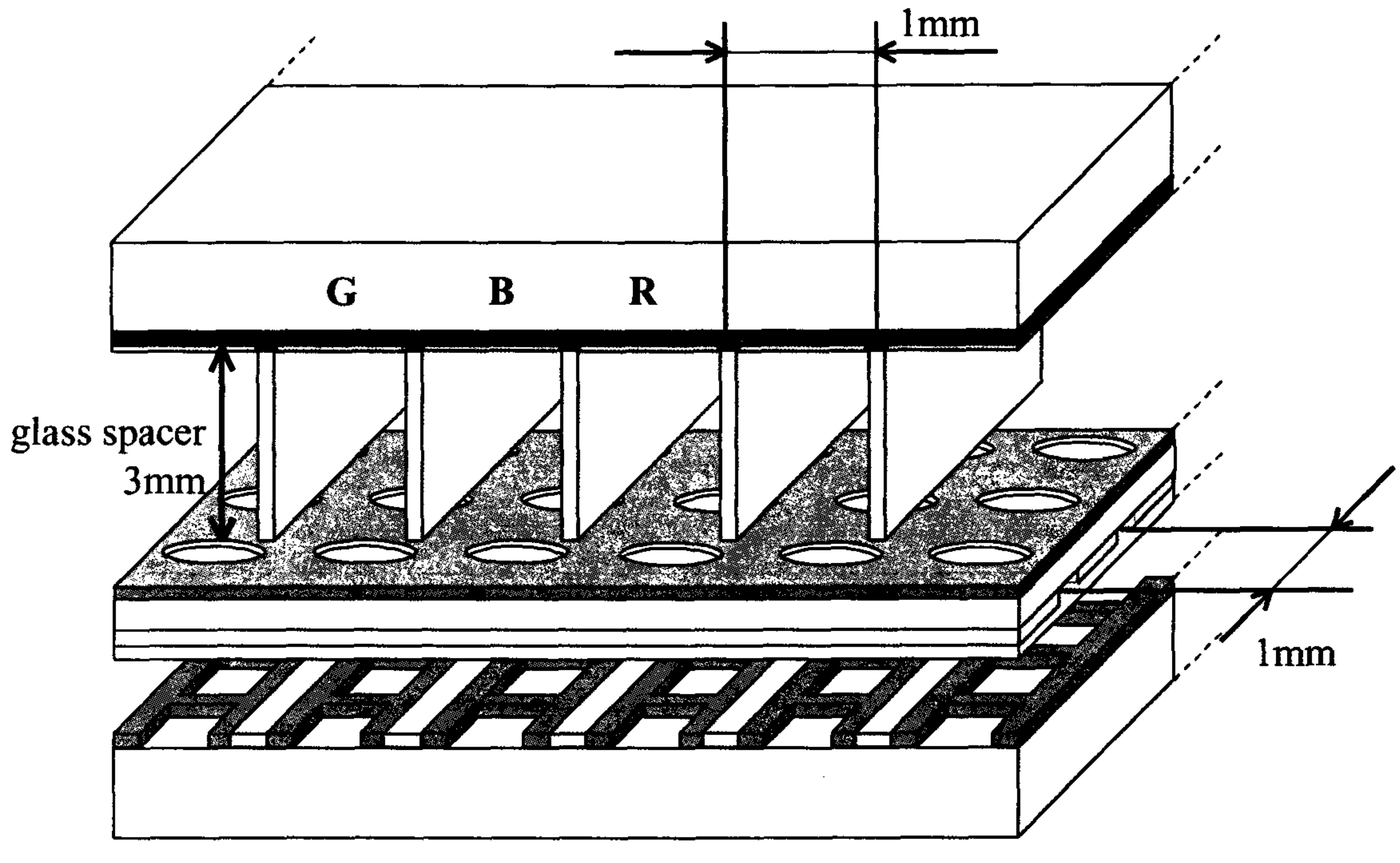


Fig.14 Schematic structure of a CNT-FED for character display. The prototype panel had 48 x 480-dots and the resolution was 1-mm. For color displays, the pixel size was 1-3 x 3-mm[3(RGB) x 1-mm].

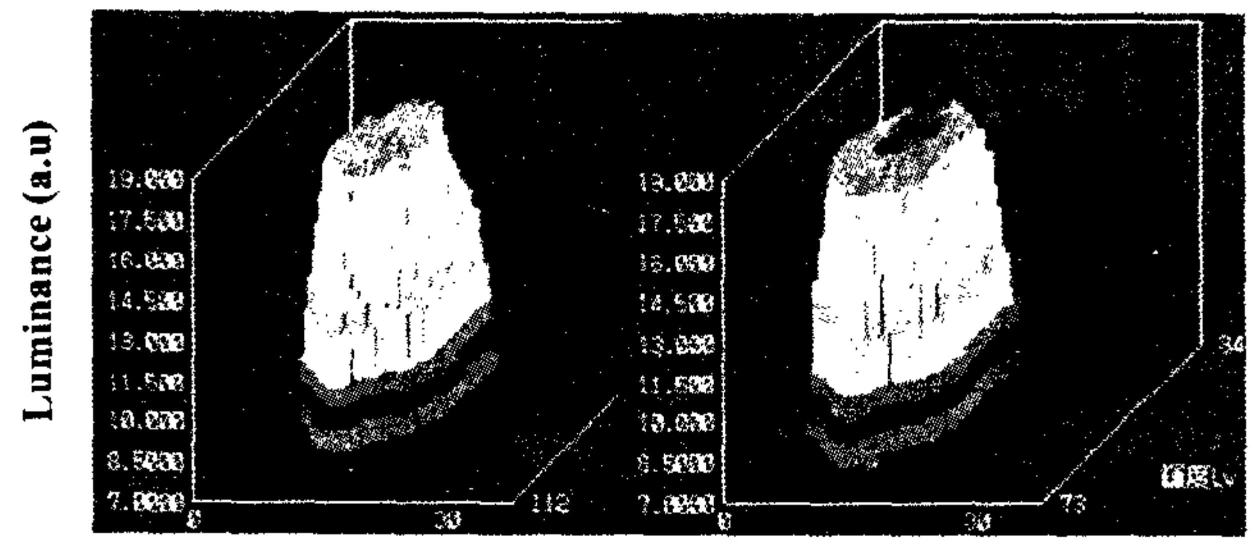
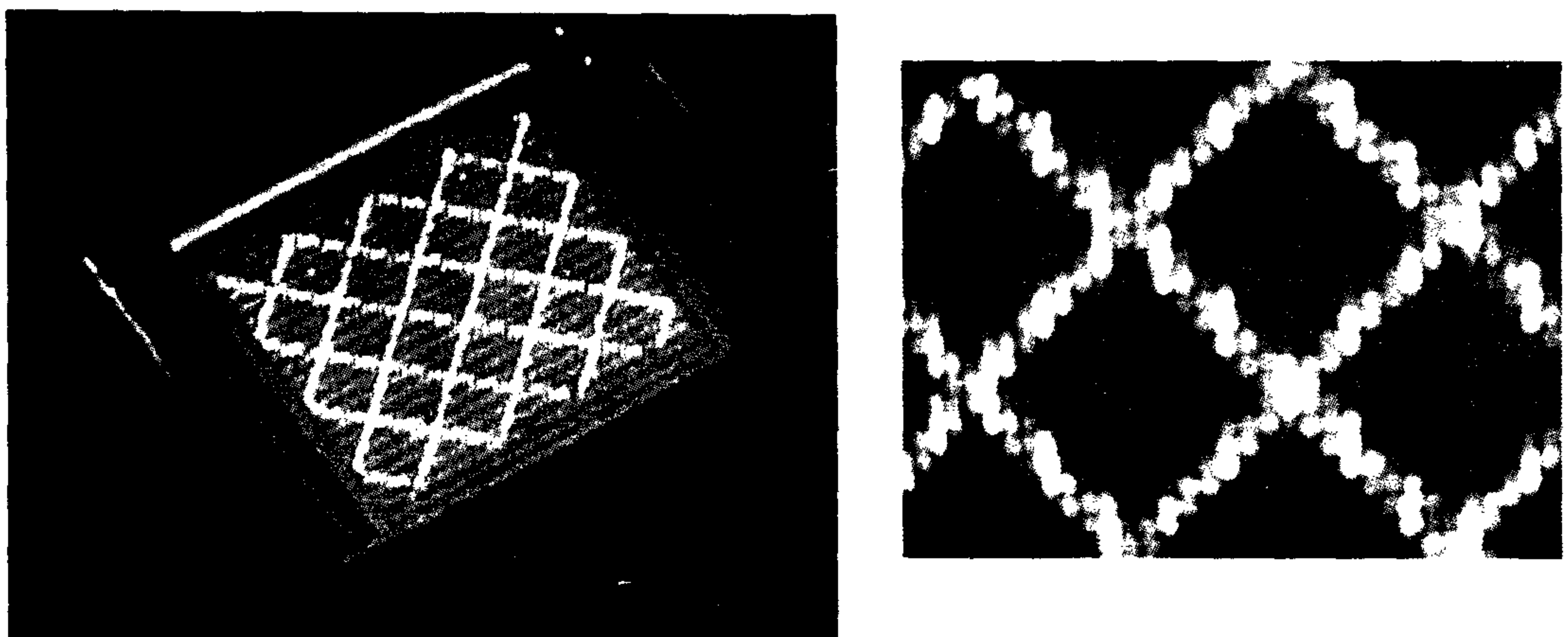


Fig.15 Luminance distribution profiles of one pixel at different electric-potential-control voltage.



(b)

(a)

Fig.16 Photographs of moving picture of a graphic image displayed over the 3.7-in experimental panel. (a) over the panel (b) a portion of the 3.7-in. panel.

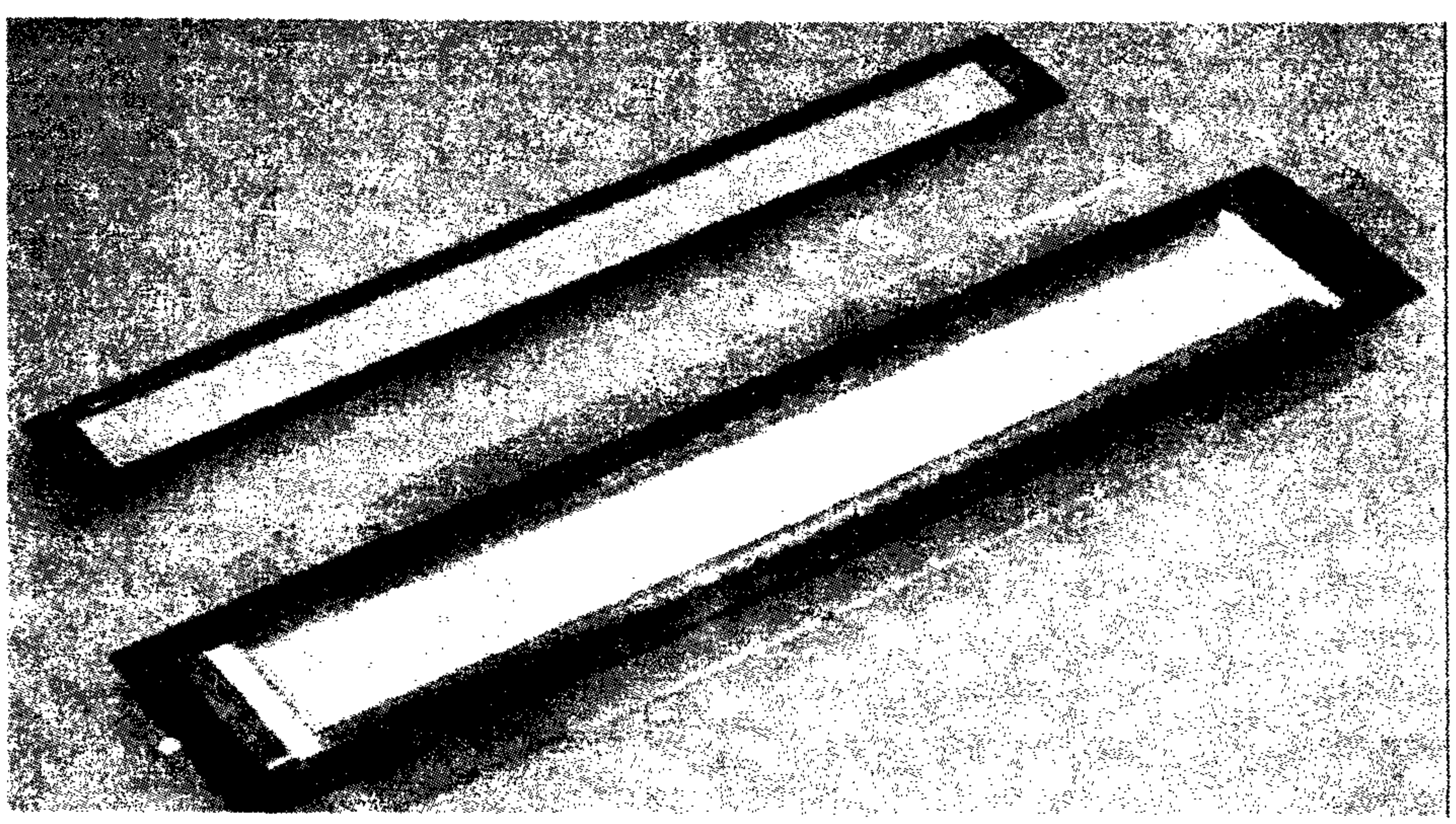


Fig.17 Photograph of the prototype of CNT-FED character display. Resolution : 1mm Display area: 48x480-dots.

(Upper device is a conventional VFD)