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Active-Matrix Cathodes though Integration of Amorphous Silicon Thin-Film Transistor with triode -and Diode-Type field Emitters

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Abstract

Amorphous silicon thin-film transistors (a-Si TFTs) were incorporated into Mo-tip-based triode-type field emitters and diode-type ones of carbon nanotubes for an active-matrix cathode (AMC) plate of field emission displays. Also, we developed a novel surface-treatment process for the Mo-tip fabrication, which gleatly enhanced in the stability of field emission. The field emission currents of AMC plates on glass substrate were well controlled by the gate bias of a-Si TFTs. Active-matrix field emission displays (AMFEDs) with these AMC plates were demonstrated in a vacuum chamber, showing low-voltage matrix addressing, good stability and reliability of field emission, and highly uniform light emissions from the anode plate with phosphors. The optimum design of AMFEDs including a-Si TFTs and a new light shield/focusing grid is discussed.

Keywords : active-matrix field emission display, active-matrix cathode, field emitter, molybdenum tip, carbon nanotubes, amorphous silicon thin-film transistor

1. Introduction

Field emission display (FED) is one of the promising next generation flat-panel-display devices due to its similarity of light emission mechanism with CRT. The matrix addressing of field emitter array (FEA) is mainly a passive multiplexing [1]. In this case, the driving voltage is high and the emission currents are very sensitive to driving voltage. These difficulties can be overcome by applying active-matrix cathode (AMC) scheme [2-5]. The control transistor for AMC is metal-oxide-silicon field effect transistor (MOSFET) or thin-film transistor (TFT) according to the substrate. The glass substrate is indispensable to the fabrication of low-price and large-area displays. Therefore, the successful implementation of amorphous silicon (a-Si) TFT to AMC is a key as pect point for the development of FED as a competitive display device. In this paper, we report active-matrix field emission displays (AMFEDs) with the AMC plates based on a-Si TFTs, and triode- and diode-type field emitters. Also, a novel process and a new cathode architecture are proposed to improve field emission stability and AMFED performances, respectively.

2. AMC Structure and Fabrication

We have developed two kinds of AMCs based on triode- and diode-type field emitters. In general, triode-type emitter arrays are composed of conical molybdenum (Mo)-tip FEA made by Spindt method. For diode-type emitters, a lot of materials have been studied, but nowadays carbon nanotube (CNT) is considered to

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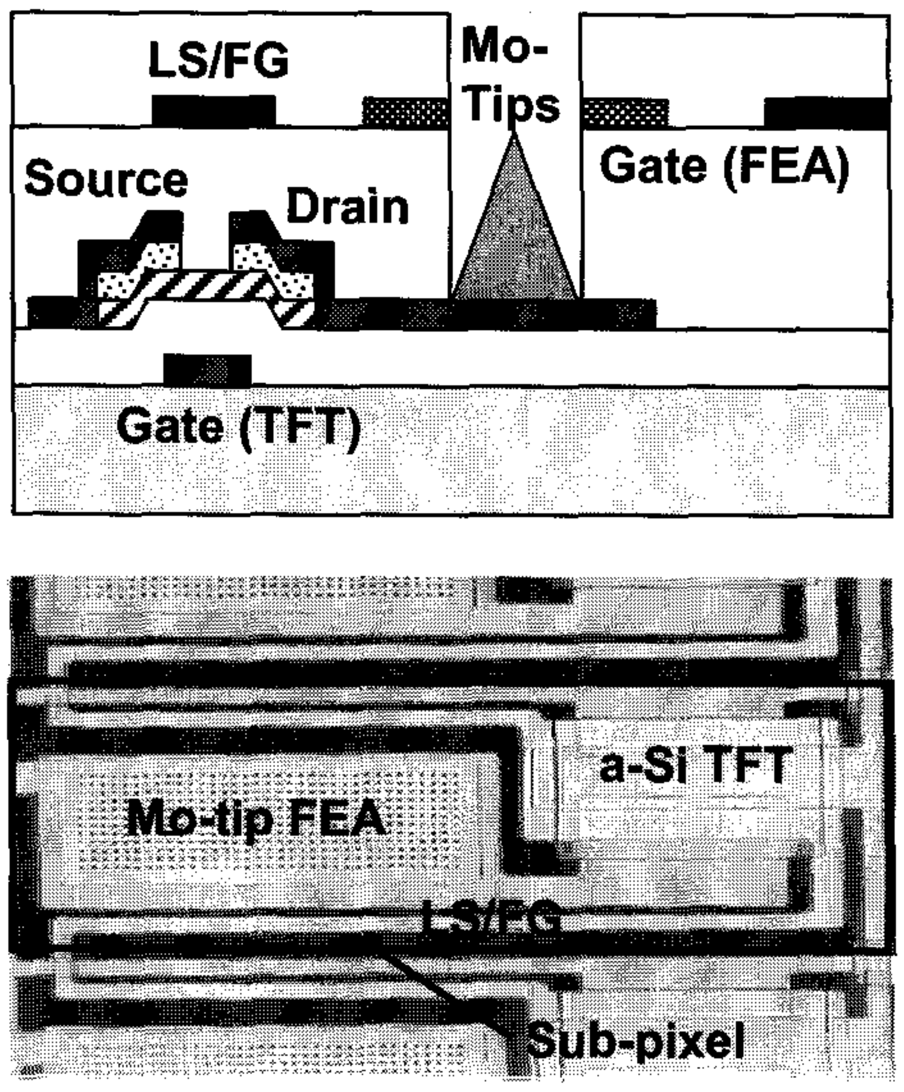

Fig. 1. The cross-section diagram and top view image of an AMC sub-pixel with Mo-tip FEA.

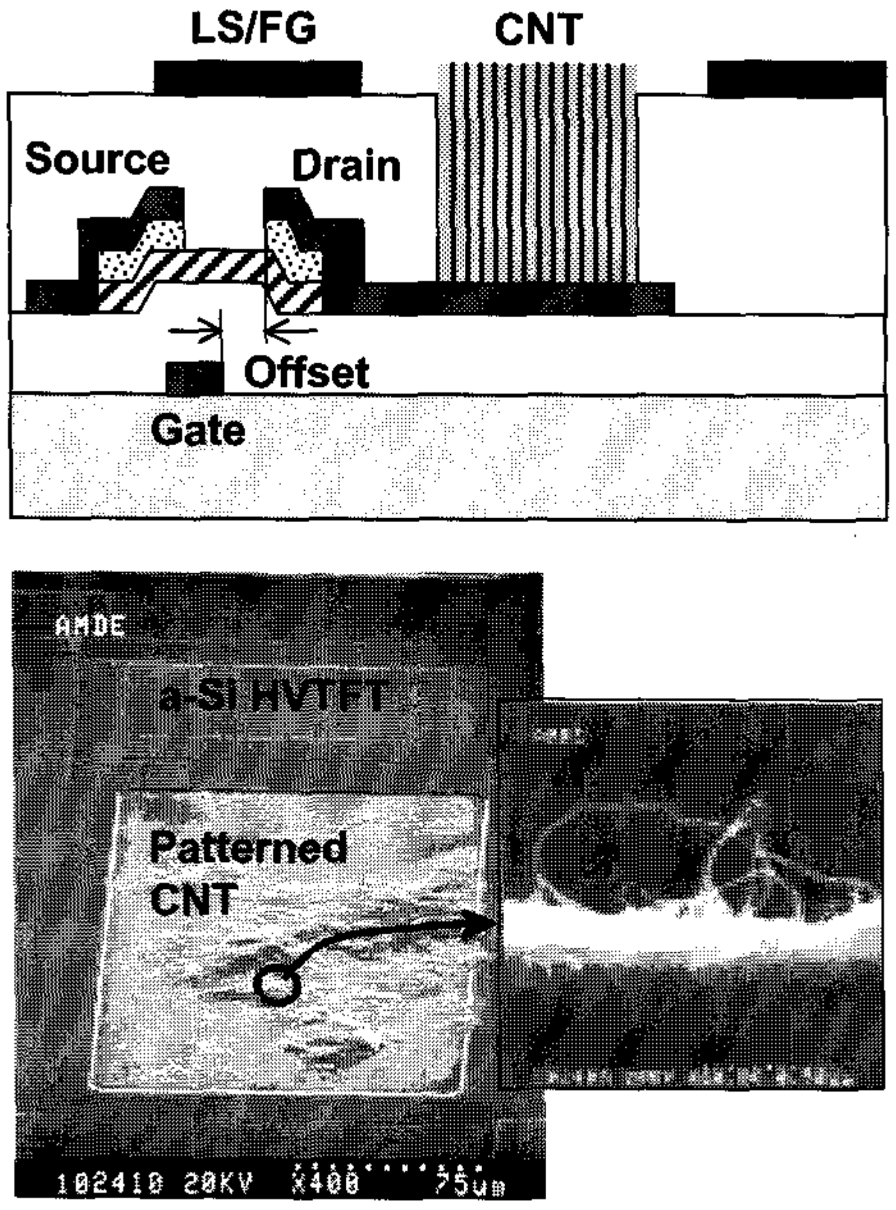

Fig. 2. The cross-section diagram and top view image of an AMC sub-pixel with CNT emitters.

be the best candidate for FED [6]. We applied both types of field emitters to AMC in which a-Si TFTs were used as a control switch for field emission.

The fabricated triode-type AMC was composed of a-Si TFTs and Mo-tip FEAs. A wet back-channel-etching was adopted for n^+-doped-a-Si etching in conventional inverted stagger-structured a-Si TFT fabrication process in order to achieve a very thin active layer of below 600 Å and minimize the number of process steps. The usual Spindt process with an Al parting layer was used for the formation of Mo-tip FEAs. The overall tip-formation process was optimized for the elimination of any side effects on a-Si TFTs. The cross-section diagram and top view image of the fabricated AMC sub-pixel is shown in Fig 1.

The diode-type AMC with CNT emitters and an a-Si high-voltage TFT (a-Si HVTFT) [4] were also fabricated. The fabrication process for a-Si HVTFT in the diode-type AMC was the same as in the triode-type case except for the gate-drain offset. The purified CNT powder was blended in a binder and coated on the PR patterned substrate. We obtained CNT patterns by the photo-resist lift-off process [7]. The patterned CNT layer was activated through a post-treatment method for good field emission. The cross-section diagram and top view image of the fabricated AMC sub-pixel including a cross-section SEM image of the patterned CNT is shown in Fig. 2.

Specifically, in order to reduce the light-induced leakage [8] and back channel currents in a-Si TFTs, and to focus emitted electron beams from the cathode on the corresponding anode pixel we have designed the AMC to have a light shield/focusing grid (LS/FG), as shown in Figs. 1 and 2. Also, a novel surface-treatment process, a cleaning with slight etching (CwE) using a solvent solution, was applied to the Mo-tip FEA to improve the stability of field emission.

3. Results and Discussion

The effects of the CwE treatment on field emission stability were observed in the FEA gate voltage-anode current characteristics at a constant TFT gate voltage, V_g(TFT), for the Mo-tip FEAs as shown in Fig. 3. We applied the CwE treatment in the final step of the two process sequences of batch 1 and batch 2. In batch 1, a pad process was followed by Al/Mo evaporation including lift-off using KOH while the Al/Mo process was performed prior to the pad step in batch 2. The results suggest that the CwE process greatly improves the stability of field emission, indicating a possibility of very stable and short aging for FED devices. The CwE effects may be attributed to the cleaning of adsorbates with an etching of MoO_x formed on the Mo-tip surface and/or Mo itself. The SEM observation showed that the

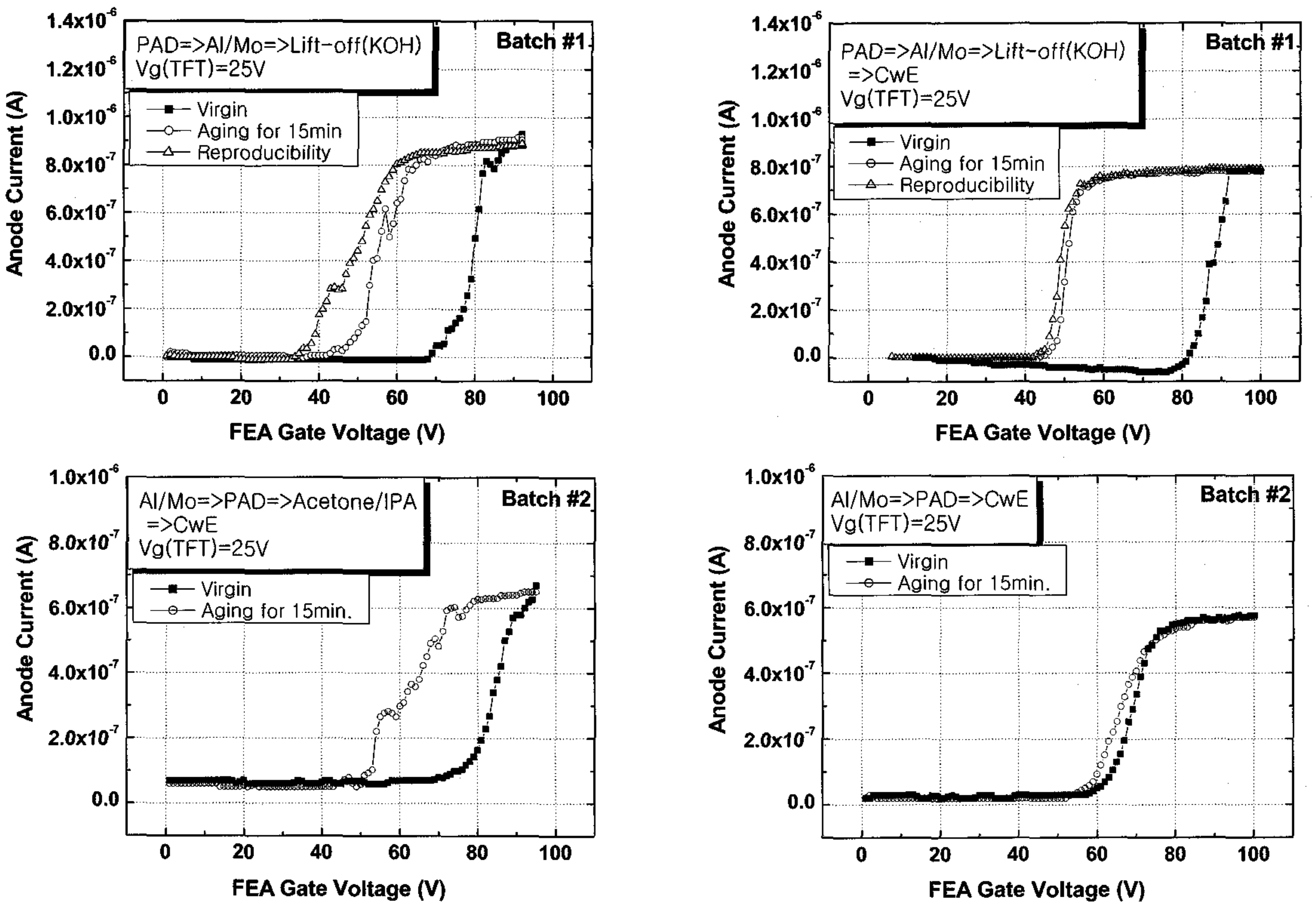

Fig. 3. The effects of CwE treatment on field emission stability in Mo-tip FEAs for the batchs 1 and 2 samples.

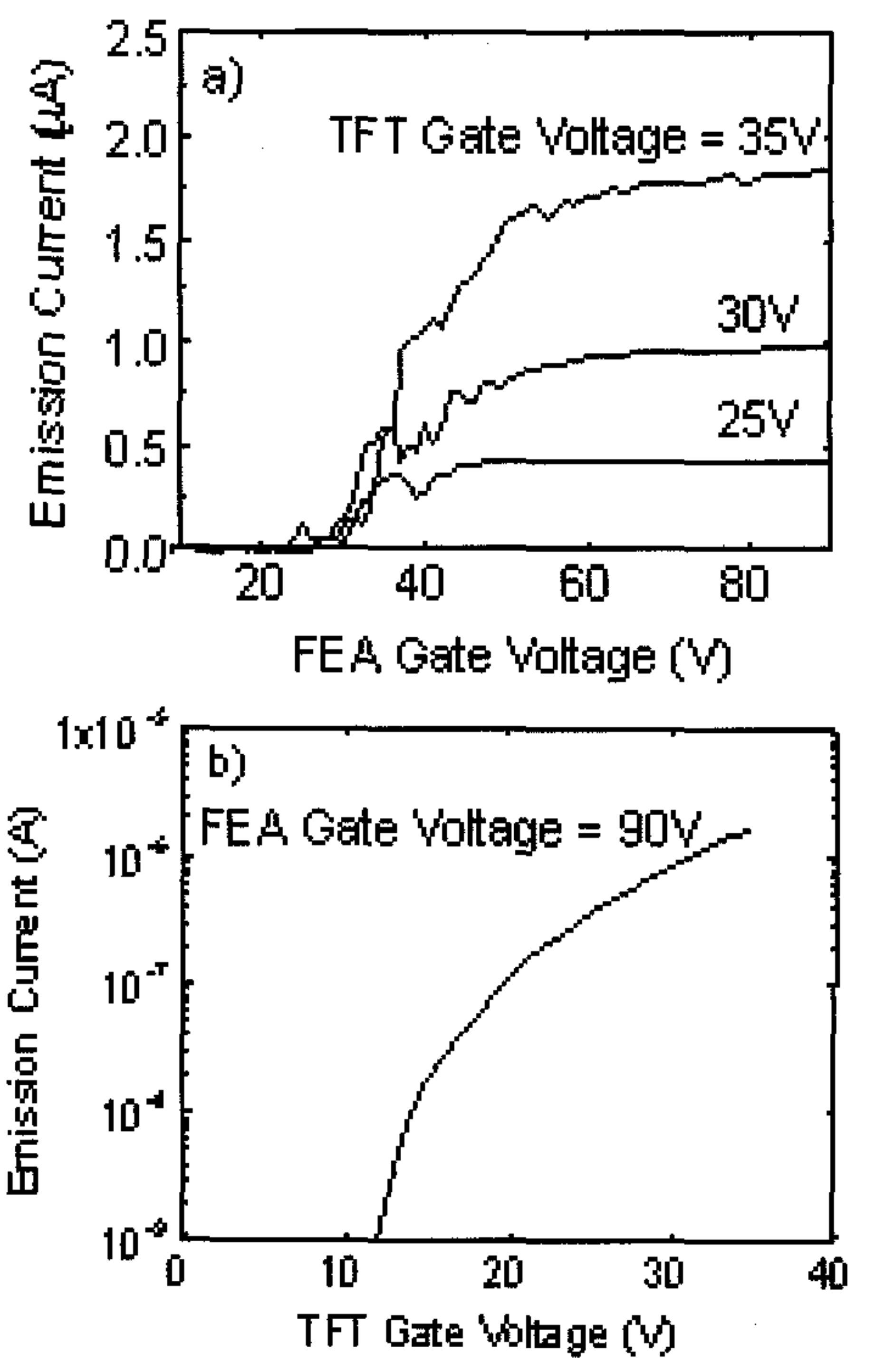

Fig. 4. The field emission characteristics of an AMC sub-pixel with Mo-tip FEA at a 400 V anode voltage; (a) as a function of FEA gate voltage at various TFT gate voltages, (b) as a function of TFT gate voltage at a 90 V FEA gate voltage.

surface of Mo-tip FEA is more or less roughened upon a short CwE treatment for below 10 min. The prolonged CwE treatments resulted in the full etching of Mo-tip FEA, and thus we could not find any Mo-tips.

Fig. 4 shows the field emission characteristics of an AMC sub-pixel with Mo-tip FEA in a high vacuum chamber. Field emission starts at about 30 V FEA gate bias and is saturated above 60 V FEA gate biases for a given TFT gate voltage. Also, the TFT gate was observed to efficiently switch field emission currents for a constant FEA gate voltage. It is specially noted that the LS/FG was biased to zero volt during the measurements shown in Fig. 4. The 0 V LS/FG bias gives rise to the complete turn-off of field emission currents at a constant FEA gate voltage. This implies that the LS/FG functions to prohibit the back channel of a-Si TFT turning-on by the FEA gate and to block the lights from the anode plate into the a-Si TFTs in AMC pixels, resulting in a high On/Off ratio of above 10^3 for field emission currents. With the introduction of the LS/FG in to AMC architecture, we can easily achieve a high contrast AMFED addressed by low-voltage row and column driver circuits. In addition, the LS/FG biased with zero or negative volt would have a role to focus electron beams from the cathode on the corresponding anode pixel, enhancing the color purity of AMFED.

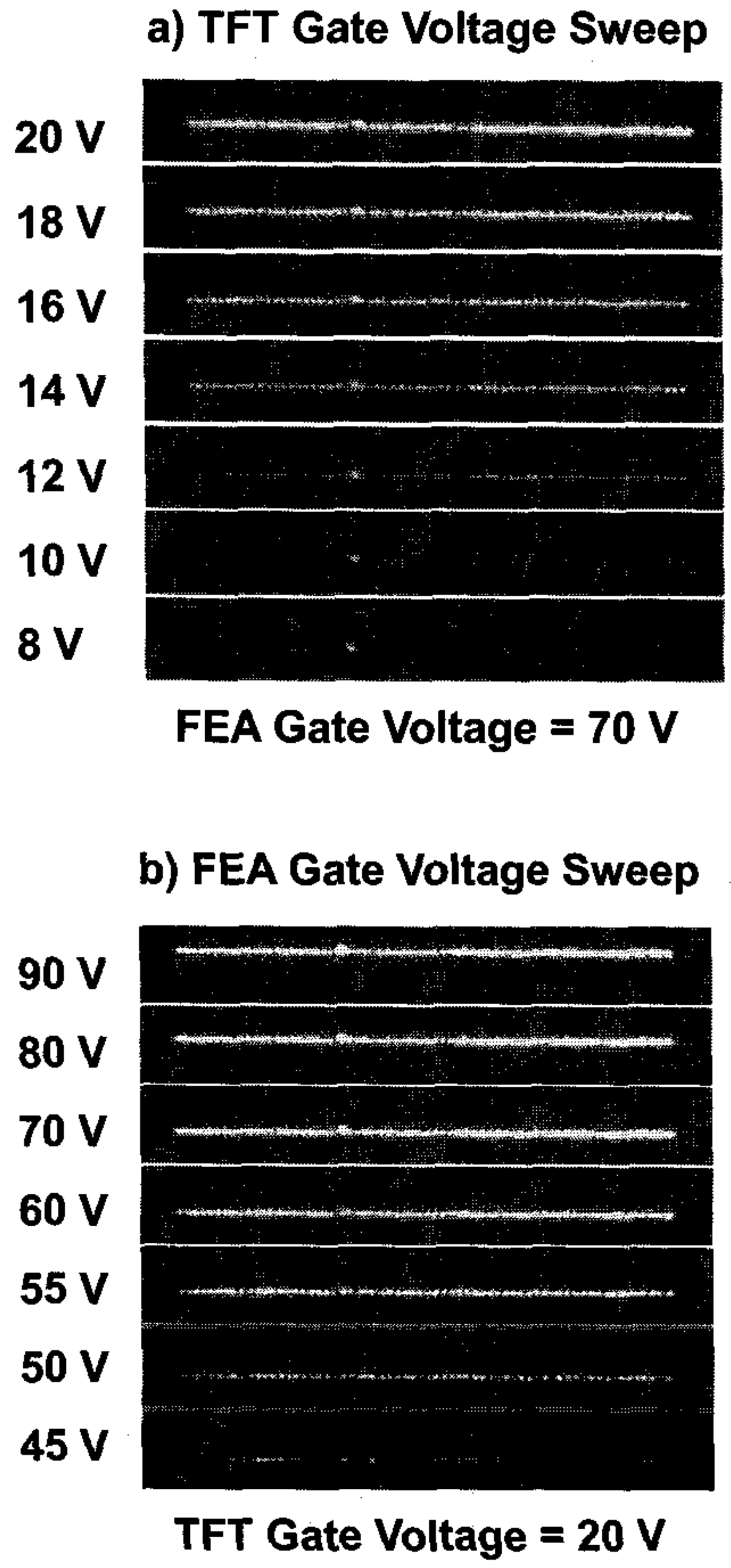

Fig. 5. The line-by-line light emissions from a 64X(64X3)-AMC with Mo-tip FEA at a 400 V anode voltage; (a) as a function of TFT gate voltage at a 70 V FEA gate voltage, (b) as a function of FEA gate voltage at a 20 V TFT gate voltage.

The line-by-line light emissions from a 64X(64X3)-AMC in a vacuum chamber were observed as functions of TFT and FEA gate voltages, as shown in Fig. 5. The anode plate had a blue phosphor of CaS:Pb grown by atomic layer deposition [9]. The light emissions are well controlled by the gate bias of a-Si TFT and saturated above 60 V FEA gate biases at a 20 V TFT gate bias as the emission current characteristics shown in Fig. 4. Also, the improved uniformity of light emissions was consistent with the electrical properties of AMC.

For the case of diode-type AMC, a very high drain voltage was induced on the control a-Si TFT under the turn-off condition at a constant anode voltage required for field emission. The well-known structure of a-Si TFT for enduring high drain voltages was a gate-drain offset structure. The operation voltage, thickness of active layer, and gate length/width determined an optimal length of the offset region. The output characteristics of the developed a-Si HVTFTs as a function of offset length are shown in Fig. 6. The results indicate that the developed a-Si HVTFTs can be used as a control switch for diode-type AMC eventhough they have the current pinching effect at low drain voltages.

The a-Si HVTFTs were measured to have nearly the same device parameters as the conventional inverted stagger a-Si TFT at high drain voltages. This high-performance of the a-Si HVTFTs may be attributed to the space-charge limited current (SCLC) of the a-Si offset at high electric fields. We have observed the SCLC transport above 10 V bias in the planar structure of n^+-i-n^+ a-Si with a channel length of 10 μm.

The stability of the a-Si HVTFTs was examined under high drain biases. A very thin active layer revealed some instability under a high drain bias, which is caused by the degradation of active layer in the offset region. Considering the inherent low off-leakage current of TFT with the offset structure, the a-Si HVTFT used in diode-type AMC should be optimized for the improvement of stability under a high drain bias.

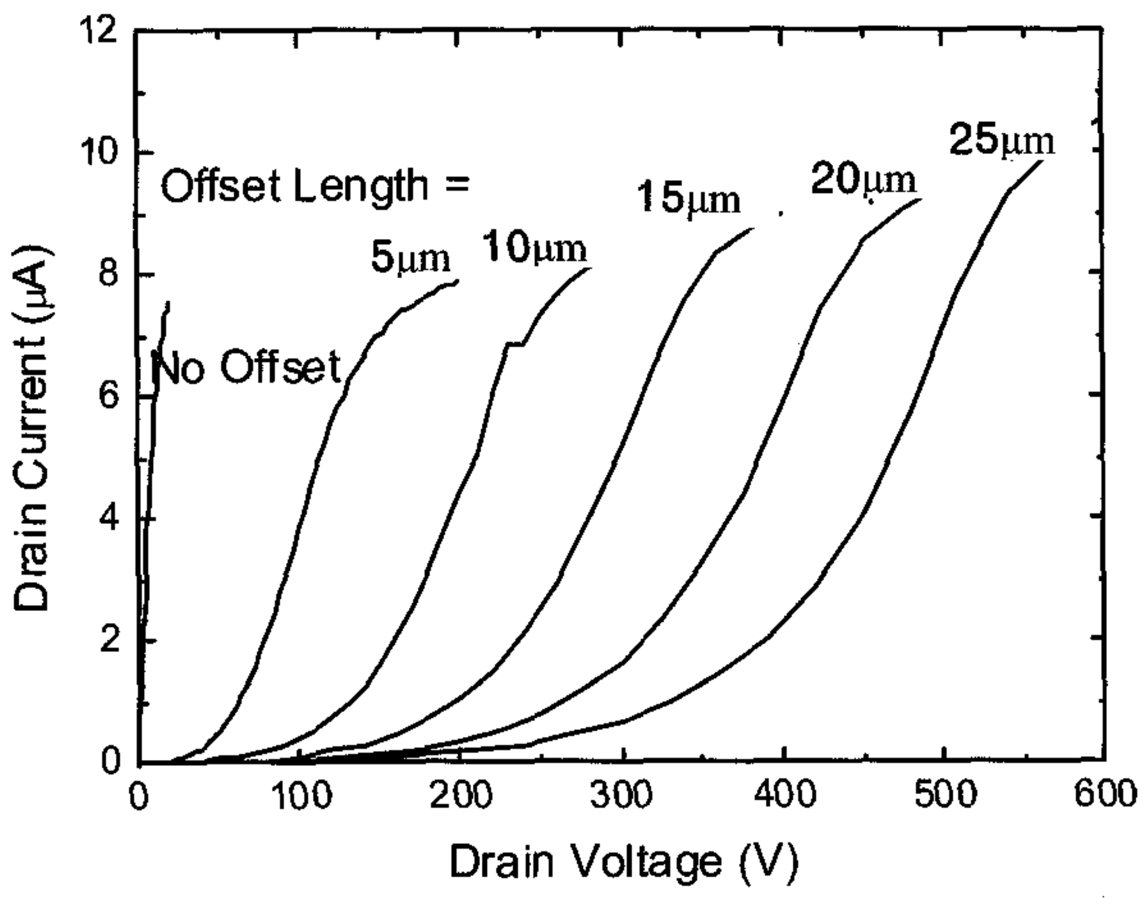

Fig. 6. The output characteristics of a-Si HVTFTs as a function of offset length.

On the other hand, the TFTs used in the two AMCs were made through PECVD process at 380 ℃ which is higher than conventional temperature in a-Si process. During the vacuum sealing process in FED the temperature of samples rises above the melting temperature of frit glass (around 350 ℃). This high temperature process may bring about serious degradations to the electrical characteristics of a-Si TFT fabricated by conventional PECVD process. Therefore, the deposition temperature of thin films in a-Si TFT must be high enough to prevent the samples from the damages caused by high temperature damage during the vacuum sealing process. The threshold voltage goes high and the field effect mobility goes down in the developed a-Si TFTs compared with ones made at normal temperature. But their characteristics are still good enough to be used as a control switch for AMC pixel.

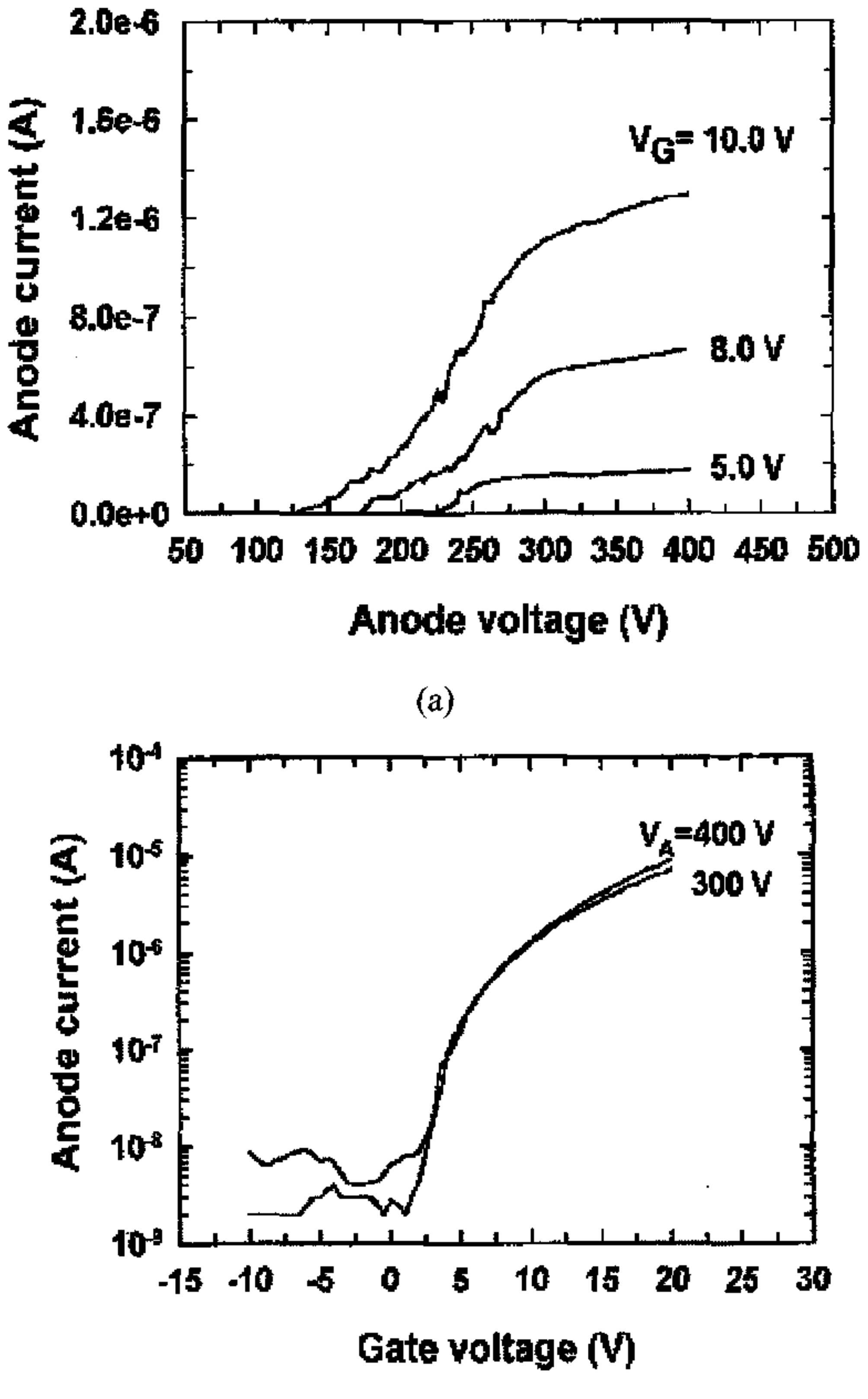

Fig. 7. The field emission characteristics of an AMC sub-pixel with CNT emitters; (a) as a function of anode voltage at various TFT gate voltages, (b) as a function of TFT gate voltage at two anode voltages of 300 V and 400 V.

Fig. 7 shows the field emission characteristics of an AMC sub-pixel with CNT emitters as functions of anode and TFT gate voltages. In the case of diode-type AMC, the anode current showed well-saturated behaviors over the large anode voltages for a given gate voltage of the a-Si HVTFT. Also, very low voltages biased to the TFT gate can switch the emission currents with a large On/Off ratio of above 10^3 for a constant anode voltage (V_A), indicating that the control voltage of diode-type emitters can be significantly lowered and so low-voltage addressable FEDs can be easily fabricated with the AMC. The controllability of TFT gate bias over field emission was also confirmed in a prototype 2-inch AMC in a vacuum chamber. Arial light emissions from the 2-inch AMFED well controlled by the TFT gate bias with a constant anode voltage required for field emission while several failures occurred in a-Si HVTFTs and CNT emitters.

4. Conclusion

AMFED technology was confirmed by integrating a-Si TFTs with Mo-tip triode emitters and CNT diode-type emitters on glass substrate. The field emission properties of both AMCs were well controlled by the TFT gate bias. The LS/FG in the AMC architecture gave a complete turn-off of field emission currents at a constant voltage required for field emission. Also, the developed CwE treatment in the Mo-tip FEA greatly improvesd the stability of field emission, showing a possibility of very stable and short aging for FED devices. A-Si TFTs must be optimized from the various viewpoints of the vacuum sealing temperature and off-leakage current controllability in case of triode-type AMC, while stability under high drain bias in case of diode-type AMC.

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