Development of Active Matrix Cathodes Composed of a-Si:H TFTs and Gated Molybdenum Field Emitter Arrays

Choong-Heui Chung, Yoon-Ho Song, Chi-Sun Hwang, Seong-Deok Ahn,
Bong-Chul Kim, [a]Young-Rae Cho, Jin Ho Lee, Kyoung Ik Cho
Basic research Lab., ETRI, 161 Gajeong-dong, Yuseong-gu, Daejon, 305-350, Korea
[a]Department of Materials Science & Engineering Pusan National University, 609-735, Gumjung-Gu, Pusan, Korea

Abstract

We successfully developed a-Si TFT controlled active matrix cathode (AMC) with gated Mo emitters. Also, we could remove emitter failures of the AMC through a novel surface treatment of Mo-tips, which indicates reduction of MoO_3 or chemical wet etching of MoO_3 by surface treatment. Transient behaviors of the AMC are strongly dependent on not only DC characteristics of device but also the device structure. Brightness and gray scale were well realized by low-voltage scan and data signals addressed to a-Si TFTs.

1. Introduction

Cold cathodes with gated Mo field emitters have received great attention because of its possible application for FEDs [1], but its applications have been limited by instability during operation, susceptibility of the emitters to failure and a high driving voltage. In order to overcome these problem, new process, e.g. molybdenum silicide formation [2], molybdenum carbide coating on Mo tips [3] and a Redox method [4], etc, and new materials such as diamond and carbon nanotubes and have been investigated. Also, Several research groups [5-6] have been reported on MOSFET or TFT controlled active matrix cathode (AMC) to improve emission stability and enable the use of low-voltage and low-cost drivers for the operation of AMFEDs.

In this paper, we report on fabrication of failure free AMCs with stable emission characteristics, which were developed by implementation of a-Si TFT to gated Mo-emitters on a soda-lime glass substrate. The electrical properties including transient behavior of the AMC were characterized.

2. Fabrication

Fabrication process of AMC can be divided into two-module process, a-Si TFTs and gated Mo field emitters.

We first fabricated an a-Si TFT for use as a control device. 5" glass wafer with a-SiN_x:H by PECVD were used as a starting substrate. Cr was deposited and defined for TFT gate layer. a-SiN_x:H / un-doped a-Si / n+-doped a-Si layers were subsequently deposited by PECVD, and then a-Si layers were defined to isolate each pixel. Cr for the source/ drain layer was deposited and patterned, and source and drain contacts are formed in n+ a-Si layer. The thin active layer (<60 nm) was achieved by adopting wet back channel etching for selective etching of n+ doped a-Si used in the inverted staggered-structured a-Si TFT fabrication process.

Gated Mo emitters were formed on the drain of the a-Si TFT using the Spindt process. Finally, we completed AMC process through surface treatment of Mo-emitters using a solvent solution.

Each pixel of the fabricated AMC consisted of an a-Si TFT with W/L=100μm / 20μm and gated 400 Mo emitters lying on the drain of a-Si TFT as shown in Fig. 1.

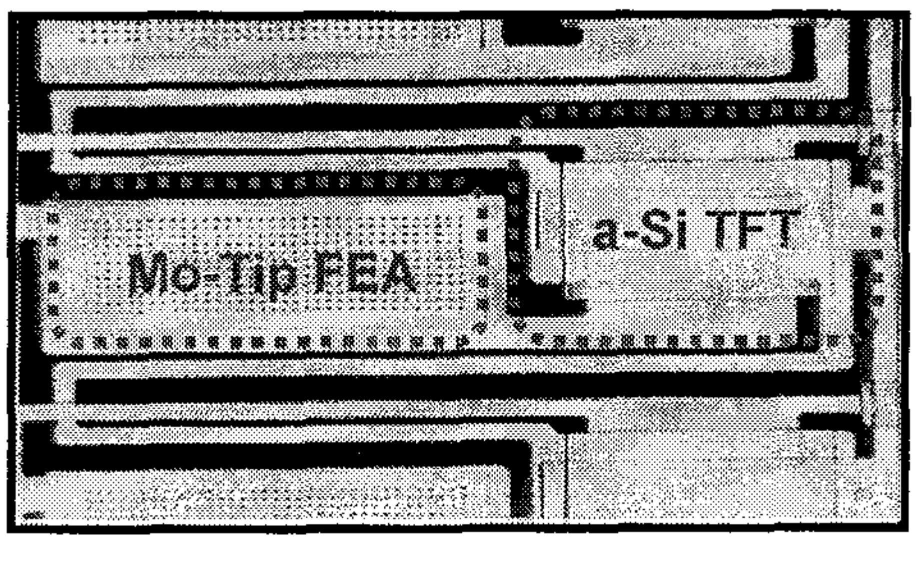
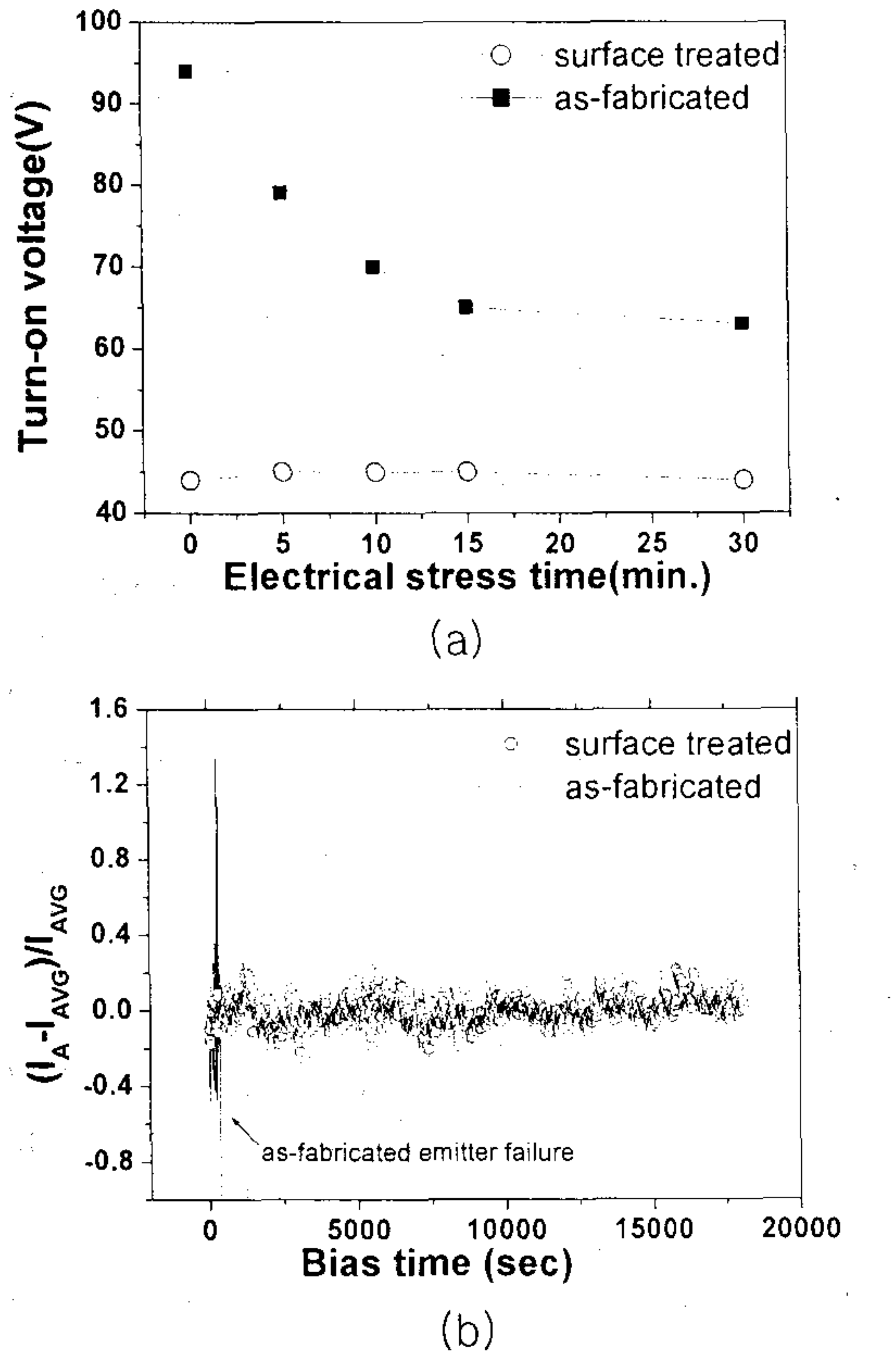


Fig. 1. Plane view of the unit pixel for the AMC.

3. Results and Discussion

3.1. Surface treatment of Mo emitters

Figure 2 (a) shows the effects of surface treatment of Mo-emitters on field emission characteristics. In case of the sample without surface treatment, the turn-on voltage for field emission was continuously changed against electrical stress time. It may mean that the surface properties of Mo emitters, such as local curvature of the emitter surface, and local work function etc., are very unstable against electrical stress. The instability of electron emission from Mo emitters often caused emitter failure. On the other hand, Mo emitters with surface treatment exhibited rigid and stable emission characteristics against electrical stress.



(a)

(b)

Fig. 2. (a) Turn-on voltage vs. electrical stress time for as-fabricated Mo emitters and surface treated Mo emitters. (b) Emission stability for as-fabricated Mo emitters and surface treated Mo emitters without control device.

Figure 2 (b) shows the emission current stability of Mo emitters over a period of 5 hours. In order to exclude the influence of the control devices, source and gate of a-Si:H TFT were not probed, and drain of that was held at grounded state. The emission current variations were normalized with average anode current at fixed FEA gate bias of 80V. Sample without surface treatment showed a large current fluctuation ranging from –149.6% to 48.1%. To make matters worse, emitter failed within 360sec for the tested all five devices. Whereas, current variation of Mo emitters with surface treatment was ranging from –31.4% to +31.3%. Furthermore, the immunity for emitter failure was achieved by surface treatment. This result demonstrates that the surface treatment of Mo emitters significantly improves the field emission stability.

To study how surface treatment through cleaning agent affects the properties of the Mo film, those were analyzed by XPS. We measured the binding energy of the Mo $3d_{5/2}$ and Mo $3d_{3/2}$ levels by narrow scanned XPS as shown Fig. 3. The sample without surface treatment contained two dominant peaks appears at 232.5eV and 235.5eV corresponding to Mo $3d_{5/2}$ and Mo $3d_{3/2}$ of Mo^{6+} in addition to Mo $3d_{5/2}$ (228eV) of clean Mo surface. The existence of Mo^{6+} is attributed to MoO_3. In the sample with surface treatment, there are two dominant peaks corresponding to Mo $3d_{5/2}$ and Mo $3d_{3/2}$ of clean Mo surface, which indicate reduction of MoO_3 or chemical wet etching of MoO_3 by surface treatment.

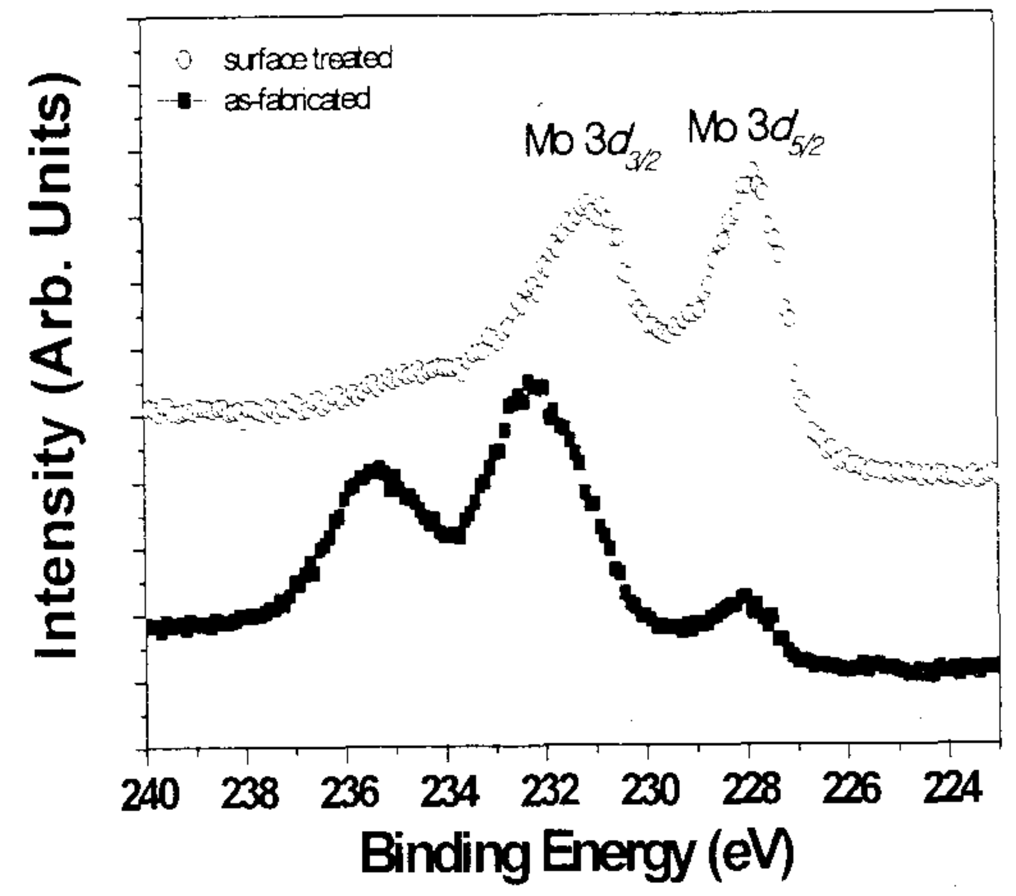
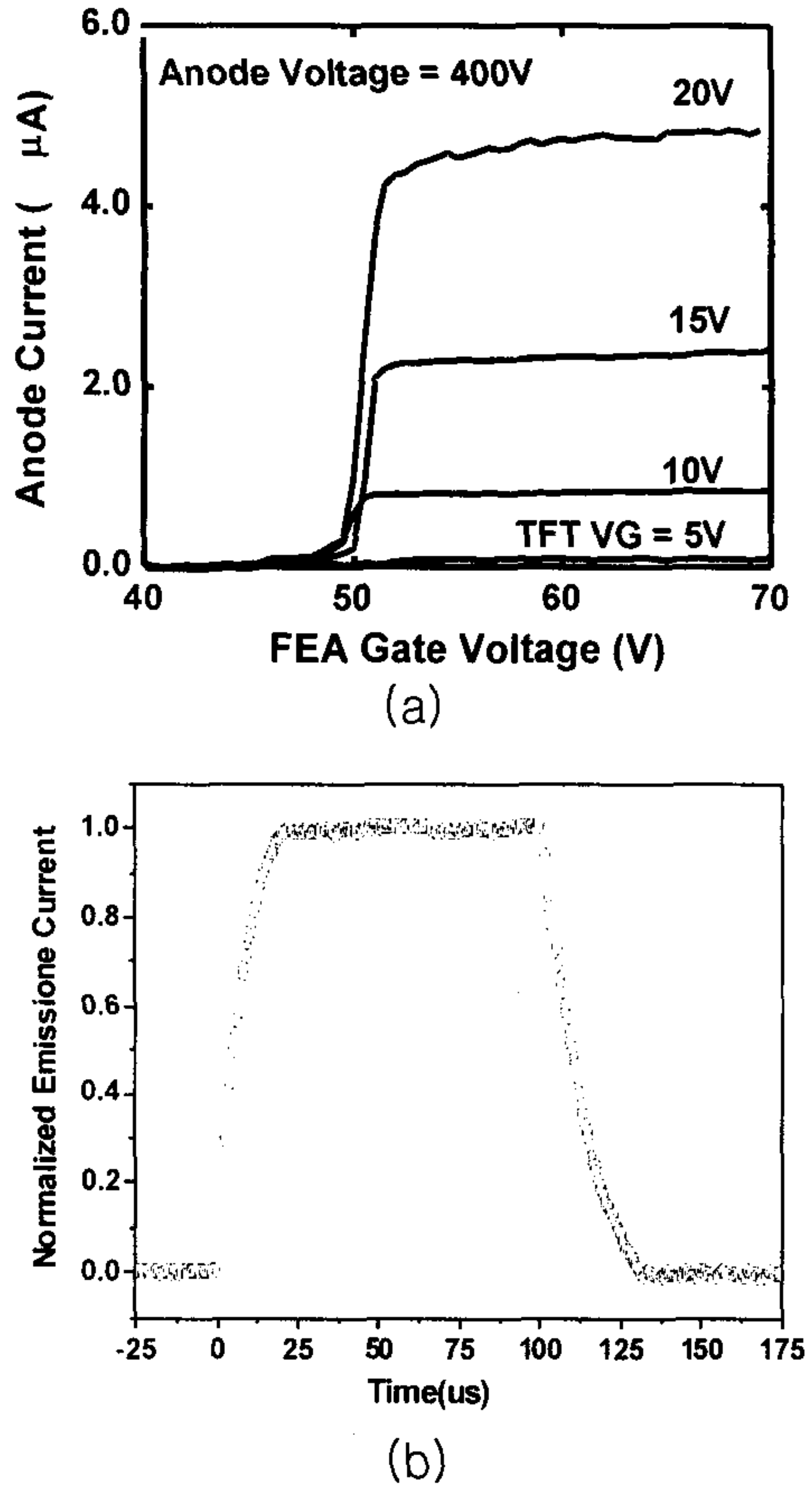


Fig. 3. XPS spectra ranging from 222 to 240 eV for as-fabricated Mo film and surface treated Mo film.

We also observed that surface roughness of Mo film was increased through surface treatment. Increase of the roughness of the Mo surface and field emission enhancement due to reduction of Mo surface have been previously reported [4].

3.2. DC characteristics of the AMC

Figure 4(a) shows the TFT controlled emission properties of the fabricated AMC. The anode current was first detected at an FEA gate voltage around 47 V, which indicates the AMC initiates a field emission at an FGT gate voltage below 50V. The anode current drastically increases with an increase in the TFT gate voltage and soon reaches a saturation point of constant current values. Anode currents of the AMC are also easily controllable by the drain current of the a-Si TFT. These results indicate that the AMC can be operated by the low-voltage of the TFT gate under a 25V bias.



(a)

(b)

Fig. 4. (a) DC anode current of the AMC. (b) Transient anode current of the AMC

3.3. Transient characteristics of the AMC

The pulse generator applies a 20V pulse with width of 100us to the TFT gate, and a anode current could be measured using a 18k Ω load resistor. Figure 4(b) shows the transient behavior of normalized anode current at a constant FEA voltage of 80V in the AMC. A 10 to 90 % rising time (t_r) was about 13 μs and a 90% to 10 % falling time (t_f) was about 23 μs. Difference between t_r and t_f is due to nonlinear characteristics of field emission ruled by Fowler-Nordheim equation.

Since capacitive loading affects the rise and falling time of the voltage at the emitter tip. Parameters such as a FEA gate capacitance between a TFT drain and a FEA gate, mobility of a-Si:H TFT and field emission properties are critical factors determining the t_r and t_f in the AMC. Therefore, with decreasing the FEA gate capacitance, increasing mobility of a-Si TFT and enhancing field emission properties, the response time (t_r and t_f) of the anode current decreased. The detailed analysis will be reported elsewhere.

3.4. Displays

2-inch AMC is composed of 192×64 pixels. The TFT gate and TFT source lines were used as scan and data lines, and were connected to row and column driver through flexible printed circuit (FPC) with a pitch of 500 μm for operating AMC, respectively. ITO glass with green phosphor was prepared as the anode plate. The distance between the AMC and the anode plate was maintained at 700 μm by glass spacers. Brightness could be stably controlled via switching bias of the scan signal with a fixed width of 70 μs at a frame-frequency of 60 Hz. At the same time, gray scale could be presented by controlling width of data signal ranging form 0 to 70 μs. By scanning a low TFT gate voltage of 25 V at a constant dc-voltage of 70 V on the FEA gate and 500 V on the anode, it was possible to achieve a moving picture of the emitting image from the AMCs as shown in Fig. 5. From this result we conclude that the AMC can be operated by a low-voltage bias of TFT gate, resulting in a low-cost driving circuit for AMC to operate.

4. Conclusion

Fully integrated an AMC was fabricated and demonstrated. Emission currents of AMC were well controlled by the TFT gate bias. The fabricated AMC was successfully demonstrated to show good emitting images with low-voltage signals addressed to a-Si TFT. We conclude that the newly fabricated AMC has great potential for the development of high-performance FEDs.

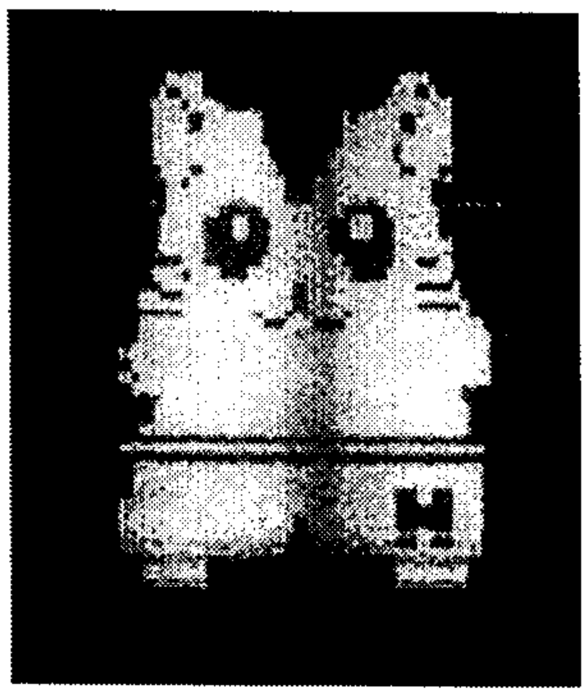


Fig. 5. Emitting image from 2-inch AMC with low driving voltage

5. Acknowledgements

This work was financially supported by the Korea Ministry of Information and Communication.

6. Reference

[1] C. A. Spindt, C. E. Holland, A. Rosengreen, and I. Brodie, IEEE Trans. Electron Devices, 38, 2355 (1991).

[2] Hyung Soo Uh, Btung Gook Park, and Jong Duk Lee, IEEE Electron Devices Letters, 19, 167(1998).

[3] Ambrosio A. Rouse, John B. Bernhard, Edward D. Sosa, and David E. Golden, Appl. Phys. Lett. 76, 2584 (2000).

[4] C. M. Lin, S. J. Chang, M. Yokoyama, I-Nan Lin, J. F. Chen, and B. R. Huang, IEEE Electron Devices Letters, 21, 560(2000).

[5] J. Itoh, T. Hirano and S. Kanamaru, Appl. Phys. Lett. 69 (1996).

[6] Y.-H. Song et al, Society for Information Display 00 Digest, 1252 (2000).