Stability of an Amorphous Silicon Oscillator

Byung Seong Bae, Jae-Won Choi, Se-Hwan Kim, Jae-Hwan Oh, and Jin Jang

An RC oscillator using amorphous silicon thin film transistors was developed. The oscillation frequency and its dependence on resistance and bias voltage were studied. The frequency was controlled by adjusting the feedback resistance of the oscillator. The highest measured frequency of the oscillator was around 140 kHz, which is acceptable for low-end radio frequency identification (RFID). Since a low-end RFID circuit needs low cost and a simple process, an amorphous silicon oscillator is suitable.

Keywords: Amorphous silicon, thin film transistors, integrated circuits, RFID, oscillator.

Manuscript received June 1, 2005; revised Oct. 14, 2005.

Byung Seong Bae (phone: +82 2 961 0971, email: bsbae3@hanmail.net), Jae-Won Choi (email: jwchoi@tftlcd.khu.ac.kr), Se-Hwan Kim (email: shkim@tftlcd.khu.ac.kr), Jae-Hwan Oh (email: jhoh@tftlcd.khu.ac.kr), and Jin Jang (email: jjang@khu.ac.kr) are with the Department of Information Display, Kyung Hee University, Seoul, Korea.

I. Introduction

An oscillator is a basic unit for operations of most circuits, and many kinds of on-chip integrated oscillators have been suggested based on different principles [1]-[6]. An exact frequency is required for the accurate operation of a circuit; therefore, precise control of frequency is necessary. For this, some crystals such as quartz are being used. High frequency with low phase noise is necessary for high-speed communication [6].

On the other hand, there is an increasing technological interest in low-frequency application because of the demand for a low-cost circuit. Since amorphous silicon or an organic thin-film transistor (TFT) can be manufactured using low-cost processes, they are adequate for low-cost circuits. However, their mobility is low and their applications are restricted to the low-frequency region.

Organic TFTs have been studied for low-cost circuits on glass or flexible substrates [7]-[15]. Radio frequency identification (RFID) and displays are typical applications of such low-cost circuits.

RFID is a means of storing and retrieving data through electromagnetic transmission to an RF-compatible integrated circuit. RFID uses three different effective frequency ranges: low, intermediate, and high. At low frequency, below several hundred kHz, RFID can be used for an inexpensive system as access control with low-reading speed. On the other hand, a high frequency system, up to several GHz, can be used for high speed reading. For low cost, several technologies can be used such as nanoblocks, or amorphous or poly-crystalline silicon TFTs [16]-[19].

Hydrogenated amorphous silicon (a-Si:H) TFTs can also provide a low-end RFID. The a-Si:H TFT is widely used as a switching element for liquid crystal displays (LCDs), and even with the low mobility of amorphous silicon, gate driver integration with a-Si:H TFT is applied to TFT LCDs [20], active-matrix organic light emitting displays [21], and sensor circuits [22]. Amorphous silicon is of interest for devices requiring low cost and a large area.

The RFID frequency ranges from below a hundred kHz up to GHz, and therefore a-Si:H TFT can contribute to the low frequency region. We fabricated and analyzed an a-Si:H TFT RC oscillator for use in low-end RF applications.

It is known that an a-Si:H TFT exhibits a threshold voltage shift by applying gate bias to the gate [23], [24]. This is due to the charge tapping and dangling bond creation in the channel. This instability can reduce the lifetime of circuits made of a-Si:H TFTs. In this paper, we studied the degradation of an a-Si:H resistive-capacitive (RC) oscillator with operation time.

To accomplish the proper operation of an oscillator, it is important to optimize each design parameter because the mobility is low and the parasitic capacitance and threshold voltage are high. Therefore, we optimized the design parameters for the best operation of the oscillator before making it.

II. Experiments

An oscillator made of conventional a-Si:H TFTs was designed and fabricated. Figure 1 shows a schematic of the oscillator studied in this work. The frequency of the oscillator is determined by RC time and the inverter output current. The conventional back-channel etched TFT structure was used. Figure 2 shows the transfer characteristics and schematic cross-sectional structure of the a-Si:H TFT used for the oscillator.

The TFT process was as follows. A chromium layer was used to form the gate electrode. After gate patterning, three layers of silicon nitride (400 nm), a-Si:H (150 nm), and n^+ a-Si:H (50 nm) were deposited by plasma-enhanced chemical vapor deposition at 280 °C. The silicon nitride was deposited with a mixture of SiH_4 (50 sccm), N_2 (200 sccm), and NH_3 (100 sccm). The undoped a-Si:H was deposited with a mixture of SiH_4 (300

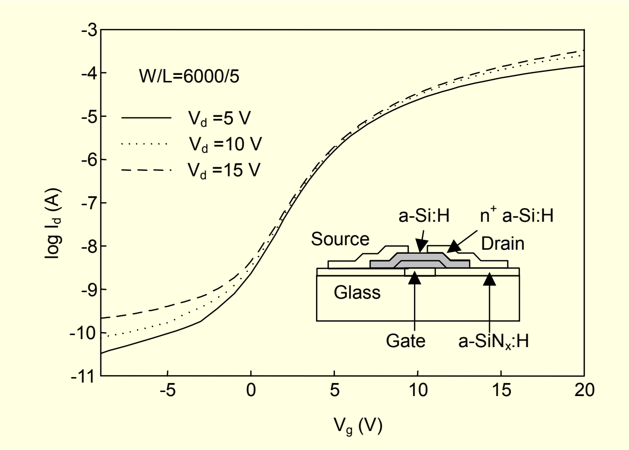


Fig. 2. The transfer characteristics and cross-sectional view of the a-Si:H TFT with back-channel etched structure.

sccm) and H_2 (90 sccm). The n^+ a-Si:H layer was deposited with a mixture of SiH_4 (300 sccm) and PH_3 (9 sccm).

After forming a-Si:H islands by dry etching, a chromium layer (150 nm) for the source/drain electrodes was deposited by sputtering and patterned by wet etching. The n^+ a-Si:H layer between the source and drain was etched away by NF_3 plasma. The contact hole was formed after the silicon nitride passivation layer. The ITO layer was used as material of resistors R1 and R2. We fabricated the oscillator with several different R1 and R2 resistances and compared the oscillation frequency between them. Two samples, sample 1 and sample 2, were measured, but unless otherwise indicated, the results shown in this paper are for sample 1 only.

III. Results and Discussion

Figure 3 shows an optical image of an RC oscillator made of a-Si:H TFTs. Since only N-channel enhancement is possible in an a-Si:H TFT, we used a bootstrapped inverter for greater performance [25].

Figure 4 shows a schematic of a bootstrapped inverter. At the

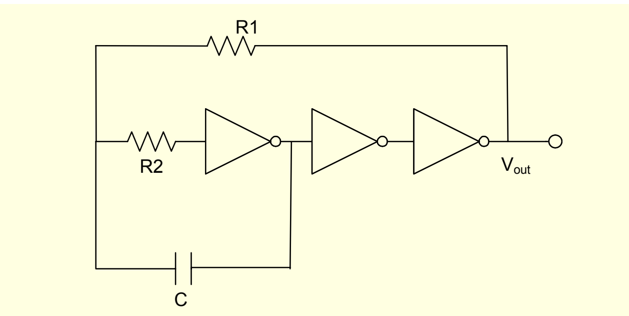


Fig. 1. A schematic view of an oscillator made of a-Si:H TFTs. The output frequency is determined by R1, C, and the inverter characteristics.

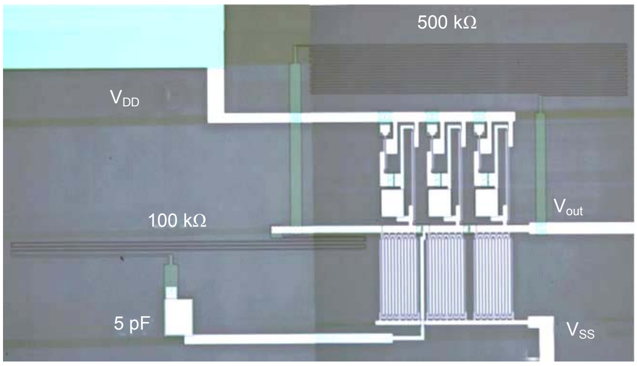


Fig. 3. The optical image of an oscillator made of a-Si:H TFTs.

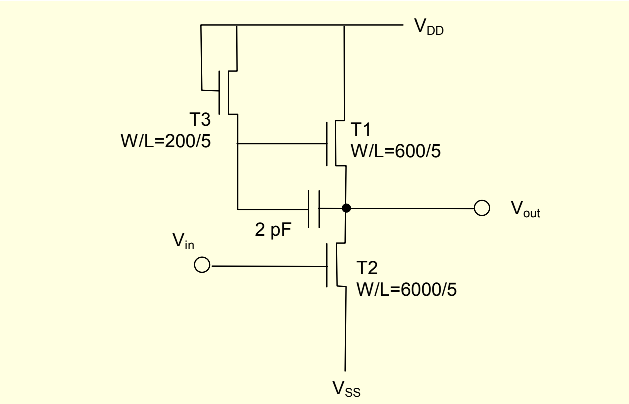


Fig. 4. An inverter circuit used for the oscillator. The bootstrapped inverter was used to avoid voltage drop in output [25].

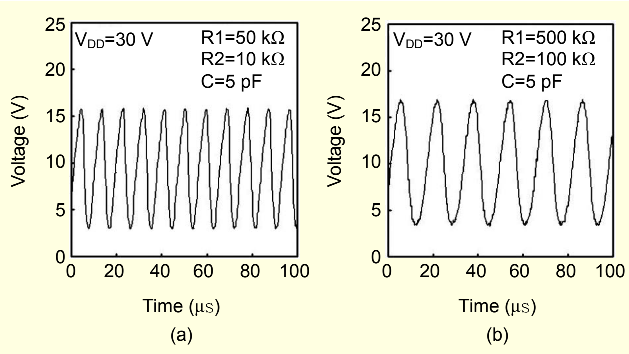


Fig. 5. Output waveforms of the oscillators with V_{DD}=30 V. The left waveform (a) shows higher frequency than the one on the right (b).

high voltage of the output node, the gate voltage of T1 increases over V_{DD} due to the bootstrapping through the capacitor of 2 pF and the parasitic capacitance of the T1 transistor. Due to the overdrive of the T1 gate, the high voltage output of the output node can be as high as V_{DD}. For proper operation of the bootstrapping, we optimized each design parameter by circuit simulation. The width/length of the drive TFT was as large as 6000/5 for enough current capability.

The oscillator functioned over a wide range of supply voltages. We applied the power voltage from a minimum operation voltage up to 30 V.

Figure 5(a) shows an output waveform of the RC oscillator when R1 = 50 kΩ, R2 = 10 kΩ, and C = 5 pF with a supply bias of 30 V. An oscillation frequency of 111 kHz was measured as voltage swung from 3.0 to 15.8 V. The voltage swing is large, and the frequency is enough for the low frequency RFID. The oscillation frequency can be adjusted by changing the resistance or capacitance, which is shown in Fig. 5(b).

Figure 5(b) shows an output waveform when R1 = 500 kΩ, R2 = 100 kΩ, and C = 5 pF with a supply bias of 30 V. Due to

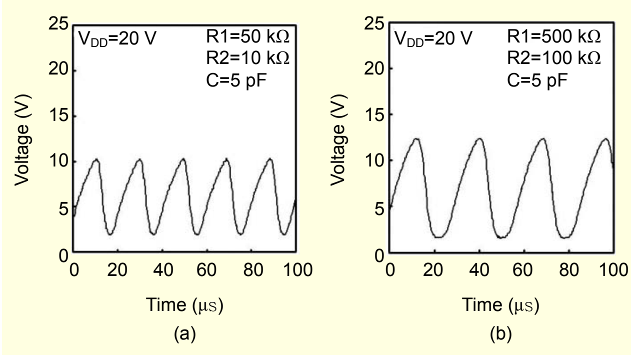


Fig. 6. Output waveforms for V_{DD} = 20 V. The frequency decreased compared to V_{DD} = 30 V. The left waveform (a) for the lower resistance shows higher frequency.

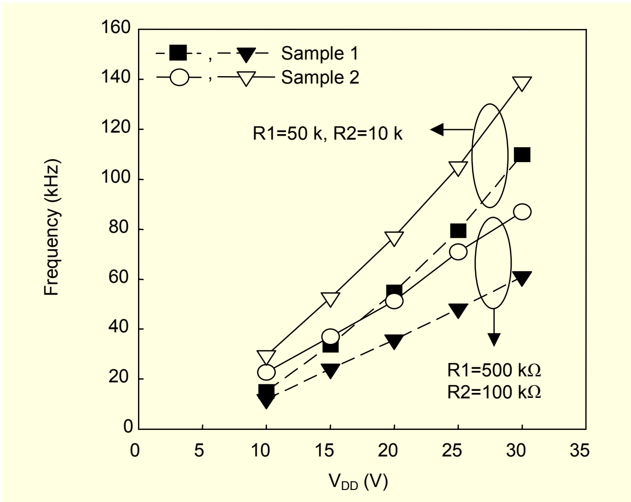


Fig. 7. The frequencies increase with increasing V_{DD}. The oscillator does not operate at a V_{DD} less than 9 V.

higher resistance, the frequency decreased to 63 kHz compared to the 111 kHz of Fig. 5(a). The output voltage swung from 3.4 to 16.9 V.

The output waveforms for the lower supply voltage of 20 V are shown in Figs. 6(a) and 6(b). The lower supply voltage results in lower swings of output voltages and lower frequency due to the decrease of inverter output current.

Figure 7 shows how the frequency changes as a function of supply voltage for the a-Si:H oscillators. Frequencies for two samples are shown. The frequencies decrease with decreasing supply voltage and there exists a minimum supply voltage to sustain oscillation. Since the process conditions affect the characteristics of a TFT, the frequencies change from sample to sample. Therefore, we need a reproducible process and some noble schematics that keep the frequency constant.

The frequency change was measured as a function of time with V_{DD} = 20 V. Since a-Si:H TFT has a threshold voltage shift with gate bias stress, frequency decreases with increasing

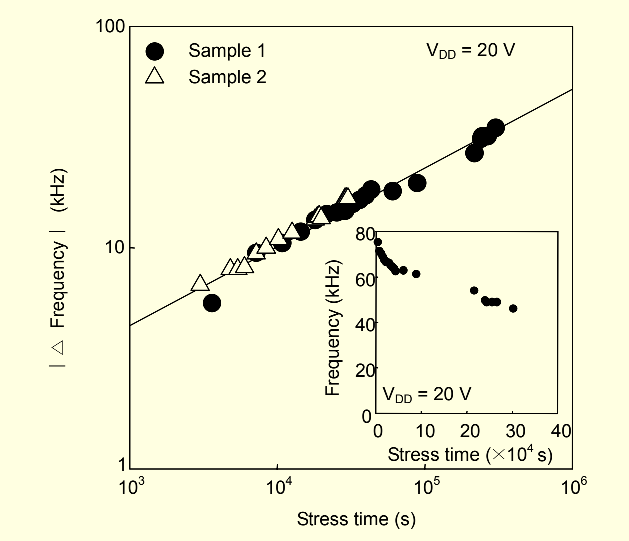


Fig. 8. The frequency shift as a function of stress time.

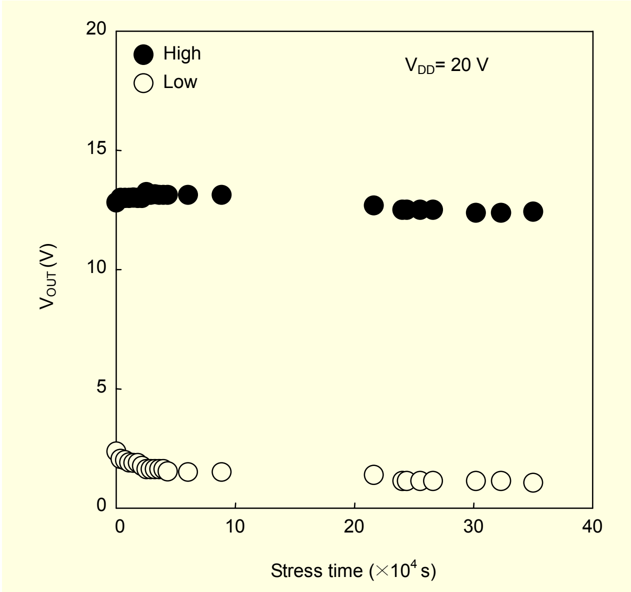


Fig. 9. The dependence of high output and low output voltages on stress time.

operation time.

Figure 8 shows the time dependence of output frequency shift for samples 1 and 2, and the inset is the frequency vs. stress time. Since the threshold voltage of the TFT increases, it decreases the output current of the inverter. This results in an increase of charging and discharging times. Therefore, the output frequency decreases.

The increase in threshold voltage results in the decrease of output voltage, as shown in Fig. 9. As the threshold voltage increases, the output voltage shifts to the lower voltage. However, as the bootstrapped inverter supplies high gate voltage to the load transistor, the voltage decrease is rather stable compared to the frequency change. Sample 2 also shows the same trend except for the start voltage. The V_{out}-high at t = 0 of sample 2 was 11.2 V, which is a little smaller than sample 1. The V_{out}-low at t = 0 of sample 2 was a little higher than sample 1. This means the swing voltage decreased a little for higher operation frequency.

Since the frequency can be controlled by the resistance or capacitance, the frequency shift can be compensated by control of resistance or capacitance. We can use an active device such as a TFT for the feedback resistor instead of R1 of Fig. 1 to suppress the change of frequency. A frequency-dependent gain loop can control the gate voltage of the TFT, which results in the resistance change of the TFT and can stabilize the oscillation.

Though the organic TFT provides a convenient and low-cost process such as printing, and low temperature process, the lifetime of the organic TFT is very short. On the other hand, amorphous silicon provides a well-established process and relatively stable operation suitable for a one-time operation or short use period of RFID. Further research would be on a reproducible operation frequency.

IV. Summary and Conclusion

We developed an a-Si:H TFT RC oscillator and studied its frequency and output waveform. We achieved good oscillation by optimization of each design parameter using circuit simulation. The performance of the oscillator was good enough for low-end RFID application. The frequency can be controlled by control of the resistance or capacitance. The oscillation frequency decreases with stress time and the output voltage shifted to a lower voltage with increasing operation time. The frequency shift can be compensated by adopting an active device combined with a frequency dependent gain loop instead of a simple resistor.

References

[1] B.Z. Kaplan and B. Zion, "On the Simplified Implementation of Quadrature Oscillator Models and the Expected Quality of their Operation as VCO's," *Proc. IEEE*, vol. 68, no. 6, 1980, pp. 745-746.

[2] A. Kobayahi, Y. Hori, and S. Nakamura, "State Variable Sinusoidal Switched-Current Oscillator," *Electronics Lett.*, vol. 27, no. 6, Mar. 1991, pp. 489-491.

[3] I.A. Kahn, M.T. Ahmed, and N. Minhaj, "Tunable OTA-based Multiphase Sinusoidal Oscillators," *Int'l J. of Electronics*, vol. 72, no. 3, 1992, pp. 443-450.

[4] M.T. Darkani and B.B. Bhatacharya, "Generation and Design of Canonic Grounded-Capacitor Variable-Frequency RC-Active

Oscillators," *IEE Proc. G, Electronic Circuits and Systems*, vol. 132, no. 4, 1985, pp. 153-160.

[5] I.-G. Lim, and W.-W. Kim, "A Numerically Controlled Oscillator with a Fine Phase Tuner and a Rounding Processor," *ETRI J.*, vol. 26, no. 6, Dec. 2004, pp. 657-660.

[6] Y.-G. Kim, C.-W. Kim, S.-I. Kim, B.-G. Min, J.-M. Lee, and K.H. Lee, "An X-Band Carbon-Doped InGaP/GaAs Heterojunction Bipolar Transistor MMIC Oscillator," *ETRI J.*, vol. 27, no. 1, Feb. 2005, pp. 75-80.

[7] A.R. Brown, C.P. Jarrett, D.M. de Leeuw, and M. Matters, "Field-Effect Transistors Made from Solution-Processed Organic Semiconductors," *Synthetic Metals*, vol. 88, no. 1, Apr. 1997, pp. 37-55.

[8] H. Klauk, D.J. Gundlach, and T.N. Jackson, "Fast Organic Thin-Film Transistor Circuits," *IEEE Electron Dev. Lett.*, vol. 20, no. 6, June 1999, pp. 289-291.

[9] B.R. Crone, A. Dodabalapur, R.W. Filas, Y.-Y. Lin, Z. Bao, J.H. O'Neill, W. Li, and H.E. Katz, "Design and Fabrication of Organic Complementary Circuits," *J. Appl. Phys.*, vol. 89, no. 9, May 2001, pp. 75-80.

[10] U. Zschieschang, H. Klauk, M. Halik, G. Schmid, and C. Dehm, "Flexible Organic Circuits with Printed Gate Electrodes," *Advanced Materials*, vol. 15, no. 14, July 2003, pp. 1147-1151.

[11] H. Klauk, M. Halik, U. Zschieschang, F. Eder, G. Schmid, and C. Dehm, "Pentacene Organic Transistors and Ring Oscillators on Glass and on Flexible Polymeric Substrates," *Appl. Phys. Lett*, vol. 82, no. 23, 2003, pp. 4175-4177.

[12] J.S. Jung, K.S. Cho and J. Jang, "A Large Grain Pentacene by Vapor Phase Deposition," *J. of the Korean Physical Society*, vol. 42, no. 92, 2003, pp. S428-S430.

[13] S.H. Kim, H.Y. Choi, B.S. Kim, M.P. Hong, K.H. Chung, and J. Jang, "Organic Thin Film Transistor with Self Organized Pentacene," *Proc. IDW'03*, 2003, pp. 200-375.

[14] C.J. Drury, C.M.J. Mutsaers, C.M. Hart, M. Matters, and D.M. de Leeuw, "Low-Cost All-Polymer Integrated Circuits," *Appl. Phys. Lett.*, vol. 73, no. 1, July 6, 1998, pp. 108-110.

[15] S. Richter, M. Ploetner, W.J. Fischer, M. Schneider, P. T. Nguyen, W. Plieth, N. Kiriy, and H.-J.P. Adler, "Development of Organic Thin Film Transistors Based on Flexible Substrates," *Thin Solid Films*, vol. 477, no. 1/2, Apr. 2005, pp. 140-147.

[16] J. Jacobsen, A. Chiang, A. Hermanns, M. McDonald, F. Vicentini, M. Marentic, J. Atherton, E. Boling, F. Cuomo, P. Drzaic, A. Holman, G. Liu, S. Pearson, W. Peschke, D.P. Vu, and R. Stewart, "Plastic Film Displays with Nanoblock IC Drivers Integrated by Fluidic Self Assembly Process," *Proc. SID*, 2002, p. 726.

[17] Y. Lee, H. Li, and S.J. Fonash, "High-Performance Poly-Si TFTs on Plastic Substrates Using a Nano-Structured Separation Layer Approach," *IEEE Trans. on Electron Devices*, vol. 49, no. 8, 2002, pp. 1353-1360.

[18] S.D. Theiss, P.G. Carey, P.M. Smith, P. Wickboldt, T.W. Sigmon, Y.J.Tung, and T.J. King, "Polysilicon Thin Film Transistors Fabricated at 100°C on a Flexible Plastic Substrate," *IEDM '98 Technical Digest*, 1998, pp. 257-260.

[19] S.H. Won, J.H. Hur, C.B. Lee, H.C. Nam, J.K. Chung, and J. Jang, "Hydrogenated Amorphous Silicon Thin-Film Transistor on Plastic with an Organic Gate Insulator," *IEEE Electron Device Lett.*, vol. 25, no. 3, 2004, pp. 132-134.

[20] J. Jeon, K.S. Choo, W.K. Lee, J.H. Song, and H.G. Kim, "Integrated a-Si Gate Driver Circuit for TFT-LCD Panel," *Proc. SID*, 2004, p. 10.

[21] A. Nathan, A. Kumar, K. Sakariya, P. Servati, S. Sambandan, and D. Striakhilev, "Amorphous Silicon Thin Film Transistor Circuit Integration for Organic LED Displays on Glass and Plastic," *IEEE J. Solid-State Circuits*, vol. 39, no. 9, Sept. 2004, pp. 1477-1486.

[22] K.S. Karim, A. Nathan, and J.A. Rowlands, "Amorphous Silicon Active Pixel Sensor Readout Circuit for Digital Imaging," *IEEE Trans. on Electron Devices*, vol. 50, no. 1, Jan. 2003, pp. 200-208.

[23] Y.J. Choi, W.K. Kwak, K.S. Cho, S.K. Kim, and J. Jang, "Hydrogenated Amorphous Silicon Thin-Film Transistor with a Thin Gate Insulator," *IEEE Electron Dev. Lett.*, vol. 21, no. 1, Jan. 2000, pp. 18-20.

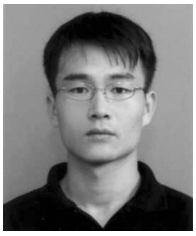
[24] K.S. Karim, A. Nathan, M. Hack, and W.I. Milne, "Drain-Bias Dependence of Threshold Voltage Stability of Amorphous Silicon TFTs," *IEEE Electron Device Lett.*, vol. 25, no. 4, Apr. 2004, pp. 188-190.

[25] J.P. Uyemura, *CMOS Logic Circuit Design*, Kluwer Academic Publisher, Norwell, MA, 1999.

Byung Seong Bae received the BS degree in atomic nuclear engineering from Seoul National University, Korea, in 1984 and the MS and PhD degrees in applied physics from Korea Advanced Institute of Science and Technology (KAIST), Korea, in 1986 and 1991. Between 1991 and 1998, he worked at Samsung Electronics on the development of amorphous and poly silicon TFT LCDs with integrated driver. From 1999 to 2003, he was charged with the set up of a high temperature poly silicon TFT LCD factory and the development of products for projection displays at ILJIN Display. From 2004, he has been a professor of the Department of Information Display at Kyung Hee University. He is a member of the Society for Information Display, the Korean Physical Society, and the Korean Sensors Society.

Jae-Won Choi received the BS degree in material physics at Dong-A University, Busan, South Korea, in 2004. He is a candidate for the MS degree of Information Display in Kyung Hee University, Seoul, South Korea. As an undergraduate student, he was involved in the semiconductor laboratory in Dong-A University. Subsequently, he joined the Advanced Display Research Center of Kyung Hee University. His research is focused on the integration of driver circuit using a-Si:H TFT and compensation pixel circuit for AMOLED.

Se-Hwan Kim received the BS degree in physics at Dong-A University, Busan, South Korea, in 2004. He is a candidate for the MS degree in information display at Kyung Hee University, Seoul, South Korea. As an undergraduate student, he was involved in the semiconductor laboratory in Dong-A University. Subsequently, he joined the Advanced Display Research Center of Kyung Hee University. His research is focused on TFT-LCDs and image sensors using a-Si:H TFT.



Jae-Hwan Oh received the BS degree in material physics at Dong-A University, Busan, South Korea, in 2002, and the MS degree in information display at Kyung Hee University, Seoul, South Korea, in 2004. He has been pursuing the PhD degree at Kyung Hee University of Information Display, Seoul, South Korea. His current research interest is in the area of semiconductor devices and deep poly-Si device technologies.

Jin Jang is a Professor of Information Display at Kyung Hee University. He received the PhD degree in applied physics from Korea Advanced Institute of Science and Technology, Seoul, in 1982. His current teaching and research programs are in display devices, electronic devices using silicon thin-films, and organic thin-film. He is the author or co-author of over 300 technical publications in international journals. He is currently running an Advanced Display Research Center (ADRC) in Kyung Hee University, Seoul, Korea. He is an editor of Journal of Display Technology (IEEE) and Journal of SID (Society for Information Display).