Temperature dependence of hydrogenated amorphous silicon thin-film transistors

BOR-YIR CHEN, WEI-HSIUNG WU, JIANN-RUEY CHEN
Department of Materials Science and Engineering, National Tsing Hua University, Hsinchu 30043, Taiwan
CHUM-SAM HONG
Materials Research Laboratories, Industrial Technology Research Institute, Hsinchu 31015, Taiwan

The temperature dependence characteristics of hydrogenated amorphous silicon thin-film transistors were investigated. The results indicate that as the temperature was increased, the threshold voltage and the field-effect mobility were first increased, and then decreased, which may be controlled by different mechanisms at low and high temperatures. In addition, if the temperature was higher than 420 K, the Fermi level was promoted to the degenerate-like states, the current channel always existed due to the temperature effect, and the threshold voltage became negative.

1. Introduction

During 1972, Spear and LeComber investigated the density of states distribution in amorphous silicon (a-Si) using an r.f. glow-discharge system by the field-effect method [1], and then in 1979, the first a-Si field-effect transistor suitable for driving liquid-crystal displays was developed by LeComber *et al.* [2]. Recently, hydrogenated amorphous silicon thin-film transistors (a-Si:H TFTs) have received extensive interest for applications as switching devices in large-area liquid-crystal display panels [3]. In order to develop new applications for a-Si TFTs, experimental investigations on the temperature effects are required. Previous works, both on the fundamental theory and on the experimental measurements of the drain-current temperature dependence [4–8] presented three distinct transport regimes. They are the hopping conduction regime for temperatures $80\,K \leq T \leq 260\,K$, the band transport regime for temperature $260\,K < T \leq 360\,K$, and the unstable region regime for $T > 360\,K$ [4]. However, the characteristics of the a-Si:H TFTs at higher temperatures were not investigated. Bae *et al.* investigated the temperature effects of a-Si:H TFTs from room temperature down to 20 K [6]. In the present work, the temperature dependence of a-Si:H TFTs between 300 and 450 K was investigated, and transport mechanisms have been proposed to explain the experimental data.

2. Experimental procedure

The structure of a-Si TFTs is shown in Fig. 1. Layers of SiN_x, a-Si:H, and n^+a-Si were consecutively deposited on the (1 1 1)-oriented silicon wafer during a single pump down in a plasma-enhanced chemical vapour deposition (PECVD) system operated at 13.56 MHz. The substrate was maintained at 250 °C during deposition. The SiN_x($\simeq 100$ nm) layer served as a gate dielectric, which was deposited from an SiH_4 and NH_3 source gas mixture with a gas ratio of about $NH_3:SiH_4 = 4:1$. The undoped a-Si($\simeq 400$ nm) layer was deposited from an SiH_4 and H_2 source gas mixture with a gas ratio of about $SiH_4:H_2 = 5:2$. In order to obtain good ohmic contact, the n^+a-Si($\simeq 50$ nm) layer was deposited between the a-Si:H layer and the aluminium source and drain metals. The n^+ a-Si layer was deposited from an SiH_4, H_2 and PH_3 source gas mixture with a gas ratio of about $SiH_4:H_2:PH_3 = 4:1:20$. The n^+a-Si layer between the source and the drain electrode was removed by plasma etching using a CF_4 and O_2 mixture with a gas ratio of about $CF_4:O_2 = 10:1$. The channel length and channel width were 50 and 2000 μm, respectively. The I–V characteristics of the a-Si TFTs were measured using an HP 4145A semiconductor parameter analyser. The threshold voltage, V_{th}, and the field-effect mobility, μ, were calculated from the $(I_D)^{1/2}$ versus V_G curves.

3. Results and discussion

Fig. 2 shows the TFT drain to source current, I_D, versus the drain to source voltage, V_{DS}, at various gate voltages, V_G. The characteristics of the TFT at the ambient temperature of 304 and 444 K are shown in Fig. 2a and b, respectively. The drain to source current, I_D, is a thermally activated current. A higher value can therefore be obtained for the saturated I_D at higher temperatures.

Fig. 3 shows the transfer characteristics at temperatures of 304 and 444 K. It is clearly shown in Fig. 3 that both the off-current and the on-current increase at higher temperature. At higher temperature, the curve shifts towards a lower value of V_G, indicating

0022–2461 © 1995 Chapman & Hall

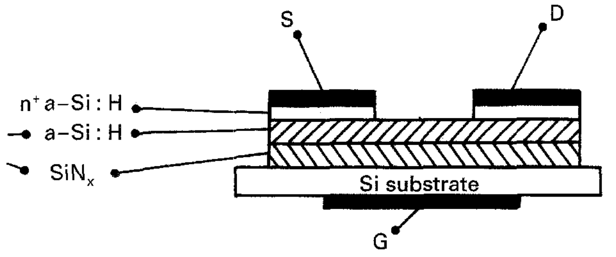

Figure 1 Structure of amorphous silicon thin-film transistors (a-Si TFT). S, source; D, drain; G, gate.

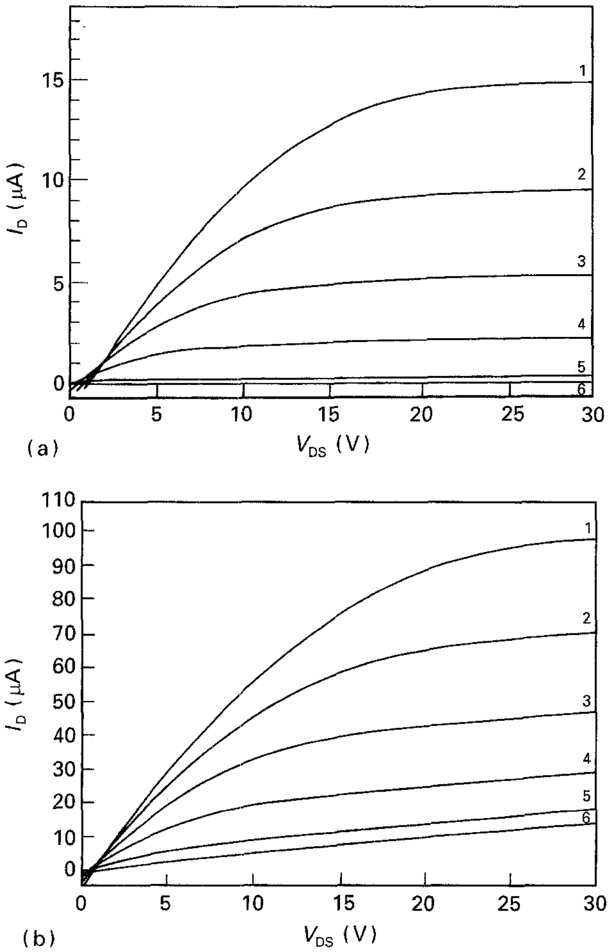

Figure 2 (a) The TFT drain to source current, I_D versus the drain to source voltage, V_{DS}, at 304 K for various gate voltages, V_G. (b) The TFT drain to source current, I_D,versus the drain to source voltage, V_{DS} at 444 K for various gate voltages, V_G. Values of V_G for curves 1–6: 0, 5, 10, 15, 20, and 25 V.

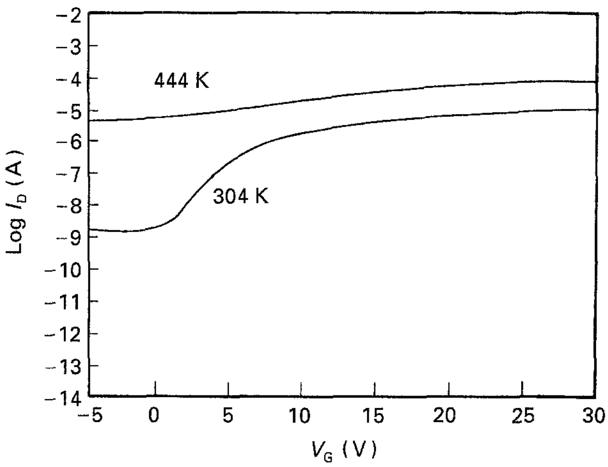

Figure 3 The transfer characteristics of a-Si:H TFTs at ambient temperatures 304 and 444 K.

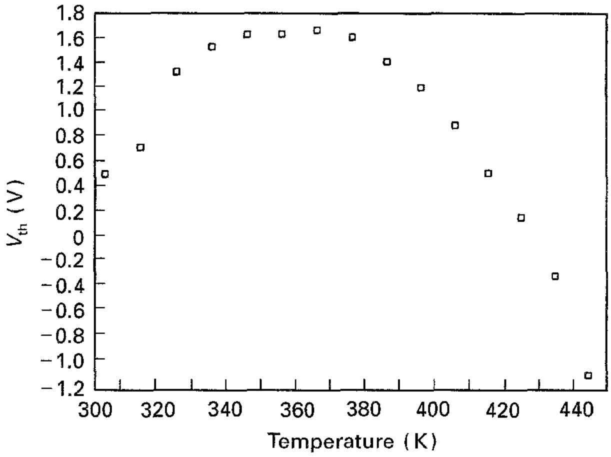

Figure 4 The threshold voltage, V_{th}, of a-Si:H TFTs at ambient temperatures from 300–450 K.

that the TFT threshold voltage, V_{th}, also decreases at higher temperatures.

Fig. 4 shows the threshold voltage, V_{th}, at various temperatures. Starting at 304 K, V_{th} increases with increasing temperature until the trend reverses at about 350 K. It was shown in Fig. 2 that I_D increases with temperature, which causes an apparent reduction in V_{th} at higher temperatures. All these data indicate that the mechanism controlling the threshold voltage at low temperatures is different from that at higher temperatures. At temperatures below 350 K, the possible mechanism includes charge trapping into the nitride and the creation of silicon dangling bonds in the channel region, whereas at temperatures above 350 K, the transport is thermally activated. At temperatures higher than 420 K, the threshold voltages even became negative values, suggesting that the Fermi level had been raised to the degenerate-like states at these temperatures.

Fig. 5 shows the measured transfer characteristics of the a-Si:H TFT at 314 K. Curve A in Fig. 5 was obtained for the sample kept at 314 K, while curve B was obtained after the sample had been subjected to a heating cycle from 314–444 K, and then cooled to 314 K. The threshold voltages, V_{th}, for the samples represented by curves A and B were 0.7 and 3.3 V, respectively. A hysteresis loop is observed in Fig. 5, indicating either more charges had been trapped in the nitride layer, or more metastable states were created in the a-Si layer during the heating cycle.

Fig. 6 shows the field-effect mobility versus inverse temperature. The field-effect mobility increases with increasing temperature until the temperature reaches about 420 K, while for temperatures higher than 420 K, the effective field-effect mobility decreases. It is clearly seen in Fig. 6 that there are two different mechanisms governing the field-effect mobility. For temperatures from 300–420 K, the current is thermally activated so that the field-effect mobility increases

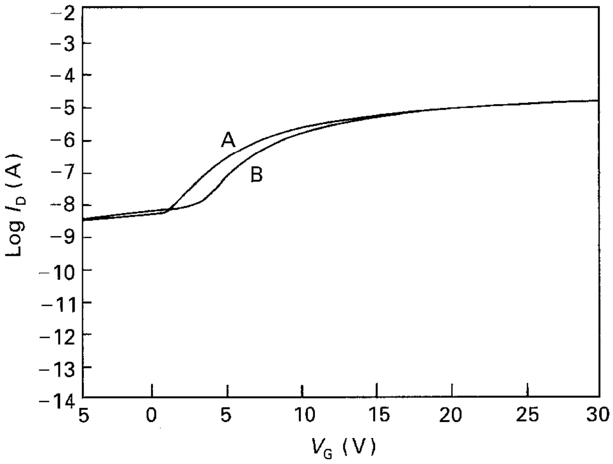

Figure 5 The measured transfer characteristics of the a-Si:H TFT at 314 K. Curve A was obtained for the sample kept at 314 K, while the curve B was obtained after the sample had been subjected to a heating cycle from 314–444 K, and then cooled to 314 K.

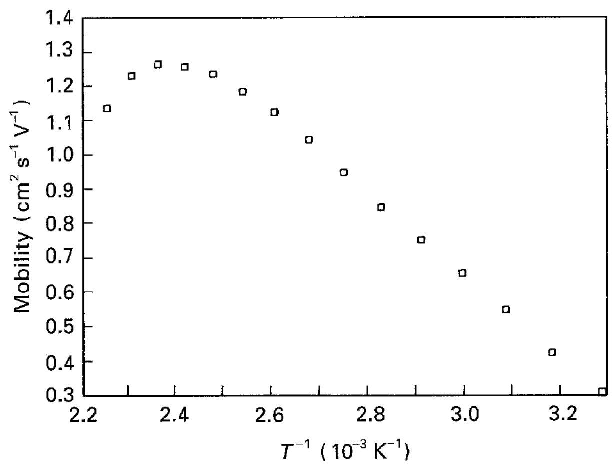

Figure 6 The field-effect mobility versus inverse temperature for ambient temperatures from 300–450 K.

with temperature, while for temperatures higher than 420 K, the Fermi level reaches the degenerate-like states, which cause the scattering mean-free path to be greatly reduced by thermal effect.

Fig. 7 shows the activation energy, E_a, as a function of the gate voltage. The monotonic decrease of E_a with V_G reflects the band bending which takes place upon application of a transverse electric filed. At zero gate voltages, the value of E_a approaches the bulk film values of 0.709 eV. As the gate voltage increases, the activation energy decreases and approaches a minimum value of approximately 0.148 eV. The minimum value of $E_a(\simeq E_C - E_F)$ may be taken as a measure of the width of the distribution of conduction band tail states [9].

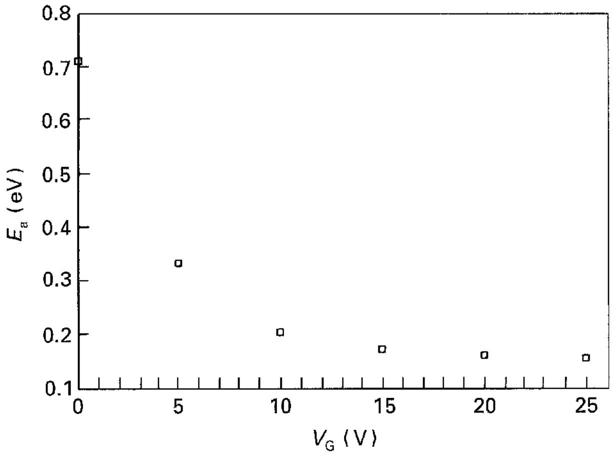

Figure 7 The activation energy, E_a, of a-Si:H TFTs as a function of the gate voltage, V_G.

4. Conclusion

The characteristics of a-Si TFTs on the temperature effect were investigated. There are two different mechanisms which control the threshold voltage, V_{th}, and the effective field-effect mobility, μ at low and high temperatures. If the ambient temperature was raised from 300 K to a higher temperature, the threshold voltage and the field-effect mobility first increased, and then decreased, which may be controlled by different mechanisms at low and high temperatures. If the ambient temperature was higher than 420 K, the Fermi level was promoted to the degenerate-like states, the current channel always existed due to the temperature effect, and the threshold voltage became negative.

References

1. W. E. SPEAR and P. G. LeCOMBER, *J. Non-Cryst. Solids* **8-10** (1972) 727.
2. P. G. LeCOMBER, W. E. SPEAR and A. GHAITH, *Electron. Lett.* **15** (1979) 179.
3. D. G. AST, in "Semiconductors and Semimetals", Vol. 21, edited by J. Pankove (Academic Press, New York, 1984) Part D, p. 115.
4. N. LUSTIG, J. KANICKI, R. WISNIEFF, and J. GRIFFITH, *Mater. Res. Soc. Symp. Proc.* **118** (1988) 267.
5. W. S. LEE, G. W. NEUDECK, J. CHOI, and S. LUAN, IEEE Trans. Electron Dev. **38** (1991) 2070.
6. B. S. BAE, D. H. CHO, J. H. LEE, C. LEE and J. JANG, *Mater. Res. Soc. Symp. Proc.* **149** (1989) 271.
7. H. Y. ZHANG and M. MATSUMURA, *ibid.* **95** (1987) 463.
8. R. SCHUMACHER, P. THOMAS, K. WEBER, W. FUHS, F. DJAMDJI, P. G. LeCOMBER and R. E. I. SCHROPP, *Philos. Mag. B* **58** (1988) 389.
9. K. D. MACKENZIE, A. J. SNELL, I. FRENCH, P. G. LeCOMBER and W. E. SPEAR, *Appl. Phys. A* **31** (1983) 87.

Received 12 April
and accepted 13 October 1994