22.4: Accelerated Stress Testing of a-Si:H Pixel Circuits for AMOLED Displays

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Abstract

Unlike OLEDs, there is no lifetime testing procedure for TFTs. In this work, we have defined such a procedure and developed a method for the accelerated stress testing of TFT pixel circuits in a-Si AMOLED displays. The acceleration factors derived are based on high current and temperature stress, and can be used to significantly reduce the testing time required to guarantee a 20000-hour display backplane lifespan.

1. Introduction

The OLED has steadily evolved since the first demonstrations of organic electroluminescence, and the lifetime to half brightness now exceeds 50000 hours. In amorphous silicon (a-Si) AMOLED displays, the OLED is coupled with a thin film transistor (TFT) circuit that drives the desired current through it, thus the degradation in both the TFT and OLED has to be considered when determining the overall lifetime of the display. OLEDs are routinely tested at high temperature, which accelerates the aging of the device degradation. However, no such procedure exists to efficiently measure the threshold voltage (V_T) shift induced time-to-failure of a TFT circuit.

V_T-shift in a-Si TFTs due to extended periods of electrical stress critically affects the performance and operational lifetime of a-Si:H based active matrix organic light-emitting diode (AMOLED) pixel circuits [1]. In order to compensate for the increase in V_T, new current and voltage programmed pixel circuits [1][2][3] have been developed, which work by increasing the gate voltage of the TFTs to overcome the increase in V_T, thereby keeping V_{GS}-V_T constant. These circuits continue to provide a stable drive current to the OLED until the critical voltages reach the supply voltage, at which point the compensation mechanism fails.

It is generally accepted that a 20000-hour pixel circuit operational lifetime is required before AMOLED displays can be commercialized. V_T-shift compensating pixel circuits can theoretically provide stable operation for such lengths of time, however there is no rapid way to experimentally verify a pixel circuit's lifetime without performing thousands of hours of measurements. It is therefore desirable to develop an accelerated testing method which can reliably predict the true long-term behaviour of the pixel circuits using shorter high-stress tests.

2. Background

Using TFTs subjected to constant voltage bias for about 20 hours, Powell et al. [2] have modeled the V_T-shift and shown that it increases with temperature. While these results cannot directly be applied to TFTs in V_T-shift compensating AMOLED pixel circuits that are subjected to constant current stress for more than 20000 hours, they do demonstrate the possibility of using temperature as an accelerating parameter in stress tests. In addition, Powell's work also shows that the gate voltage (or drain current) is proportional to the V_T-shift, hence voltage/current stress levels can also be incorporated into the acceleration factor analysis.

In this work, we have quantified the effects of high temperature and high current on the V_T-shift of TFTs that are under constant current stress. This research applies directly to both voltage and current programmed V_T-shift compensating AMOLED pixel circuits.

3. Experiment

The current through the OLED is given by the following equation:

$$I_{OLED} = \frac{\mu_{eff}}{2} C_i \frac{W}{L_{eff}} (V_{GS} - V_T)^2 \tag{1}$$

Powell et al. [4] showed that V_T-shift is directly proportional to V_{GS}-V_T, i.e. to the square-root of the drain current. Hence,

$$\Delta V_T = (V_{G0} - V_{T0}) \left(\frac{t}{\tau} \right)^{\beta} \tag{2}$$

$$= \left(\frac{t}{\tau} \right)^{\beta} \sqrt{\frac{I_{DS}}{(\mu_{eff} C_i W)/(2L_{eff})}} \tag{3}$$

Using equations (2) and (3) in combination with measurement data, we can deduce the required acceleration factors.

3.1 High Temperature Acceleration

We performed current stress measurements on TFTs to determine the V_T-shift model [4] parameters, β and τ. Since both β and τ are dependent on hydrogen diffusion, they vary with temperature and have to be extracted separately for 75°C and 25°C. The graph of V_T-shift at 25°C for 50 hours is shown in Fig. 1. Fig. 2 shows the comparison of V_T-shifts in a TFT stressed at 75°C and 25°C, which shows the effect of the difference in stress temperature.

Using the model and the extracted parameter values, we defined a temperature acceleration factor by taking the ratio of the V_T-shift at both temperatures.

$$A.F. = \frac{\Delta V_T(75°C)}{\Delta V_T(25°C)} = \frac{\left[(V_{G0} - V_{T0}) \left(\frac{t}{to} \right)^{\beta} \right]_{75°C}}{\left[(V_{G0} - V_{T0}) \left(\frac{t}{to} \right)^{\beta} \right]_{25°C}} \tag{4}$$

The acceleration factor thus obtained is time varying, and is shown in the Fig. 3. From this graph, we see that if we test a circuit at 75°C for 5000 hours, we get a temperature acceleration factor of approximately 1.8.

3.2 High Current Acceleration

The above acceleration factor does not take into account the increase in the effective mobility of the TFT at the higher temperatures. The drain current of a TFT is highly temperature dependent since the effective mobility of a TFT increases with temperature. Therefore, to be able to compare the electrical stress on TFTs at different temperatures, we have characterized the ON-current of an unstressed TFT (W/L =1000um/23um), which is shown in Fig. 4.

From the figure, we can see that as the temperature is increased, the drain current level for the same applied gate voltage will increase due to the increase in effective mobility. We can determine that a TFT passing 5μA of current at 25°C will experience the same level of gate stress as the same TFT passing 10μA at 75°C due to the increase in mobility. The results are consistent with all other TFTs that were tested.

4. Discussion

This data, combined with the fact that V_T-shift is directly proportional to the square-root of the drain current, provides us a guideline for high temperature accelerated testing of pixel circuit. Thus if the desired current acceleration factor is χ, we need to stress the circuit at a current equal to χ^2 times the nominal operating current. Assuming that each pixel is required to drive 5μA through the OLED in normal operating conditions and that the required overall acceleration factor (temperature and current combined) is 4, this paper shows that we can test the circuit at 75°C (producing a temperature acceleration factor of 1.8), and at 44μA drive current (producing a current acceleration factor of 2.2).

5. Conclusion

In this paper, we analyzed the threshold voltage shift in the TFTs of a V_T-shift compensating AMOLED pixel circuit with the aim of deriving an acceleration factor for long-term stress testing. In our analysis, we took into account the temperature dependence of effective mobility in the a-Si:H TFTs. Using a combination of both high temperature and high current stress, we have obtained a acceleration factors of close to 4, thereby reducing the required testing time for a 20000-hour a-Si:H pixel circuit lifetime to around 5000 hours.

6. References

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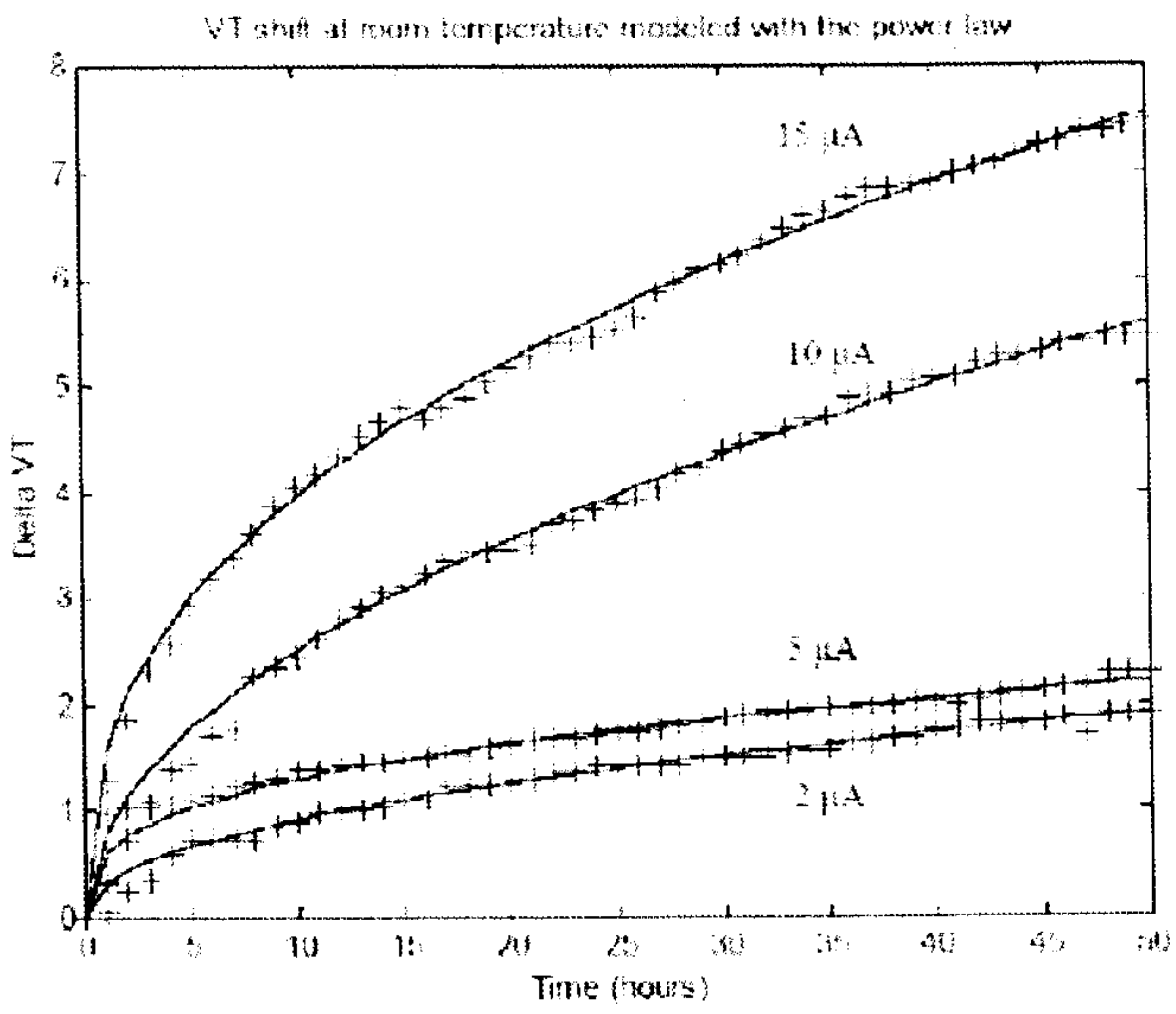

Figure 1. Curve fit of the power law model to the room temperature 50 hr V_T-shift data.

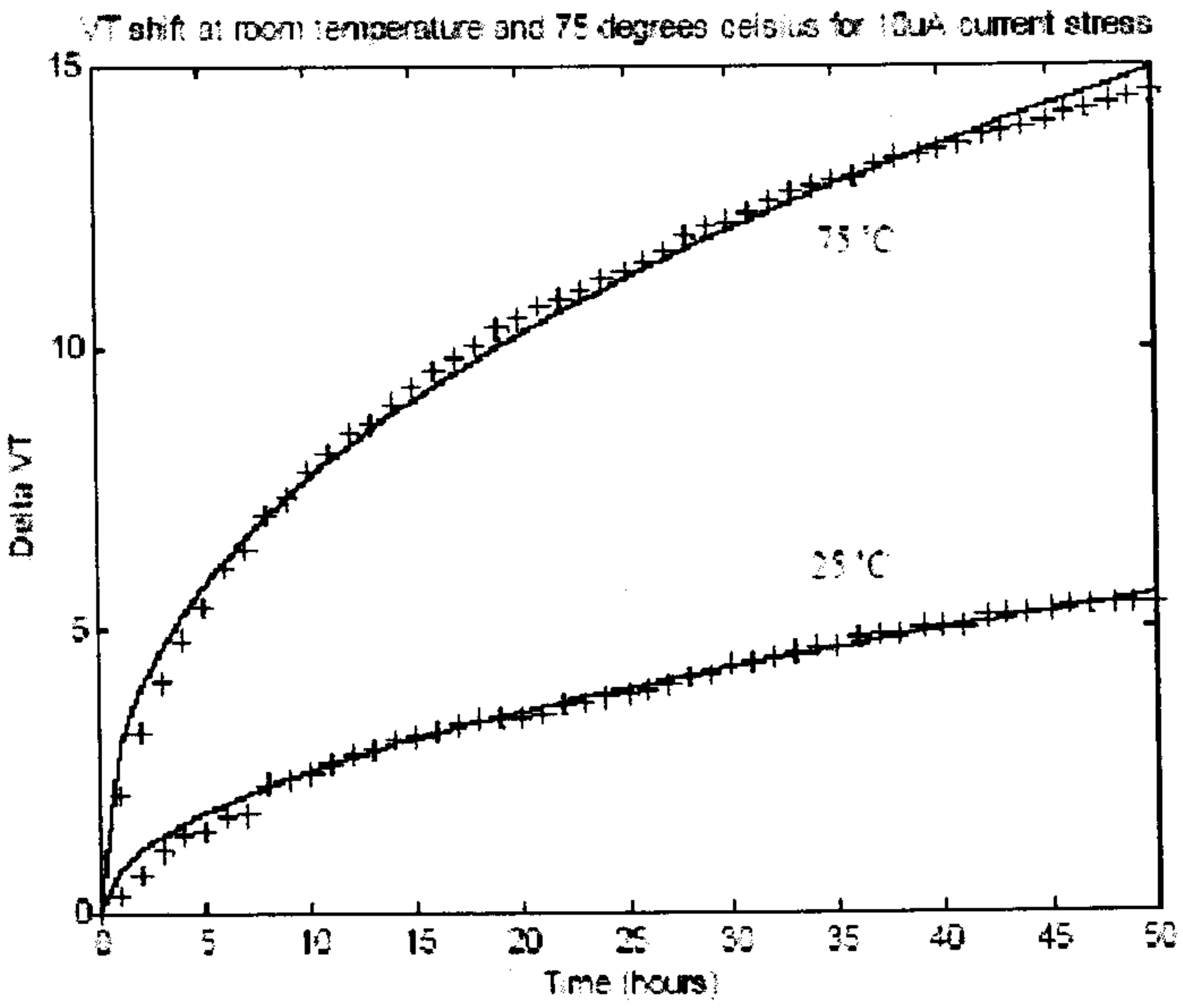

Figure 2. Comparison of V_T-shift at room temperature and 75 °C.

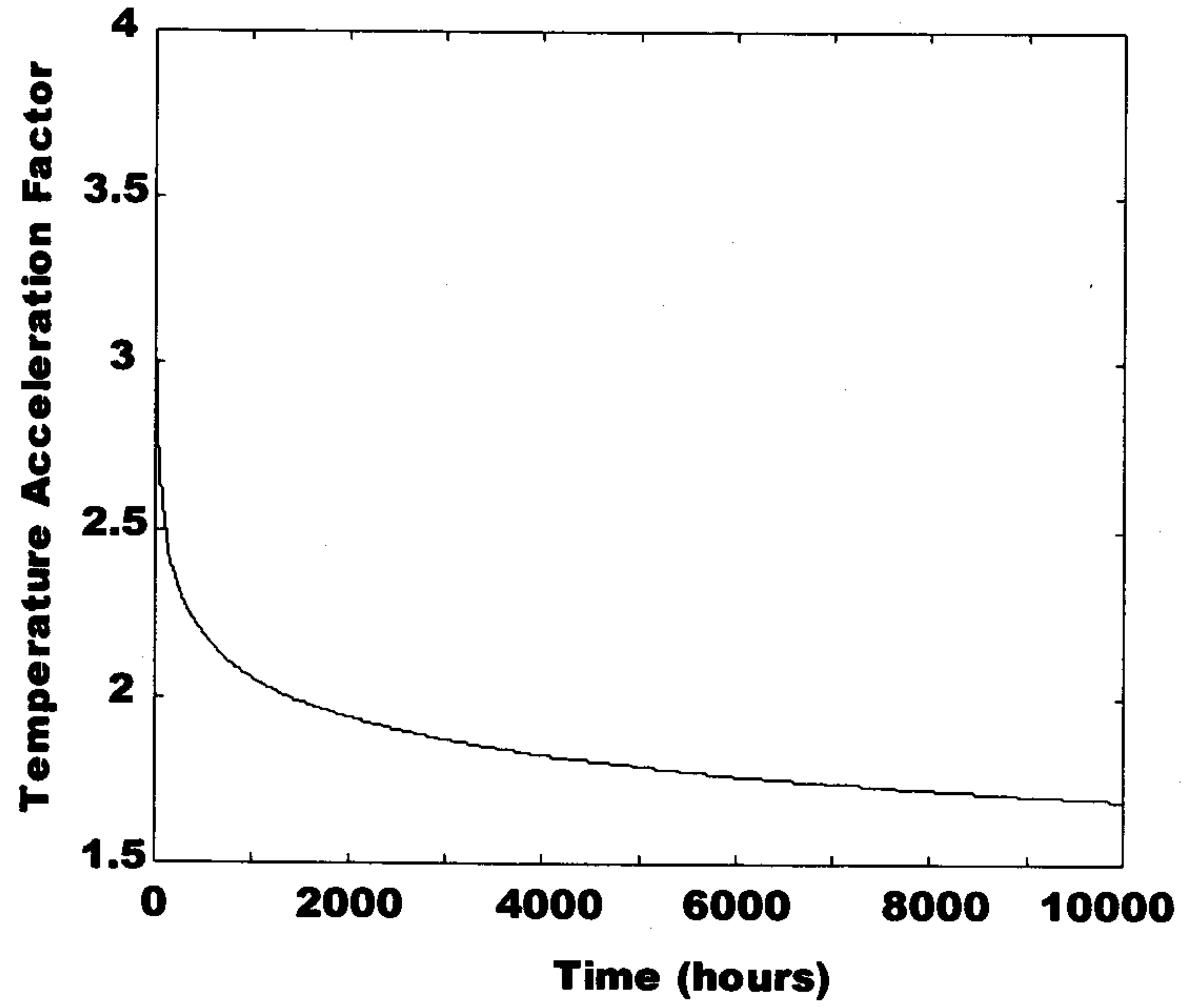

Figure 3. Derivation of the high temperature V_T-shift acceleration factor for current stressed TFTs.

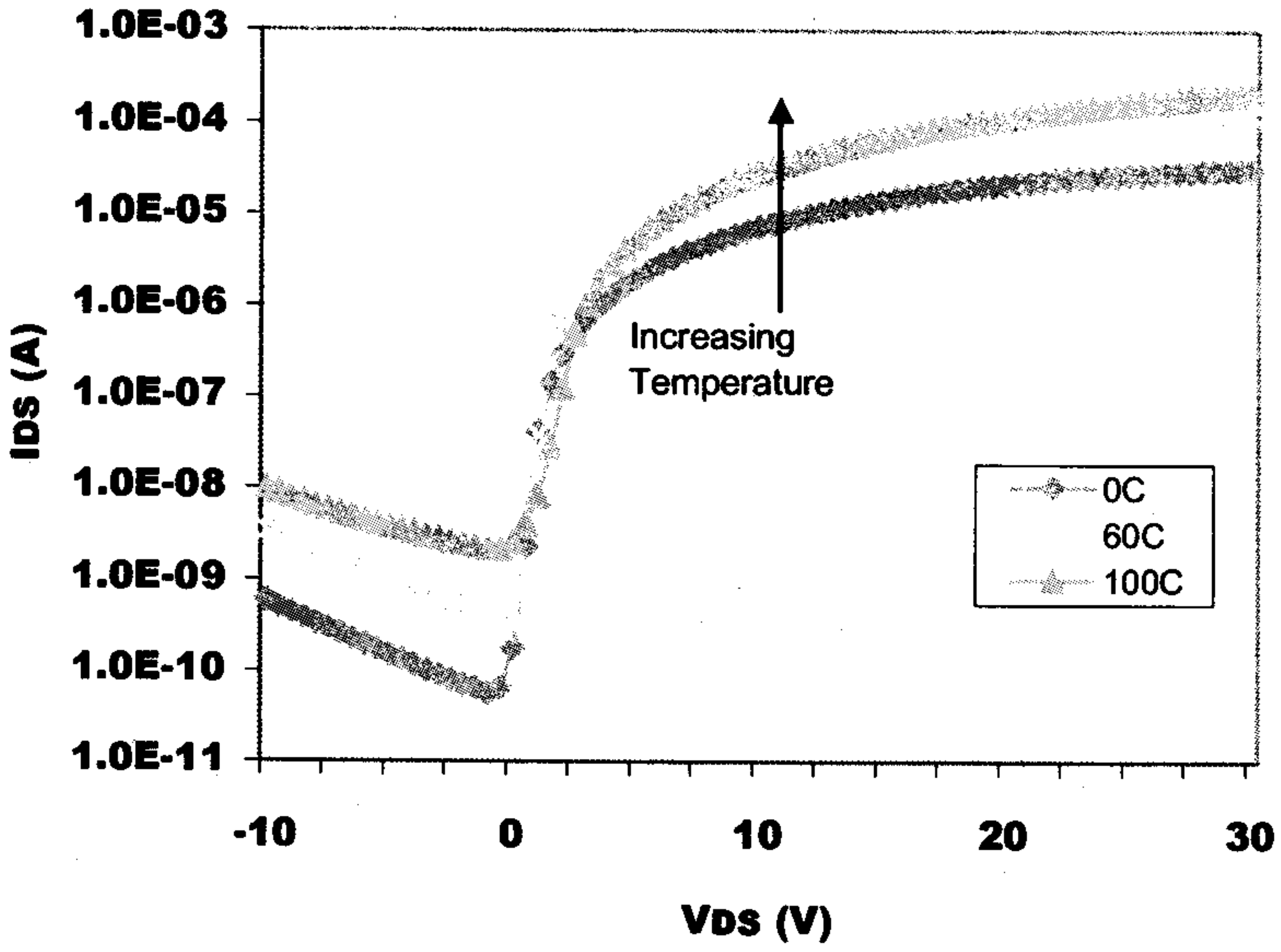

Figure 4. I-V Transfer Characteristics of a 1000um/23um TFT (V_{DS}=30V) at various T.