Photosensitivity of a-Si:H TFTs

Jean-Dominique Gallezot, Sandrine Martin and Jerzy Kanicki

The University of Michigan, Organic and Molecular Electronics Laboratory, EECS Department
1067 BIRB 2360 Bonisteel Blvd Ann Arbor, MI 48109-2108 USA
Tel: 1 734 615 1519, Fax: 1 734 615 2843, E-mail: sandrine@eecs.umich.edu

Abstract

We present a detailed experimental study of the hydrogenated amorphous silicon (a-Si:H) thin-film transistors (TFTs) behavior under white and monochromatic illuminations for photosensor applications. We have identified the different TFT operating regimes under illumination and shown that the a-Si:H TFT has the highest photosensitivity in the low-accumulation regime. The effect of the gate and drain voltages, TFT geometry and illumination conditions on the TFT photosensitivity are described.

Introduction

A detailed analysis and full understanding of the effect of illumination on the hydrogenated amorphous silicon (a-Si:H) thin film transistor (TFT) electrical performances is necessary before the device can be used as a photodetector or photosensor. We present in this paper an experimental study of the a-Si:H TFTs behavior under white and monochromatic light illumination. We have identified the different TFT operating regimes under illumination and have shown that the highest sensitivity to the illumination is obtained in the low-accumulation regime, and not in the OFF-state as it is often believed.

Experimental methods

We have used bottom-gate back-channel etched a-Si:H TFTs in this study. The amorphous silicon and amorphous silicon nitride thicknesses were 1500Å and 3000Å, respectively. Devices were illuminated by either white or monochromatic light. The TFT transfer characteristics were measured both in the dark and under illumination, at room temperature. Figure 1 shows a-Si:H TFTs transfer characteristics in the dark and at two different levels of white light illumination. Under illumination, there are three main TFT operating regimes [1]: (i) electron conduction branch, (ii) no accumulated carriers, and (iii) hole conduction branch. However, under the measurement conditions used here, e.g. relatively low negative gate voltages, the hole accumulation regime can not always be clearly identified.

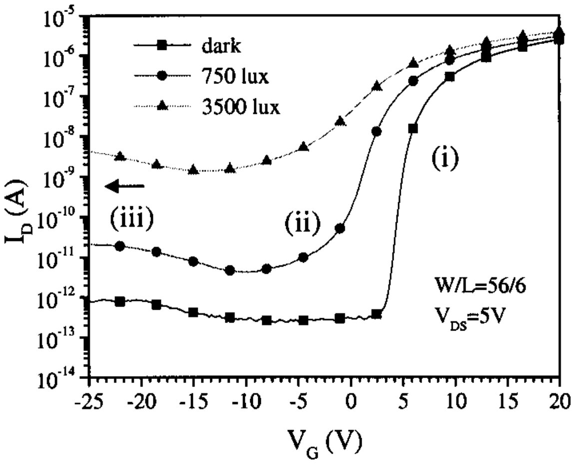

Figure 1: a-Si:H TFT transfer characteristics in the dark and under white light illumination.

Results and analysis

To analyze in detail the photosensitivity of the a-Si:H TFTs, we have defined the ratio between TFT current under illumination and in the dark $R_{L/D} = I_{D\,illum} / I_{D\,dark}$. Figure 2 shows the typical variations of $R_{L/D}$ with the TFT gate voltage. We can clearly see on this figure a peak corresponding to the TFT weak accumulation regime, typically observed for small positive gate voltages. In strong accumulation regime, the TFT current ratio decreases, as expected, because of the dominant effect of the gate voltage on the concentration of accumulated carriers. In the OFF-state, $R_{L/D}$ is significantly higher than in the ON-state but still several decades lower than the peak value. The existence of the peak in the weak accumulation regime can be understood by looking at the TFT transfer characteristics (Figure 1). Because of the degradation of the subthreshold slope under illumination, we can identify a small gate voltage range for which the TFT is in the

OFF-state in the dark and almost in the ON-state under illumination. This gate voltage range will therefore provide the highest $R_{L/D}$ ratio.

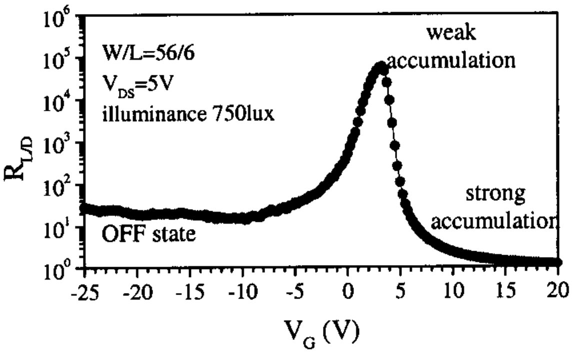

Figure 2: Typical behavior of the ratio between TFT drain current under illumination and in the dark ($R_{L/D}$) as a function of the TFT gate voltage, under white light illumination.

The $R_{L/D}$ peak value can be as much as 2 to 3 orders of magnitude above the current ratio in the TFT OFF-state and could therefore be used to very easily detect the presence of light, even at low intensities. However, we should note that the $R_{L/D}$ peak is quite narrow, with a typical width at half height of a few volts or less. Consequently, the $R_{L/D}$ peak value strongly depends on the considered gate voltage, and a slight shift of the TFT transfer characteristic could result in erroneous values. We therefore believe that the peak ratio in the low accumulation regime should be used to detect the presence of light but not to accurately quantify the light intensity. The OFF-regime, in which $R_{L/D}$ is much less sensitive to the gate voltage, would be more appropriate for this purpose.

In addition, we have observed that $R_{L/D}$ does not significantly depend on the drain voltage used for the measurements, for values between 0.1 and 15V. We have also investigated the effect of the TFT geometry on the TFT electrical characteristics. First, we have considered the effect of the TFT channel width, as shown in Figure 3.

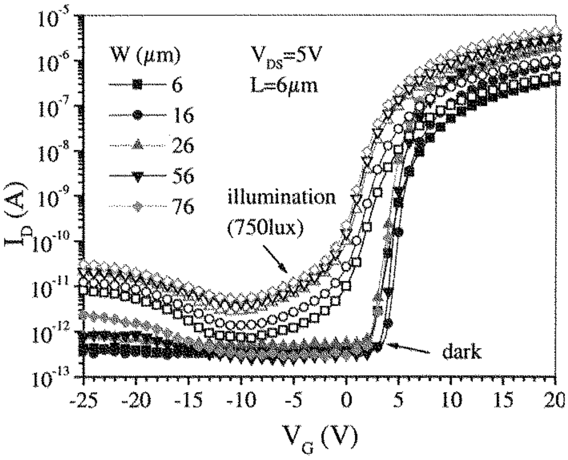

Figure 3: a-Si:H TFT transfer characteristics in the dark (solid) and under 750lux white light illumination (open) for different values of the TFT channel width.

The TFT current in the ON-state is proportional to the channel width, as expected, both in the dark and under illumination. On the other hand, the TFT OFF-current in the dark is usually channel length independent. We believe that this is related to the very low value of the TFT OFF-current in the dark: what we measure might be either measurement noise or transient current in which other mechanisms are involved. When the TFT is under illumination, the carrier concentration is increased and the OFF-state conduction mechanisms are similar to the ON-state situation [1]; the current is therefore again proportional to the channel width, as shown in Figure 3.

If we consider a gate voltage corresponding to the peak value of $R_{L/D}$ (typically, V_G=2.5V), we can clearly see in Figure 4 that the TFT current is proportional to the TFT channel width under illumination and channel width-independent in the dark, although it is quite noisy. Consequently, the peak value of $R_{L/D}$ will increase with increasing channel width. Indeed, $R_{L/D}$ peak increases from 5.3×10^2 to 2.8×10^4 when the TFT channel width changes from 6 to 76μm.

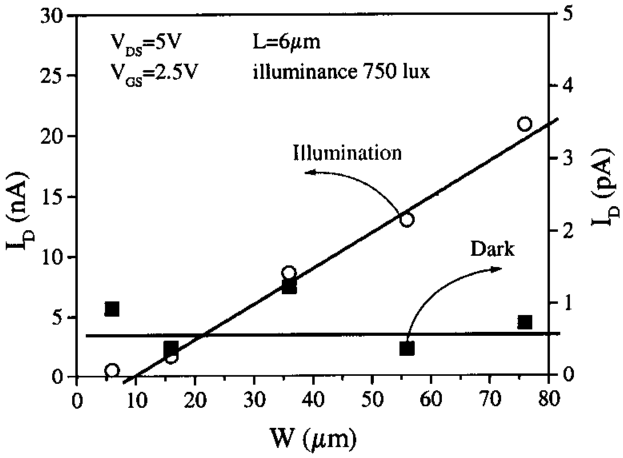

Figure 4: a-Si:H TFT drain current in the dark and under white light illumination (750 lux) as a function of the TFT channel width.

We have observed a similar behavior of the TFT current with respect to the channel length. As expected, the TFT ON-current, both in the dark and under illumination, is roughly proportional to the reciprocal of the channel length, neglecting the source and drain series resistances. On the other hand, the TFT OFF-current in the dark is channel length independent. Under illumination, because of the increase in carrier concentration, the TFT OFF-current is again proportional to the reciprocal of the channel length, as shown in Figure 5.

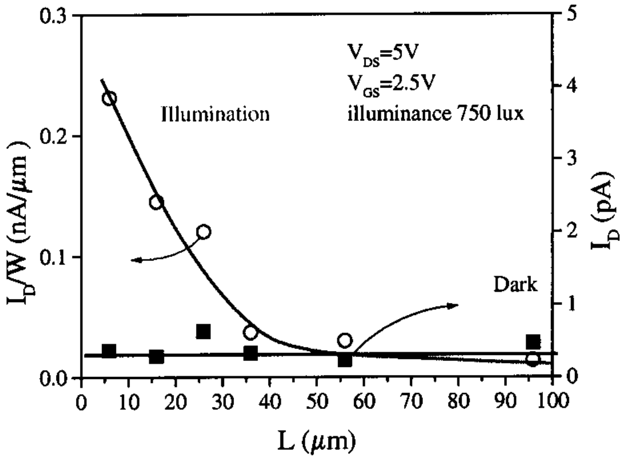

Figure 5: a-Si:H TFT drain current in the dark and under white light illumination (750 lux) as a function of the TFT channel length.

Consequently, we expect that the maximum value of $R_{L/D}$ will decrease with increasing channel length. Indeed, $R_{L/D}$ peak decreases from 5.6×10^4 to 2.4×10^3 when the TFT channel length changes from 6 to 96μm.

The effect of the illumination intensity on the TFT electrical characteristics is critical if the a-Si:H TFTs are to be used as photosensors or photodetectors. Figure 6 shows the $R_{L/D} - V_G$ curves for different white light illuminances.

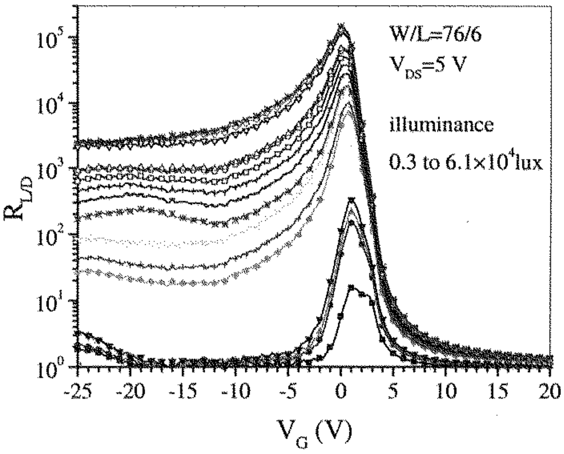

Figure 6: $R_{L/D}$ as a function of the TFT gate voltage, for different white light intensity values.

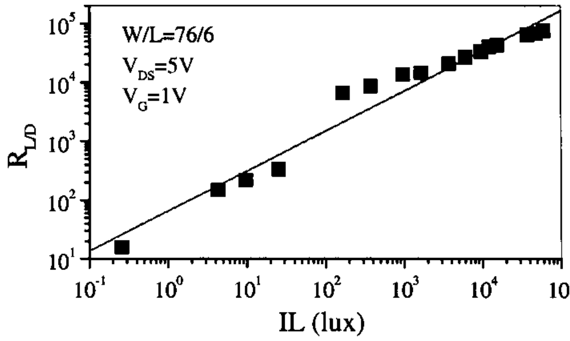

Figure 7: $R_{L/D}$ (for V_G=1V) as a function of the illuminance (IL). Symbols show experimental data, the solid line shows the fit to a power law behavior, with an exponent γ~0.7.

We can clearly see on Figure 6 that the $R_{L/D}$ peak is still significant even for very low illuminance values. The variations of $R_{L/D}$ (at V_G=1V) with the illuminance (IL) are shown in Figure 7 and clearly exhibit a power law dependence, e.g. $R_{L/D} \propto IL^{\gamma}$, with γ=0.7.

The effect of the illumination wavelength on the TFT photosensitivity has also been studied. Two types of measurements were performed using monochromatic light at different wavelengths: constant optical power (1.5×10^{-4} W/cm^2) or constant optical flux (6×10^{14} photons/cm^{2}s). As shown in Figure 8, the results in both cases are quite similar: we observed a significant increase of the TFT photosensitivity with increasing photon energy. This behavior is clearly associated with the absorption curve of amorphous silicon, as seen in Figure 8.

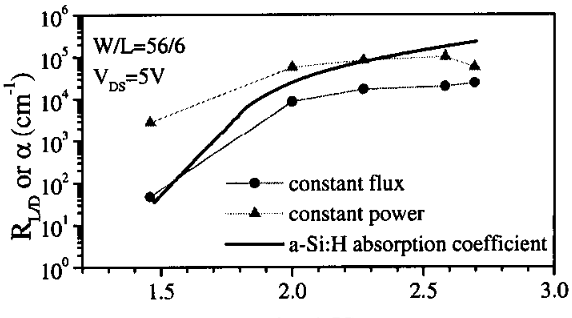

Figure 8: Peak value of the ratio between the TFT drain current under illumination and in the dark ($R_{L/D\ max}$) as a function of the energy of the monochromatic light.

The effect of the TFT operation temperature has also been investigated. We have performed this study under monochromatic light (λ=620nm, P=77μW) to avoid any parasitic heating of the sample that can occur under white light illumination. Figure 9 shows the $R_{L/D}-V_G$ curves for different temperatures. These curves exhibit significant noise, especially at high temperature in the OFF-state, which is related to our temperature regulation system.

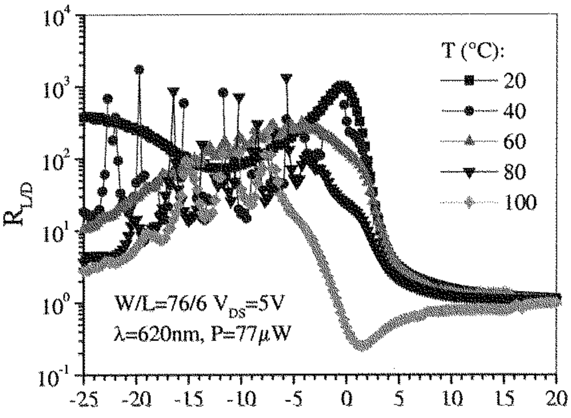

Figure 9: $R_{L/D}-V_G$ curves under monochromatic illumination at different temperatures.

As we have mentioned before, the $R_{L/D}$ peak involves the TFT current in the OFF state in the dark and in weak accumulation regime under illumination. As shown in Figure 10, we have observed that, for the same gate voltage, the TFT current increases with temperature much faster in the dark (OFF state) than under illumination (weak accumulation regime). We can therefore expect $R_{L/D}$ to decrease with increasing temperature. In spite of the measurement noise, this is clearly confirmed by the experimental data plotted in Figure 9.

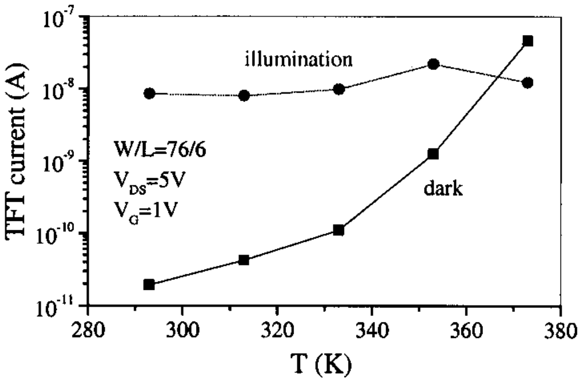

Figure 10: Variations of the TFT drain current with the temperature, for a constant gate voltage (V_G=1V) in the dark and under monochromatic light illumination (λ=620nm, P=77μW).

Conclusion

We have presented a detailed experimental study of the a-Si:H TFTs behavior under white and monochromatic illumination. We have identified the different TFT operating regimes under illumination and shown that the a-Si:H TFT has highest photosensitivity in the weak-accumulation regime. The effect of the device geometry, operation and illumination conditions on the TFT photosensitivity have been described and these results can be used to optimize the a-Si:H TFT geometry and operating conditions for its application either as photodetector or photosensor.

References

[1] S. Martin, J. Kanicki, N. Szydlo and A. Rolland, AMLCD'97 Proceedings p211 (1997).