New procedure for the extraction of AIMSpice level 15 a-Si:H TFT model parameters

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Abstract

A new procedure is presented to extract level 15 AIMSpice model for amorphous thin film transistor model in the above-threshold region. It is based on the integration of the experimental data current which has the advantage of reducing the effects of experimental noise. With this procedure, numerical non-linear optimization, which is the method basically used up to now when using the program extractor included in AIM-Spice can be avoided. The method is applied to the linear and saturation regions for the above-threshold regime and allows the extraction of all the above-threshold parameters. The accuracy of the simulated curves using the parameters extracted with the new procedure is verified with measured and calculated data using the expressions contained in the model.

1. Introduction

The AIM-Spice level 15 model for a-Si:H TFT [1] provides a well accepted way of simulating these devices. However the number of parameters requested by this model is high. Those related to geometrical and technological factors are not difficult to determine. They are the overlap capacitance (CGSO and CGDO), the oxide thickness (TOX), dielectric constant of the oxide (EPSI) and the substrate layer (EPS) and zero-bias leakage current (IOL). Others, related to the trap distribution and intrinsic layer impurity concentration as the Fermi level position (DEFO); the minimum density of deep states (GMIN); characteristic voltage for deep states (V0) can be estimated from physical ideas and procedures previously reported [2-4]. The other 18 parameters must be also determined, but the way to do it is not straightforward. To extract these parameters, AIM-Spice provides a parameter extractor, which tries to optimize several of these parameters at the same time, in order to fit simulated curves to experiment. This is usually troublesome and a satisfactory fit of both simulated $I_{DS}$-$V_{GS}$ and $I_{DS}$-$V_{DS}$ curves to experimental curves using this extractor is not always possible to achieve for the same model parameters.

Recently, a direct extraction method was proposed in [5]. However the method proposed has two problems. First, the extraction of the model parameters for the mobility variation is done using the slope of the log-log characteristic. Because the threshold voltage is unknown, a high variation of the slope is possible. Second, the extraction of parameter, $m$, is made using graphical method, which is neither practical nor precise. The effect of the series resistance R is not considered.

In this article we present a new method to extract all above-threshold parameters of the AIM-Spice level 15 model for a-Si:H TFT. They are determined from the transfer and output characteristics of the transistor without non-linear optimization or graphical data processing. Using the extracted parameters, $I_{DS}$-$V_{GS}$ and $I_{DS}$-$V_{DS}$ curves were calculated using analytical expressions and also simulated in AIM-Spice. Both results are compared with experiment.

2. a-Si:H TFT AIMSpice level 15 model parameters

The drain current in the linear and saturation regions for the above-threshold regime in the AIM-Spice level 15 model [1] is expressed as:

$$I_{DS} = \frac{K}{V_{AA}^\gamma} \cdot (V_{GS} - V_T)^{1+\gamma} \cdot V_{DS} \left(1 + \lambda \cdot V_{DS}\right) \left(1 + \frac{V_{DS}}{V_{DSat}}\right)^{-m}$$

where $K = (W/L)C_i \mu_0$;

$W$- channel width;
$L$- channel length;
$C_i$- gate capacitance;
$\mu_0$- band mobility;
$V_T$- threshold voltage;
$R$- source plus drain resistance;
$\gamma$ and $V_{AA}$- empirical parameters defining the variation of mobility;
$m$- sharpness of the knee region;
$\lambda$- channel length modulation.
Eq (1) neglects the leakage current and is the result of considering that the field effect mobility increases with the gate voltage as:

$$\mu_{FET} = \mu_0 \left( \frac{V_{GS} - V_T}{V_{AA}} \right)^\gamma$$

(2)

The intrinsic channel conductance $g_{ch}$ for the low drain voltage (linear region) can be expressed as:

$$g_{ch} = \frac{W}{L} C_i \mu_{FET} (V_{GS} - V_T) = \frac{W}{L} C_i \mu_0 \frac{1}{V_{AA}^\gamma} (V_{GS} - V_T)^{1+\gamma}$$

(3)

The drain current in the linear region (for small drain voltage) from eq (1) and for $V_{GS} > V_T$ can be written as:

$$I_{DSlin} = \frac{K}{V_{AA}^\gamma} (V_{GS} - V_T)^{1+\gamma} V_{DS}$$

(4)

The effect of the series resistance at drain $R_D$ and source $R_S$, ($R=R_D+R_S$) is introduced in the expression for the channel conductance obtaining:

$$g_{ch} = \frac{g_{ch}}{1 + R \cdot g_{ch}}$$

(5)

In a-Si:H TFT transistor both series resistance are high, so the effect introduced by $R$ can be significant even at relatively low currents.

From eq (3), (4) and (5) the drain current can be written as:

$$I_{DSlin} = \frac{K}{V_{AA}^\gamma} (V_{GS} - V_T)^{1+\gamma} V_{DS} \frac{1 + R \cdot \frac{K}{V_{AA}^\gamma} (V_{GS} - V_T)^{1+\gamma}}{1 + \frac{K}{V_{AA}^\gamma} (V_{GS} - V_T)^{1+\gamma}}$$

(6)

The saturation voltage is defined as through the saturation modulation parameter $\alpha_S$, which is usually less that 1:

$$V_{DSsat} = \alpha_S (V_{GS} - V_T)$$

(7)

The sharpness of the knee region of transition between linear and saturation regions is defined by $m$.

For the saturation condition $V_{DS} = V_{GS} > V_{DSsat}$, the drain current in eq (1) can be approximated by:

$$I_{DSsat} = \frac{K}{V_{AA}^\gamma} \alpha_S (V_{GS} - V_T)^{2+\gamma}$$

(8)

3 Extraction procedure

The procedure consists of the following 5 steps.

Step No.1. Parameters $\gamma$ and $V_{AA}$ can be extracted from eq (4) in the linear region. These parameters may vary from one to another transistor, and are highly dependent on technology. Considering the exponential behavior of eq. (4), the integral procedure proposed in [6] is applied, in this case, to the linear region to extract $V_T$ and $\gamma$. The function $H(V_{GS})$ is defined as in [5]:

$$H(V_{GS}) = \frac{\int_0^{V_{GS}} I_{DS}(x)dx}{I_{DS}(V_{GS})}$$

(9)

After integrating and dividing by $I_{DS}$ the following expression is obtained.

$$H(V_{GS}) = \frac{1}{2 + \gamma} (V_{GS} - V_T)$$

(10)

$V_T$ is obtained from the intercept, and $\gamma$ from the slope of the linear region of eq. (10) for $V_{GS} > V_T$.

This method using an integral function will give better results because integration avoids problems related with the experimental noise. An important feature is that to determine $\gamma$, it is not necessary to know $V_T$.

Step No.2. Using eq (4) the expression $I_{DS}^{1/(1+\gamma)}$ vs. $V_{GS}$ is obtained. After calculating the slope $S_l$ of the expression $I_{DS}^{1/(1+\gamma)}$ vs. $V_{GS}$, the value of $V_{AA}$ can be extracted from:

$$V_{AA} = \left[ \frac{K V_{DS}}{S_l^{1/(1+\gamma)}} \right]^{1/(1+\gamma)}$$

(11)

In this manner the three parameters that determine the effective change of the field effect mobility, eq (2), are extracted with the above-described procedure.

Step No.3. The total series resistance $R$ can be extracted evaluating eq (6) at the maximum value of gate voltage. Using this procedure, the drain and source series resistance are determined for values of the current in which their effect becomes more important.

Step No.4. Next step in the extraction procedure uses the saturation current characteristic for $V_{GS}=V_{DS}$. The expression $I_{DSsat}^{1/(2+\gamma)}$ vs. $(V_{GS} - V_T)$ is obtained from eq. (8) and its slope $S_s$ is calculated. Parameter $\alpha_S$ is extracted as:

$$\alpha_S = \frac{S_s^{2+\gamma} V_{AA}^\gamma}{K}$$

(12)
Step No. 5. The values of parameters $m$ and $\lambda$ can be extracted from the expression for the output current characteristic, eq (1). Parameter $m$ is determined at the saturation voltage, eq (7), and its value is obtained from:

$$m = \log 2 / \log \left[ \frac{K \alpha_s (V_{GS} - V_T)^{2/\gamma}}{V_{AA}^{\gamma} I_{DSsat} (V_{DSsat})} \right].$$

Finally, the channel length modulation parameter $\lambda$ is extracted evaluating eq (1) at the maximum values of $V_{DS}$ and $V_{GS}$ voltages to fit the slope of the experimental data.

With the above five steps procedure, all parameters included in the above-threshold model, $V_T$, $\gamma$, $V_{AA}$, $R$, $\alpha_s$, $m$ and $\lambda$ are extracted. In our comparison with experiment we used default values for the rest of the model parameters.

Some authors, for example, [7] define the field effect mobility $\mu_{FET0}$ as the value of the mobility extracted from the approximated saturation current formula:

$$I_{DSsat} = \frac{W}{L} C_i \frac{\mu_{FET0}}{2} (V_{GS} - V_T)^2$$

This value is normally used to evaluate the fabrication process. In our case, using eq (8) and eq (14), a value for $\mu_{FET0}$ can be obtained expressed through previously. Extracted parameters as shown in the following expression:

$$\mu_{FET0} = \mu_0 \frac{\alpha_s 2}{V_{AA}^{\gamma}}.$$ (15)

3 Comparison with experiment

An a-Si:H TFT with stacked structure and Cr gate, drain and source contacts, fabricated in our laboratory, was used to demonstrate the extraction procedure, Fig. 1. The technological data is:

- SiO$_2$ gate thickness - 300 nm;
- intrinsic layer thickness - 300 nm;
- channel width - 600 $\mu$m;
- channel length - 40 $\mu$m.

The band mobility parameter $\mu_0$ was taken equal to its default value of 10 cm$^2$/V s.

The experimental data corresponding to the transfer characteristic in the linear region at $V_{DS}$= 0.1, was mathematically processed following Step No.1. The following two parameters were extracted:

- $V_T$= 5.6 V;
- $\gamma$= 0.324.

Following Step No.2 the value of $V_{AA}$= 35240 V was obtained.

Following Step No.3 the value of $R$= 1700 $\Omega$ was obtained.

Fig. 2 shows the comparison of the linear characteristic calculated using eq (4) with the experimental data.

Following Step No. 4, the extracted parameters $V_T$, $\gamma$ and $V_{AA}$ were used in conjunction with the experimental data from the current in the saturation region, eq (8), in order to extract the value of $\alpha_s$= 0.47 (eq (11)).

Following Step. No. 5, the experimental data of the output characteristic was processed to obtain $m$=2.2 at $V_{GS}$= 30 V using eq (13).

Finally the value of $\lambda$= 1.76E-3 1/V was obtained following also Step No. 5.

Fig. 1 Schematic diagram of the a-Si:H TFT transistor used to evaluate the extraction procedure.

In Fig. 3 the experimental data is compared with the calculated output characteristic using eq (1) and with the simulated using AIM-Spice. Both calculated and simulated are fit quite well with experiment, validating the new method of extraction proposed.
Fig. 3. Experimental, calculated and simulated with AIMSpice $I_{DS}$ vs $V_{DS}$ characteristic for $V_{GS} =$ 10, 20 and 30 V.

The procedure also allows the calculation of the value of mobility $\mu_{FET0}$ substituting the extracted parameters in eq (15). A value of $\mu_{FET0} = 0.32 \text{ cm}^2/\text{Vs}$ was obtained, see Fig. 4.

Fig. 4. Dependence of the field effect mobility at the gate voltage, indicating the calculated value of $\mu_{FET0}$.

### 3. Conclusions

A new simple and precise procedure to extract all above-threshold parameters of the level 15 model in AIM-Spice is presented. No graphical methods or non-linear optimization are needed to calculate any of the parameters.

Using an integral method to avoid noise, the values of $V_T$ and the exponent $\gamma$ can be extracted independently one from the other using one single mathematical processing. The extraction of the total resistance is included.

Comparison of experimental $I_{DS}$ vs $V_{GS}$ and $I_{DS}$ vs $V_{DS}$ characteristics with calculated transfer and output curves using model expressions (eq (1), (4) and (8)) and with the simulated curves in AIMSpice using the parameters extracted with the new procedure show good results, thus, validating the procedure.

### 4. Acknowledgments

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### References

[1]. AIM-Spice, Circuit Simulation Program by AIM-Software. (www.aimspice.com)


