6th MOS-AK 2022 Guangzhou Compact Modeling

A Surface Potential Based Drain Current Model of InGaZnO TFTs with Relaxation Method

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11-12th. August. 2022

Outline

01 Part1： Introduction

02 Part2： Relaxation method

03 Part3： Surface potential and drain current

04 Part4： Results and discussions

01

Part1: Introduction

Part1： Introduction

1、Background

InGaZnO thin film transistors (TFTs) have been regarded as the most promising candidate in the field of flexible electronic devices. In addition, InGaZnO TFTs have been widely used in sensors, memories and liquid crystal displays because of their good uniformity, high mobility and low leakage current. Especially in the display field, a-InGaZnO TFTs have the advantages of low cost and compatibility compared with poly-Si TFTs or a-Si: H TFTs, which make it to be put into large-scale production and application in society. With the increasing number of these products, people's requirements for performance are also slowly improving. Hence, it is necessary to have an analytical model to understand the electrostatic characteristics of a-InGaZnO TFTs.

2、Research status

At present, researchers tend to derive the equations of current or voltage [1-9] to obtain the drain current model of InGaZnO TFTs. Of course, more and more people begin to use surface potential to establish drain current model and the model based on surface potential has become the industry standard.

Part1： Introduction

3、 Research methods

- Region method: Sub- and above-threshold regions.
- Effective charge density method: Convert multiple charge densities into one effective charge density.
- Intelligent algorithm: Using PSO, immune and genetic algorithms to fit the *I-V* characteristic curve and obtaining the required parameters.

4、Difficulties and shortcomings

- The tail state density and the deep state density have to be considered in modeling. (Accuracy)
- Lambert W function is not an elementary function. (Efficiency)
- Lack of sufficient physical meaning. (transition region, ignoring percolation, etc.)

5、Target

- **Improving a trad-off between accuracy and efficiency in a-InGaZnO TFTs' compact model.**

02

Part2: Relaxation method

Part2:Relaxation method

- Definition: The relaxation method mainly refers to the use of relaxation technique [10] and applies it to linear equation. i.e.,

$$ax + by + c = 0 \tag{1}$$

➢Usually, ($x0$, $y0$) is substituted into Equation 1 as an approximate solution, so that a very small value $r0$ can be obtained and called the residual.

$$ax_0 + by_0 + c = r_0 \tag{2}$$

➢If linear increments Δx and Δy can be found in the x-direction and y-direction respectively. And they can just satisfy the following equation

$$a\Delta x + b\Delta y = -r_0 \tag{3}$$

➢Then, combine Equations 2 and 3 to get

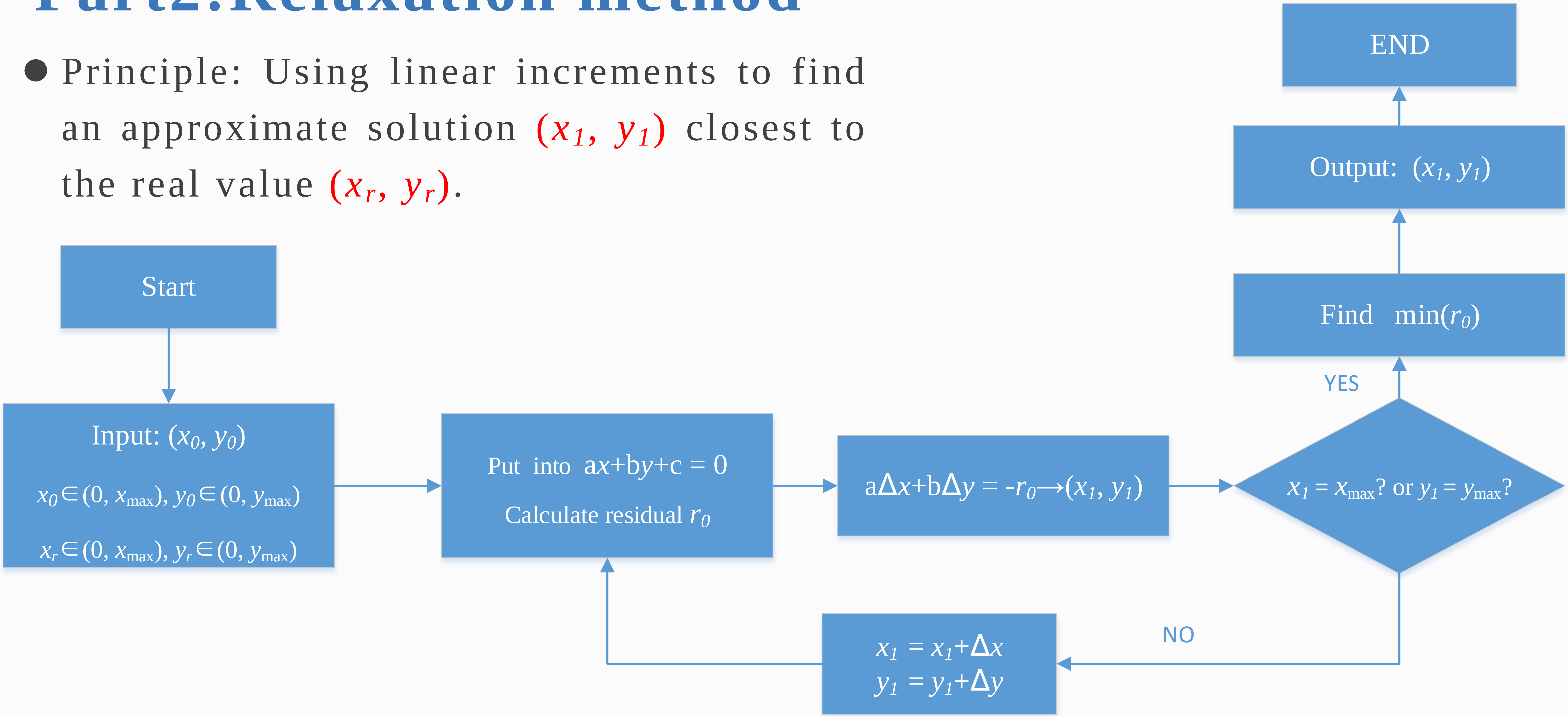
$$a\left(x + \Delta x\right) + b\left(y + \Delta y\right) + c = 0 \tag{4}$$

➢Hence,

$$\left(x_1, y_1\right) = \left(x_0 + \Delta x, y_0 + \Delta y\right) \tag{5}$$

Part2:Relaxation method

- Principle: Using linear increments to find an approximate solution (x_1, y_1) closest to the real value (x_r, y_r).



Start

Input: (x_0, y_0)

$x_0 \in (0, x_{\max}), y_0 \in (0, y_{\max})$

$x_r \in (0, x_{\max}), y_r \in (0, y_{\max})$

Put into $ax+by+c = 0$

Calculate residual r_0

$a\Delta x+b\Delta y = -r_0 \rightarrow (x_1, y_1)$

$x_1 = x_{\max}$? or $y_1 = y_{\max}$?

YES

Find $\min(r_0)$

Output: (x_1, y_1)

END

NO

$x_1 = x_1+\Delta x$

$y_1 = y_1+\Delta y$

Figure 1. Iterative calculation flow chart of relaxation method。

03

Part3: Surface potential and drain current

Part3-1： Surface potential model

1. Following the gradual channel approximation and neglecting percolation conduction[11]. We can obtain a one-dimensional Poisson equation as

$$\frac{d^2\varphi}{dx^2} = \frac{q}{\varepsilon_{igzo}}\left[n_0 \exp\left(\frac{\varphi - V_{ch}}{V_T}\right) + N_T \exp\left(\frac{\varphi - V_{ch}}{E_T/q}\right) + N_D \exp\left(\frac{\varphi - V_{ch}}{E_D/q}\right)\right] \tag{6}$$

2. According to Gauss law and corresponding boundary conditions, a closed equation about gate voltage and surface potential can be obtained as

$$f_1 = \left(V_{gs} - V_{fb} - \varphi_s\right)^2 - \frac{2q\varepsilon_{igzo}}{C_{ox}^{\ 2}}\left\{n_0 V_T\left[\exp\left(\frac{\varphi_s - V_{ch}}{V_T}\right) - 1\right] + N_T \frac{E_T}{q}\left[\exp\left(\frac{\varphi_s - V_{ch}}{E_T/q}\right) - 1\right] + N_D \frac{E_D}{q}\left[\exp\left(\frac{\varphi_s - V_{ch}}{E_D/q}\right) - 1\right]\right]\right\} \tag{7}$$

3. Combining the relaxation method and Equation 7, yielding:

$$\left(V_{gs}, \varphi_s\right) = f_1\left(V_{gs0} + \Delta x, \varphi_{s0} + \Delta y\right) \tag{8}$$

Here, V_{gs0} and φ_{s0} are the starting points and do not depend on the initial values. Δx and Δy are linear increments in the direction of gate voltage and surface potential, respectively.

Part3-2：Drain current model

1. Similarly, we can also get the expressions of drain current as:

$$\left(V_{gs}, I_{ds}\right) = f_2\left(V_{gs0} + \Delta x, I_{ds0} + \Delta y\right) \tag{9}$$

$$\left(V_{ds}, I_{ds}\right) = f_3\left(V_{ds0} + \Delta x, I_{ds0} + \Delta y\right) \tag{10}$$

2. Here, f_2 and f_3 represent the functional relationship between gate voltage, drain voltage and drain current, which is derived as

$$f_2\left(V_{gs}, I_{ds}, \frac{t_{igzo}}{2}\right) = \frac{\frac{2W}{L} C_{ox} \mu\left(V_{gs}, \frac{t_{igzo}}{2}\right)\left(V_{gs} - V_t\right)}{1 + R_S \frac{2W}{L} C_{ox} \mu\left(V_{gs}, \frac{t_{igzo}}{2}\right)\left(V_{gs} - V_t\right)} \times \frac{V_{ds}}{\left\{1 + \left[\frac{V_{ds}}{\alpha_S\left(V_{gs} - V_t\right)}\right]^m\right\}^{\frac{1}{m}}}\left(1 + \lambda V_{ds}\right) \tag{11}$$

$$f_3\left(V_{ds}, I_{ds}, \frac{t_{igzo}}{2}\right) = \frac{\frac{2W}{L} C_{ox} \mu\left(V_{gs}, \frac{t_{igzo}}{2}\right)\left(V_{gs} - V_t\right)}{1 + R_S \frac{2W}{L} C_{ox} \mu\left(V_{gs}, \frac{t_{igzo}}{2}\right)\left(V_{gs} - V_t\right)} \times \frac{V_{ds}}{\left\{1 + \left[\frac{V_{ds}}{\alpha_S\left(V_{gs} - V_t\right)}\right]^m\right\}^{\frac{1}{m}}}\left(1 + \lambda V_{ds}\right) \tag{12}$$

04

Part4: Results and discussions

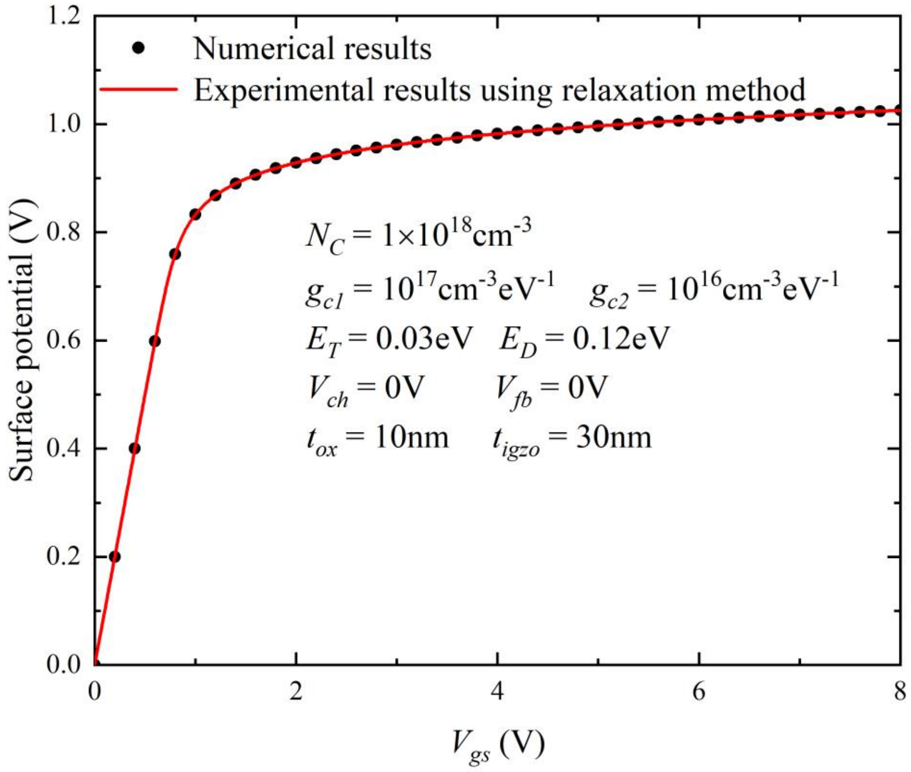


Figure 2. Numerical results and experimental results using relaxation method of the surface potential.

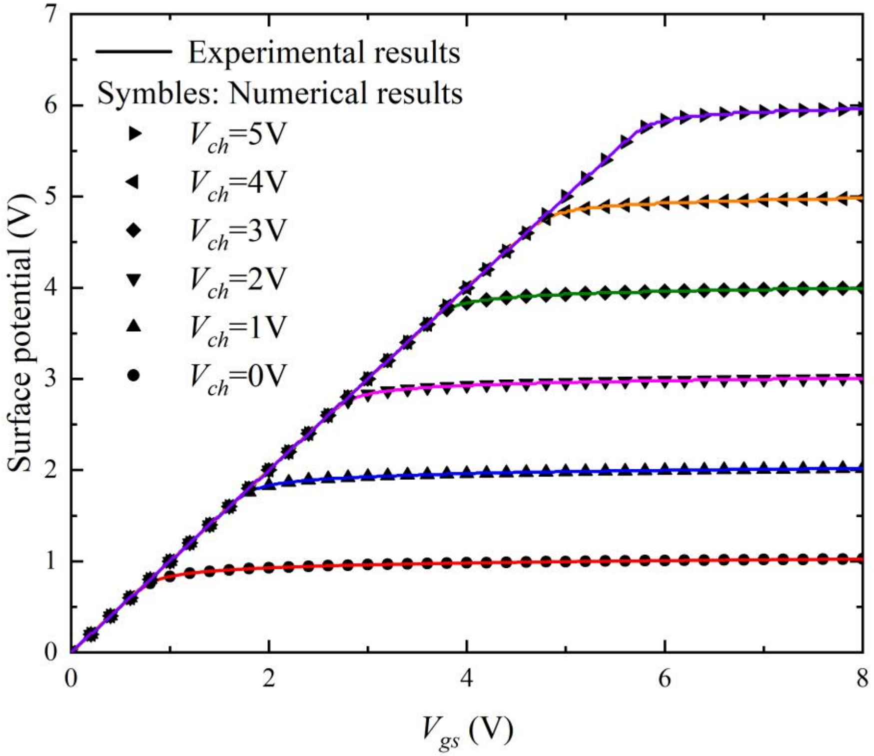
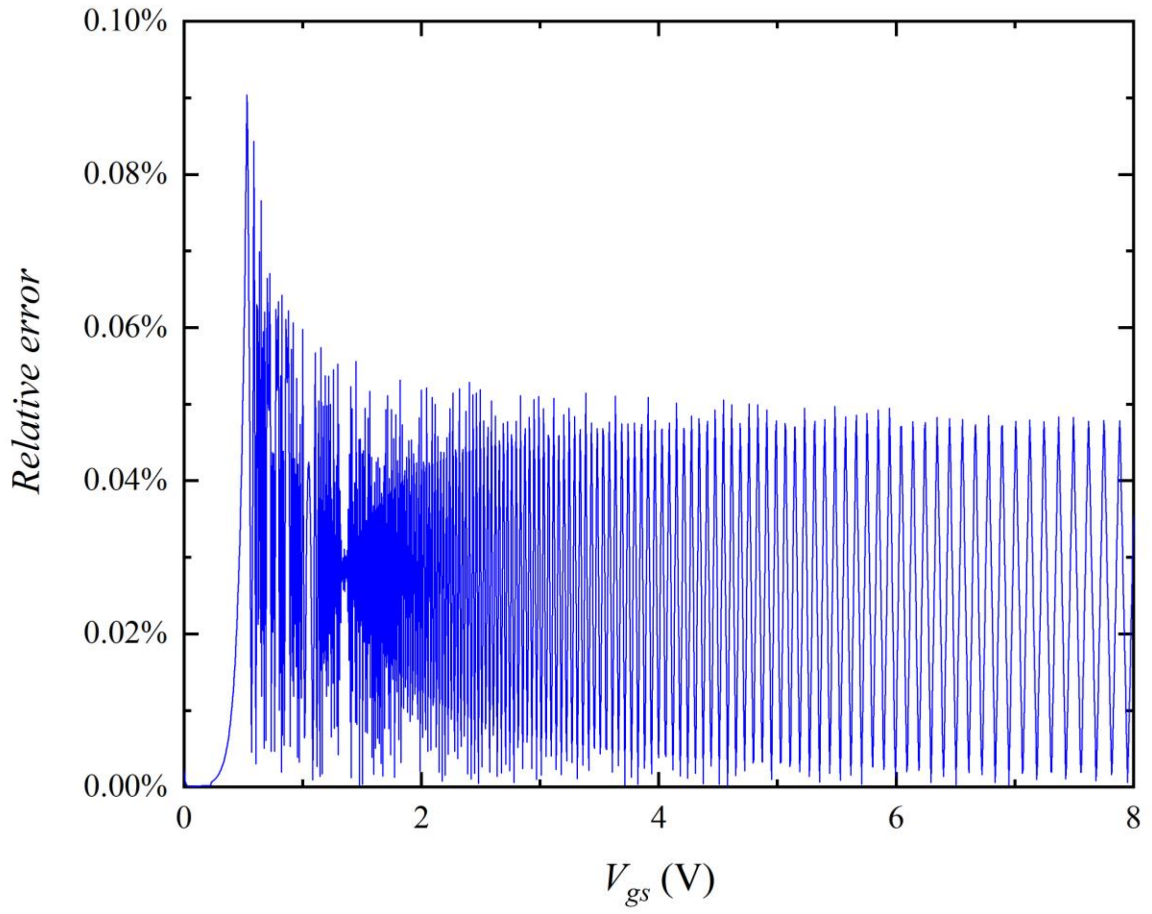


Figure 3. Numerical results and experimental results using relaxation method of the surface potential for different V_{ch}.

Analysis and discussion: The consistency between numerical results and experimental results proves that the surface potential model has good accuracy.



set:

- $\Delta x = 0.05$

  $\Delta y = 0.01$

- Accuracy:

  The relative error is mainly below 0.05%

- Efficiency: Compared with Lambert W function, the simulation efficiency is improved by 11%.

Figure 4. The relative error percentage between numerical resultsand experimental results using relaxation method of the surface potential.

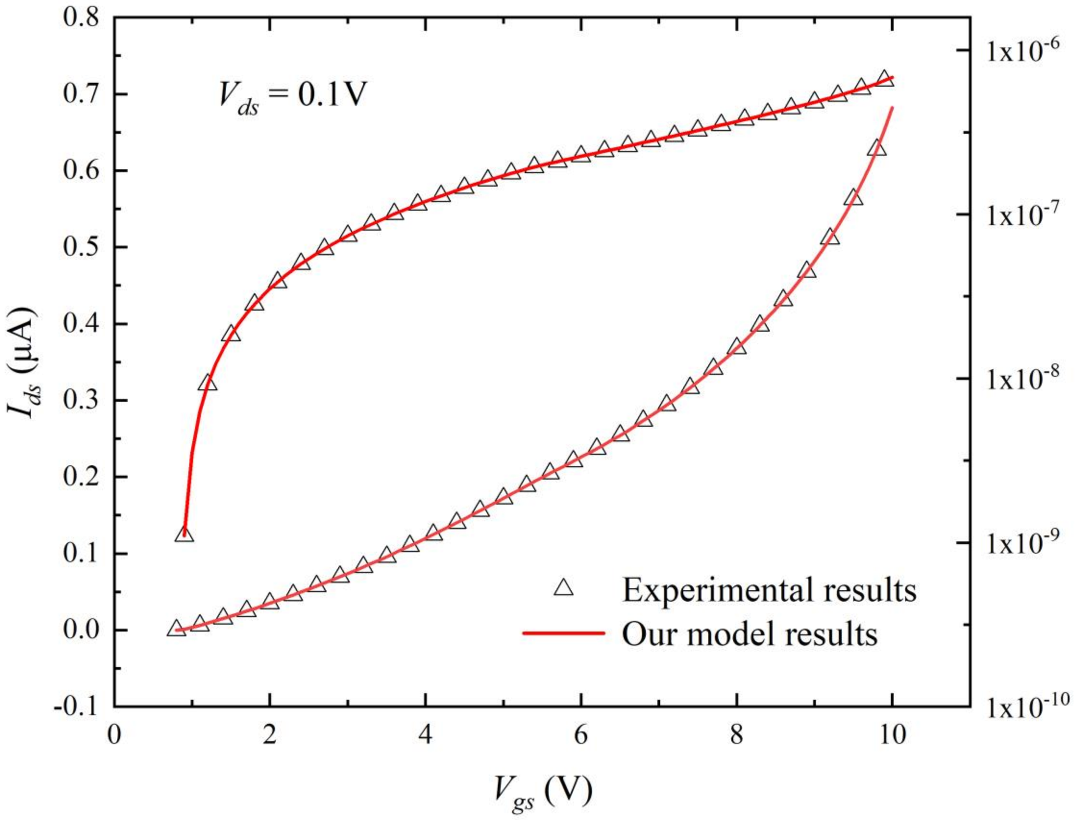


Figure 5. Comparison of transfer characteristics between our model results and experimental results [12] for I_{ds} versus V_{gs}.

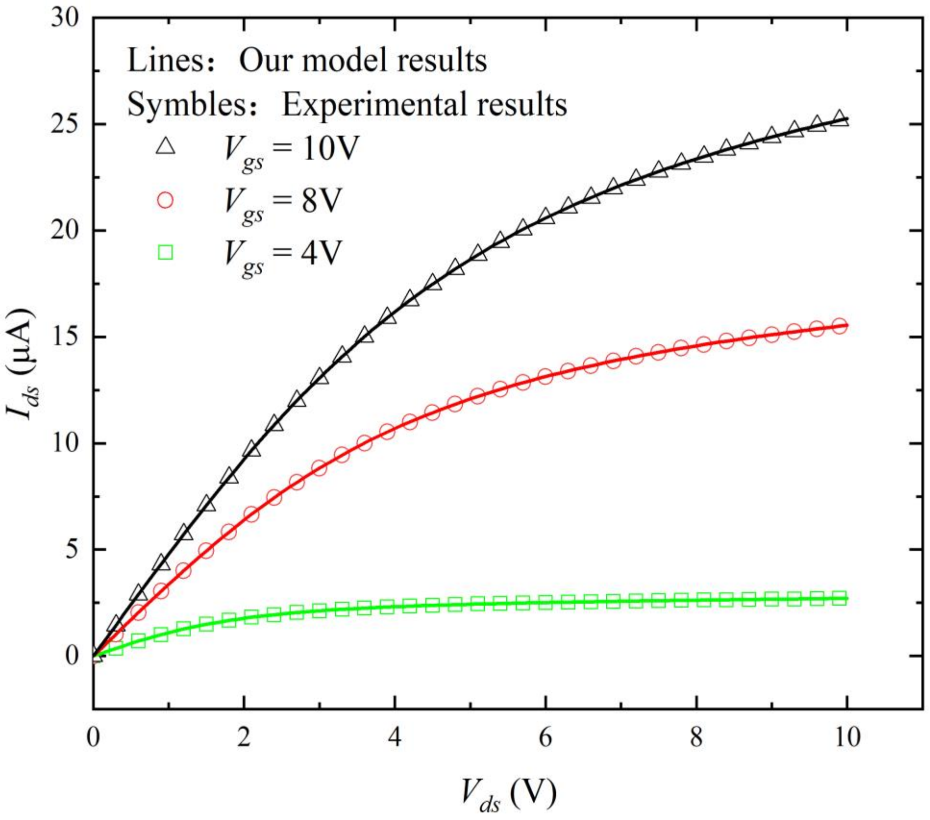


Figure 6.Comparison of output characteristics between our model results and experimental results [12] for I_{ds} versus V_{ds}.

Analysis and discussion: The consistency between our model results and experimental results proves that the drain current model has good accuracy and effectiveness.

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Thank you!

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