Setting of SOI MOSFET Model Parameters based on BP Neural Networks Algorithm

Jingjing Dai, Chong Li, Tian Lan, Zhiyong Wang*
Beijing University of Technology, Beijing, 100124
*Corresponding author e-mail: zywang@bjut.edu.cn

Abstract: With development of SOI technology, SOI MOSFET technology is developed as well. Most traditional MOSFET parameter models adopt semi-empirical and semi-physical model, and simplification assumption is introduced during modeling. However, as SOI MOSFET devices keep downsizing, the short-channel effect and quantum effect are more obvious so that it is more complicate to calculate and extract characteristic parameters of SOI MOSFET. This paper proposes a kind of SOI MOSFET characteristic parameter modeling method based on BP neural networks algorithm. Compared to other semi-empirical models, this method needs not to calculate characteristic parameters of devices. In stead, it calculates current and voltage output characteristics and transfer characteristics of devices through BP neural network models according to test data. Through verification, the trained and predicted output relative error is within 5%. The model has short operation time, high calculation precision and good stability. The models established may be applied extensively to other types of transistor, and feasible for practical engineering application.

1. Introduction
From 1970s, the microelectronics industry developed for nearly half a century according to Moore's law. At present, the characteristic size of devices has approached to 10nm. The silicon material-based CMOS technology is challenged severely by basic physical characteristics of materials, manufacturing costs and even economic operation law in aspects of speed, power consumption, integration and manufacturing costs. In international academic cycle and the industrial cycle, it is

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widely believed the three development trends of micro-nano electronic industry in the “Post-Moore time” are: continuing the Moore’s law, i.e., the semi-conductor device keeps downsizing; expanding the Moore’s law, i.e., pursuing diversified system integration functions; exceeding COMS. They bring great challenges to bulk silicon materials. The application development of the traditional bulk-Si IC with silicon material as substratum is restricted due to parasitic SCR lock effect, soft failure under radiation, parasitic capacitance and hot carrier effect, seriously limiting further improvement of integration level [1]. Currently, people may realize IC in various material systems, including: Group III-V compound semiconductor material with representative of InP, SOI (Semiconductor On Insulator), Si3N4/SiO2, class material, polymer material, and metal/dielectric substance which may generate surface plasma excimer [2-3]. Different photonic integrated circuit technologies may be selected for different applications. Due to particularity of SOI substrate structure, SOI substrate provides feasible platform for active and passive RF components, and meanwhile provides miniature COMS to digital system modules so that SOI substrate has better development. Compared to traditional bulk silicon, SOI IC has many obvious advantages: low power consumption, high speed, radiation resistance, high-temperature resistance, higher integration level and better ability of scale down. It has been extensively applied to server, microprocessor, printer, game devices, network and storage devices as well as ultra-low power consumption occasions such as watch and auto electronics, and also provides a platform for photoelectric integration [4-5].

With development of SOI technology, SOI MOSFET technology is also developed further. The new SOI MOSFET could not only avoid latch-up effect but also better lower parasitic capacitance effect. As the device is downsized and substrate is changed, the parameter module of SOI MOSFET becomes more complex. In order to better simulate electrical behavior of SOI MOSFET device, many companies and research institutions at home and abroad studied parameter performance of SOI MOSFET and proposed multiple computational modules, in which three are applied the most extensively: one is BSIM SOI module proposed by Pin Su of University of California Berkeley [6], which is a kind of physical model covering characteristics of part of partly-depleted and fully-depleted SOI devices, and could provide DC analysis, instant analysis and AC analysis of standard circuits. It is selected as industrial standard module by the modeling committee. Another one is the PSP-SOI module developed by Gildenblat team of Arizona State University. This module is formulated based on the bulk-Si PSP module according to the latest industrial standard, and could represent specific floating-body effect, parasitic triode module and self-heating effect of SOI [7]. Some scholars also used other modules such as Spice module to study relevant parameters of SOI MOSFET. However, that module has not become mature yet, and is still under continuous development.

This paper offers a kind of parameter modeling and fitting method for SOI MOSFET with neural network algorithm. With device grid voltage and drain voltage as variables, this paper acquires DC parameters of SOI MOSFET through test data of documents [8]. The calculation error of the method is within 5% through comparison with test data. This method is feasible and applicable.

2. Artificial neural network

2.1 Artificial neural network

In the artificial neural network, the neuron is the basic component, and the simplification and simulation of biological neuron. Many neurons are connected to each other to form a neural network.
Therefore, the neural network is usually a nonlinear structure with multi-inputs and single-output [9], as shown in Fig. 1.

A typical artificial neural network is comprised of input, neuron network weight and threshold, sum unit, transfer function and network learning. The neuron input $p$ may be expressed by one dimensional vector $r \times 1$; dimensional vector $r$ is the number of neuron inputs, as shown in Formula 1.

$$
\bar{p} = [p_1, p_2, ..., p_r]^T, \quad r = 1, 2, ..., N,
$$

(1)

The weight of neuron network means the connection strength between neurons, represented by $w$; the weight of neuron may be deemed as one $1 \times r$ dimensional vector, as shown in Formula 2.

$$
\bar{w} = [w_1, w_2, ..., w_r], \quad r = 1, 2, ..., N
$$

(2)

The sum unit is used to simulate the weighted sum of input signals, and form a linear combiner. Specific expression is as follows,

$$
n = \bar{p} \cdot \bar{w} + b = \sum_{i=1}^{r} p_i w_i + b, \quad r = 1, 2, ..., N
$$

(3)

In the formula, $n$ is the input signal of transfer function, and $b$ is threshold of neuron network. Function $f$ is the core of artificial neural network, and greatly affects the output capacity of neural network. Output $a$ may be acquired through transfer function $f$ through operation of input signals.

$$
a = f(n)
$$

(4)

Usually one artificial neural network system is comprised of multiple neurons in parallel connection, and every neuron has the same input vector. Therefore, specific form of network weight matrix $w$ and threshold $b$ can be seen in Formula 5, in which, $s$ is the number of neurons.
Learning is an important characteristic of the artificial neural network. The artificial neural network is capable of learning from the system and self-improvement. The learning process is a process of network weight and threshold neuron adjustment. During learning, the weight and threshold level of neural network are revised continuously according to certain metric values, finally gaining output results.

2.2 Back propagation (BP) algorithm

BP neural network comprises input layer, hidden layer and output layer. To reach intended objective, BP neural network algorithm adjusts network weight through calculating the error between actual objective and expected value, inputs information and calculates from input layer to output layer through the hidden layer. If output required is not acquired from the output layer, the change in output layer error will be calculated, and the wrong signal will be returned till the expected objective is reached through revising weight of each layer of neurons [10].

a) Forward information propagation

The output of the ith neuron on the hidden layer shall be:

$$a_1^i = f^1\left(\sum_{j=1}^{r} \omega_{1j}P_j + b_1^i\right) \quad (i = 1, 2, \cdots, r)$$

The output of the kth neuron on the output layer shall be:

$$a_2^k = f^2\left(\sum_{i=1}^{s} \omega_{2i}^k a_1^i + b_2^k\right) \quad (i = 1, 2, \cdots, s1)$$

b) Error back propagation

The output of the ith neuron on the hidden layer shall be (change in weight of output layer):

$$\Lambda \omega_{2y}^k = -\eta \frac{\partial E}{\partial \omega_{2y}^k} = -\eta \frac{\partial E}{\partial a_2^k} \cdot \frac{\partial a_2^k}{\partial \omega_{2y}^k} = \eta(t_k - a_2^k) \cdot f^2(\cdot) \cdot a_1^i = \eta \cdot \delta^2 \cdot a_1^i$$

The weight from the jth to the ith output (weight change of the hidden layer) shall be:

$$\Lambda \omega_{1y}^i = -\eta \frac{\partial E}{\partial \omega_{1y}^i} = -\eta \frac{\partial E}{\partial a_2^k} \cdot \frac{\partial a_2^k}{\partial \omega_{1y}^i} \cdot \frac{\partial a_1^i}{\partial \omega_{1y}^i} = \eta \sum_{k=1}^{s1} (t_k - a_2^k) \cdot f^2(\cdot) \cdot \omega_{2k}^i \cdot f^1(\cdot) \cdot p_j = \eta \cdot \delta^1 \cdot p_j$$

In general, a declinational network and at least one S type hidden layer and one linear output layer may fit any rational function [11]. Therefore, this paper adopts three-layer BP network fitting empirical data. With input neuron number as 1, hidden layer neuron number as 5, and output layer neuron number as 1, the hidden layer transfer function shall be Sigmoid function, while output layer transfer function shall be linear function.
3. SOI MOSFET modeling

3.1 Basic structure of SOI MOSFET

In order to explain the basic structure and operating principle of SOI MOSFET, firstly, the structure of SOI MOSFET is analyzed. N-SOI MOSFET structure is shown in Fig. 2. The bottom layer of the substrate is bulk-Si layer, middle is buried oxide layer and top is p-Si layer. According to nature of carrier, MOSFET may be divided to N-MOSFET and P-MOSFET structure. The N zone is respectively the drain zone and source zone of MOSFET, and aims to make Ohmic contact; during work process, the electron starts from the source electrode S and flows out from drain electrode D. The distance between two N zones is known as channel length, and the silicon dioxide layer separates from grid to channel.

![Basic structure of N-SOI MOSFET](image)

**Fig. 2** Basic structure of N-SOI MOSFET

3.2 Structure and operating principle of SOI MOSFET

The circuit pattern symbol of N-SOI MOSFET can be seen in Fig. 3. In the figure, arrow means the direction of carrier movement; the carrier is electron, and the electron flows from S to D. The D current $I_D$ is controlled by grid-source voltage $V_{GS}$. The curve showing relationship between $I_D$ and D-S voltage $V_{DS}$ with $V_{GS}$ as parameters is known as output characteristics of MOSFET. The output characteristics are divided to three zones, respectively cut-off zone, linear zone and saturation zone.

![Equivalent circuit diagram of N-SOI MOSFET](image)

**Fig. 3** Equivalent circuit diagram of N-SOI MOSFET
3.3 BP neural network calculation

This paper establishes SOI MOSFET output characteristic curve and transfer characteristic curve module with BP neural network. The neural network selected is of five-layer structure, and the test curve could be converged successfully with maximum training time within 100 times. The parameters of SOI MOSFET with grid length of 0.5μm are calculated. Fig.4 shows the error between SOI MOSFET output characteristic curve calculated by BP neural network module and module prediction results under different $V_{GS}$ conditions. The circle in the figure means test number, and the straight line means the predicted results. Fig.5 is the transfer characteristic curve of SOI MOSFET calculated by BP neural network module under different $V_{BS}$ conditions.

![Fig. 4 (a) SOI MOSFET output characteristic curve](image1)

![Fig. 4 (b) Analysis on BP neural network prediction error](image2)

![Fig.5 SOI MOSFET transfer characteristic curve](image3)
4. Conclusion

This paper adopts neural network algorithm to simulate output characteristic curve and transfer characteristic curve of DC parameters of SOI MOSFET. According to analysis results of prediction error, the error scope is within 5%, showing favorable fitting precision. By selecting suitable BP neural network function and tier, the algorithm is converged before 100 times of training. This method is independent of physical model of devices and materials, and complex calculation and simplification is unnecessary. It is of powerful actual application and universality, and could be expanded to calculation of other SOI MOSFET parameters.

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