Comparative Study on III-V MOSFET and Si-MOSFET Model Parameters based on BP Neural Networks Algorithm

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Abstract: MOSFET is the basic unit of modern integrated circuit, and main basic characteristics are: current-voltage (IV) characteristics, capacitor-voltage (CV) characteristics and source-drain contact characteristics. The introduction of group III-V semi-conductor, high k- metal date and SBSD allows MOSFET device characteristic device may keep downsizing based on Moore's Law. However, as II-V 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 III-V MOSFET. This paper proposes a kind of III-V MOSFET characteristic parameter modeling method based on BP neutral 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 neutral 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

According to the Moore’s Law and development of international technical road map for semi-conductor, LSI technology develops based on the miniaturization of MOSFET (Metal-Oxide-Semiconductor Field Effect Transistor), and CMOS device could be expanded continuously relying on novel device structure, high k-medium, metal gate and high-mobility channel materials [1]. Since III-V materials have higher mobility, the development of III-V MOSFET may be more driven by radioactive and digital application. During study and development, the scale-free MOSFET [2] with

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A gate smaller than 10nm is prepared successfully after a large amount of miniaturization practices, and transistor operation is realized. ITRS 2006 predicts that the MOSFET device with 9nm physical gate will be put into large scale production in 2016.

At present, due to the restriction of carrier mobility, the size of Si-MOS device has gradually reached the theoretical limit. People have studied and developed MOSFET devices made of different materials, and the trend of MOSFET manufacture is to apply other substrate materials such as Ge material, III-V compound semiconductor materials, and blue-P materials [3-4]. Compared to silicon materials, those materials have higher carrier mobility, and are suitable to replace silicon substance and use to manufacture high-frequency and high-speed devices. Among the materials, III-V compound semiconductor material such as GaAs, InAs, InGaAs, InGaAsP, which are of higher electron mobility than Si and Ge. Thus, they are suitable to N-MOSFET device manufacture. Therefore, III-V compound semiconductor material have been studied for a long time as active materials for high-speed electronic devices, high-efficient PV devices and multiple optoelectronic devices. The extensive application of III-V semiconductor depends on the advantages of direct band gap and high electron mobility. In III-V compound semiconductor, GaAs has higher band gap and extremely high electron mobility (about 5~6 times of that of Si), and could operate under temperature of -200-200°C. Thus, the semiconductor devices made of GaAs are usually featured in high frequency, high speed, high temperature and low temperature performance. Those advantages offer a prosperous future for application of MOS devices with GaAs substrate.

However, in spite of outstanding performance of III-V semiconductor, its large scale production encounters multiple problems. Compared to Si-channel, III-V compound materials have higher electron mobility and lower effective quality, showing high injection speed and lower back scattering. In the meantime, III-V Nano-scale MOSFET devices have higher dielectric constant and lower band gap so that they are easier to be affected by short-channel effects (SCEs). In order to overcome those barriers, people proposed various new device structures in recent years. Thus, the building of III-V MOSFET parameter model is particularly important. Most of current models are based on Si-MOSFET [5] while few studies are on MOSFET modeling. Therefore, it is necessary to further study parameter models suitable to III-V MOSFET.

This paper offers a kind of parameter modeling and fitting method for III-V MOSFET with the 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 [6]. The calculation error of the method is within 5% through comparison with test data. This method is feasible and applicable.

2. Characteristic analysis of III-V MOSFET

2.1 Basic characteristics of III-V materials

III-V compound semiconductor materials could be used as channel materials to manufacture MOS devices due to higher carrier mobility. Among the materials, GaAs has high electron mobility, and is suitable for manufacture of n-MOSFET with ultra high speed and low power consumption. Table 1 lists characteristics of Si, Ge and some common III-V compound semiconductors. Among III-V compound semiconductor, GaAs has higher band gap and extremely high electron mobility (about 5~6 times of that of Si), and could operate under temperature of -200-200°C. Thus, the semiconductor devices made of GaAs are usually featured in high frequency, high speed, high temperature and low
temperature performance. Those advantages offer a prosperous future for application of MOS devices with GaAs substrate.

### Table 1. Characteristics contrast of semiconductor materials

|              | Si  | GaAs | InP  | In_{0.53}Ga_{0.47}As |
|--------------|-----|------|------|----------------------|
| Electron mobility | 1450  | 8000 | 4600 | 120000               |
| Hole mobility    | 500  | 400  | 150  | 300                  |
| Band gap        | 1.12 | 1.42 | 1.35 | 0.74                 |
| Dielectric constant | 11.9 | 12.9 | 12.6 | 13.9                |

2.2 Basic structure of III-V MOSFET

In order to explain the basic structure and operating principle of III-V MOSFET, firstly, the structure of III-V MOSFET is analyzed. III-V N-MOSFET structure is shown in Fig.2. The bottom layer of the substrate is p-GaAs substrate, middle is III-V compound semiconductor and high $\kappa$ material is adopted for gate. The middle channel layer may adopt InGaP/InGaAs, InP/InAlAs/InGaAs structure [7] and compound semiconductor structure such as AlGaAs/InGaAs [8]; the two-dimension electron gas is used as conducting mechanism, with large current density and 5000 cm$^2$/V·s electron mobility. Therefore, III-V MOSFET shows great advantages in power application.

![Fig. 11 Basic structure of III-V N-MOSFET](image)

2.3 Conducting mechanism of III-V MOSFET

The crystal structure of GaAs belongs to Blende-type structure, as shown in Fig.2. It is non-equivalent along [111] direction and so it has polarity. When AlGaAs and GaAs form heterojunction, the different lattice constants may make both GaAs and AlGaAs suffer stress; electrostatic charge may be formed on the interface due to piezoelectricity, which absorbs electrons...
and form a layer of two-dimension electron gas (2DEG) with high concentration on interface. Fig.3 shows the energy band of AlGaAs/GaAs heterojunction.

![fig2](image_url)

**Fig. 2 Equivalent circuit diagram of III-V N-MOSFET**

![fig3](image_url)

**Fig.3 Conducting mechanism of 2DEG**

3. **BP neural network calculation**

This paper establishes III-V MOSFET and Si-MOSFET output characteristic curves and transfer characteristic curves module with BP neural network [9-11]. The neural network selected is of three-layer structure, and the test curve could be converged successfully within training precision of 0.1%. The parameters of III-V MOSFET and Si-MOSFET under different temperatures are calculated with comparison. Fig.4 shows the III-V MOSFET and Si-MOSFET output characteristic curves calculated by BP neural network module under different temperature conditions. The circles and star points in the figure mean test number, and the straight line means the predicted results. Fig.5 is the transfer characteristic curves of III-V MOSFET and Si-MOSFET calculated by BP neural network module under different temperature conditions. According to the figure, the output characteristics and transfer characteristics of III-V MOSFET are superior to that of Si-MOSFET.
4. Conclusion

This paper adopts neural network algorithm to simulate output characteristic curves and transfer characteristic curves of DC parameters of III-V MOSFET and Si-MOSFET, with error scope of 5%. According to contrastive analysis results of prediction error, the III-V MOSFET has better characteristics while BP neural network has favorable fitting precision. By selecting suitable BP neural network function and tier, the algorithm is converged within training precision of 0.1%. 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 III-V MOSFET parameters.
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