Abstract—A simple semi-empirical compact MOSFET model has been developed, which is called MIT virtual source (MVS) model. Compare to other model used in industry, MVS model requires only a few parameters, most of which can be directly obtained from experiment, and produce accurate results. One aim of this paper is to test the applicability of the MVS model to transistor made from MoS$_2$ rather than silicon. Another target is to determine the sustainability of the MVS model under different transistor tests. To achieve these goals, the MVS model will be used to fit the experimental data on MoS$_2$ transistors. Also, various tests will be implemented on the MVS model to see whether it is able to pass the tests. After the above steps, the fitting result suggests that MoS$_2$ device has some special characteristic which cannot be described using MVS model. And the MVS model passes the symmetry tests well but fails in some other tests. Thus, despite the simplicity and accuracy of the model, more research can be conducted on this model in order to improve its generality.

Index Terms—virtual source, FET, compact model, MOSFET, nanotransistor

I. INTRODUCTION

MOSFET modeling for circuit simulation plays an important role in modern circuit design. Among various MOSFET model, this paper focuses on one of the compact semi-empirical model for nanoscale transistor developed in [1]. This model is based on the physics of electron transport at the virtual source and uses an empirical expression to make the results continuous across all regions of operation. The model is developed at MIT and is known as the MIT Virtual Source model (MVS Model). The model requires only ten parameters and six of them can be directly obtained from experiment. Besides its simplicity, the model provides remarkable accuracy. It is also widely applicable, not only for silicon MOSFET [1], but also for InGaAs HEMT [1], graphene FET [2]. One purpose of this paper is to test the applicability of the MVS model to MoS$_2$ FET, which is a novel material for making transistors. Another purpose of this paper is to use different benchmark tests[3] for compact MOSFET models to test the quality of the MVS model. This is for determining its suitability for robust circuit simulation in SPICE compatible environments. In the process, a rappture tool will also be created to exercise and test the model.

II. Test the Applicability of MVS Model to the MoS$_2$ FET

MoS$_2$ transistor is currently a hot research topic. Unlike graphene, which doesn't have an energy gap, MoS$_2$ has an indirect band gap of 1.2 eV. The mobility of multilayer MoS$_2$ FET achieves 700 cm$^2$/(V·s) [4] and single layer MoS$_2$ transistor exhibits an on/off current ratio as high as $10^8$ [5]. There are so many promising features of MoS$_2$ FET that cannot all be listed here. However, it also has some special characteristics that makes the MVS model fail to fit the experimental data. The data were measured on a multi-layer back gated MoS$_2$ FET by the authors in [4]. From the transfer characteristic plot in Figure 1, the DIBL varies greatly between different lines. However, the MVS model assumes a constant DIBL. The non-uniform DIBL will cause the model deviates from the measured data especially in the sub-threshold and transition region, even though the model can produce a good result above threshold.
In the output characteristic plot, when $V_{ds}$ becomes larger, the varying DIBL effect will cause difficulty in matching the on-current of the device. Although the MVS model is modified for this particular device to include the non-constant DIBL effect, it doesn't make too much difference. The final fitting results is shown in Figure 2.

There are many kinds of benchmark tests to determine the suitability of a compact model for SPICE simulation. Some of these test was implemented on MVS model to see whether it can succeed in passing the model tests.

A. Gummel Symmetry Test (GST) [6]

The source and drain terminal of a MOSFET has no difference if the MOSFET is put in a black box. The model should provide a same result if source and drain terminal is interchanged. Also, SPICE simulation requires the model to produce a continuous curve rather than curve consisting many pieces. Thus, the $n^{th}$ order derivative of the output characteristic plot should be continuous and symmetry about either the origin or the drain current axis. The MVS model passes the GST and result is presented in Figure 3.
B. Reciprocity Test [3]

This test is similar with GST. The core idea is also that interchanging source and drain terminal should not make differences. This test requires the trans-capacitance of source to drain equal to the trans-capacitance of drain to source at zero drain source bias ($C_{sd} = C_{ds}$ at $V_{ds} = 0$). In the MVS model, the test is modified equivalently to require source charge equals to the drain charge at $V_{ds} = 0$ since it can be tested more easily. The results in Figure 4 shows the MVS model passes the symmetry test.

C. Slope Ratio Test [3]

The main purpose of the slope ratio test is to distinguish a model in its sub-threshold region and above threshold region. The slope ratio for the MVS model is given by

$$S_R = \frac{(I_2 + I_1)(V_{DB2} - V_{DB1})}{(I_2 - I_1)(V_{DB2} + V_{DB1})}$$

at $V_{DB1} = 0.01$ V and $V_{DB2} = 0.02$ V, which is the most common drain voltages for this test. At room temperature,

$$\lim_{V_{gb} \to -\infty} S_R \approx 1.3, \quad \lim_{V_{gb} \to \infty} S_R \approx 1$$

However, for MVS model, the slope ratio displays kinks and glitches at low $V_{gb}$, which means it fails the slope ratio test.

D. Sub-threshold region test [3]

The purpose of this test is similar to the slope ratio test. It is proved by authors in [3] that

$$\left(\frac{\partial}{\partial V_d} [g_{ds} \cdot \exp(V_d/\Phi_T)]\right) = 0$$

Thus, the slope of the line in Figure 6 should be zero. However, after the test is implemented on the MVS model, the slope is not zero in the plot, which means the MVS model fails in the sub-threshold region test.
IV. The Rappture Tool on Nanohub

Nanohub is an online platform for many resources about nanotechnology including online simulation. Rappture stands for rapid application infrastructure, which can be used to create many tools with user friendly interface. A rappture tool that exercises the MVS model was created. The interface is presented in Figure 7.

The script running this tool is written in terms of the MVS model. After the parameters are entered and output limits are specified, the tool will generate the I-V curve for the virtual device. Users can also choose to upload experimental data to this tool in a specified format, fit the data with the MVS model and extract the parameter after the curve generated by the MVS model matches the actual data. This rappture tool provides an interface for users to do the fitting work. More information about this tool can be found at the supporting documents tab of the tool on nanohub.

V. Conclusion and Future Work

Although the MVS model can be widely applicable to many kinds of FET, it seems that this model cannot describe the behavior of MoS2 FET. From the model test results, the MVS model passes symmetry tests well but fails in other tests, which means it can be improved in the sub-threshold and transition region. Besides, since the MVS model is being updated frequently, the online rappture tool should also be updated accordingly and more features can be included in the tool as well.

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REFERENCES


