

Improving Semiconductor Device Modeling for Electronic Design Automation by Machine Learning Techniques

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Abstract—The semiconductors industry benefits greatly from the integration of machine learning (ML)-based techniques in technology computer-aided design (TCAD) methods. The performance of ML models, however, relies heavily on the quality and quantity of training datasets. They can be particularly difficult to obtain in the semiconductor industry due to the complexity and expense of the device fabrication. In this article, we propose a self-augmentation strategy for improving ML-based device modeling using variational autoencoder (VAE)-based techniques. These techniques require a small number of experimental data points and do not rely on TCAD tools. To demonstrate the effectiveness of our approach, we apply it to a deep neural network (DNN)-based prediction task for the ohmic resistance value in gallium nitride (GaN) devices. A 70% reduction in mean absolute error (MAE) when predicting experimental results is achieved. The inherent flexibility of our approach allows easy adaptation to various tasks, thus making it highly relevant to many applications of the semiconductor industry.

Index Terms—Data augmentation, electronic design automation (EDA), gallium nitride (GaN), machine learning (ML), semiconductor devices.

I. INTRODUCTION

ELECTRONIC design automation (EDA) has been crucial in advancing the semiconductors industry by simplifying

design tasks and reducing their time consumption [1]. One particular EDA technique, technology computer-aided design (TCAD), has been especially useful in the area of semiconductor devices. TCAD solves basic physics equations using the finite element method, such as the Poisson and Schrödinger equations, which provides easy access to simulated results that would be difficult to solve manually [2], [3], [4]. In addition, TCAD has significantly reduced the cost of experiments during device design by avoiding them altogether [5].

Nevertheless, simulating complex 3-D device structures requires significant computational resources. While many models and methods have been developed to reduce resource consumption, exploring novel methodologies of TCAD remains a pressing issue to balance the accuracy and time consumption of sophisticated physics simulations. So far, machine learning (ML)-based solutions have been successfully employed in many device modeling cases and offer the advantage of low-resource consumption after model training [6], [7], [8], [9], [10]. However, with expanding size of the ML models, there is an increasing need for input data to fully complete model training [11].

TCAD-based data augmentation, a technique that has garnered significant attention in the semiconductor industry since 2019 [9], [12], [13], [14], has been employed to generate artificial data that can be fed into deep neural network (DNN)-based models. This approach could provide an expanded dataset and then significant boost to DNN-based modeling within the TCAD industry's development. However, many problems in the semiconductor industry cannot be directly solved by TCAD tools, such as the simulation of the formation of ohmic contacts in gallium nitride (GaN) devices, which imposes a formidable challenge on the TCAD-based augmentation technique.

Recently, a study by Sheelvardhan et al. [15] highlighted the potential of knowledge-based ML algorithms in overcoming the limitations of traditional ML-based approaches for semiconductor device modeling. By leveraging prior knowledge, these algorithms offer a promising solution to address the complexities associated with establishing and training ML models. This research represents a significant advancement toward the development of next-generation ML-based TCAD toolkits.

Manuscript received 17 July 2023; accepted 17 August 2023. This work was supported in part by CSIRO's Impossible Without You Program. The review of this article was arranged by Editor H. Agarwal. (Corresponding authors: Zeheng Wang; Timothy van der Laan; Muhammad Usman.)

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Color versions of one or more figures in this article are available at <https://doi.org/10.1109/TEDE.2023.3307051>.

Digital Object Identifier 10.1109/TEDE.2023.3307051

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