

Achieving Sustainability in the Semiconductor Industry: The Impact of Simulation and AI

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Abstract—Computational simulation has been used in the semiconductor industry since the 1950s to provide engineers and managers with a faster, more cost-effective method of designing semiconductors. With increased pressure in the semiconductor industry to move towards greener and more sustainable manufacturing, it is crucial to understand the impact of computational simulation and artificial intelligence on environmental sustainability, specifically reducing greenhouse gas (GHG) emissions. This paper quantifies the degree to which various types of simulation used for hardware, process, and device optimization can be adopted for different applications in wafer fabrication equipment research and development, along with the potential reduction in physical experimentation, saving silicon, gases, chemicals, and wafers. With this understanding and an estimation of the equivalent carbon cost impact of the computation itself, analyzed projects demonstrated a significant (>80%) decrease in emissions, primarily driven by the ability to use fewer patterned and blanket wafers whose carbon footprint appears to be orders of magnitude larger than that of used modeling resources. The paper concludes with an attempt to quantify the environmental savings from virtualization across our entire research organization and to illustrate the potential future impact of described activities.

Index Terms—Artificial intelligence, carbon emissions, carbon footprint, carbon reduction, computational modeling, environmental factors manufacturing, low carbon economy, machine learning, net zero, numerical simulation, predictive models, semiconductor materials, simulation, sustainable development.

I. INTRODUCTION

FOR DECADES, semiconductor manufacturing has powered increasingly large segments of the global economy. The drive for additional and less expensive computational power requires continuing advances in chip technologies, with semiconductors becoming more complex and intricate with each new generation [1]. Naturally, the increased sophistication of semiconductor devices cannot be achieved without an analogous growth in resources devoted to research and development (R&D). Each new generation of semiconductor chips calls for additional experimentation at every step of the R&D process, including developing more advanced wafer

fabrication equipment (WFE) that can satisfy the tightening specifications required by chip manufacturers.

This technological challenge presents a conundrum for the semiconductor industry since it has committed itself to an environmentally sustainable path. Many major semiconductor companies have set a goal to achieve Net Zero emissions by 2050 – or earlier – to combat climate change and stop the continuous rise of greenhouse gas (GHG) concentration in the atmosphere [2]. This goal will require significantly curbing GHG emissions in each phase of the semiconductor manufacturing ecosystem [3], [4]. In our view, the R&D stage is a particularly promising area for decreasing the carbon footprint of the semiconductor industry despite increasing technical complexity. The reason for our optimism is that while fabricating actual devices invariably requires material resources, physical experimentation during the R&D phase can be at least partially replaced by simulation and virtualization. The end goal of R&D is technological insight, not the production of actual semiconductor devices. Simulation and virtual development can also lead to lower emission manufacturing pathways, further reducing GHG emissions.

Computational modeling and simulation have been indispensable for decades. These methods can save costs, accelerate development, and enable a greater understanding of the physical mechanisms behind complex processes in each manufacturing step (e.g., etching, deposition, lithography). Simulation can also predict overall device performance (e.g., response time, noise level, current-voltage characteristics) [5], [6], [7]. The rise of new computational semiconductor design techniques powered by artificial intelligence (AI) is accelerating the value provided by simulation and data modeling, so much so that it is expected to generate tens of billions of dollars in revenue for semiconductor companies [8]. However, it is important to study not only the financial and labor implications of these advanced design tools, but also their environmental footprint. In this paper, we analyze how several types of simulation used in the R&D environment can reduce the overall environmental impact of semiconductor projects. We will review the impact of simulation on R&D projects such as the development of new etch and deposition processes, prototyping of wafer fabrication equipment, and optimizing wafer integration processes. This work is representative of projects conducted at Lam Research during the design of equipment used to manufacture next-generation logic and memory devices.

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computing are relatively minor compared to the environmental cost of producing semiconductor-grade Si wafers and patterning them into short-loop and full-loop structures. While the exact quantification of the impact remains highly dependent on the individual application, we remain confident that the increase in simulation and modeling techniques in R&D will positively change our industry and contribute to the transition towards sustainable operations.

We hope to see further studies detailing the environmental considerations of semiconductor development, not only in the context of GHG emissions but also in water consumption, air pollution, PFAS, and other topics. While our paper has focused on the operational emissions savings from simulation over physical experimentation, the associated emissions with the production of virtualization hardware will likely be smaller than that required to manufacture semiconductor test equipment and cleanroom spaces. We expect similar dynamics to occur in manufacturing, where physical resources will continue to play a vital role as the industry makes physical goods. There are many opportunities to improve yield, decrease the need for metrology, and simplify integration flows with simulation.

The extent to which simulation methods successfully transform the semiconductor industry will depend on their accuracy and the time to solution versus traditional physical experimentation. Therefore, continuing research to improve and expand simulation capabilities while considering environmental implications is critical. Our industry continuously expands and adapts to pursue increasingly more challenging technological objectives. We are used to balancing complex trade-offs such as cost, performance, and speed. We hope to see the environmental impact become a fixed consideration for all upcoming transitions, as, without a doubt, simulation techniques have a lot to offer for our industry.

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