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Editorial: Emerging chip materials and devices for post Moore's era

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Editorial on the Research Topic

Emerging chip materials and devices for post Moore's era

Introduction

The slowdown of equivalent scaling and the end of classical Moore's Law have brought about significant challenges for silicon-based CMOS integrated circuits. This has spurred the urgent need for the development of novel materials, device structures, integration processes, and specialized system architectures for the post Moore's era. Inspired by More Moore, More than Moore and Beyond CMOS strategies (Ref 1: <https://irds.ieee.org/>), next-generation ICs demand performance improvements in various areas, including non-silicon semiconductors, beyond CMOS devices, high-density integration processes, and unique system architectures and emerging applications. Concurrently, advances in layered semiconductors, lateral epitaxial heterojunctions, integrated biochips have been propelled by the development of superior devices, enabling more energy-efficient and high speed signal processing, storage, detection, communications and system function (Figure 1).

This Research Topic serves as a forum for researchers to present the state-of-the-art progress and review recent developments, challenges, and opportunities in materials, structure, devices, integration, and system to light up the post Moore's era. This includes optimized silicon based materials, emerging layered semiconductors (Wang et al., 2018; Xie et al., 2018), next-generation interconnect materials, novel device structures (Duan et al., 2014; Li et al., 2015), new working principle devices (Liu et al., 2021; Zhang et al., 2022a), 3D integration processes (Zhang et al., 2022b; Zhang et al., 2022c), and recent progress in bioelectronics (Wang et al., 2022) and sensor technologies (Abiri et al., 2022), underlining the need for ongoing research and innovation in this field.

For the optimized silicon based materials, Islam et al. presented a simple and environmentally friendly method for low-cost production of silicon thin films on quartz substrates using aluminothermic reduction. This innovative approach addresses the long-standing challenge of obtaining high-quality silicon films using cost-effective and sustainable methods. The researchers utilized aluminothermic reduction, converting the surface of the

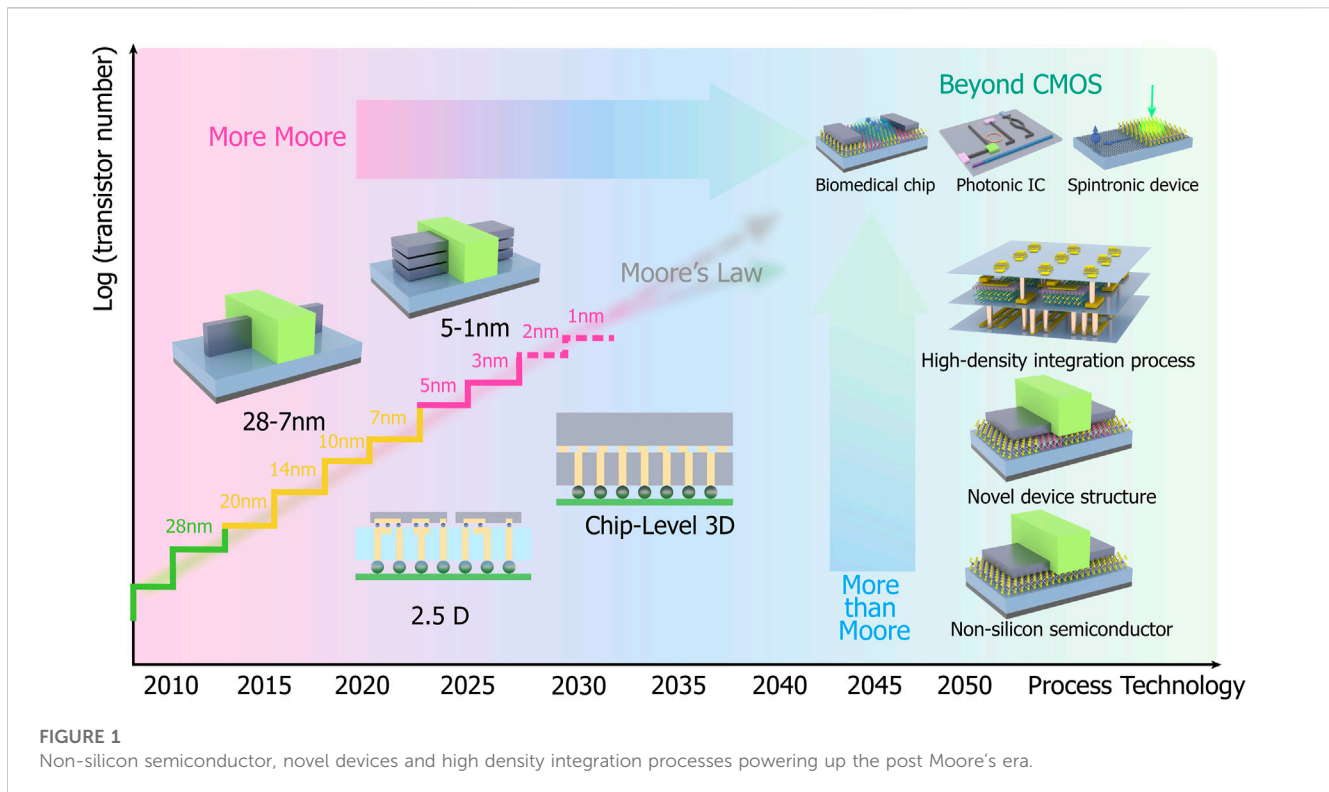


FIGURE 1

Non-silicon semiconductor, novel devices and high density integration processes powering up the post Moore's era.

quartz substrate in contact with an aluminum (Al) layer into elemental Si during high-temperature annealing. This research has potential applications in energy devices, electronics, Si on insulators, Si/SiO₂ superlattice, and photonic crystals. The findings of this study pave the way for further investigations into the optimization of aluminothermic reduction parameters, such as the initial Al content and reduction temperature, to achieve even higher-quality Si films.

Another view from Zhang et al. addressing the challenges of synthesizing 2D lateral heterojunctions by reporting the successful growth of sub-2 nm WS₂ quantum well arrays within monolayer WSe₂. No double similar quantum well superlattice structures could be formed in diverse lateral heterojunctions, offering a rich array of photonic electronic properties and opening new avenues for studying topological insulators and superconductors in 2D quantum materials and devices. The innovative approach to synthesizing quantum well superlattices demonstrates the potential of these structures for a variety of applications, including advanced optoelectronics, sensors, and quantum computing.

Another milestone review from Chen et al. is focusing on electrical impedance-based sensors, specifically electrochemical impedance spectroscopy (EIS) and electrical impedance tomography (EIT), which have been explored for clinical applications over the past few decades. These applications include detecting cardiac output, pulmonary function, atherosclerotic plaques, and fatty liver disease. A critical aspect of these applications is the electrochemical properties of the interface electrodes, which determine the signal-to-noise ratio and sensitivity of measurements in biological environments. Carbon-

based nanomaterials become potential candidates for enhancing the conductive properties of bioimpedance sensor electrodes. It discusses the strengths of various nanomaterials in optimizing charge transfer and measurement sensitivity. Recent advancements in wearable and implantable bioelectronics are also examined, alongside current biomedical applications of EIS and EIT. Moreover, the review identifies unmet clinical needs, such as adapting to different hemodynamic conditions and blood vessel geometries, that can be addressed by novel biomaterials for future EIS-based sensors. Despite the limiting effects of the post-Moore's era on the development of conductive nanomaterials, further research and commercialization efforts are necessary to ensure that these novel materials meet regulatory requirements and become viable for clinical use.

Last but not least, efficient and environmentally friendly metal material machining processes are crucial in modern manufacturing. In the study from Li et al. a process condition-oriented method is proposed for predicting resource environment load data, which is essential for assessing and enhancing the environmental performance of metal material machining processes. The method introduces process conditions that comprehensively describe various aspects of the machining process, including process type, materials, processing mode, equipment, and process parameters. A resource environment load database is constructed based on these process conditions. By using limited sample data, a process condition similarity matching method based on weighted Euclidean distance is employed for predicting resource environment load data under new process conditions. The proposed method demonstrates an average prediction accuracy exceeding 90%, with environmental performance predictions

using the predicted data achieving over 93% accuracy. Future research in this area may explore the impact of data set size on prediction results and compare the proposed method with alternative data-driven approaches. The development of more accurate prediction methods and the incorporation of additional factors, such as energy consumption and waste generation, could further enhance the environmental performance of metal material machining processes.

Conclusion

The Research Topic of studies in this Research Topic showcases the latest advances in novel materials and devices, addressing the few of most key challenges faced in the post-Moore's era. As the scaling of silicon-based CMOS integrated circuits slows down, researchers are exploring alternative materials, structures, and architectures to meet the performance requirements of next-generation ICs. The studies presented here offer promising solutions to these challenges by developing innovative methods, such as aluminothermic reduction for silicon layer formation and dislocation-driven growth of quantum well superlattices. Furthermore, the research focuses on enhancing bioelectronics, such as sensors and actuators, which have far-reaching applications in disease diagnosis and the interface between organisms and devices. The development of novel nanomaterials for use in electrochemical impedance spectroscopy exemplifies the potential of these materials in biomedical applications. While the post-Moore's era poses significant challenges, this Research Topic demonstrates that progress is being made in the development of emerging materials, devices, and architectures that can address these challenges and pave the way for a new era of innovation.

References

- Abiri, P., Luo, Y., Huang, Z.-Y., Cui, Q., Duarte-Vogel, S., Roustaei, M., et al. (2022). 3-Dimensional electrical impedance spectroscopy for *in situ* endoluminal mapping of metabolically active plaques. *Sensors Actuators B Chem.* 354, 131152. doi:10.1016/j.snb.2021.131152
- Duan, X., Wang, C., Shaw, J. C., Cheng, R., Chen, Y., Li, H., et al. (2014). Lateral epitaxial growth of two-dimensional layered semiconductor heterojunctions. *Nat. Nanotechnol.* 9, 1024–1030. doi:10.1038/nnano.2014.222
- Li, M.-Y., Shi, Y., Cheng, C.-C., Lu, L.-S., Lin, Y.-C., Tang, H.-L., et al. (2015). Epitaxial growth of a monolayer WSe₂-MoS₂ lateral p-n junction with an atomically sharp interface. *Science* 349, 524–528. doi:10.1126/science.aab4097
- Liu, Y., Duan, X., Shin, H.-J., Park, S., Huang, Y., and Duan, X. (2021). Promises and prospects of two-dimensional transistors. *Nature* 591, 43–53. doi:10.1038/s41586-021-03339-z
- Wang, C., He, Q., Halim, U., Liu, Y., Zhu, E., Lin, Z., et al. (2018). Monolayer atomic crystal molecular superlattices. *Nature* 555, 231–236. doi:10.1038/nature25774
- Wang, S., Nie, Y., Zhu, H., Xu, Y., Cao, S., Zhang, J., et al. (2022). *Sci. Adv.* 8, eabl5511.
- Xie, S., Tu, L., Han, Y., Huang, L., Kang, K., Lao, K. U., et al. (2018). Coherent, atomically thin transition-metal dichalcogenide superlattices with engineered strain. *Science* 359, 1131–1136. doi:10.1126/science.aao5360
- Zhang, S., Deng, X., Wang, Y., Wu, Y., Ke, S., Li, L., et al. (2022). *China semiconductor Technology international conference*. China: CSTIC.
- Zhang, S., Deng, X., Wu, Y., Wang, Y., Ke, S., Zhang, S., et al. (2022). Lateral layered semiconductor multijunctions for novel electronic devices. *Chem. Soc. Rev.* 51, 4000–4022. doi:10.1039/d1cs01092a
- Zhang, Z., Huang, Z., Li, J., Wang, D., Lin, Y., Yang, X., et al. (2022). Endoepitaxial growth of monolayer mosaic heterostructures. *Nat. Nanotechnol.* 17, 493–499. doi:10.1038/s41565-022-01106-3

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