From Atoms to Architectures: Two-Dimensional Materials for Energy-Efficient AI and Emerging Computing

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Abstract:

As conventional silicon and copper technologies approach fundamental limits in scaling, power density, interconnect performance, and integration, two-dimensional (2D) materials offer new opportunities for energy-efficient information processing. Their atomically thin bodies, pristine van der Waals interfaces, tunable electronic properties, and compatibility with low-temperature processing enable innovations spanning nanoscale devices, beyond-copper interconnects, and monolithic three-dimensional (M3D) integration.

This talk will present an atoms-to-architectures research framework that connects the physics and engineering of 2D materials to the energy, communication, memory, and integration requirements of future AI and emerging computing systems. Topics will include predictive approaches to metal-contact and interface engineering in 2D semiconductors; ultra-low-power transistors enabled by atomically sharp electrostatics; intercalation-doped multilayer graphene for beyond-copper interconnects and ultra-compact graphene kinetic inductors; and low-temperature 2D-material integration for densely interconnected three-dimensional logic and memory. The talk will also highlight how the diverse electronic properties of layered materials can enable novel neuromorphic and quantum-device concepts.

Finally, Professor Banerjee will discuss the translation of these advances from fundamental materials discoveries to manufacturable semiconductor technologies, including CMOS-compatible graphene synthesis, foundry validation, technology-roadmap adoption, and commercialization. Together, these developments illustrate how atomically engineered materials, interfaces, and architectures can address the power, communication, memory, and thermal bottlenecks that increasingly limit the energy efficiency of AI-era computing.

References:

[1] W. Cao *et al.*, *Nature*, **620** (7974), 501–515, (2023).
[2] A. Pal *et al.*, *Nature Electronics* **7**, 1147-1157 (2024).
[3] A. Pal *et al.*, *Nature Communications* **15** (1), 3392 (2024).
[4] J. Jiang *et al.*, *Nano Letters*, **17** (3), 1482-1488 (2017).
[5] J. Kang et al., *Nature Electronics* **1**, 46-51 (2018).
[6] J. Jiang *et al.*, *IEEE Journal of the Electron Devices Society,* **7**, 878-887 (2019).