Monolithic 3D Integration of Functionally Diverse 2D Devices

Saptarshi Das
Associate Professor
Engineering Science and Mechanics (ESM)
Materials Science and Engineering (MATSE)
Electrical Engineering and Computer Science (EECS)
Materials Research Institute (MRI)
The Pennsylvania State University
Email: sud70@psu.edu

Three-dimensional (3D) integration is not only being explored to achieve "More Moore" (greater device density) but also to introduce new functionalities known as "More than Moore". Currently, most 3D integrated circuits (ICs) are based on silicon and are readily available in the market. However, there's a fascinating realm of emerging nanomaterials, like two-dimensional (2D) materials, which possess unique capabilities. Surprisingly, there has been limited exploration of 3D integration using these novel nanomaterials. Our research addresses this gap, and we successfully demonstrated the integration of more than 10,000 field-effect transistors (FETs) in each tier of a wafer-scale and monolithic 2-tier 3D integration based on MoS_2 while keeping the thermal conditions at a low 180 ºC. Additionally, we accomplished a 3-tier 3D integration using both MoS_2 and WSe_2, with approximately 800 FETs in each tier. Moreover, we pushed the boundaries further with a 2-tier 3D integration utilizing 200 aggressively scaled MoS_2 FETs in each tier. Even more impressively, our research has led to the realization of a 3D circuit that exhibits multifunctional capabilities, such as sensing and storage. We firmly believe that our demonstrations will lay the foundation for even more sophisticated, highly compact, and functionally diverse integrated circuits with a larger number of tiers stacked together in the third dimension.