A Center for Power Electronics Materials and Manufacturing Exploration (APEX)
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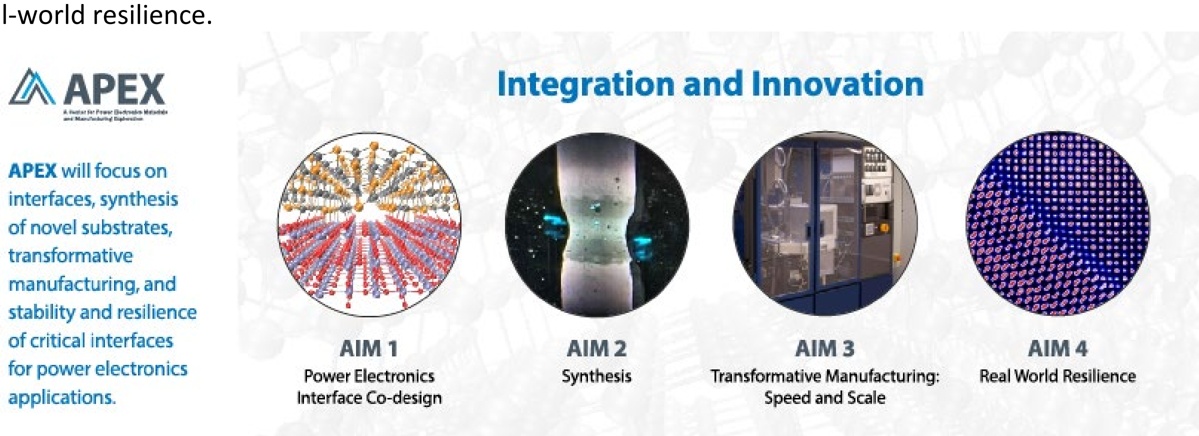
Lead Institution: NREL
Class: 2024 – 2028

Mission Statement: *To expand interdependent materials and manufacturing choices for substrates, ultrawide-bandgap semiconductors, contacts, thermal sinks, and critical interfacial layers and advance fundamental understanding of structurally, chemically, thermally, and electrically dissimilar interfaces.*

Next-generation power conversion technologies have the potential to significantly improve energy efficiency and reduce global energy consumption. **APEX** (A Center for Power Electronics Materials and Manufacturing Exploration) will enable a wider selection of materials and manufacturing methods built for speed and scale for next-generation power electronics by understanding and elucidating chemical, physical, thermal, and electrical requirements at dissimilar interfaces. We are motivated by a co-design vision for "A on B," where "A on B" can encompass a range of materials and interfaces that promise to unlock new functionality but may be more difficult to achieve from a synthesis standpoint. The APEX team, an interdisciplinary community of scientists, is driven by the greatest energy challenge of our time: the urgent need to innovate our way to a highly electrified, sustainable, and clean energy ecosystem.

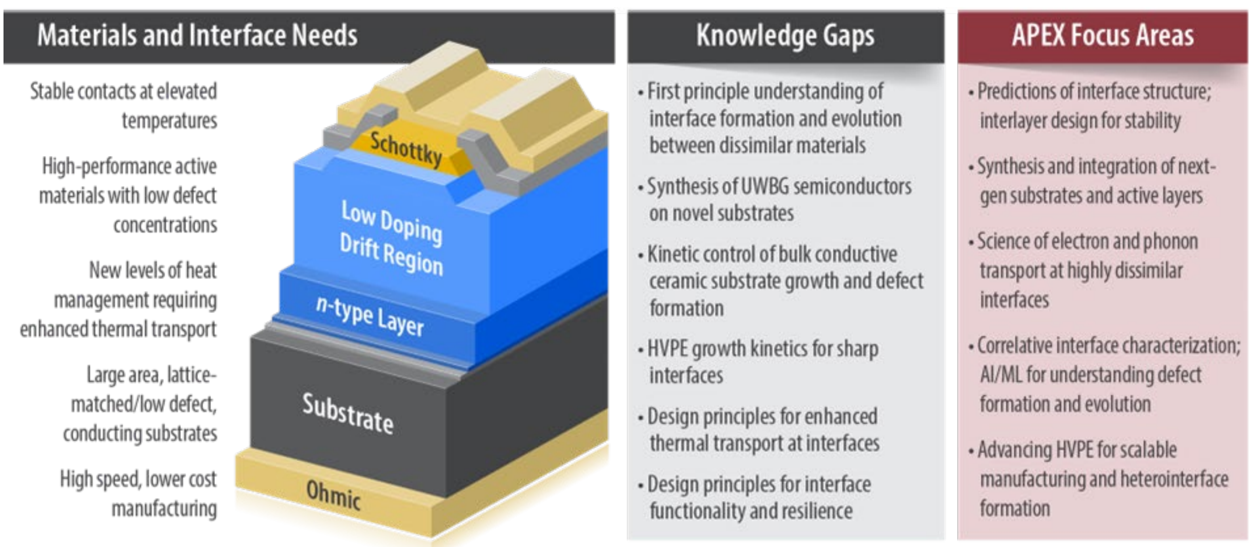
Transformative device design and associated manufacturing of power electronics will be required to fully achieve broad electrification of transportation, industrial process decarbonization, and the development of the "grid of the future." APEX combines theory-driven interface co-design, synthesis, scalable manufacturing techniques, and advanced characterization to address the needs for better thermal management and increased power capacity, while also reducing device size and weight and increasing real-world resilience.



Selection of the best materials for a given function is often limited by the challenges of connecting highly dissimilar materials in stable, reliable, and resilient ways. APEX will expand the range of interdependent materials choices. Our focus will be borides, nitrides, carbides, and/or oxides, which hold potential to advance performance and transform manufacturing approaches for power electronics by enabling the design of smaller devices that can handle more current. These materials include semimetallic borides and metallic carbides, which are ideal partners for advancing AlGaN technology, with favorable lattice and thermal expansion coefficients, as well as novel oxide interfacial layers applicable to Ga_2O_3 and SiC. APEX will conduct basic research in theory-guided interface design for stabilization and thermal conductance, novel substrates, kinetics of hydride vapor phase epitaxy (HVPE) growth, and interface resilience, using a co-design approach to enable demanding combinations of electronic, thermal, and mechanical properties that are required to boost power electronics performance.

The desire to move from lateral to vertical architectures to reduce electrical resistance and manage current crowding issues means that the substrate (whether dictated by growth or by liftoff and integration) will participate in future device operation in a more critical way. Today's "tyranny of the substrate" (constraints related to the synthesis, doping and cost of suitable large, high-quality crystals) limits both the substrate materials available for power electronics and the quality of the active layers grown on them. This research aims to lift those constraints.

The aims of APEX are: (1) develop design rules for broader heterointegration through a co-design approach that includes first-principles theory and experimental studies of formation and design of highly dissimilar interfaces; (2) demonstrate novel growth of conductive bulk single crystal carbide and boride substrates and related innovation in active layer heterogeneous integration, liftoff, and transfer; (3) transform manufacturing via HVPE to achieve both scale and speed, including studying AlGaN growth kinetics, incorporating in-situ diagnostics, and combining HVPE with layer liftoff as a manufacturing pathway; and (4) understand and control interfacial phases, reactions, and evolution to further the science for real-world performance, stability, and resilience, applying multi-modal, multi-scale structural, thermal, and electronic characterization to study interface stability under relevant temperatures and electric fields and using new machine learning/artificial intelligence (ML/AI) tools to increase correlative insight.



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