

Ultra Materials for a Resilient, Smart Electricity Grid (ULTRA)

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Mission Statement: *To understand fundamental phenomena in UWBG materials – including synthesis, defect and impurity incorporation, electronic structure at interfaces, the interaction of electrons and phonons at high fields to achieve extreme electrical properties, and phonon phenomena that affect thermal transport. The Future Grid Co-Design Ecosystem enables communication across all levels of the science and technology.*

A resilient, smart electricity grid is necessary to integrate multiple energy sources, power storage capabilities and diverse electrical needs; ultra-wide bandgap (UWBG) semiconductors have been identified as a crucial enabling materials technology. These UWBG semiconductor and dielectric materials (or ‘Ultra materials’) present a new realm for high field transport, electron-phonon interactions, and heat transport. Understanding these materials and their novel properties will enable efficient energy conversion and control and a great reduction in size where a substation could be replaced by a suitcase sized power converter (Fig. 1).

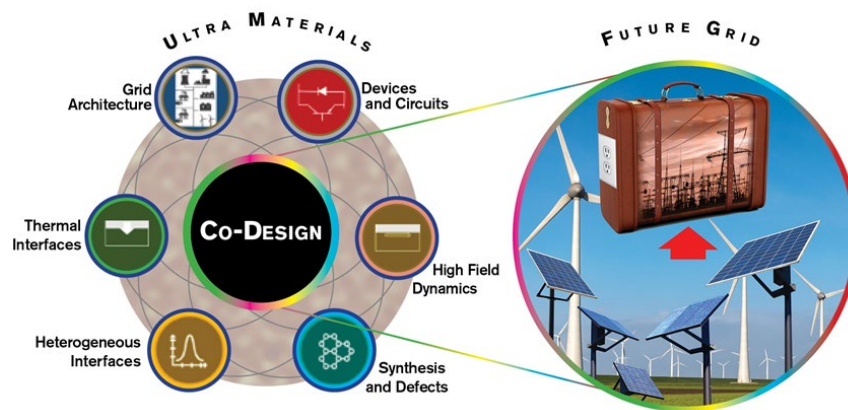


Figure 1. Schematic of ULTRA EFRC Thrusts as part of a Co-design ecosystem that will impact the future electricity grid including the “Substation in a Suitcase” concept.

ULTRA EFRC is focused on basic science challenges in four thrust areas: (1) growth, defects and impurities, (2) heterogeneous interfaces, (3) carrier dynamics and high field transport, (4) thermal energy transport and interfaces. The UWBG semiconductors of interest include cubic diamond, hexagonal AlN and $B_xAl_{1-x}N$ alloys, and oxide, nitride and fluoride materials as dielectrics and alternative semiconductors. ULTRA EFRC established the Future Grid Co-design Ecosystem and has developed a knowledge-base of UWBG materials and properties to “Reinvent the Electricity Grid.” The research will establish a roadmap to achieve a breakdown field greater than 10 MV/cm, current densities greater than 100,000 A/cm², interface-constrained effective heat dissipation > 1 kW/cm², and voltage (current) slew rates of 250 V/ns (100 A/ns). Significantly, ULTRA is providing critical input into design simulation tools for a new generation of high-power devices and power conversion modules and continues to work with grid architect researchers to emphasize the most relevant properties of the UWBG semiconductors as part of the Future Grid Co-design Ecosystem.

The goals of ULTRA EFRC are:

Synthesis, Defects and Impurities: Understand growth chemistry, defect formation and impurity incorporation during scalable synthesis of UWBG materials, substitutional doping and co-doping to span intrinsic to degenerate doping, distributed polarization doping of polar UWBG semiconductors, and *in situ*, real time characterization for machine learning and precision design.

Heterogeneous Interfaces: Efficiently employ different growth systems (MBE, MOCVD, PECVD, ALD) to enable epitaxial UWBG heterostructures, and dielectric heterostructures. Develop interface control to impact band offsets, interface states, polarization design and doping, Fermi level control and charge transfer - modulation doping.

Carrier Dynamics and High Field Transport: Employ designed field control structures for high field carrier transport, breakdown phenomena and electron-phonon interactions at UWBG heterostructures and dielectric interfaces. Consider multi-mode transport for high current including photoexcitation to describe breakdown in UWBG Materials.

Thermal Energy Transport and Interfaces: Understand thermal transport in UWBG materials, the dependence on doping, isotope and composition, and at their interfaces, including effects from phonon dispersion and scattering, electron-phonon interactions and the electrothermal behavior of materials. Determine how interface disorder and interfacial layers affect thermal transport across boundaries.

Future Grid Co-design Ecosystem: Integrate theory, synthesis, fabrication, and characterization in the four research thrusts as a co-design process to rapidly meet the research goals and objectives of ULTRA EFRC. Utilize ULTRA research outcomes to make predictive assessments of their potential impact in power electronics as shown in Fig. 2, and the electric grid network, and identify critical areas for UWBG research.

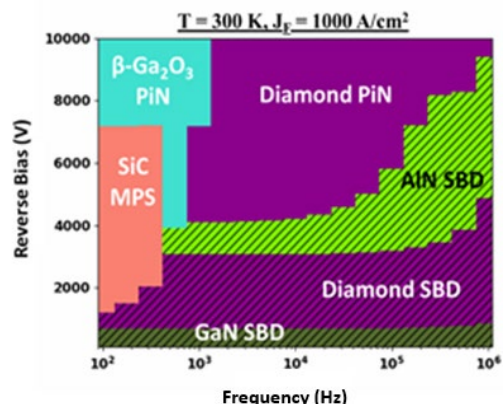


Figure 2. Color map showing a comparison of different material and device technologies based on the lowest power dissipation at a given operating point in terms of reverse bias and frequency for a fixed current density.

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