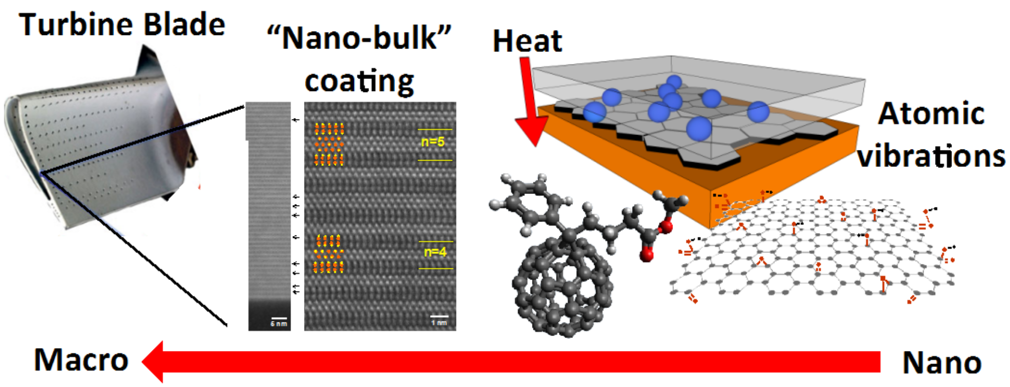

Our research interests encompass both experimental and theoretical efforts focusing on short-pulsed interactions with solids and resulting electron, photon, and phonon interactions in nanosystems, with an emphasis on nanoscale energy transport. The overarching goal of our research group is to study thermal transport processes on the nanoscale, and how they affect performance and reliability on the device scale. Experimentally, our research efforts focus on building diagnostics to measure thermal scattering processes in novel nanosystems centered around femtosecond laser systems. The various experimental efforts that are pursued in our group are used to study photon-electron interactions, electron-Fermi relaxation, electron-phonon coupling, and electron and phonon interactions at the surfaces and boundaries in nanosystems. The experimental work is supported with various theoretical efforts using Boltzmann, Green's function, and perturbation theory-based formalisms to further understand the fundamental interaction mechanisms driving nanoscale thermal transport processes.

Experiments & Simulations in Thermal Engineering Group

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"Developing novel heat transfer diagnostics for nanosystems."

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Thermal transport in nanoscale to bulk materials

Thermal management has assumed a critical role in the design and development of electronic devices, power generation modules, and waste energy harvesting techniques. In these applications, performance depends vitally on the thermal conductivity (κ) of the component material. Yet, while the electrical conductivity in a typical semiconductor system can be tuned via doping, no such analog, in terms of absolute control and precision exists with κ, regardless of mechanisms or material system. However, thermal transport processes on the nanoscale present such a regime in which exciting and unique mechanisms such as boundary scattering, ballistic transport, and wave effects offer potential new degrees of freedom in the thermal engineering of material systems. The ability to precisely control the heat transfer in nanostructures would provide novel thermal solutions for a wide variety of applications on the bulk scale. Our group is investigating mechanisms of both designing and actively controlling the thermal conductivity on the nanoscale in solid and liquids to directly influence the energy transport in bulk materials and processes.

Thermal conductivity of carbon-based organic/inorganic hybrid composites

Novel nanomaterials that incorporate carbon-based nanosystems have the potential to uniquely define the atomic scale chemical interactions via molecular engineering. These atomic forces unique define the frequencies of atomic vibrations and subsequent thermophysical properties. Using a series of nanoscale growth techniques, we are designing composite systems using molecular engineering to intimately control the thermal properties of hybrid systems based on the molecular interactions with the inorganic materials. Our group has studied the manipulation of thermal conductivity in a range of carbon-based composites, and demonstrated through this approach, we can synthesize the world's best, fully dense insulator

Short-pulsed laser interactions with solids and interfaces

Short-pulsed lasers with sub-picosecond pulse duration have found widespread use in research and material processing. Laser energy deposition on femtosecond time scales triggers a cascade of highly nonequilibrium phenomena including generation of athermal, non-Fermi electronic distributions, electron-phonon nonequilibrium, enhanced surface recombination and optical non-linearities, ballistic electron energy transport, thermo-mechanical material response to the fast heating and strong temperature/pressure gradients created in the surface region of the target, as well as structural and phase transformations occurring under conditions of ultrafast heating and high deformation rates. While the conditions of strong electronic, thermal, mechanical, and phase non-equilibrium present a challenge for theoretical and computational description of short-pulse laser materials interactions, they also open up unique opportunities for laser material processing and fabrication under conditions that cannot be achieve by any alternative technique. We are seeking to fully harness the power of short-pulsed lasers by providing an improved understanding of the laser-material interactions.

RECENT RESEARCH DEVELOPMENTS

- Voltage tunable phonon thermal conductivity in ferroelectric materials (Nano Lett. **15**, 1791 (2015))
- Tunable electrical and thermal contact resistance with plasma-based surface modification of graphene (Nano Lett **15**, 4876 (2015))
- Tunable heat capacity and thermal conductivity of organic/inorganic superlattices (Phys. Rev. B **93**, 024201 (2016))
- Cross over from ballistic to diffusive vibrational heat transfer in phosphonic acid monolayers (J. Phys. Chem. C **119**, 20931 (2015))
- Thermoelectric response in metal-organic frameworks (MOF) (Adv. Mat. **27**, 3453 (2015))
- Phonon thermal transport opposing the direction of ballistic electron transport (J. Appl. Phys. **117**, 105105 (2015))

RECENT GRANTS

- DOD/AFOSR – Scattering and Relaxation Mechanisms During High Energy Photo-Excitation of Electronic Materials
- DoD/ONR - Ultrafast sensing of nanoscale thermomechanical energy transfer mechanisms among of various phases of matter
- DoD/DARPA - Nanoscale Engineered Transductional Thermoelectrics
- DoD/MURI - The Science of Entropy Stabilized Ultra-High Temperature Materials
- NSF - Mitigation of Thermal Resistance in High Power Photodiodes as a Means to Increase Device Performance

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