"Upscaling" Nanoscale Thermoelectrics: The Mesoscale Design Challenge for Real-World Energy Needs

Opportunity

Next-generation high-efficiency thermoelectrics (TEs) can solve 'Waste Heat' and 'Heat Management' problems

- E.g., Dramatic impact on energy utilization/security challenges
- E.g., Enabling-technology for microelectronics/solid-state lighting
- Also: radioisotope TE generators for interplanetary/deep-space exploration; rapid-response thermocouples; detector energy control

Materials efficiency driver: TE 'Figure-of-Merit', ZT

- Semiconductor nanowires can be tailored at the nanoscale to achieve optimized ZT ($ZT = S^2\sigma/\kappa$)

Device efficiency driver: High ZT coupled with large ΔT

- Bulk material advantage: 'thick' devices are required

Meso Challenge

How can nanoscale TE functionality be translated across the mesoscale gap to macroscale utility?

- Nanoscale: 1D NW and junction/interface opportunities & challenges
- Mesoscale: Fractional dimensionality of nanomaterial network (1-2D) affords new degrees of complexity/disorder
- Macroscale: Percolation effects in bulk assemblies of nanomaterial networks and matrix integration challenges for maximal ZT/ΔT combinations

How can we best take advantage of the mesoscale opportunity for emergent functionality at the interfaces between nano and meso or meso and macro?

Approach

Establish new methodology for interconnecting and integrating nanomaterial building blocks

- ZT-optimized semiconductor nanowires as fundamental units
- Thermally insulating support matrix
- Hierarchy of controlled complexity by directed assembly
- Macroscale "addressable"

Probe/understand effects of transition from simple nano-structures to complex networks via advanced characterization tools and new theoretical/modeling approaches

- Interplay of S, σ, κ across scales: feedback to materials design

Impact

Path forward for functional integration of optimized TE nanomaterials across mesoscale gap for real-world device performance

- New understanding of effects of junction formation, extreme anisotropies of scale, percolation processes, & matrix integration on ZT parameters – S, σ, κ
- New tools for materials predictive design ranging from nano/meso-scale to macroscopic device-level modeling

Realize TE's potential to impact wide-ranging technological applications in energy (heat) harvesting, utilization and management

- Bridge mesoscale gap to achieve nano-enabled *and optimized* 'bulk' TE devices

Contacts: Jennifer Hollingsworth
Andrei Piryatinski

Los Alamos NATIONAL LABORATORY EST. 1943

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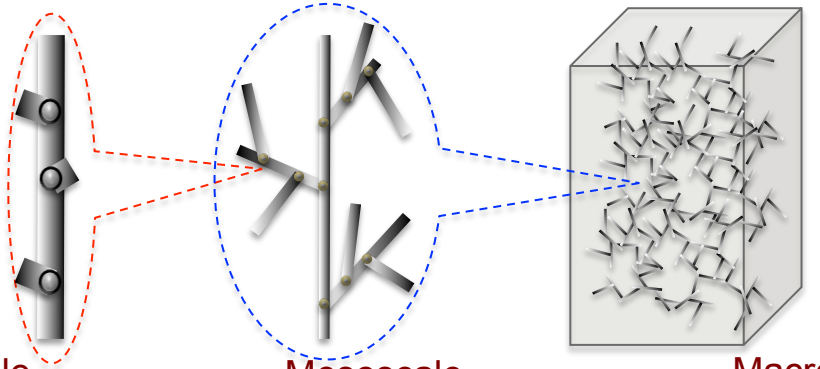
Understanding, Optimizing and Exploiting New Physics of Scale



Nanoscale
1D nanomaterial + junctions/interfaces

Mesoscale
Fractional dimensionality of networked structures (1-2D)

Macroscale
Bulk assemblies of networks/compositing (3D)

Unprecedented opportunity to solve waste heat utilization & thermal management challenges

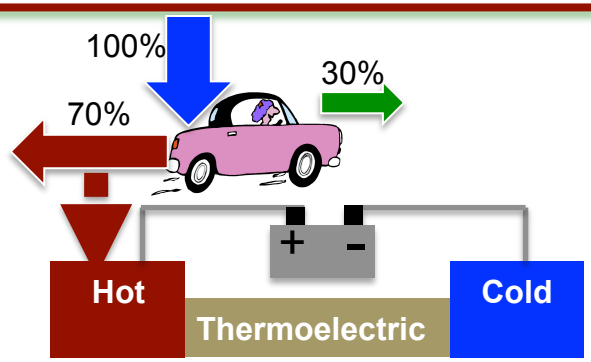


Image: from *How Stuff Works*

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