ENERGY NANOTECHNOLOGY
--- A Few Examples

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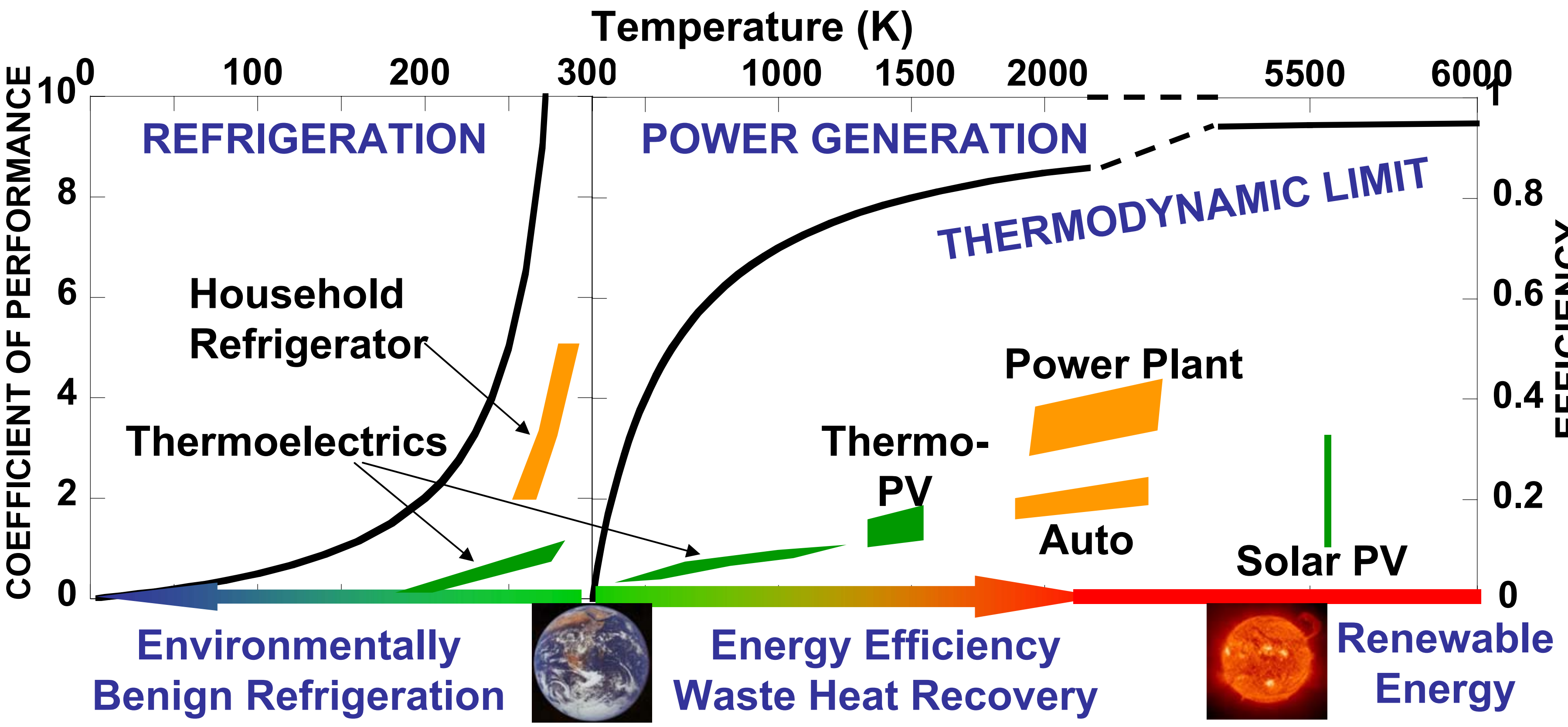
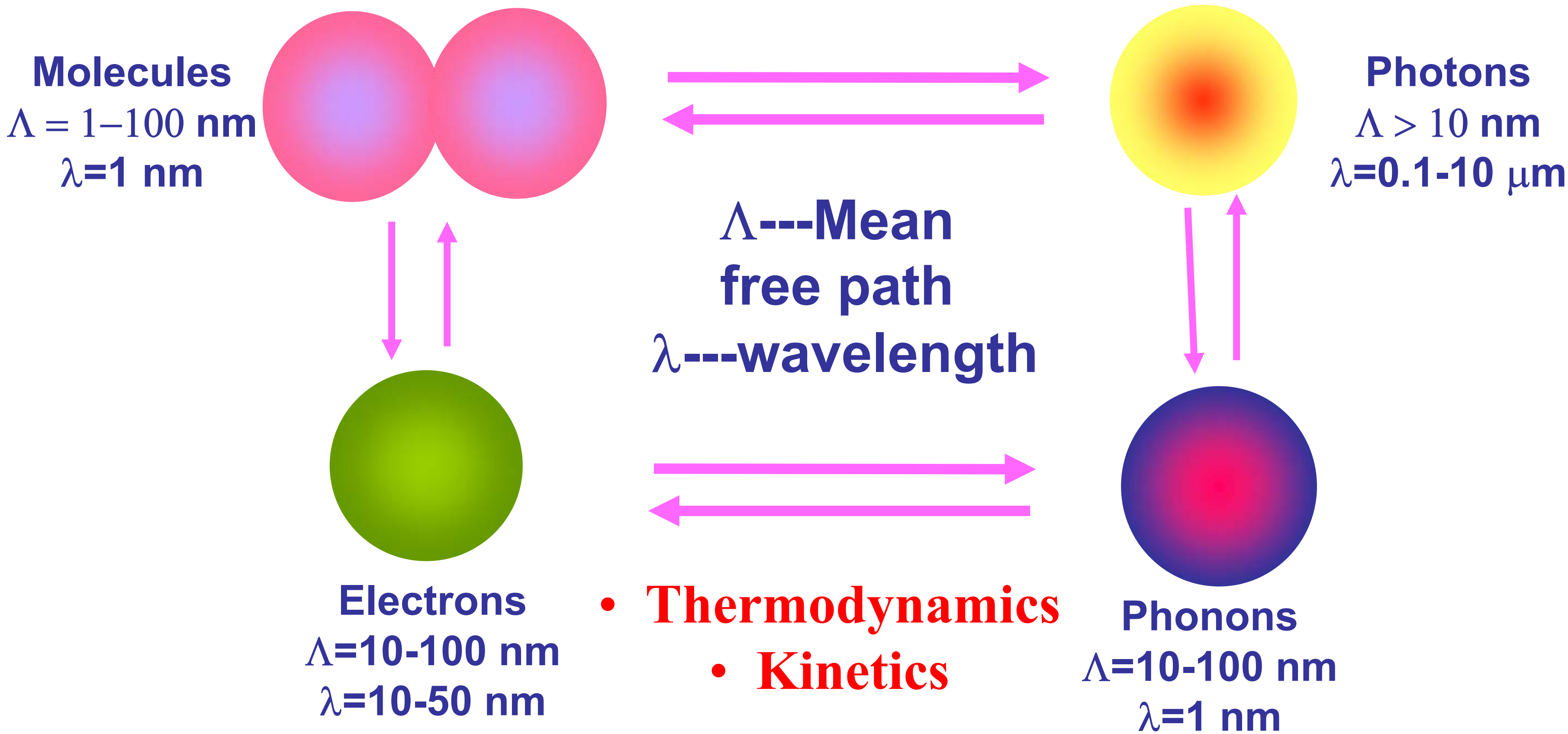
Thermal-Electrical Energy Conversion



Grand Challenges: Efficiency and cost effective mass production

Nano for Energy

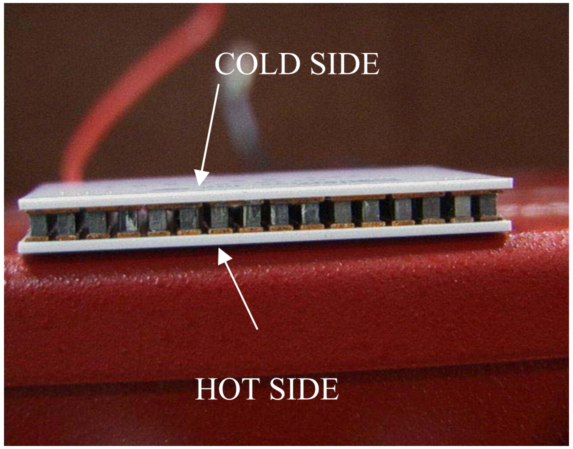
- Increased surface area
- Interface and size effects

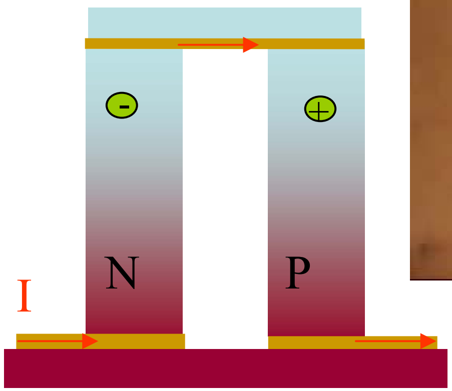


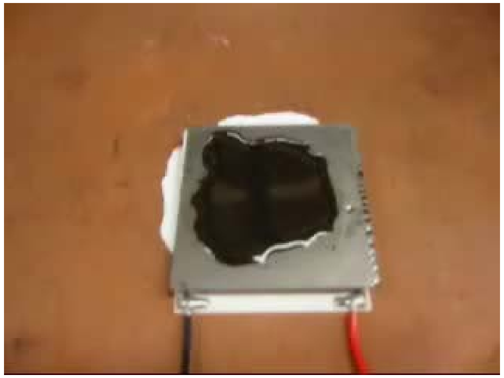
- **Thermodynamics**
- **Kinetics**

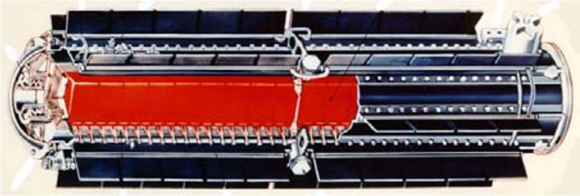
Phonon and Electron Engineering for Thermoelectric Materials

Thermoelectric Devices









GPHS Radioisotope Thermoelectric Generator

Nondimensional Figure of Merit

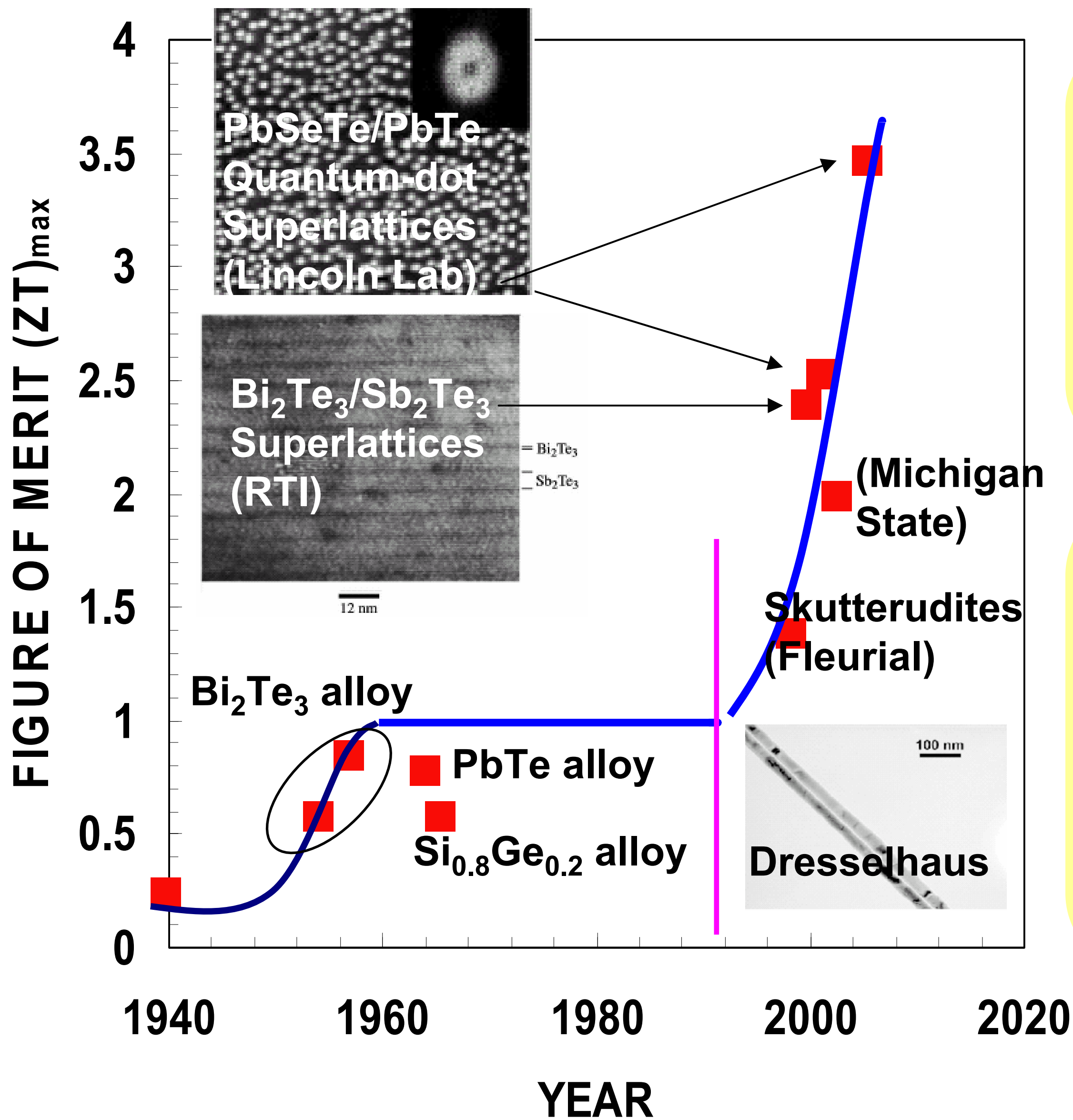
Joule Heating → σ

Seebeck Coeff. Electron Cooling → S

$$ZT = \frac{\sigma S^2 T}{k}$$

Reverse Heat Leakage Through Heat Conduction → k

State-of-the-Art in Thermoelectrics



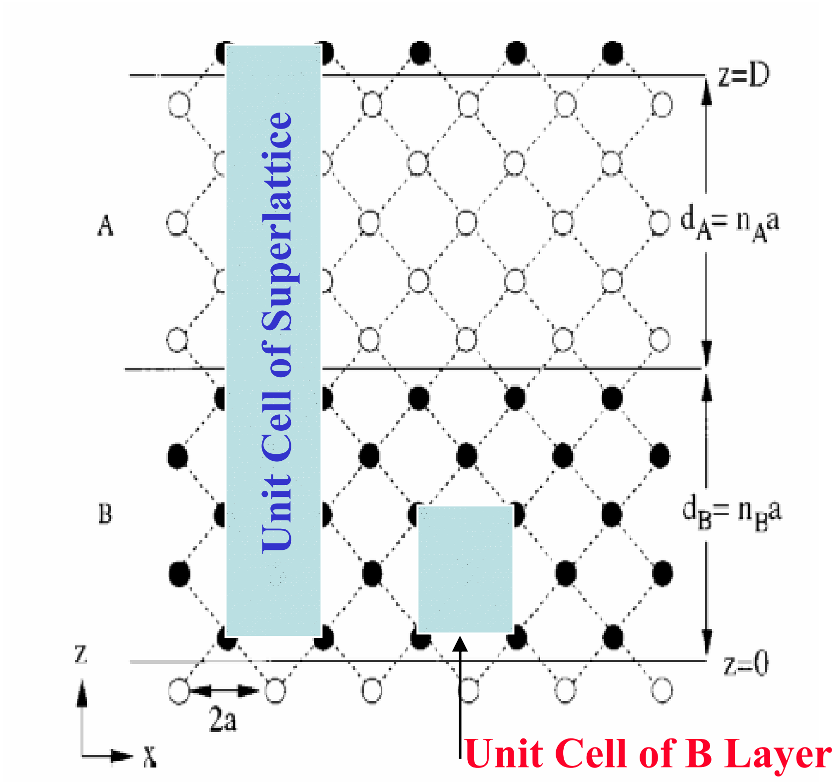
PbTe/PbSeTe	Nano	Bulk
$S^2\sigma$ ($\mu W/cmK^2$)	32	28
k (W/mK)	0.6	2.5
ZT (T=300K)	1.6	0.3

Harman et al., Science, 2003

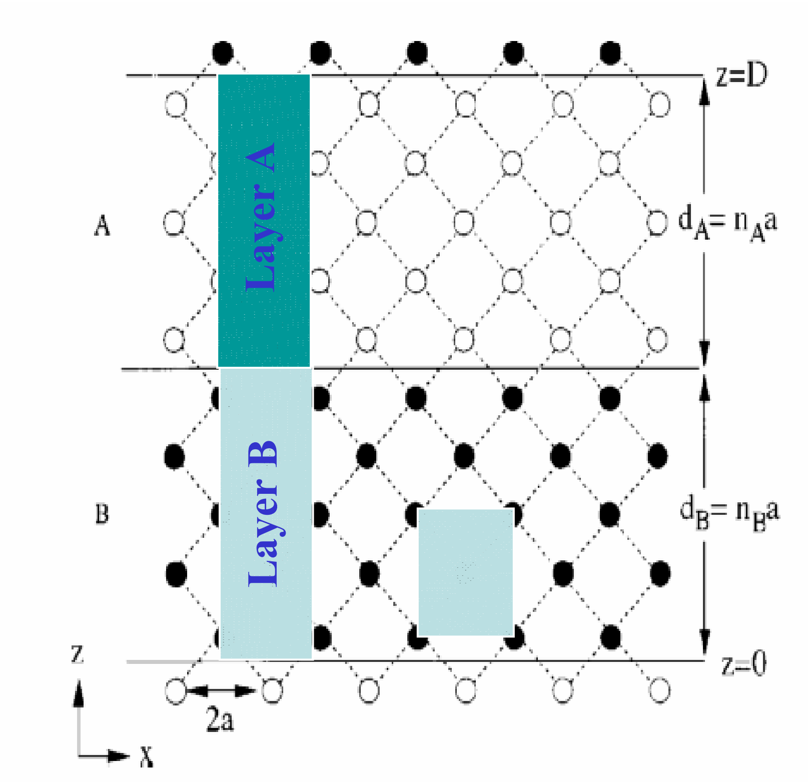
Bi_2Te_3/Sb_2Te_3	Nano	Bulk
$S^2\sigma$ ($\mu W/cmK^2$)	40	50.9
k (W/mK)	0.6	1.45
ZT (T=300K)	2.4	1.0

Venkatasubramanian et al., Nature, 2002.

Heat Conduction Mechanisms

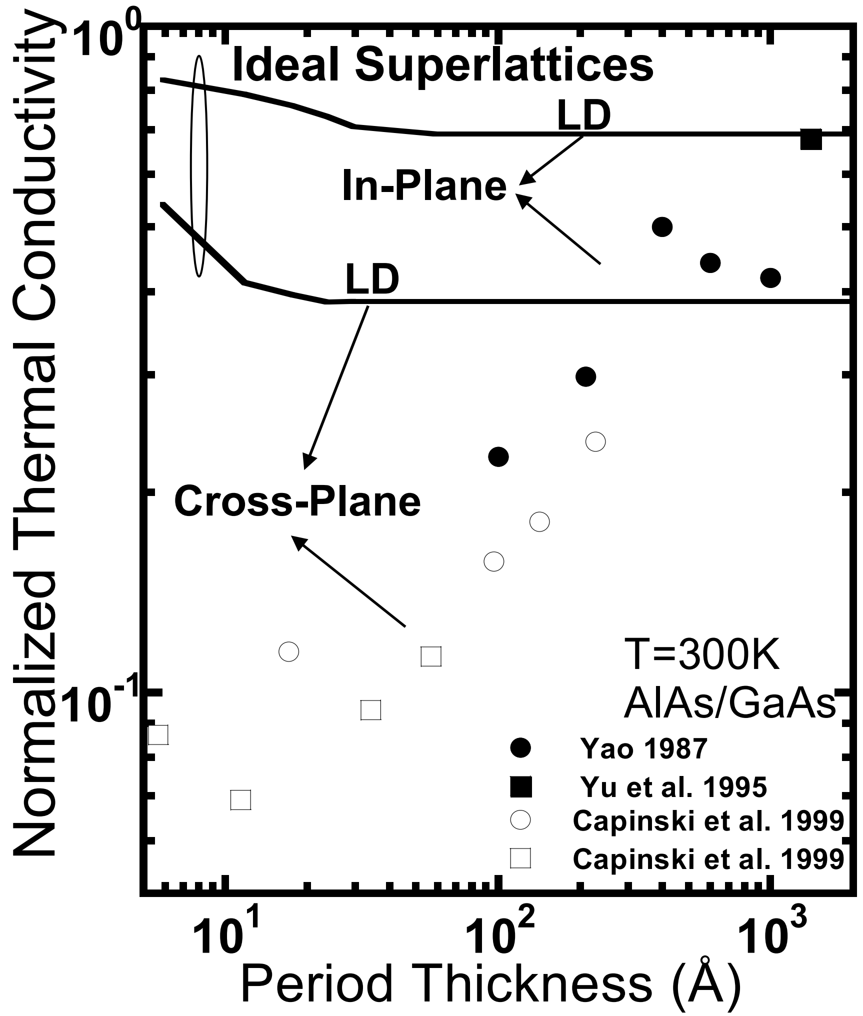


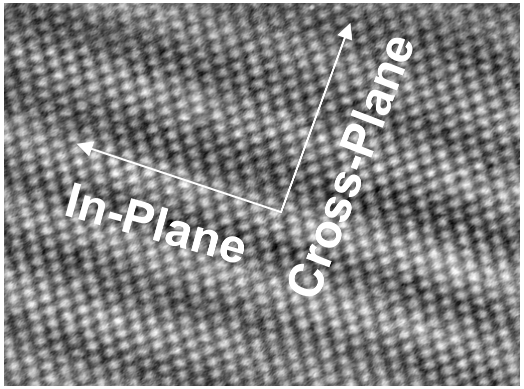
A New Crystal?



Inhomogeneous Multilayers?

Heat Conduction Mechanisms in Superlattices





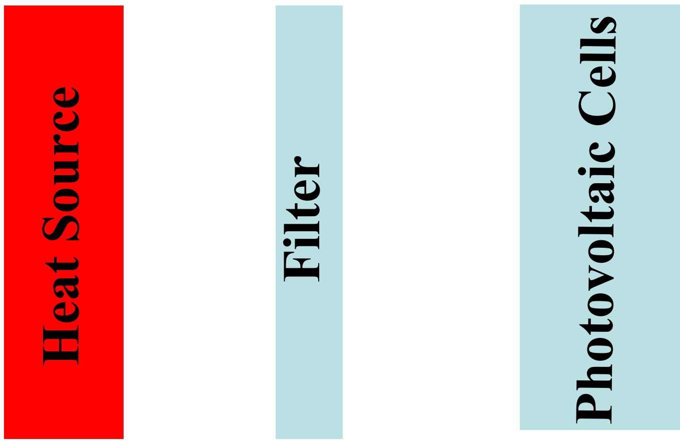
Major Conclusions:

- Ideal superlattices do not cut off all phonons due to pass-bands
- Individual interface reflection is more effective
- Diffuse phonon interface scattering is crucial

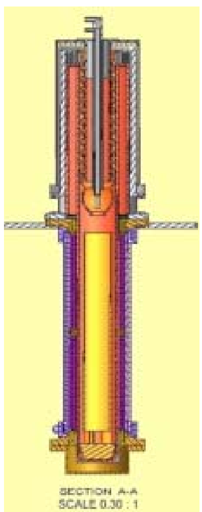
Coherent Structures Are Not Necessary, Nor Optimal!

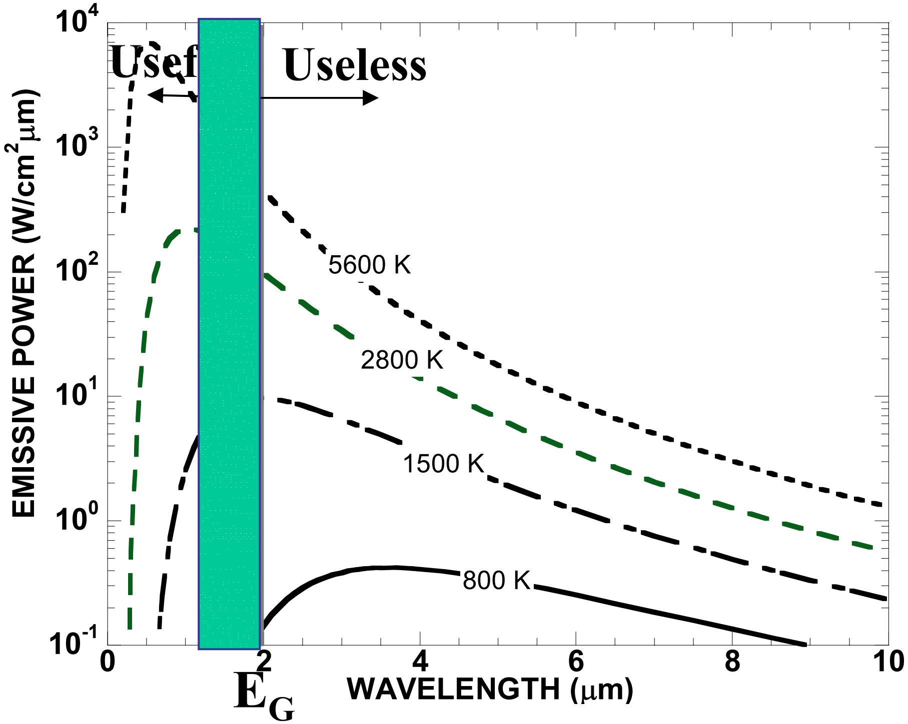
Photon Engineering: Thermophovoltaics

Thermophotovoltaics



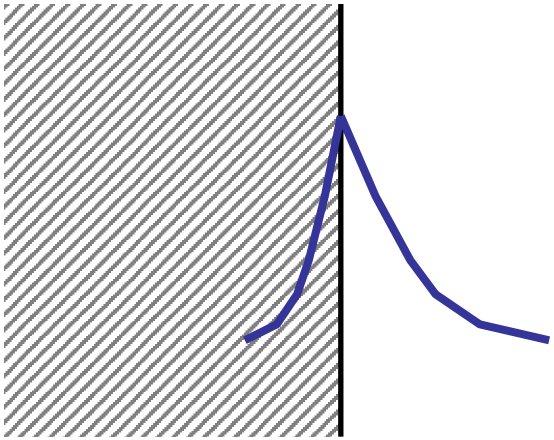
Midnight Sun® Stove
100 W of electricity
25,000 BTU/hour of heat

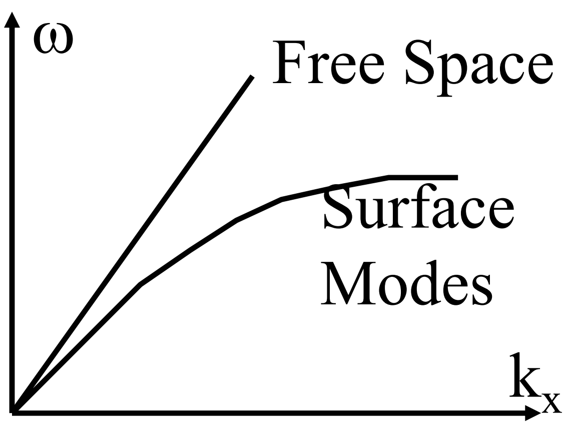


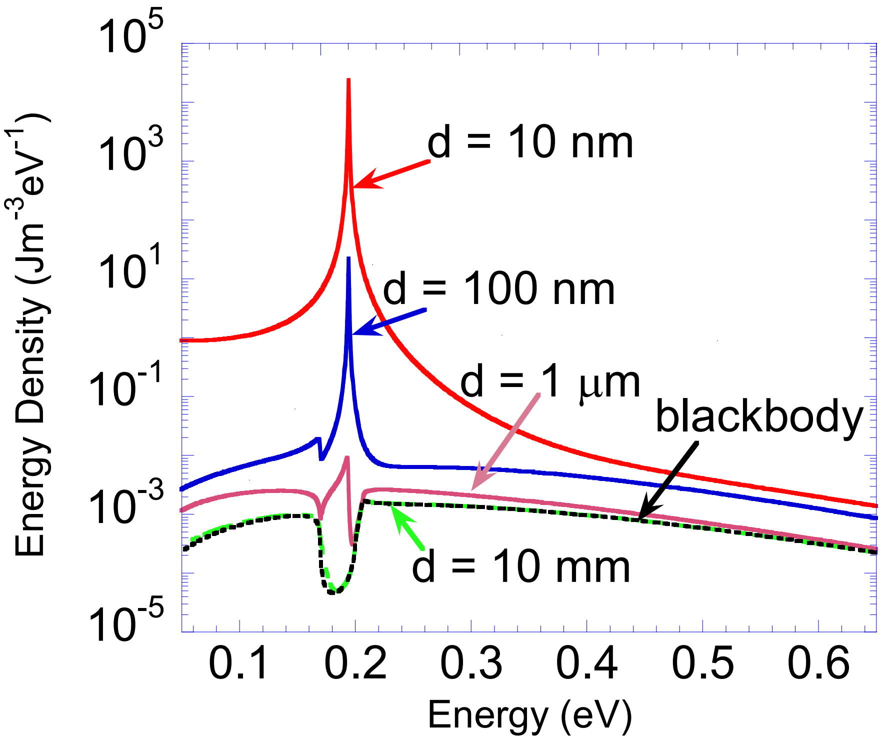


- Frequency Selective Emitter
- Frequency Selective Filters
- Photon Recycling Structures
- Evanescent Wave Structures
- High Efficiency PV Cells

Surface Waves and Near Surface Energy Density





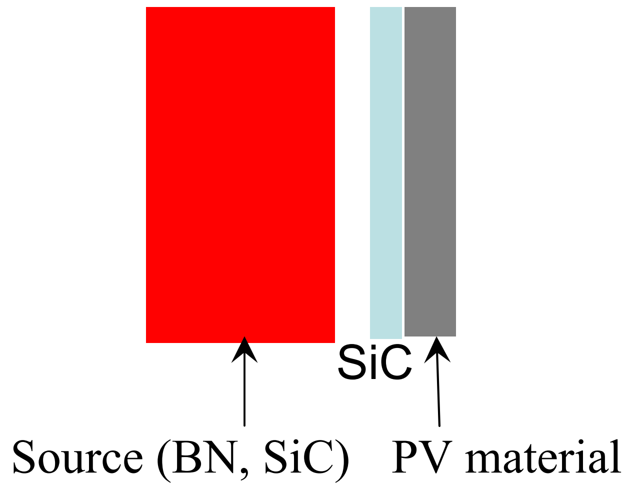


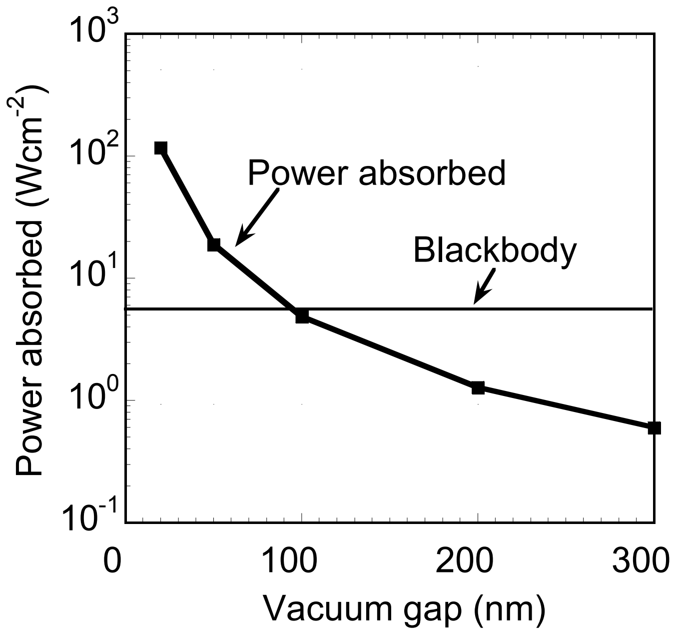
Energy density in the vicinity of a half-plane of BN.

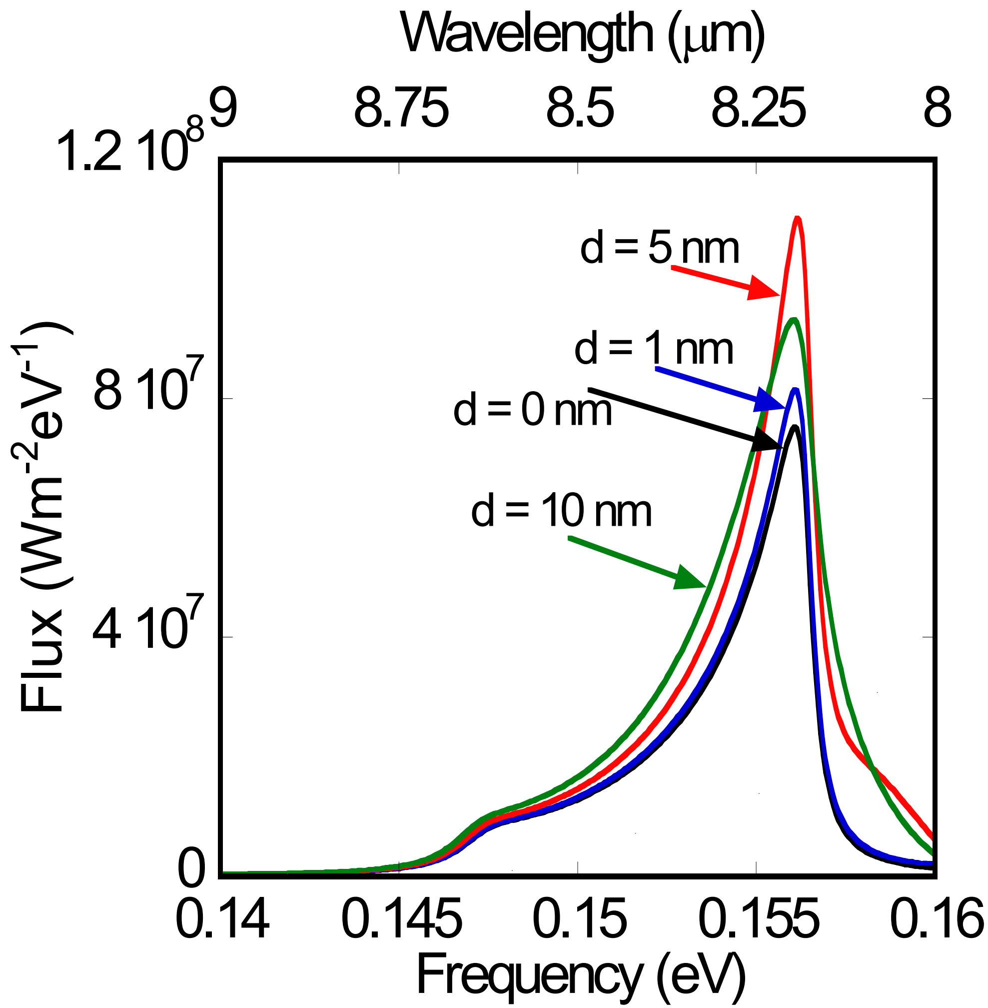
High Energy Density, Monochromatic EM Fields Exists Near Surfaces When ε is Equal but of Opposite Signs. But They Are Non-Emitting!

Surface Plasmons and Surface Phonon Polaritons

Near Field Energy Conversion



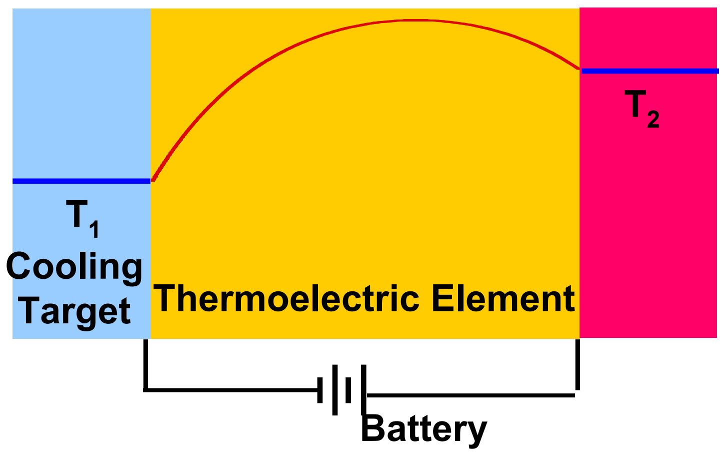




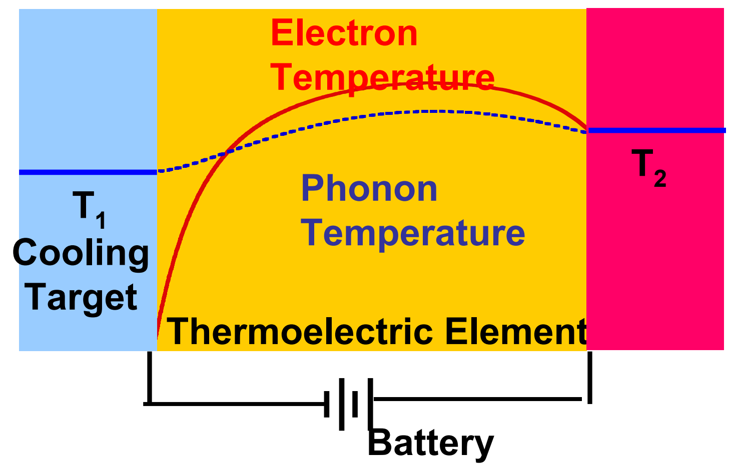
Coupled Conduction and Radiation Nonequilibrium Thermoelectric Devices

Nonequilibrium Transport

Conventional TE Cooler



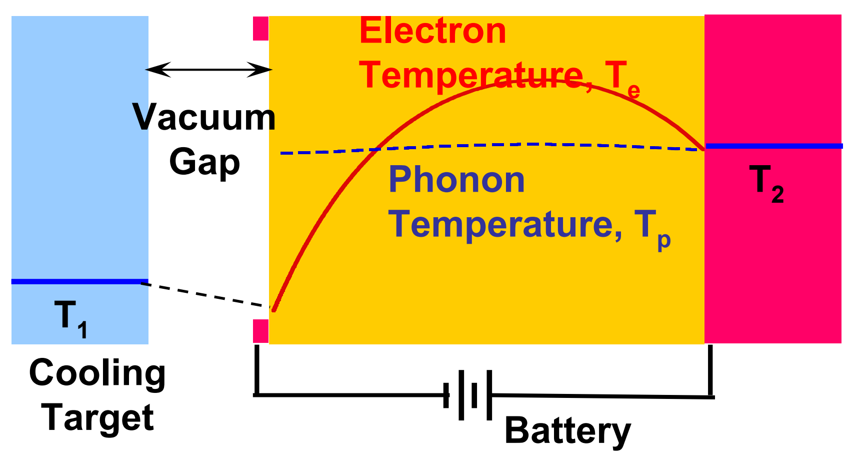
Conventional Micro TE Cooler



Proposed Nonequilibrium Thermoelectric Devices

- Explore nonequilibrium between electrons and phonons
- couple the cooling target with thermoelectric element without direct lattice contact

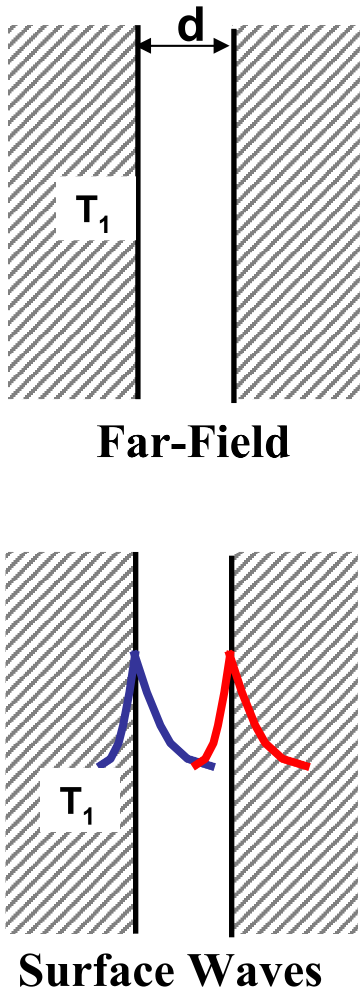
$$ZT = \frac{\sigma S^2 T}{k_e + k_p}$$



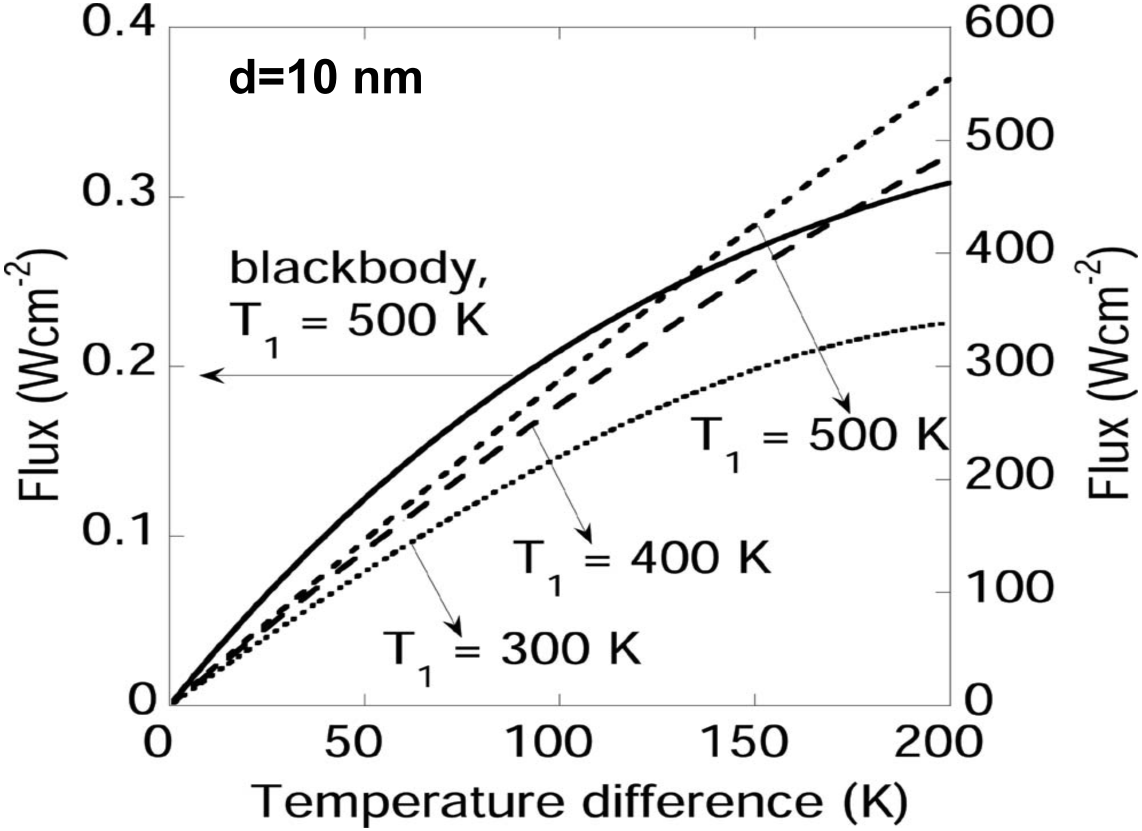
Surface Plasmon Coupling of Electrons

Macroscale gap

Nanoscale gap

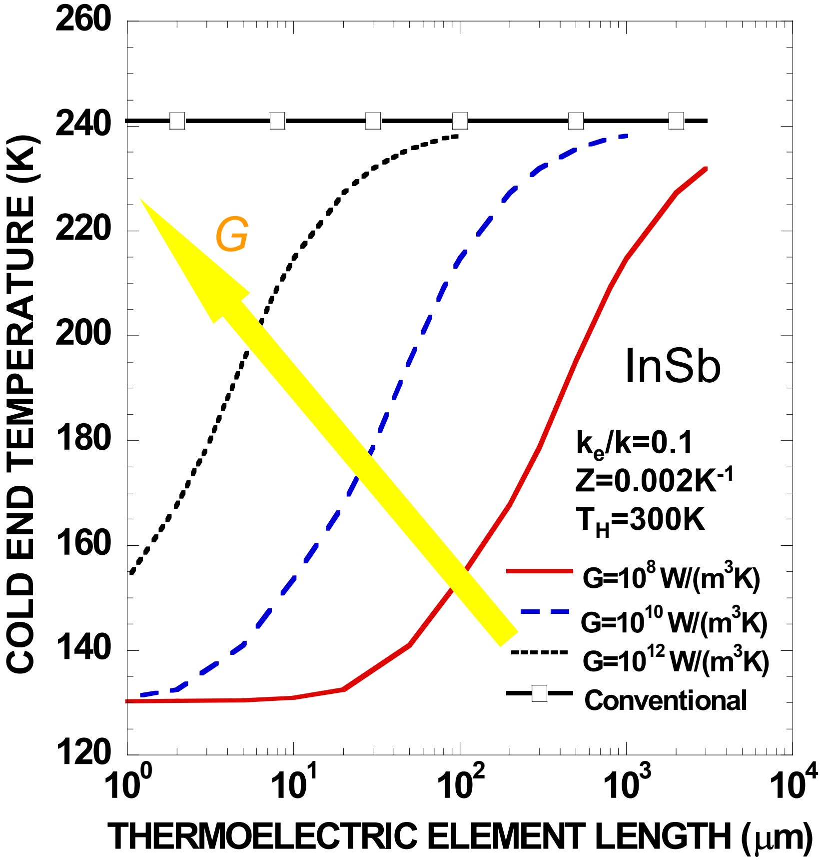


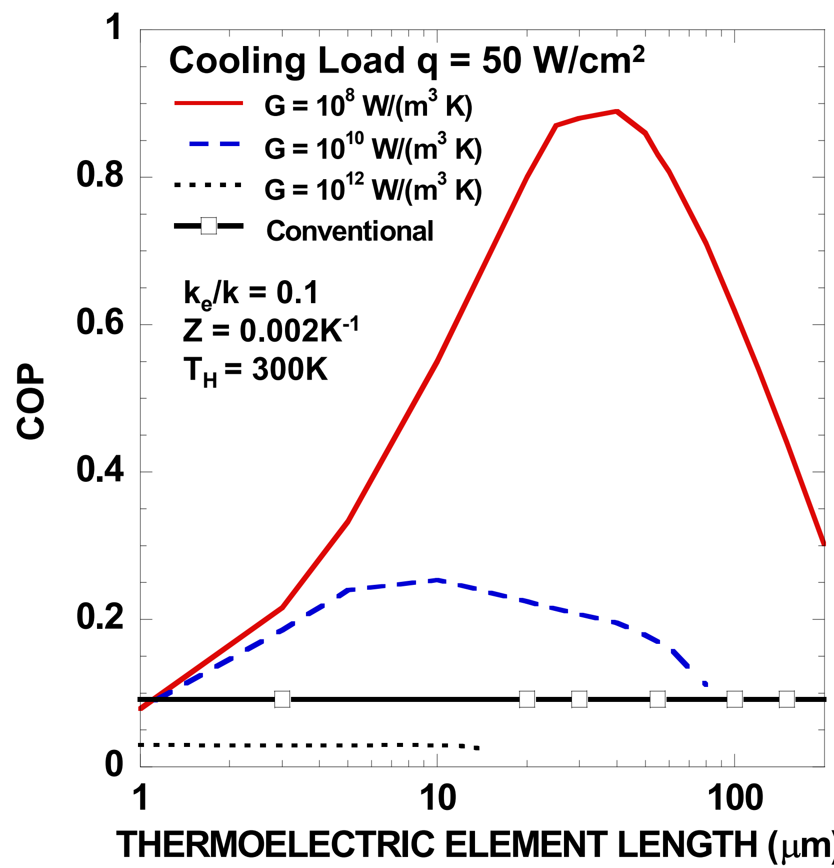
Model Based on Fluctuation-Dissipation Theorem



Three orders of magnitude increase in energy transfer flux due to surface plasmon resonance

Surface-Plasmon Enabled Nonequilibrium Thermoelectric Refrigerators





- Performance is determined by the doping concentration and operation temperature.
- Principle works for both refrigerators and power generators.

Key Points

- Nanoscale effects are enabling breakthroughs in energy technologies.
- Need cost-effective and mass producible nanotechnology for energy applications.
- Fundamental understanding leads to new manufacturing paradigms.
- Fundamental research problems exist in both individual nanostructures and mesoscopic nanostructures.
- Multidisciplinary research and interdisciplinary researchers are needed.

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- **Current Members**

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Z. Chen (Metamaterials, TPV)
S. Goh (polymers)
T. Harris (Thermoelectrics&Nanomaterials)
Q. Hao (Thermoelectrics)
D. Kramer (Solar thermoelectrics)
H. Lee (Thermoelectric Materials)
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A. Narayanaswamy (Metamaterials, TPV)
G. Radtke (hydrogen storage)
A. Schmidt (ps pump-and-probe)
E. Skow (polymers)
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Dr. X. Chen (thermoelectrics, Pump-and-Probe)
Dr. D. Vashee (thermoelectrics)
Prof. Y.T. Kang (nanofluids)

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J. Joannopoulos (MIT, Photonic Crystals)
Z.F. Ren (BC, Thermoelectric Materials, CNT)
X. Zhang (Berkeley, Metamaterials)

- **Past Members (Partial List)**

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Prof. T. Zeng (Thermionics, NCSU)

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