DoD Interests in High Efficiency Thermoelectrics

Presented at the

DOE/EPRI Thermoelectrics Workshop

by

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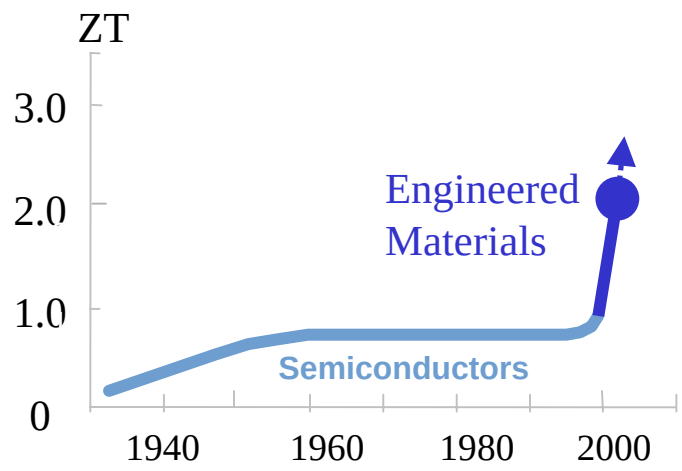
DoD Thermoelectrics Initiative
(1992-2002)

OBJECTIVES:

Develop and demonstrate new and innovative approaches leading to vastly improved thermoelectric materials for cooling applications



ACCOMPLISHMENTS:

- New approaches to the engineering of thermoelectric materials were investigated and significant breakthrough concepts identified.
- Joint DARPA /Navy/Army initiative has recorded ZT gains over the broad temperature range from 100 - 850 K.

ARMY RELEVANCE:

- Cryogenic Coolers for Night Vision
- Cooling of Microelectronics
- Refrigeration / Air Conditioning
- Low-Power Generation

DoD Thermoelectric Program

1992: ARO and ONR Independently Start Funding MIT-Lincoln Labs to Investigate Bandgap Engineering of BiSb (T. Harman)

ONR Funding of Skutterudite Studies at JPL (J.P. Fleurial)

1993: Theoretical Prediction of Enhanced Thermoelectric Properties via Quantum Enhancement Effects in Superlattice Systems (MIT-M. Dresselhaus)

1995-6: Preliminary Experimental Confirmation of Enhanced Thermoelectric Effects in both Superlattice (MIT-LL) and Skutterudite Systems (JPL)

1997: DARPA (S. Wolf) Initiative in Thermoelectics Launched

ONR Funded MURI Center in Quantum Structure for Thermoelectric Applications was initiated at UCLA (G. Chen)

1999-2000: Efficacy of Quantum-dot (MIT-LL) and Cross-plane Superlattice (R. Venkatasubramanian at RTI) Approaches Demonstrated

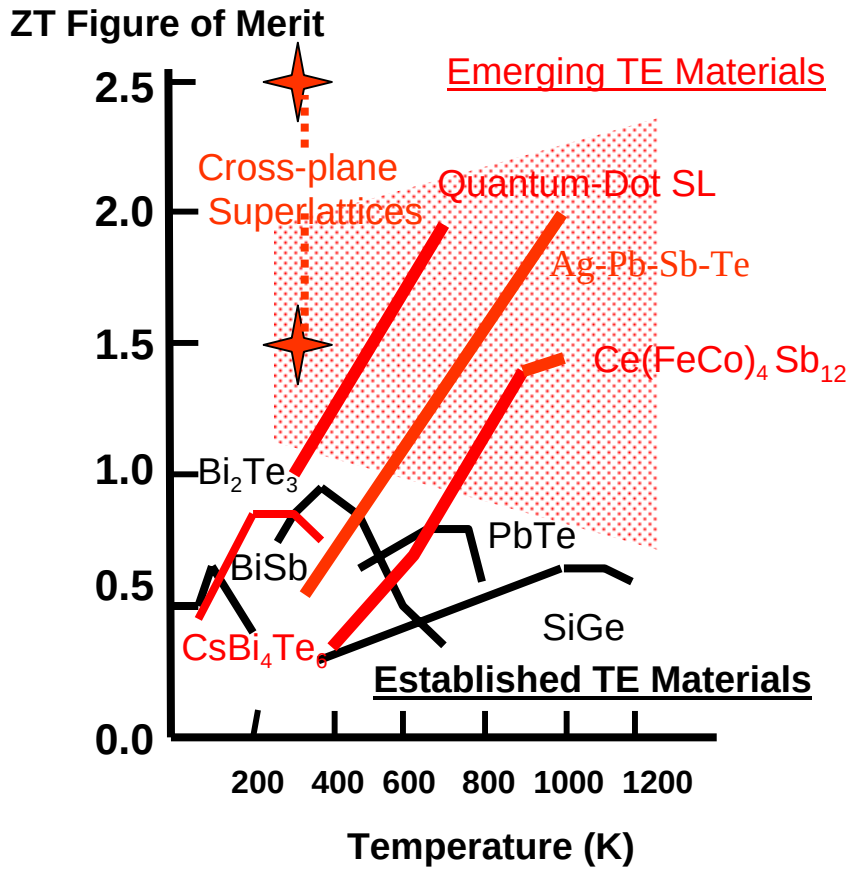
Paradigm-Shifting Concepts for TE Materials

1) Bandgap Engineering of Electrical Properties

- Band Engineering in low-D Systems
- Quantum Confinement Effects on Density of States
- Energy Filtering at Band Offsets
- Mobility Enhancement via Modulation Doping

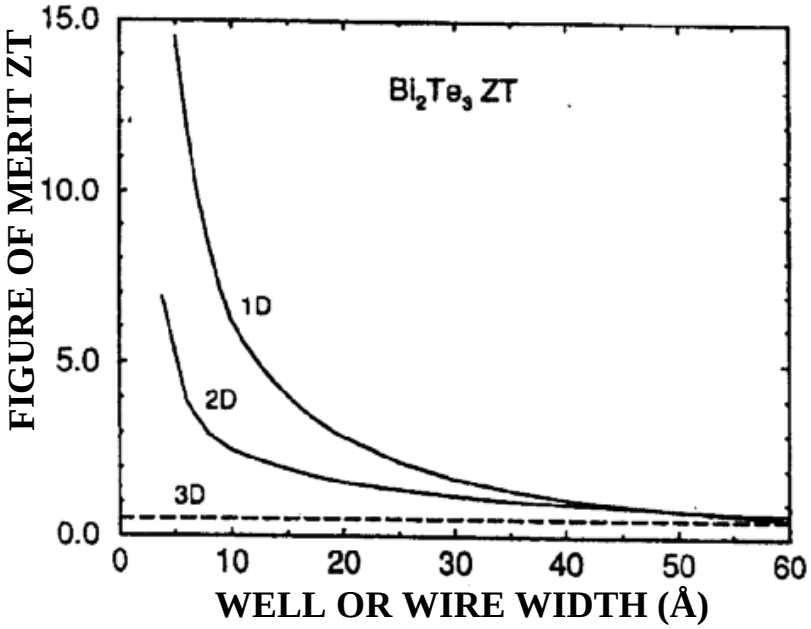
2) Phonon Engineering

- Phonon Rattlers in Bulk Systems
- Interface Scattering in Superlattices



Note: Most of these concepts have yet to be implemented in a bulk material!

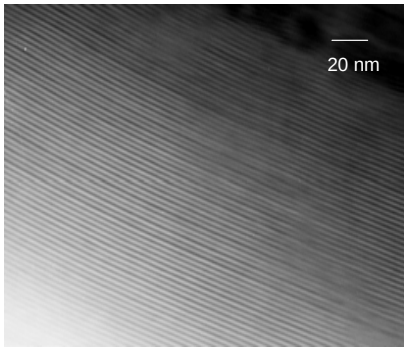
Prediction of Quantum Confinement Effects in Low-D Systems



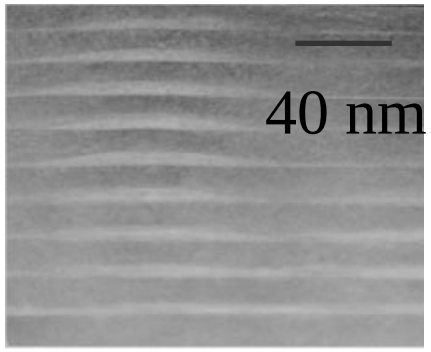
Note: Conduction is assumed to be along the extended dimension

2D, 3D: Hicks and Dresselhaus, Phys. Rev. B47 (1993), p. 12727-31

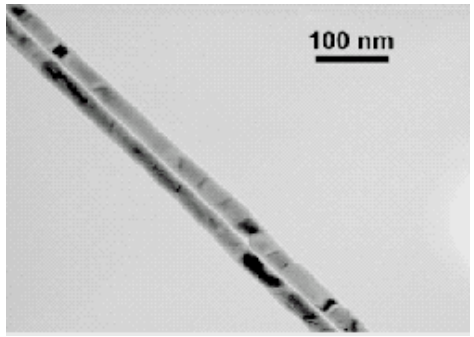
1D: Hicks and Dresselhaus, Phys. Rev. B47 (1993), p. 16631-34



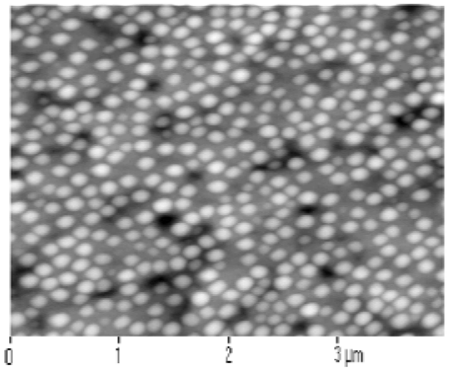
Bulk



Superlattice
2D



Nanowire
1D



Quantum Dots
0D

Bulk Thermoelectrics Challenge

Bulk Crystal Crowth:

Solid State Chemistry – Mercouri Kanatzidas at Michigan State University

Nanoparticle Synthesis and Consolidation:

Synthesis and Self-Assembly of Nanoparticles - C. O'Connor at U New Orleans and C. Murray at IBM Watson RC

Nanowire Composites Prepared by High Pressure Injection into Porous Dielectrics – T. Huber (Howard Univ) ; M. Dresselhaus (MIT)

** Solicitation on Nanostructured Thermoelectric Composites (Proposals due 4-15-04)

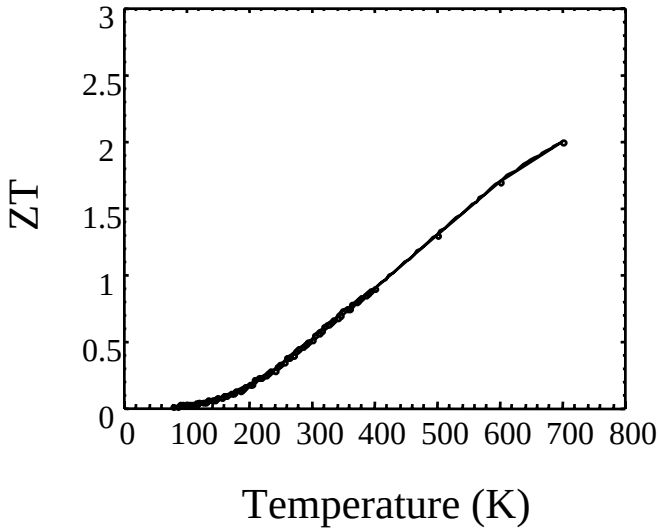
See: FY04 Small Business Technology Transfer (STTR), Army Topic A04-T007
http://www.dodsbir.net

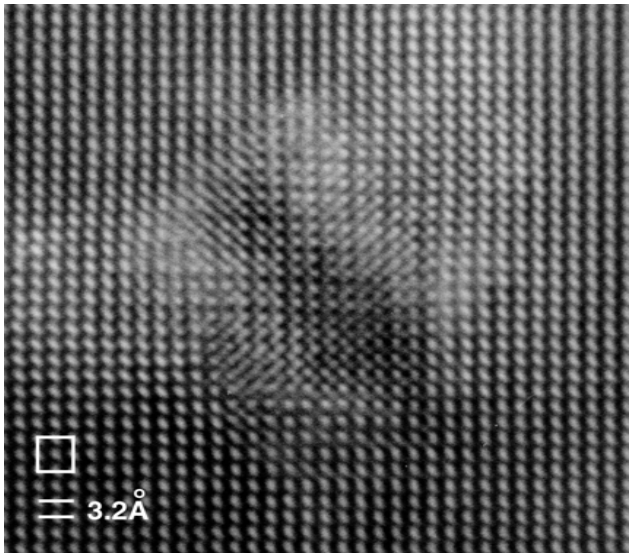
ONR/DARPA Thermoelectrics MURI (FY03-08)

Mercouri Kanatzidas, Michigan State Univ.

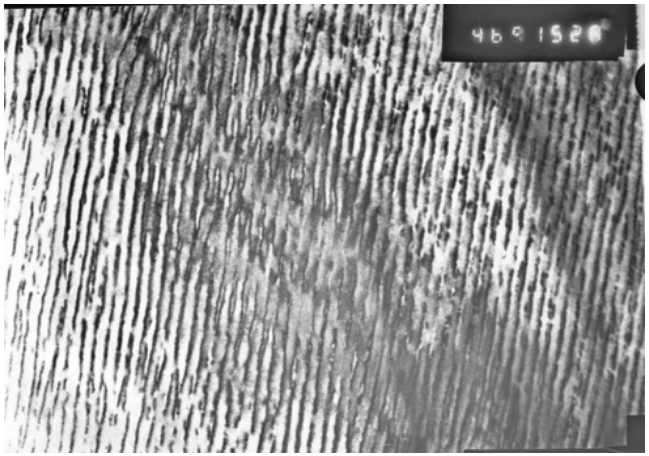
$Pb_lAg_mSb_nTe_{l+m+n}$ System

Promising new materials for power generation
High Power Factors between 300-~800 K
Segregation at the nanoscale?





AgSb-rich Nanodot in $AgPb_{18}SbTe_{20}$



Composition modulations in $AgPb_{10}SbTe_{12}$

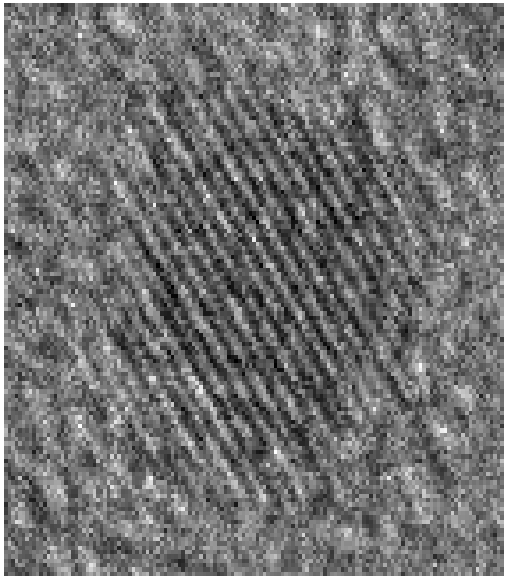
Nanophase Materials for Thermoelectric Applications

C. O'Connor at U New Orleans and C. Murray at IBM Watson RC

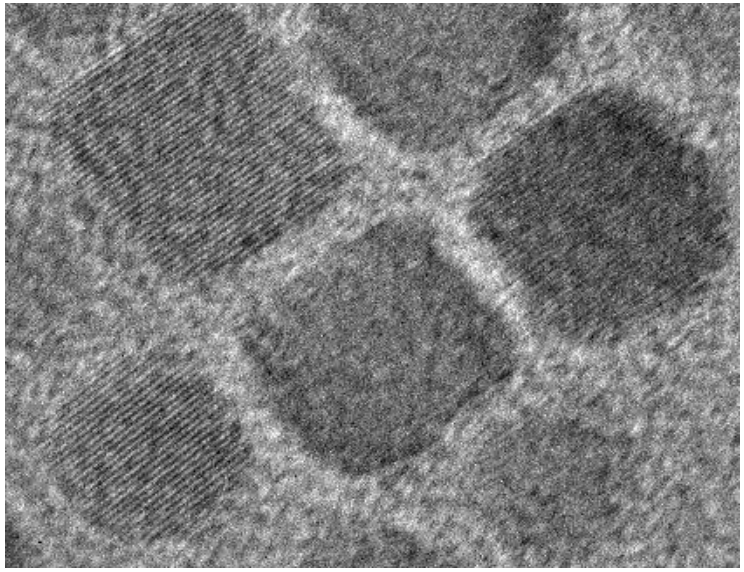
OBJECTIVE: Investigate synthesis and self assembly of nanoparticles for thermoelectric applications

ACCOMPLISHMENT: Synthesized PbSe and Bi nanoparticles (1-30 nm) by various liquid phase chemical techniques. Post synthesis size selection techniques result in nearly monodisperse distributions of particle sizes, which results in well ordered arrays of self assembled dots

HIGH RESOLUTION TEM IMAGES OF PbSe NANOPARTICLES



single 4 nm particle



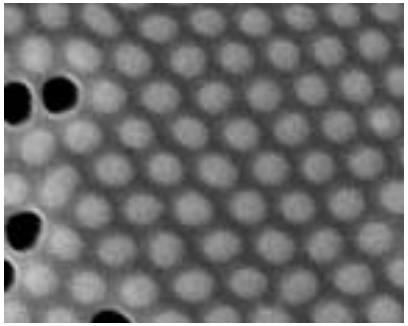
8 nm spherical particle and 12 nm cubic particles

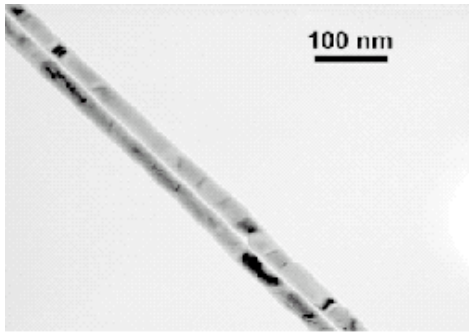
Nanowires

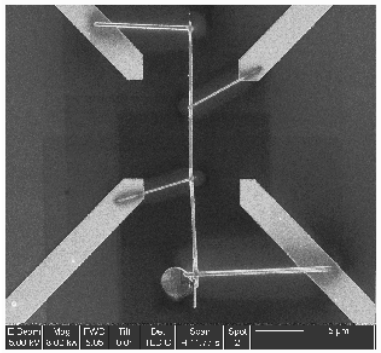
T. Huber at Howard Univ; M. Dresselhaus at MIT

Objective: Investigate Thermoelectric Properties of Nanowire Composites Prepared by High Pressure Injection into Porous Dielectrics

Results: High pressure injection of molten Te, Bi and BiPb into the cylindrical channels (20-200nm) of anodized aluminum (porous Al2O3) has produced densely packed, highly oriented, crystalline nanowire composites. However, preliminary ZT values have been disappointing, apparently due to nanowire oxidation.







Army Applications for Thermoelectrics

Cooling of Electronics a & Optics

- Microelectronics / Communications
- IR Detectors for Night Vision (Cryogenic Cooling & Temperature Stabilization)
- Temperature Stabilization of Optics
- Cryogenic Electronics (e.g. Quantum Computing)

Soldier Body Cooling

- Tank & Helicopter Crews
- Protective / Survival Suits

Refrigeration & Air Conditioning

- Medical Supplies

Power Generation from Waste Heat (Vehicles / Shelters / Kitchens)

- Remote Power
- Battery Recharging
- Blowers for Heating Units

Chameleon IR Surfaces

Acknowledgements

- DARPA (Dr. Stu Wolf and Dr.Valerie Browning)
- ONR (Dr. John Pazik, Dr. Mihal Gross)
- Dr. Ted Harman (MIT Lincoln Labs)
- Dr. Rama Venkatasubramanian (RTI)
- Dr. Gang Chen (MIT)
- Dr. Jean-Pierre Fleurial and Dr. Terry Caillat (JPL)
- Mercouri Kanatzidas (Michigan State Univ.)

SUMMARY

- Significant increase in thermoelectric figure-of-merit has been reported in recent years, in thin films and some bulk materials.
- New insights have been gained on thermoelectric behavior using a combination of theory and experimental data.
- With recent demonstration of high ZT materials the potential exists for realizing systems with efficiency of 20%. However, continued material development, particularly of bulk materials, will be required to actually translate these into practice.
- Commercial impact of improved thermoelectrics could be great