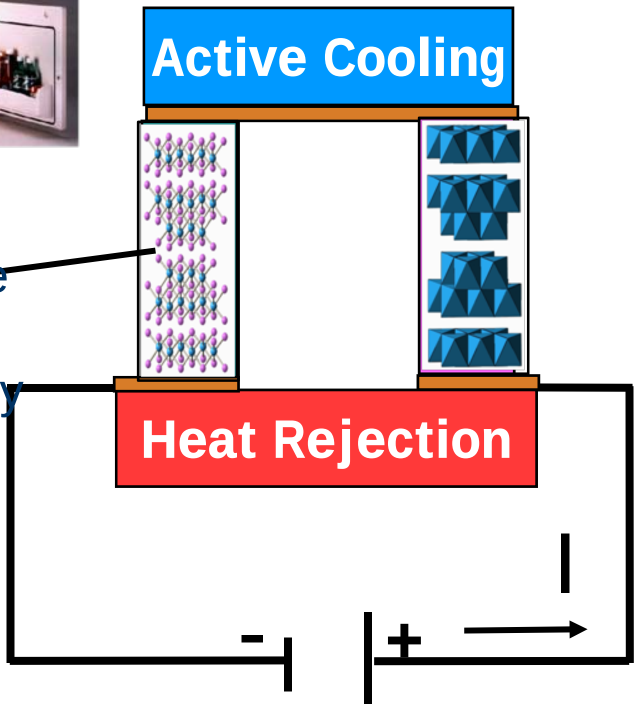
Class 12: Thermoelectrics

Peltier Effect

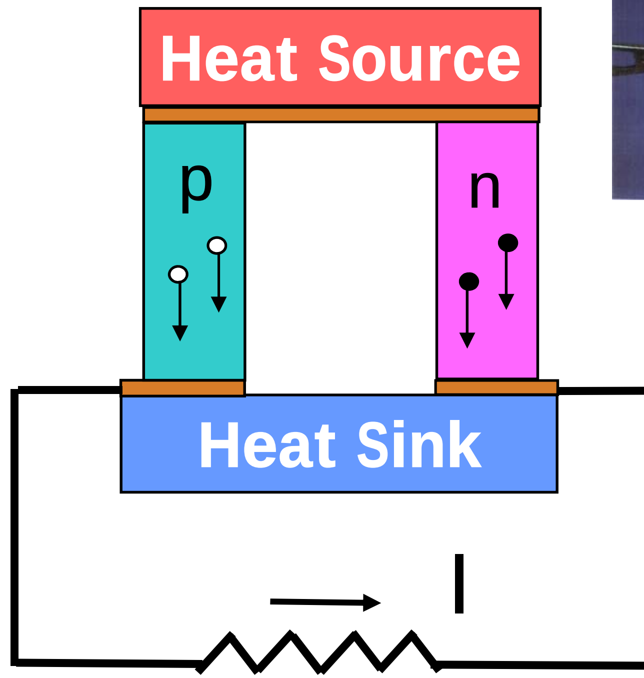


Solid State materials are the key

Refrigeration Mode

"Refrigeration without moving parts and chemical refrigerant"

Seebeck Effect



Power Generation Mode

"Electricity from waste-heat"

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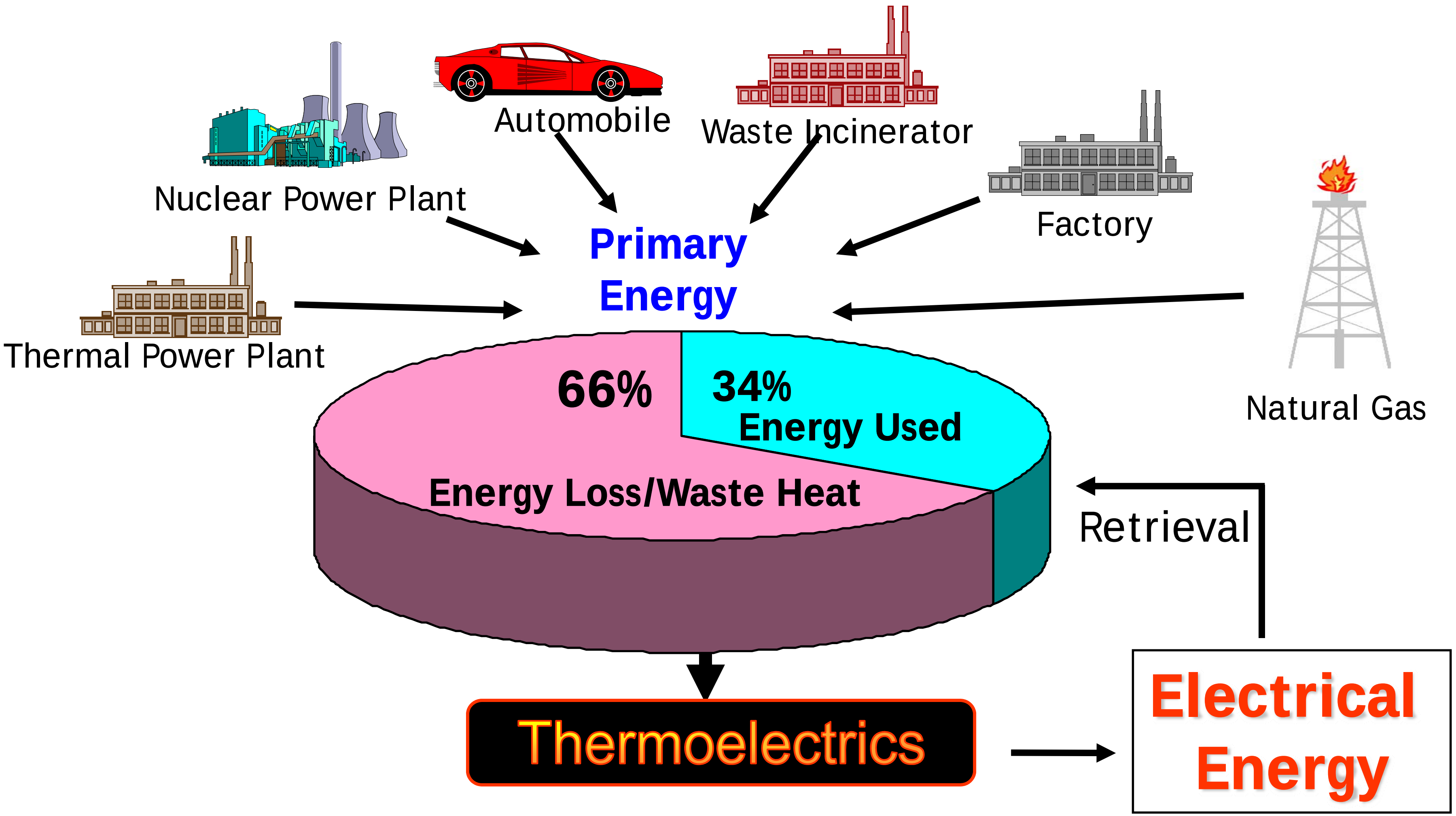

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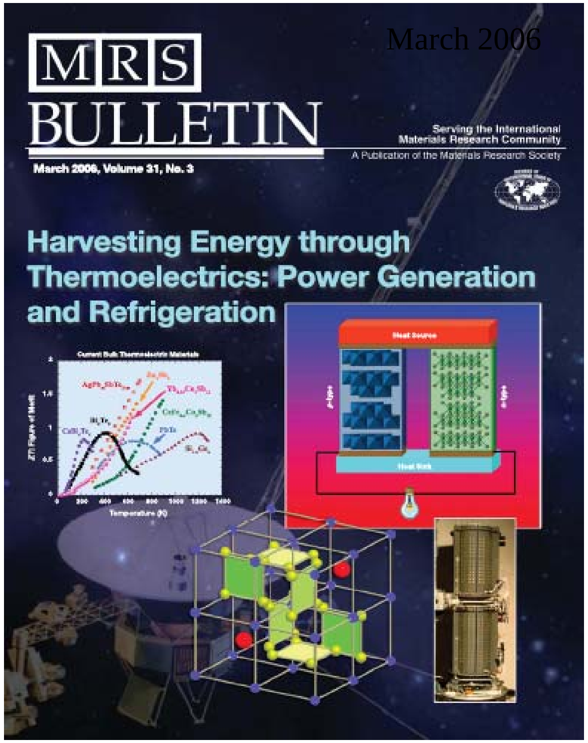
March 2006



Guest Editors:
Tritt and Subramanian

Thermoelectric Materials, Phenomena, and Applications: A Bird's Eye View: **T. M. Tritt, M. A.Subramanian**

Recent Developments in Bulk Thermoelectric Materials: G. S. Nolas, M. Kanatzidis

Properties of Nanostructured One-Dimensional and Composite: Thermoelectric Materials : A. M. Rao, X. Ji, and **T. M. Tritt**

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Electrical conductivity

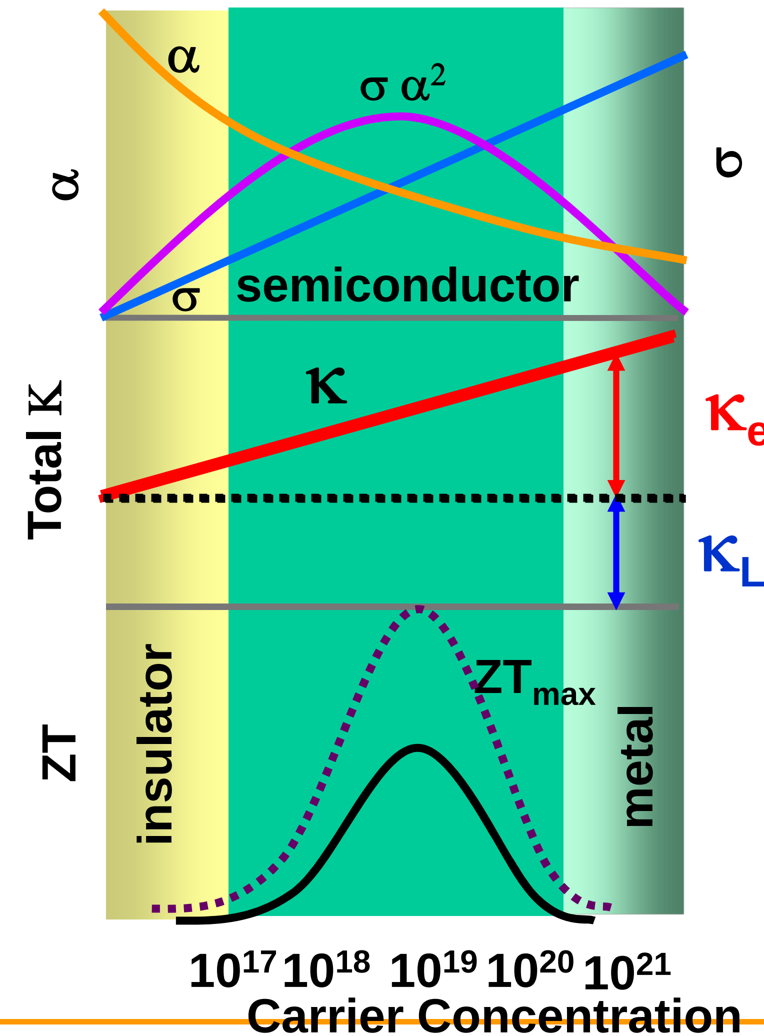
Seebeck coefficient or thermopower ($\Delta V/\Delta T$)

$$ZT = \frac{\sigma\,\alpha^2}{(\kappa_e + \kappa_L)} \cdot T$$

Total thermal conductivity

No upper limit for ZT

Contra-indicated Properties



+

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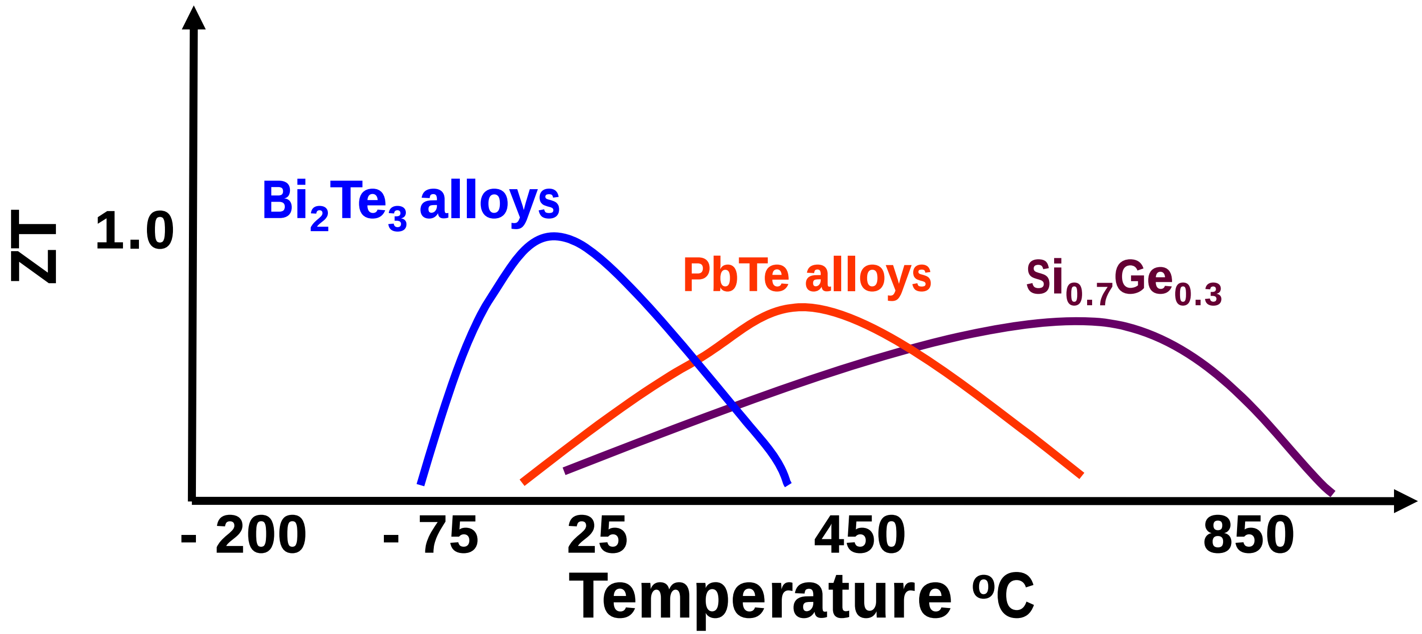
Glass (amorphous)
Very low
thermal conductivity

Metal
High
electrical conductivity

Semiconductor
High
Thermopower

Ram Seshadri x6129 seshadri@mrl

$$ZT = \frac{\sigma\,\alpha^2}{(\kappa_e + \kappa_L)} \bullet T$$



- **Narrow band gap semiconductors (increasing numerator)**
- **Elements of high atomic weight – e.g. Bi, Pb, Hg, Te (decreasing the denominator)**

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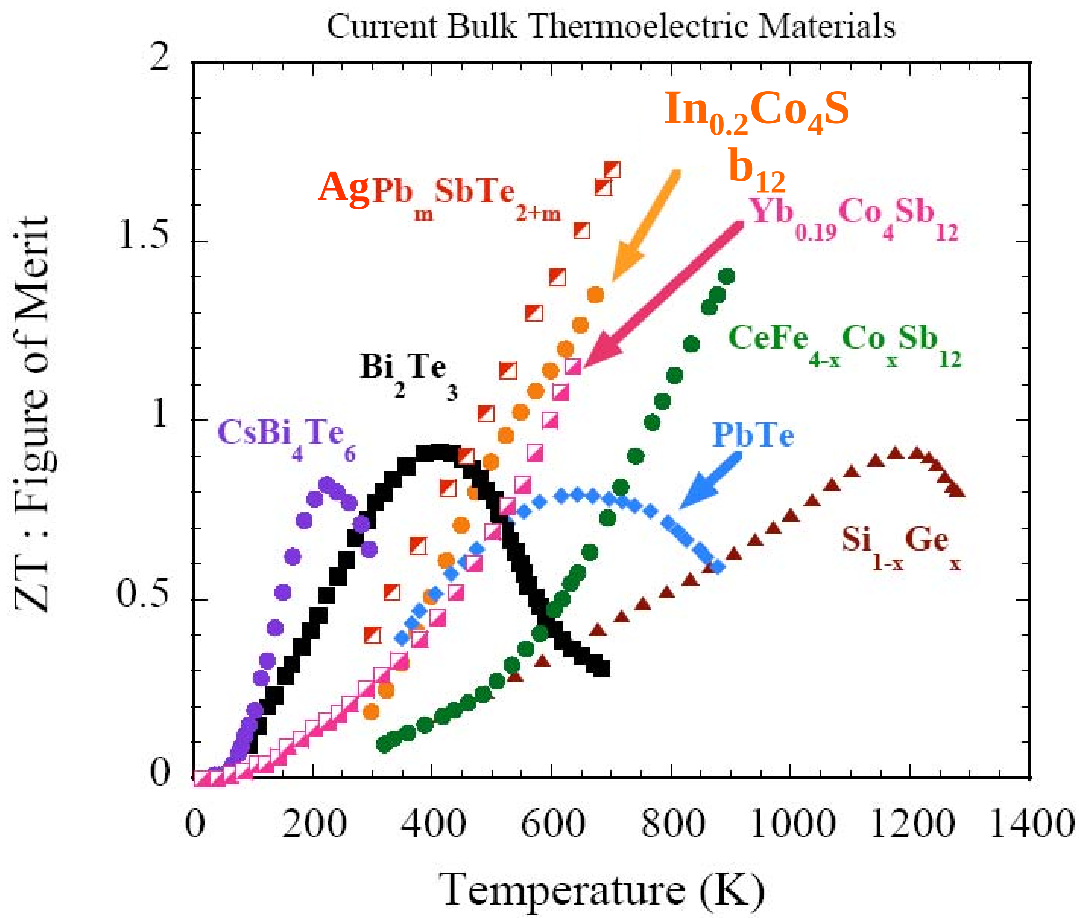

$CsBi_4Te_6$:
Kanatzidis et al., *Science*, **287, 1024(2000)**

$AgPb_mSbTe_{2+m}$:
Kanatzidis et al., *Science*, **303, 818 (2004)**

$In_{0.2}Co_4Sb_{12}$:
Subramanian et al., *Chemistry of Materials*, **18, 759 (2006)**

$Yb_{0.19}Co_4Sb_{12}$:
Nolas, Tritt et al., *J. Appl. Phys*. **97, 113715 (2005).**

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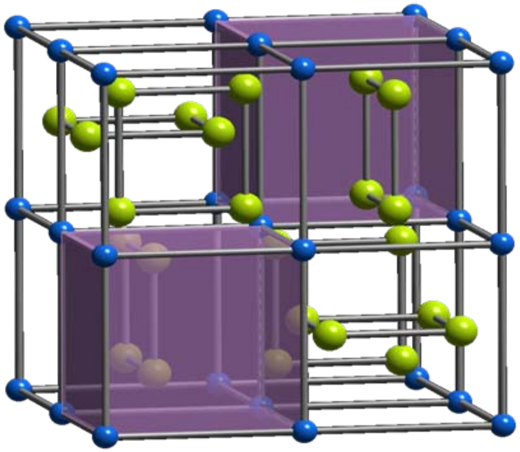
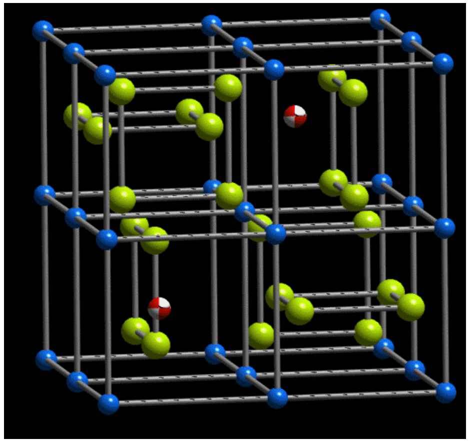
$$ZT = \frac{\sigma\,\alpha^2}{(\kappa_e + \kappa_L)} \bullet T$$





Co_4Sb_{12}

Large numerator

<u>Large Denominator</u>

ZT ~ 0.4 at 600K

$R_xCo_4Sb_{12}$ (R = Rare-earth, In)

Large numerator

<u>Small denominator</u>

ZT~ 1.3 at 600K

Subramanian et al., *Chemistry of Materials*, **18, 759 (2006)**
Nolas, Tritt et al., *J. Appl. Phys*. **97, 113715 (2005)**
Singh et al., *Phys. Rev*. **B 53, 6273 (2003)**

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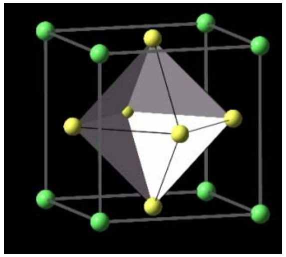
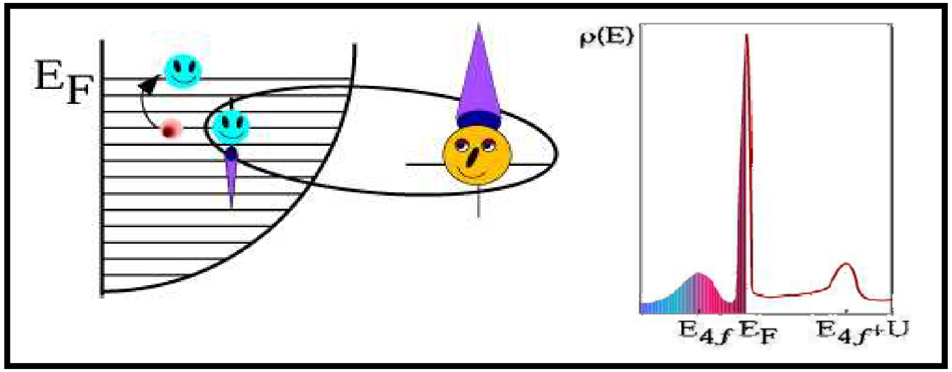
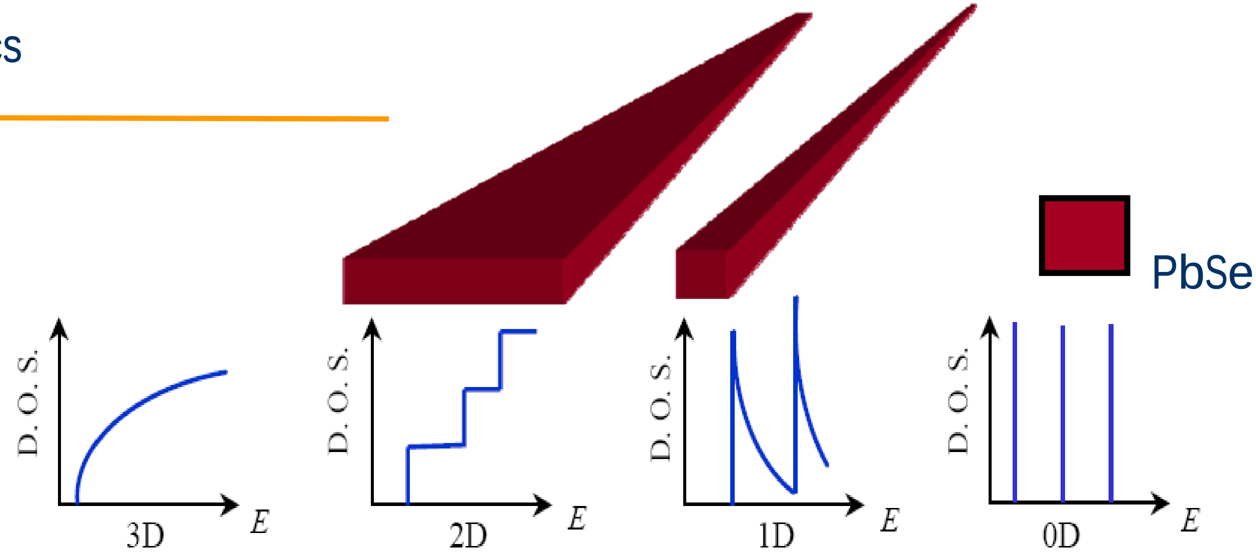
$$ZT = \frac{\sigma\,\alpha^2}{(\kappa_e + \kappa_L)} \bullet T$$

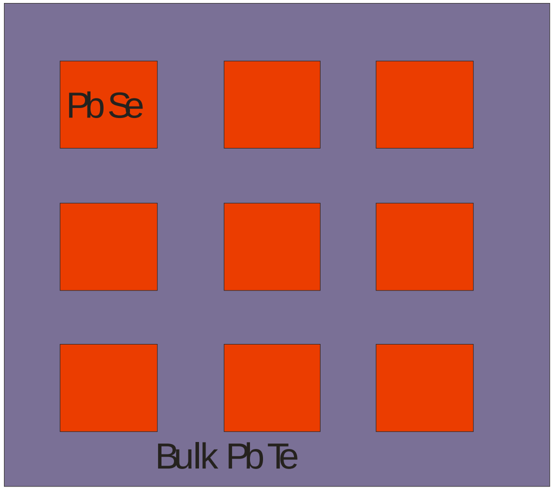
- Intermetallics with rare earths in intermediate valence states
  - Yb $^{2+,3+}$ ($4f^{13}$-$4f^{14}$) ; Ce $^{3+,4+}$ ($4f^{1}$-$4f^{0}$)
  - Large Density of States at the Fermi Level
    - interaction between conduction electrons and partially localized 4f electrons leads to large α
    - very large numerator (power factor)
    - large denominator (thermal conductivity) – low ZT

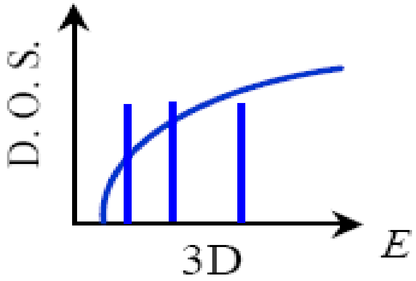


$YbAl_3$ and $CePd_3$



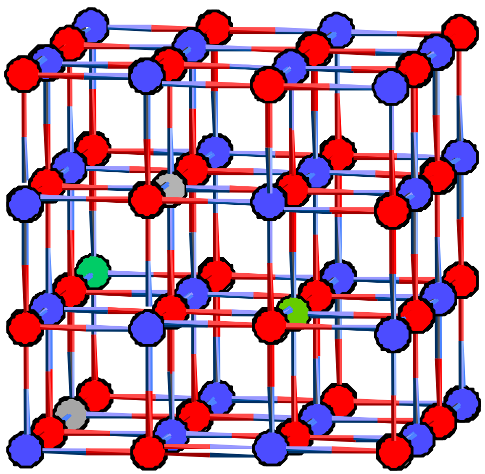


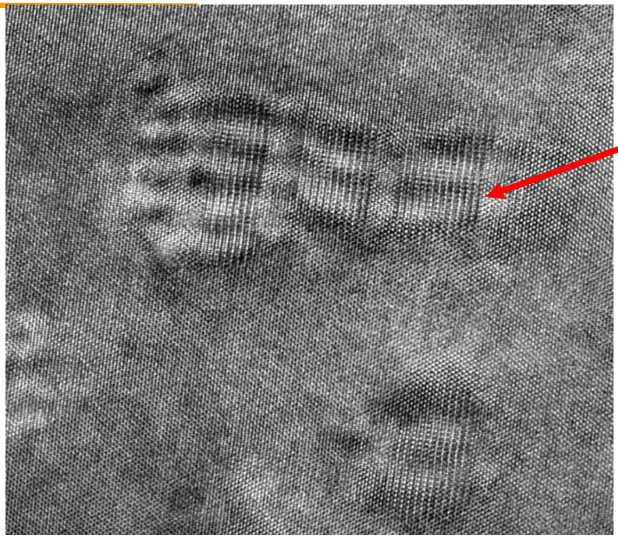




$$\alpha = \frac{\pi^2 k_B^2 T}{3e} \frac{d(\ln \sigma(E))}{dE}\Bigg|_{E = E_F}$$

- Electronic properties may be dramatically modified due to carrier confinement in nanostructures
- Thermoelectric power enhancement (rippling effect on DOS)

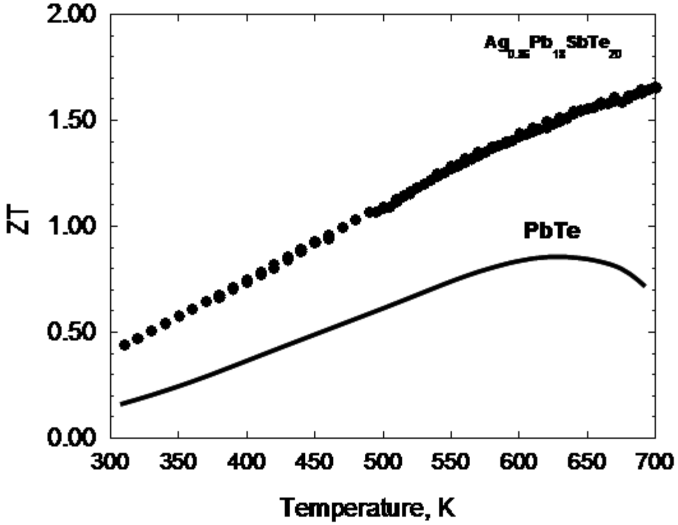


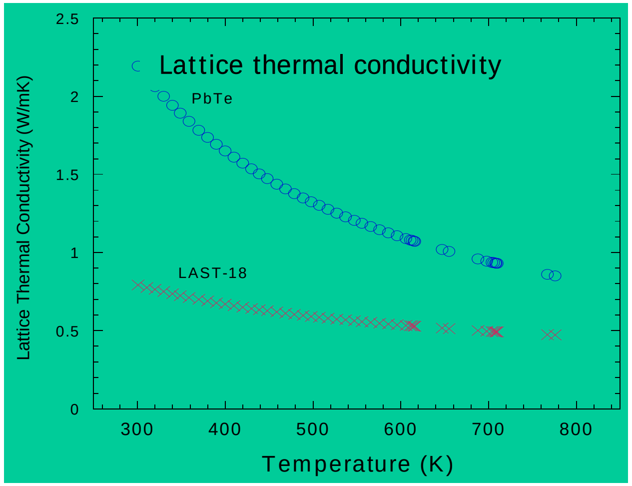


nanostructure

$AgPb_{18}SbTe_{20}$

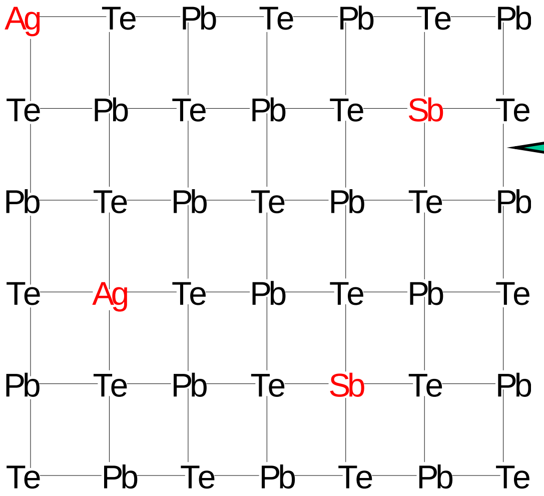
Power factor still high

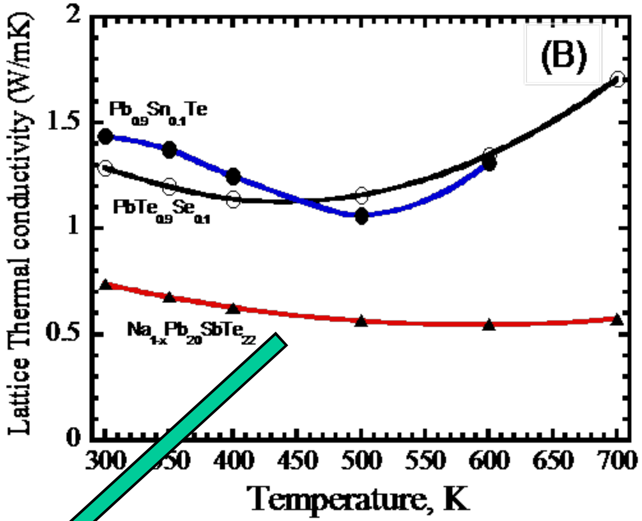


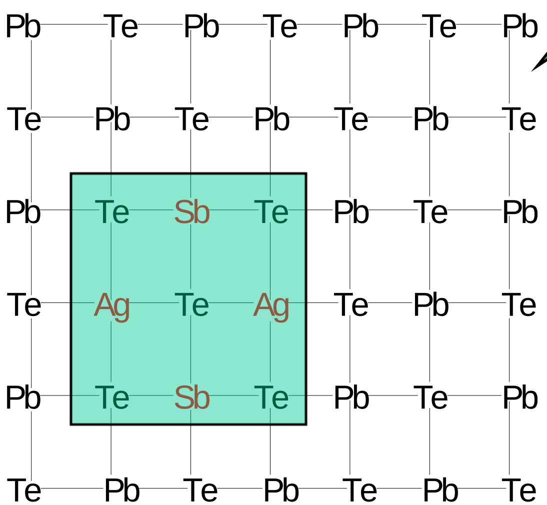


Kanatzidis et al *Science*, 2004, 303, 818

Dissociated state..unstable







Associated state..stable

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