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Thermoelectric phenomenon: An overview, selection criterion and challenges

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Thermoelectric phenomenon: An overview, selection criterion and challenges

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Abstract

Among various static energy conversion technologies, the thermoelectric (TE) energy conversion has gained the most interest due to their ability to directly convert waste heat into electricity. TE materials can be used for power generation as well as cooling applications. NASA has been using high temperature TE materials (PbTe, SiGe, etc) for several years to power radioisotope thermoelectric generators (RTG) in space missions. On the other hand, Bi-based materials have been of great interest to the TE community with optimum efficiency near room temperatures for cooling and low temperature power generation applications. One of the main objectives to design an efficient TE material is to suppress the phonon conduction without significantly deteriorating electrical conduction through the system. A brief discussion of the selection criterion to achieve this goal and challenges will be presented along with the traditional as well as newer approaches for optimizing performance of these materials.[1-3]

Attributes of Thermoelectrics

- ❖ Refrigeration and/or Power Generation Capabilities
- ❖ Small Size and Lightweight
- ❖ Solid State Technology: no moving parts (**Silent**, no vibrations)
- ❖ Environmentally "Green"(no CFC's, HFC's, etc.)
- ❖ High Reliability (Long term use, low maintenance)

Thermoelectric Generation and Refrigeration: Conversion efficiency is determined in terms of dimensionless figure of merit ZT:

$$\eta_{TE} = \eta_{Carnot}\, \eta_{ZT\ term}$$

$$ZT = \frac{\alpha^2 \sigma T}{\kappa_{electronic} + \kappa_{lattice}}$$

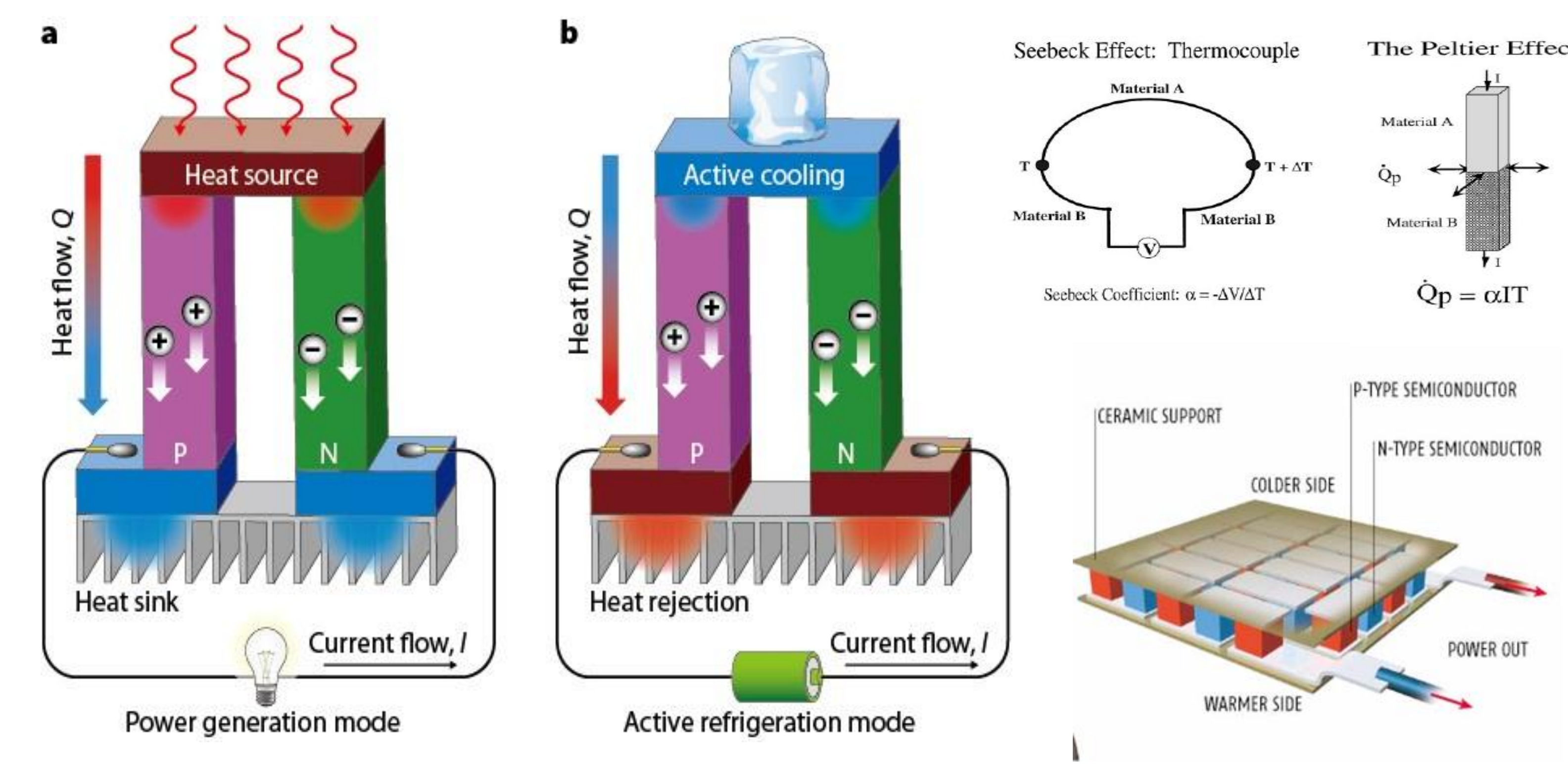
→ **Power Factor (Electrical behavior)**

→ **Total Thermal Conductivity (Thermal behavior)**

Heat carried by charge carriers ($\kappa_{electronic}$) | **Heat carried by phonons** ($\kappa_{lattice}$)

α= Thermopower (Seebeck coefficient)
σ = Electrical conductivity
η_{Carnot} = Carnot efficiency term $(T_{hot}-T_{cold})/T_{hot}$

Thermoelectric Generation and Refrigeration



Seebeck Effect | Peltier Effect | TE module

TE Generator → Converts waste heat from exhaust or radiator system to electricity

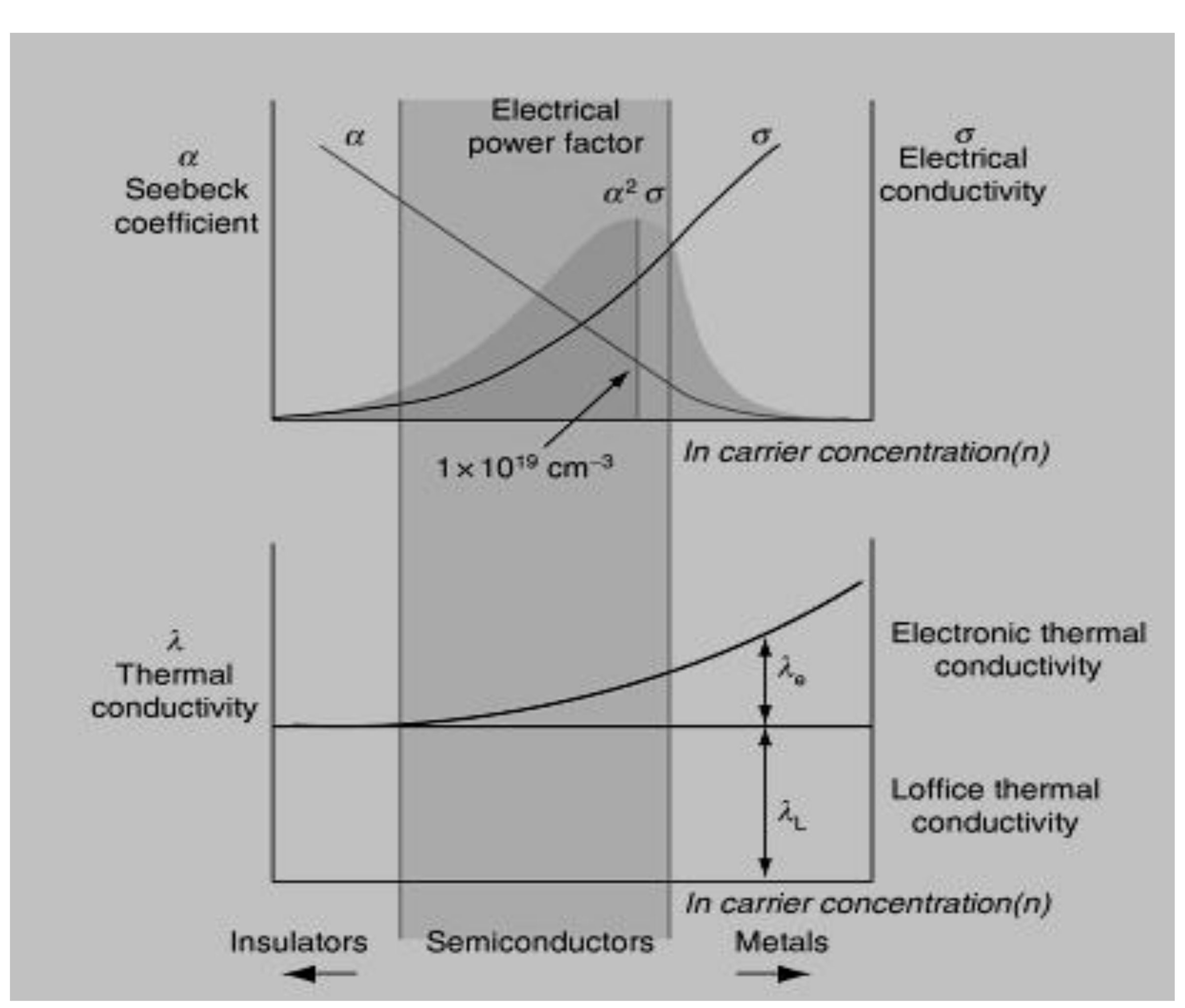
(Large amount of Waste Heat ← Energy Harvesting!!) Huge Potential!

GOAL: Achieve ZT of 2-3 in both n- and p-type materials (η = ε ≈ **15 - 20% of Carnot efficiency and above)**

Current status: ZT ~1.7 (n-type bulk materials)[4-5]

Requirements and Limitations:

- ✓ Heavily doped system (← degenerate semiconductors)[6]
- ✓ Electron crystal and phonon glass behavior (PGEC)
- ✓ Coupled transport properties



Current Applications

❖ NASA's Radioisotope Thermoelectric Generators (RTG's):

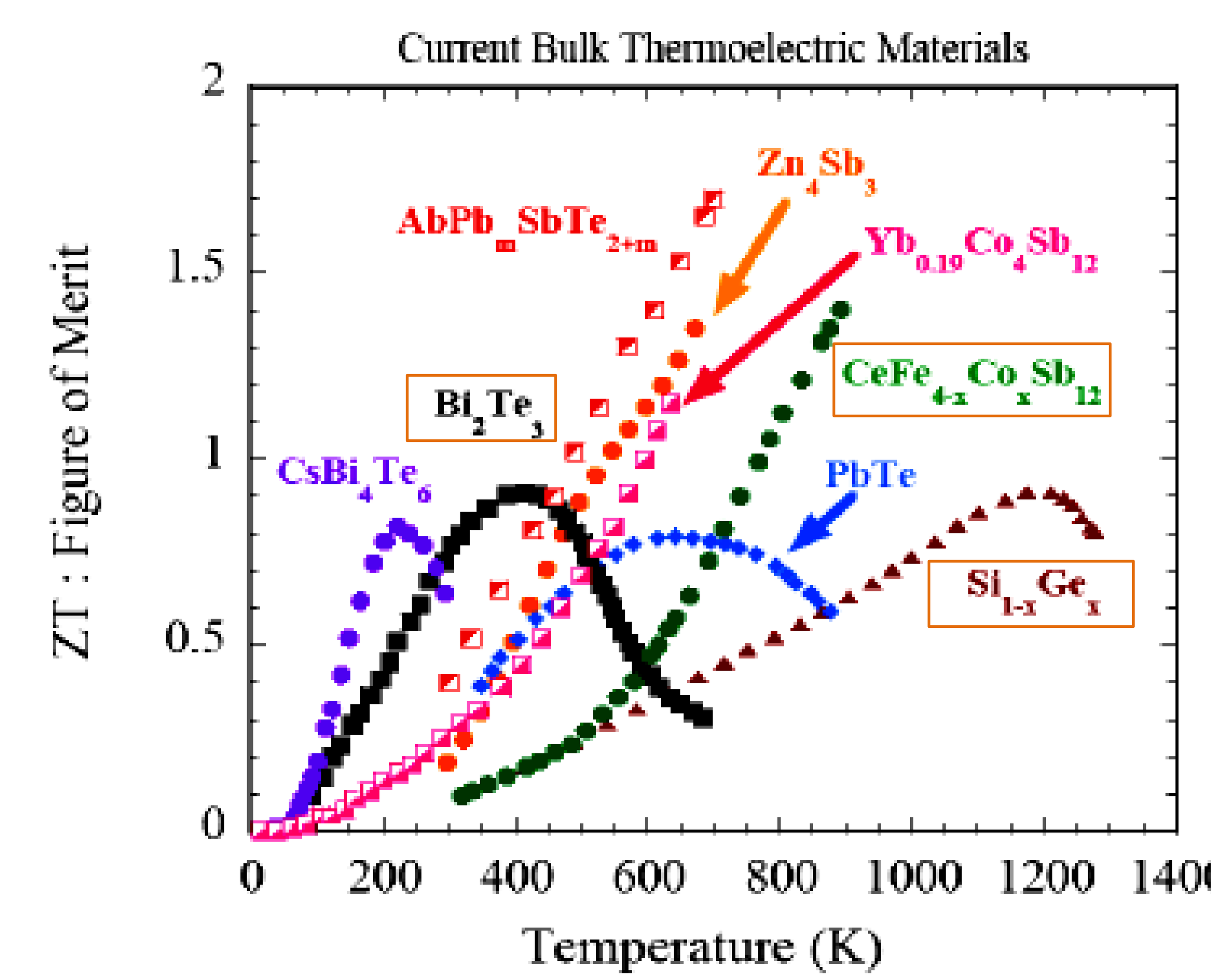
Use as power source for deep space probes: (SiGe & PbTe); Voyager I and II (over 25 yrs of operation); Apollo, Pioneer, Viking, Galieo and recently Cassini (1997); Prometheus & JIMO (Jupiter Icy Moons Orbitor)

❖ Refrigeration Applications:

➢ Infrared (IR) Detectors & Laser Diodes:(Enhanced Performance w/cooling[7]) Computer Chips (CMOS) ; Localized climate control or temperature stabilization.

❖TE heating and cooling systems:

➢Automotive -- Climate controlled seats[8] and
➢Biological -- powering implants like pacemakers and defibrillators by recovering body heat[9] .



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