Characterization of Rare Earth Doped III-V Thermoelectric Materials

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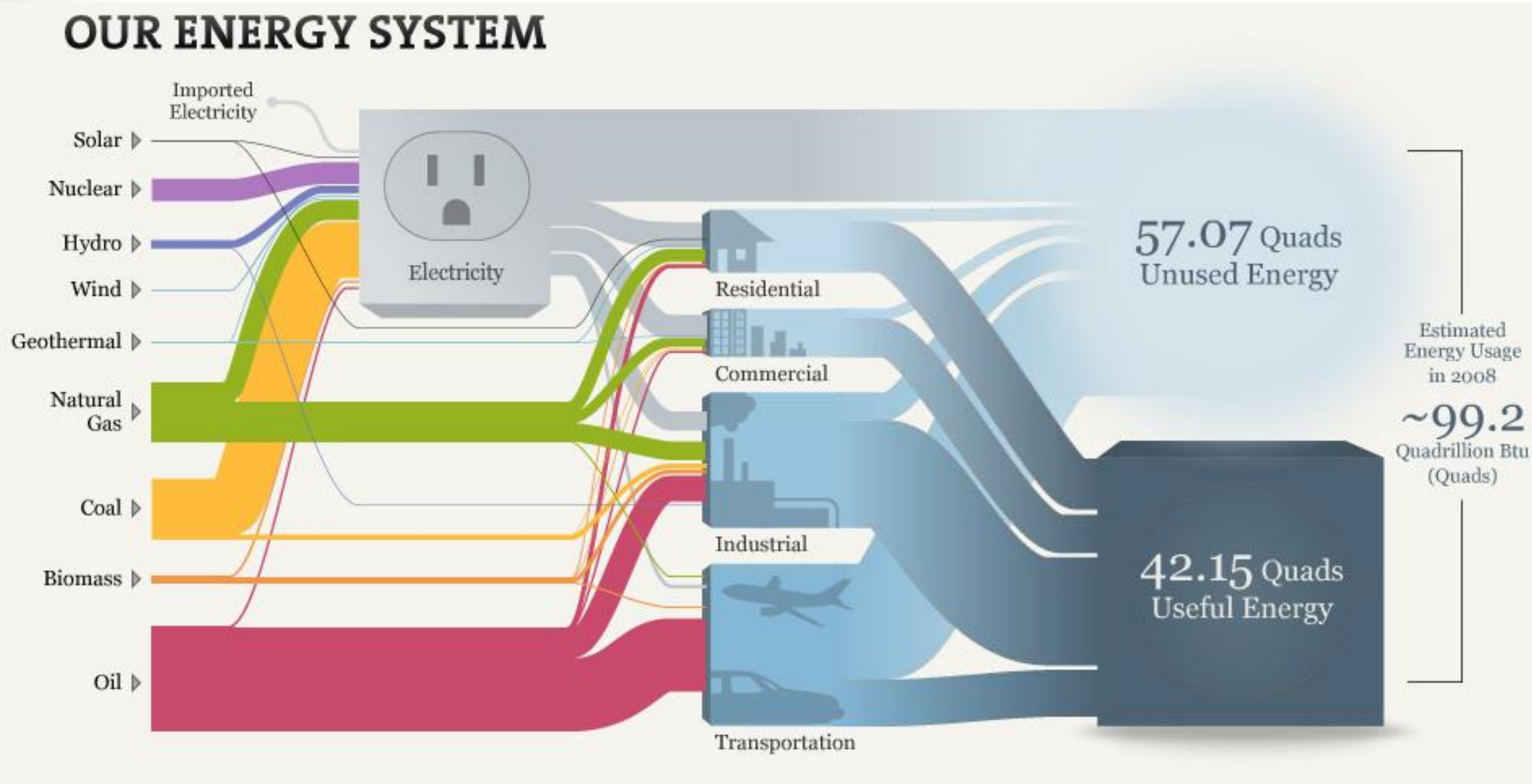
Energy: we lose more than we use



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What are Thermoelectrics?

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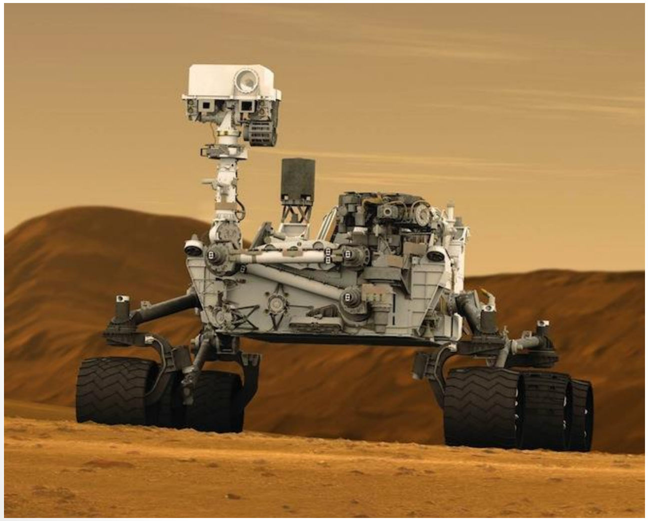

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Convert waste heat into usable electricity

Solid-state, robust, and require little maintenance

The Thermoelectric Figure of Merit (ZT)

Seebeck Coefficient

Electrical Conductivity

$$ZT = \frac{\alpha^2 \sigma}{\kappa} T$$

Temperature

Thermal Conductivity

Maximizing Thermoelectric Performance

(HIGH)
Seebeck Coefficient

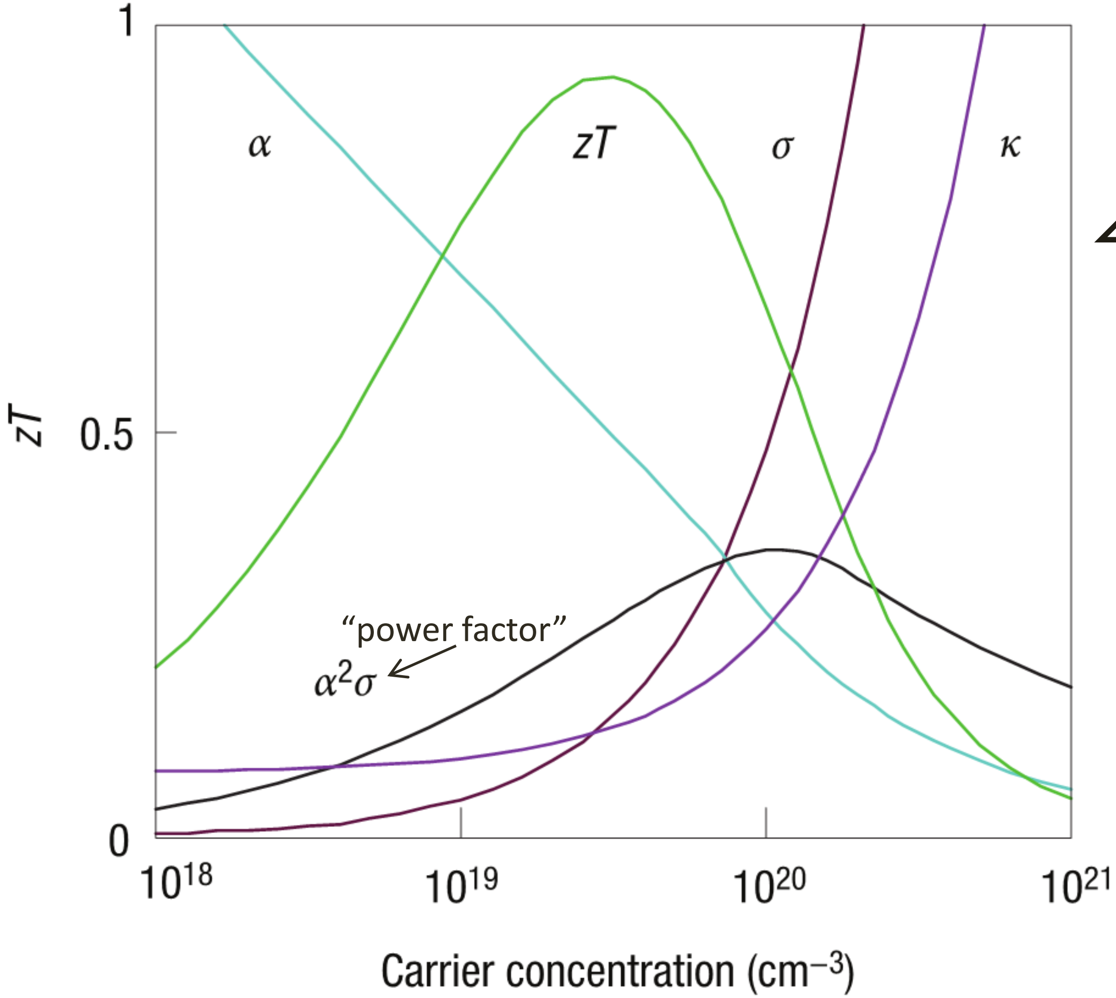
(HIGH)
Electrical Conductivity

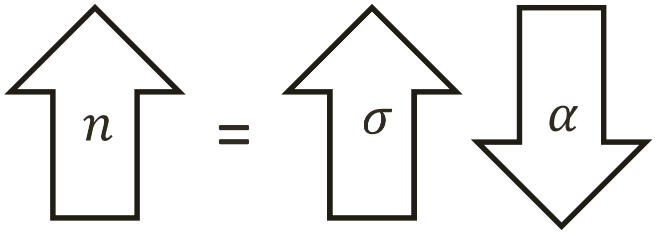
$$ZT = \frac{\alpha^2 \sigma}{\kappa} T$$

Temperature

Thermal Conductivity
(LOW)

Balancing the Components of ZT

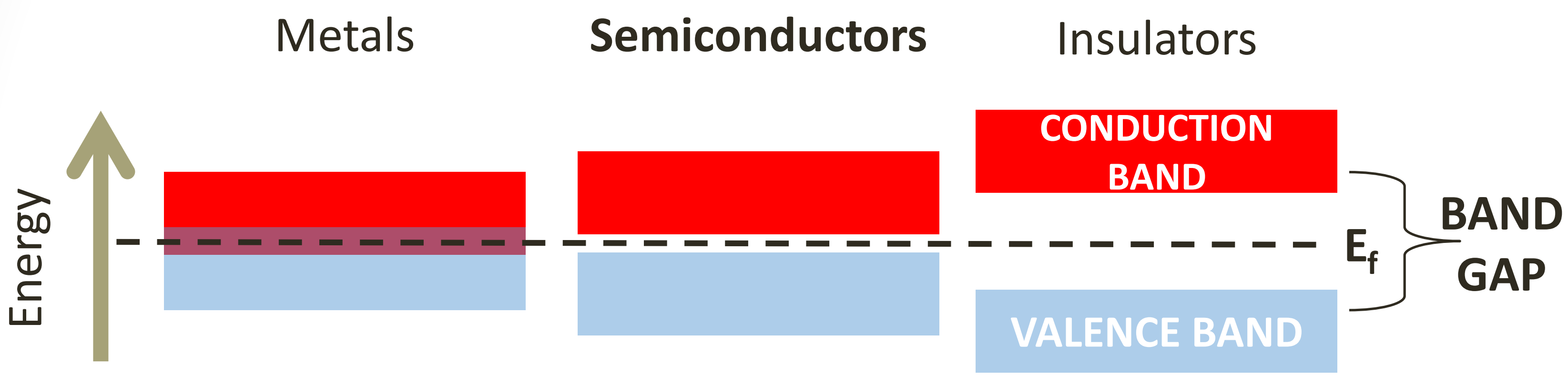




$$ZT = \frac{\alpha^2 \sigma}{\kappa} T$$

Snyder GJ, Toberer ES. Nat Mater 2008;7:105.

Why Semiconductors?



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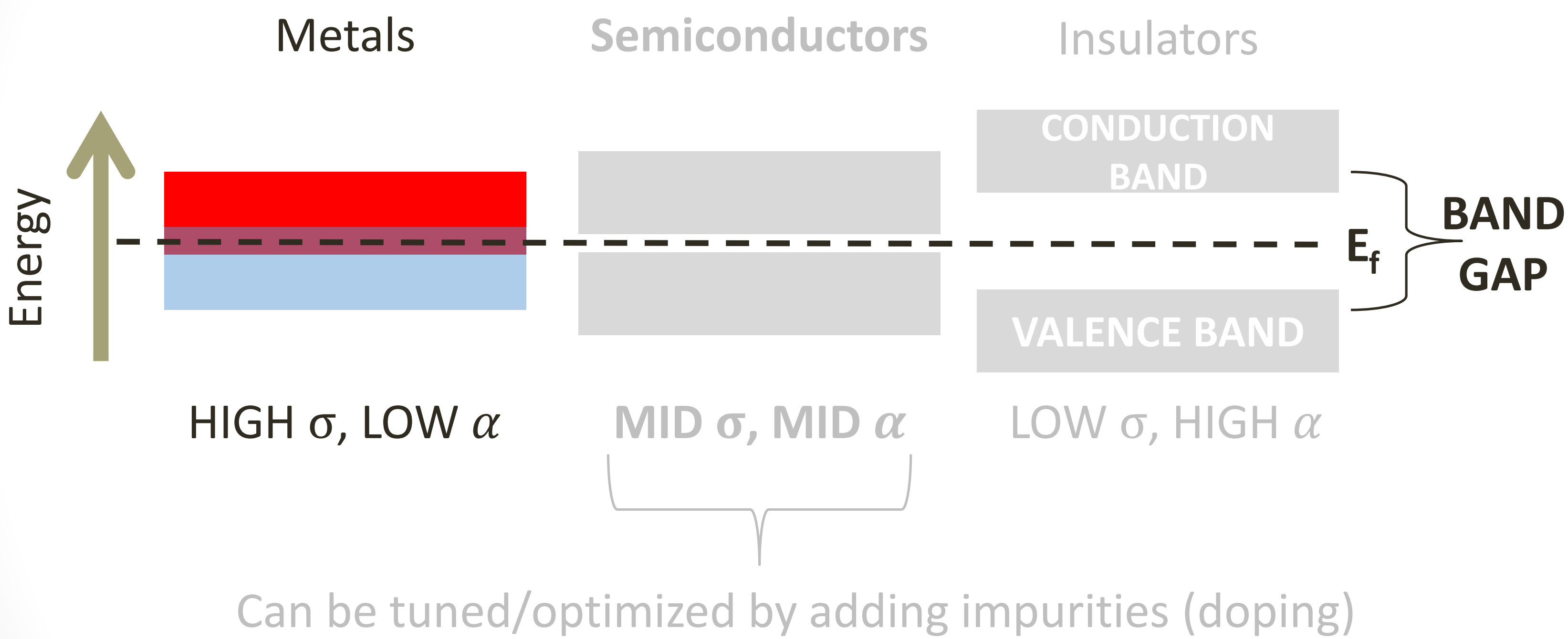

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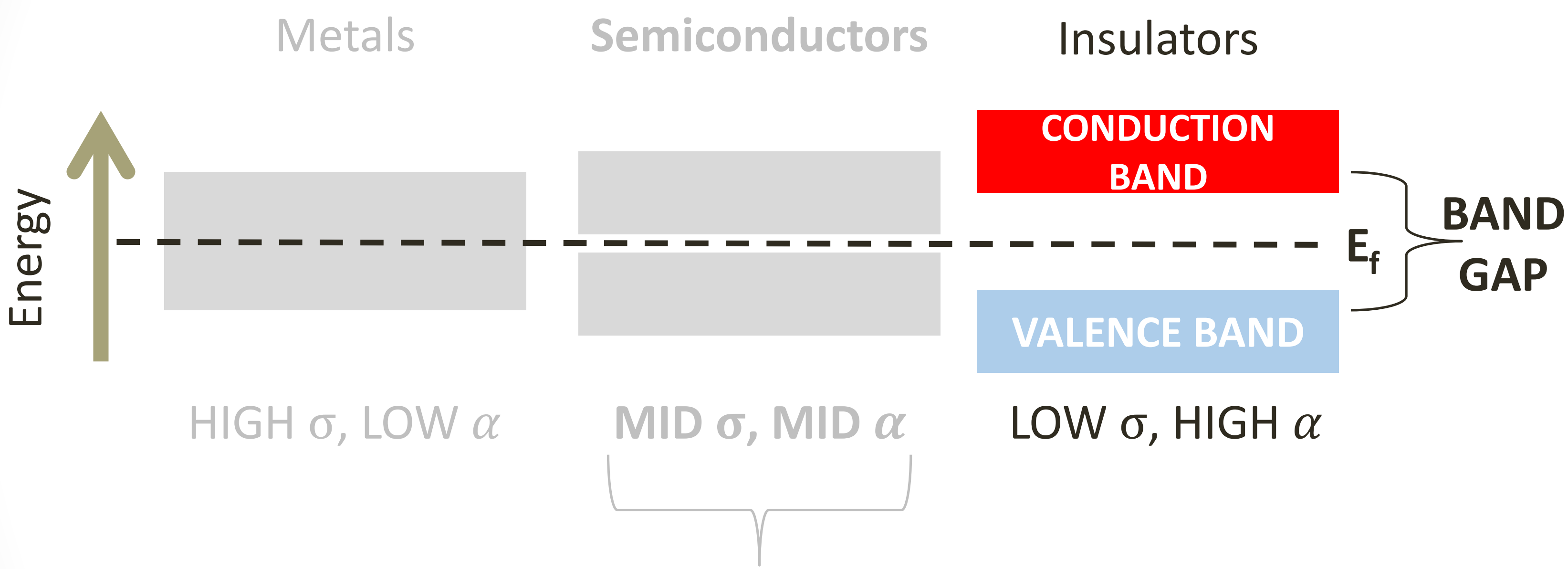
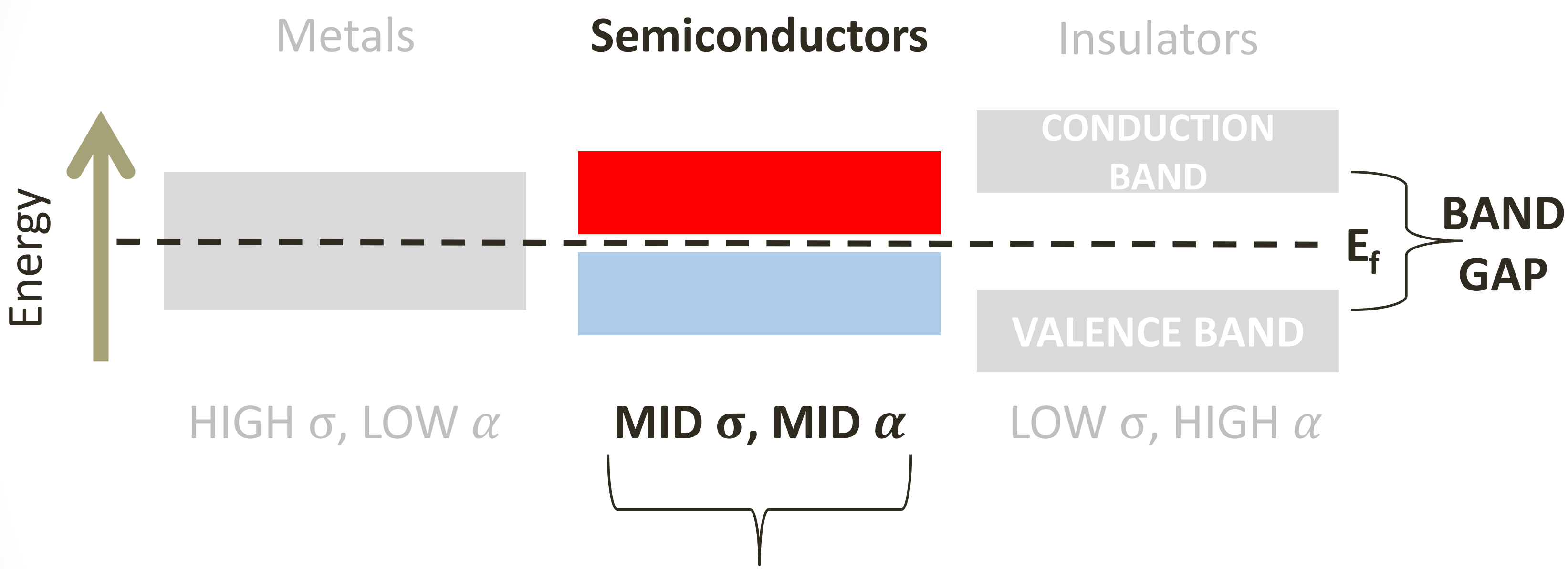


Can be tuned/optimized by adding impurities (doping)

Why Semiconductors?



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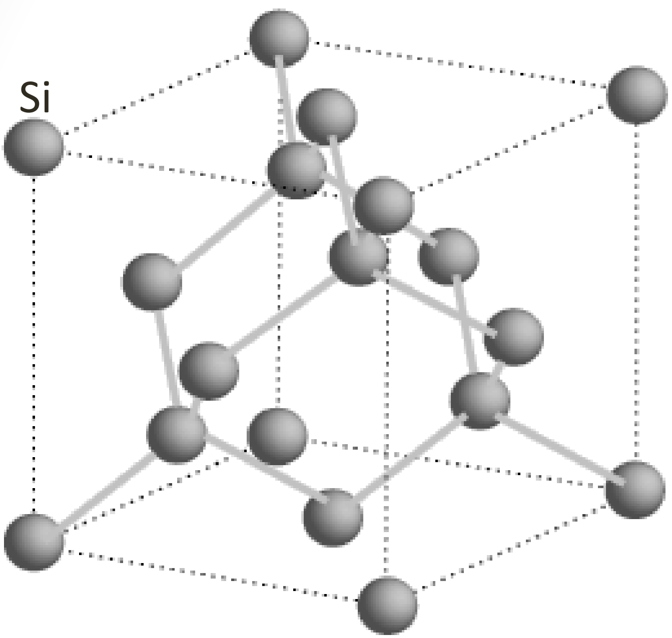
Conventional Semiconductors



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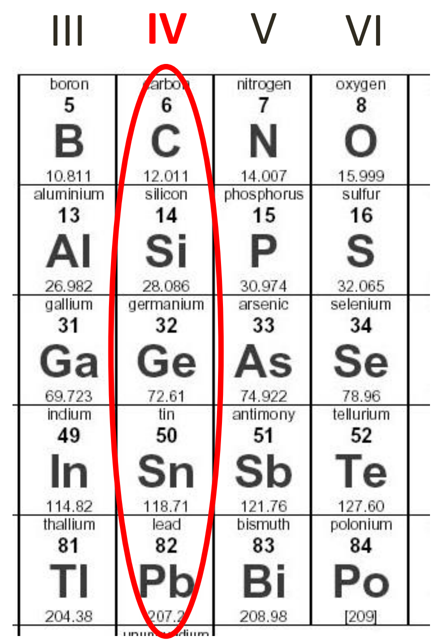

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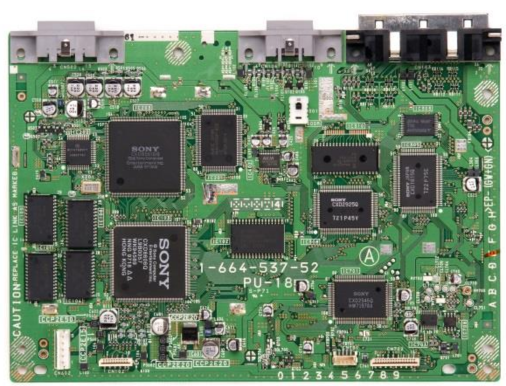

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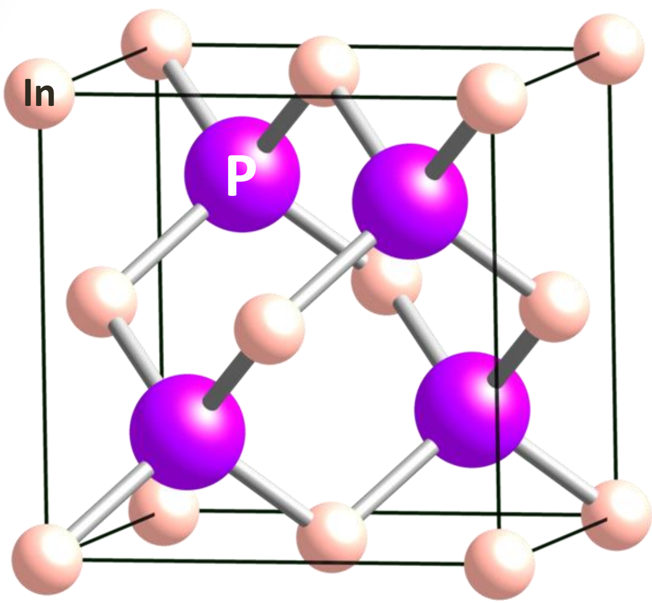
III-V Semiconductors



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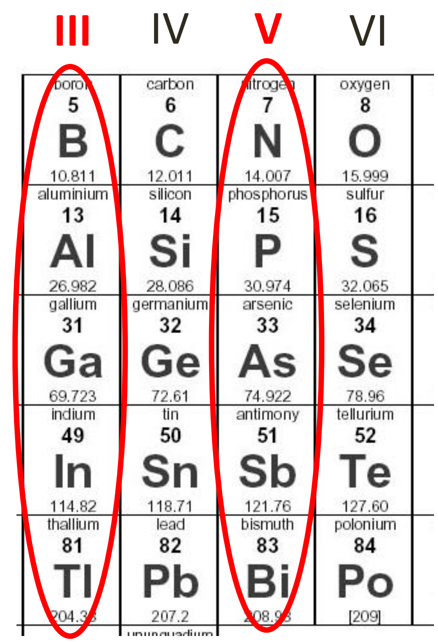

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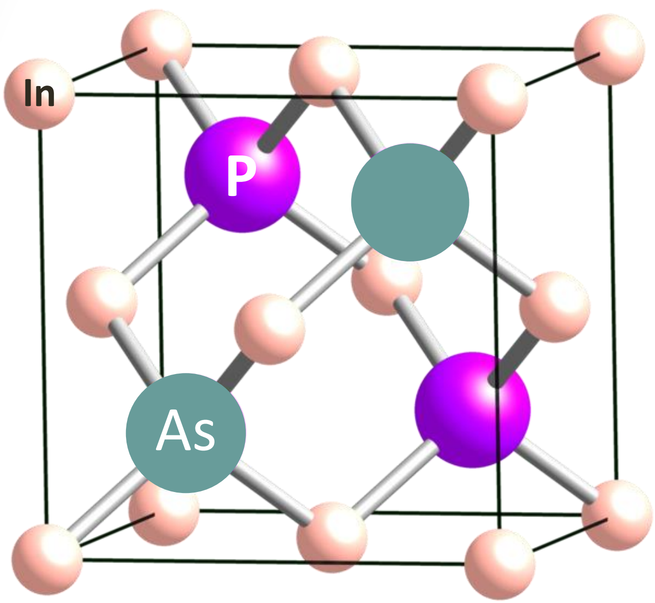
Can alloy elements from groups III and V to make III-V semiconductors

Different sizes of atoms causes a drop in thermal conductivity due to “phonon scattering”

Material System: $InAs_xP_{1-x}$



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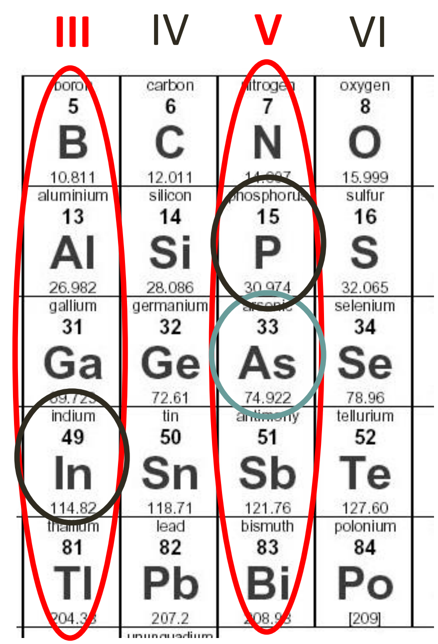

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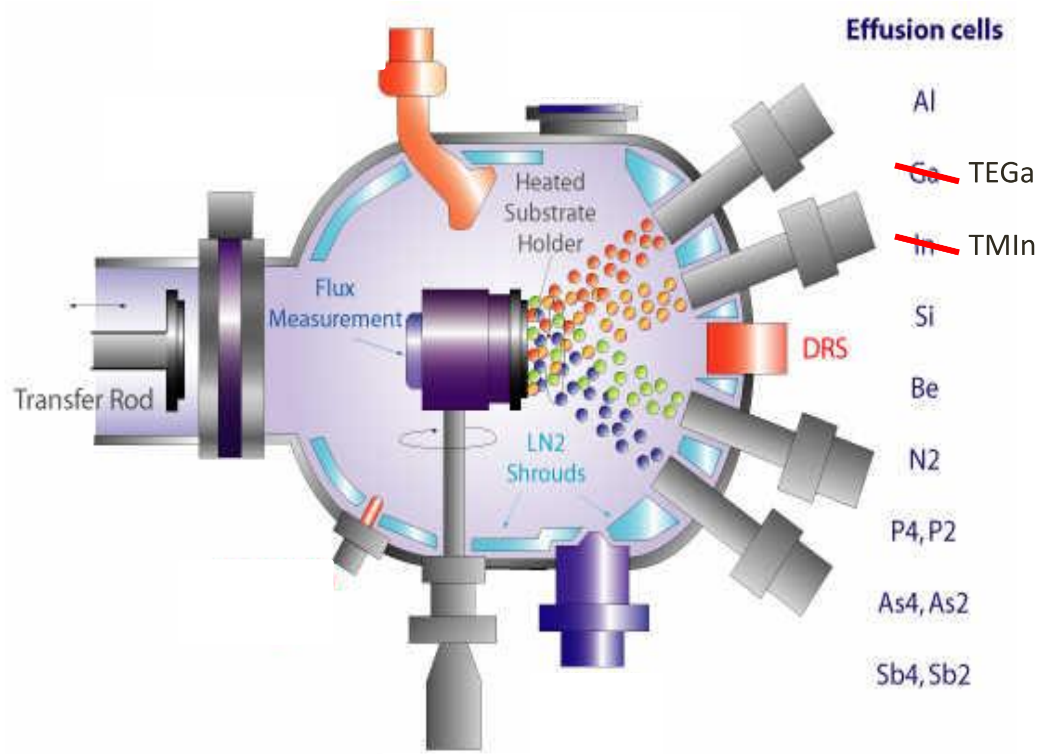
$InAs_xP_{1-x}$ layer

InP substrate

Growth by Chemical Beam Epitaxy (CBE)

- Liquid or gas sources
- Alloy group V elements
- Switch sources without compromising vacuum
- Faster growth rate than molecular beam epitaxy

Arsine, phosphine, and trimethyl indium gases are beamed at InP substrate to grow the material



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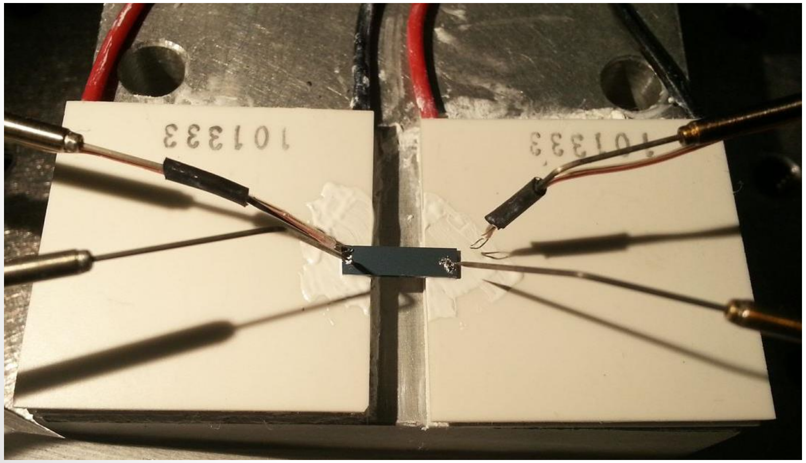
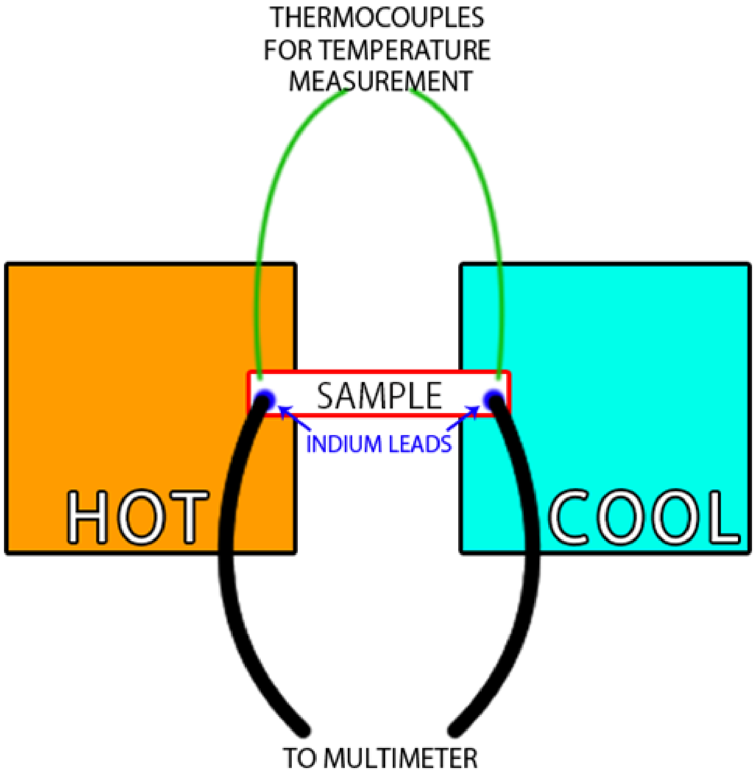
"Thermopower" – The Seebeck Coefficient

$$ZT = \frac{\alpha^2 \sigma}{\kappa} T$$

$$\alpha = \frac{\Delta V}{\Delta T}$$





The Hall Effect and Electrical Conductivity

$$ZT = \frac{\alpha^2 \sigma}{\kappa} T$$

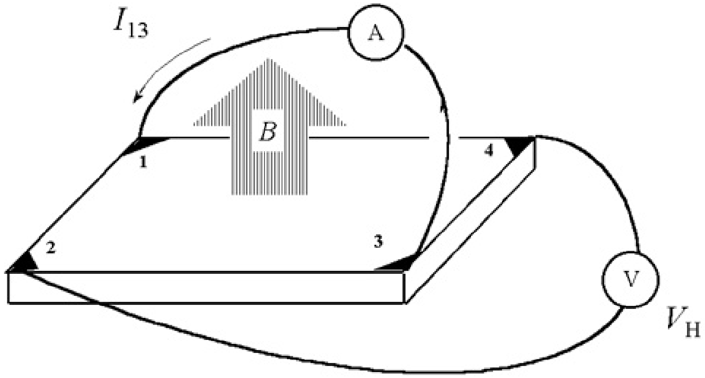
$\sigma =$ carrier density

$\times$

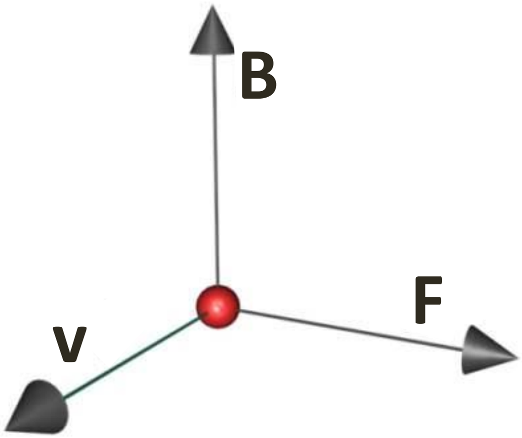
carrier mobility

$\times$

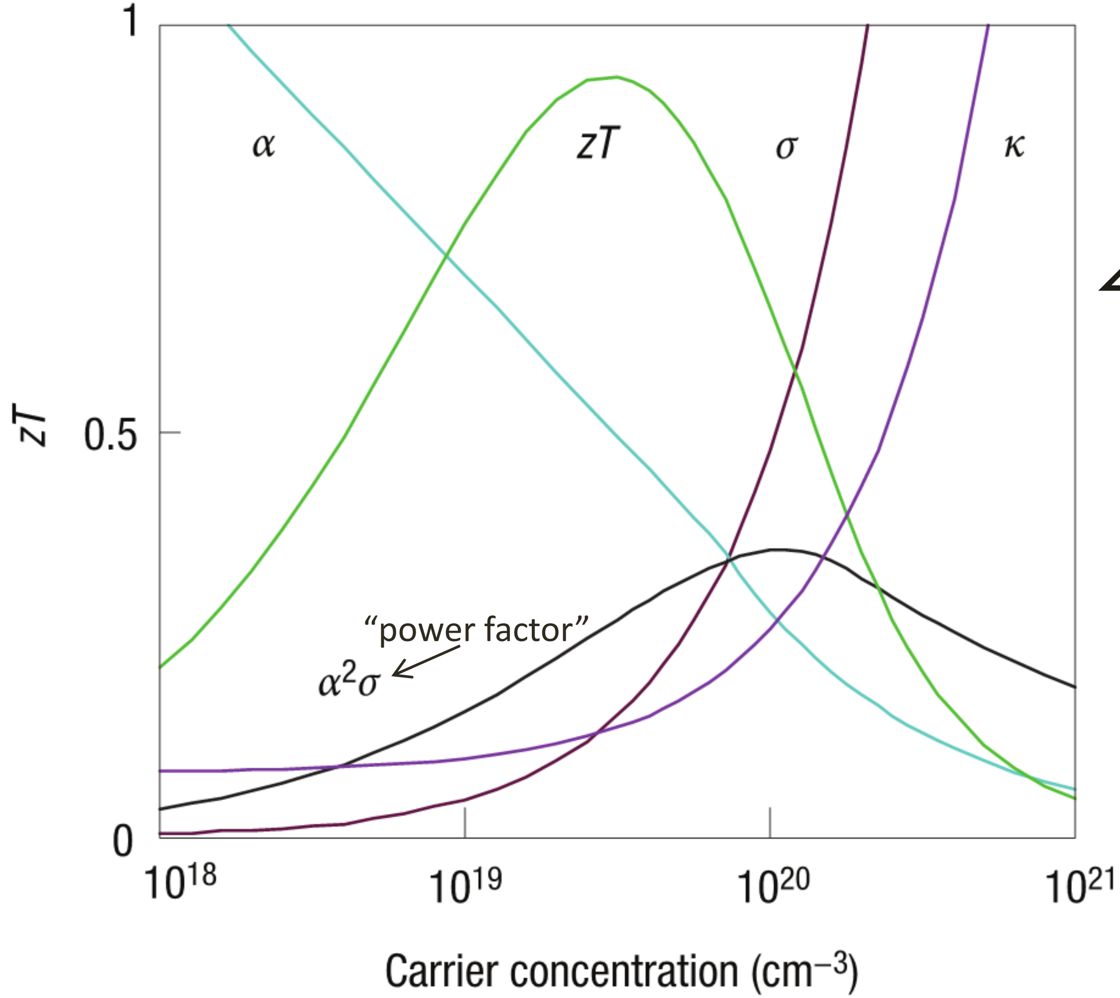
elementary charge

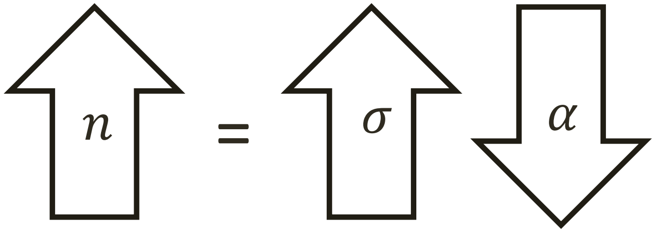


Original Image: http://tau.nanophys.kth.se/cmp/hall/node5.htm



Balancing the Components of ZT





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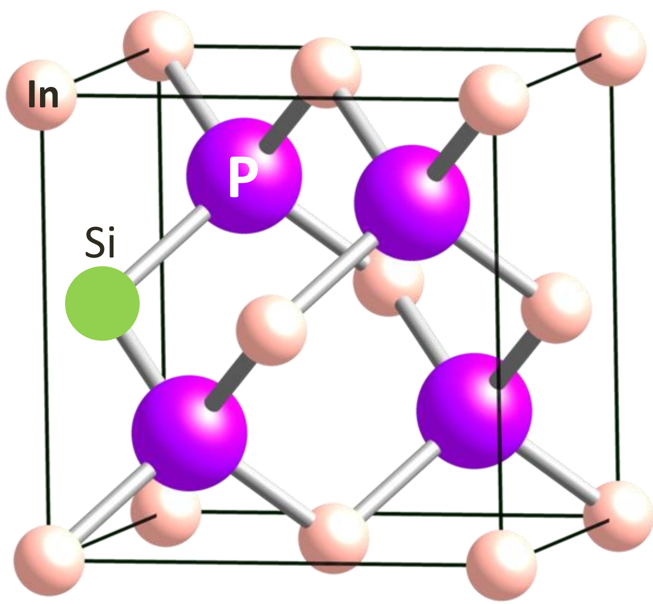
Conventionally (Si) doped InP



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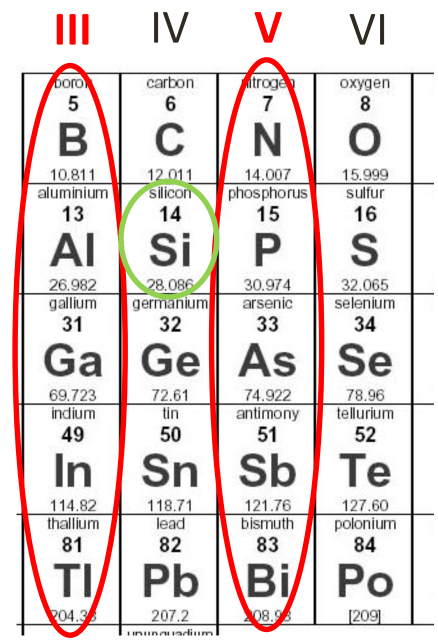

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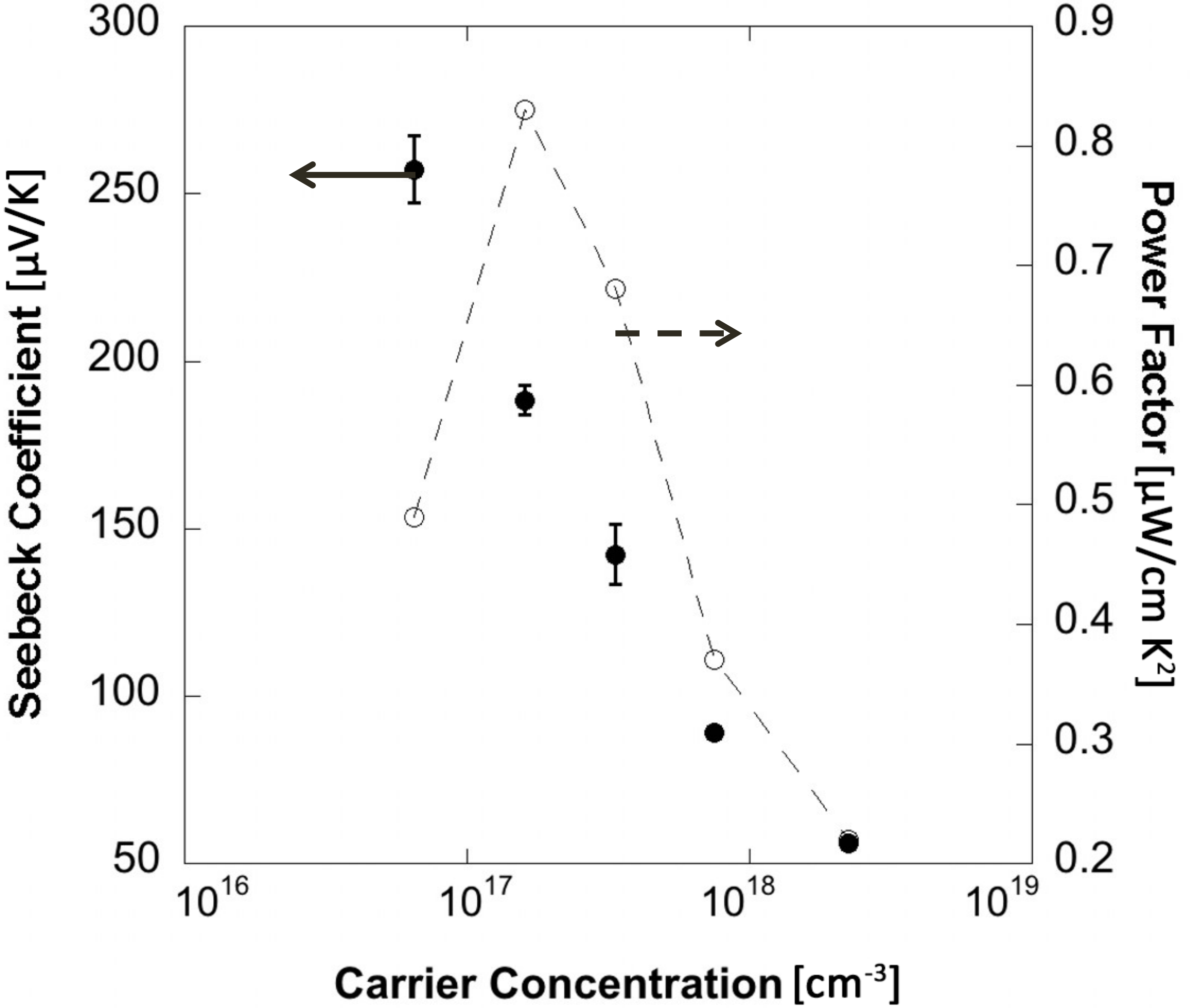
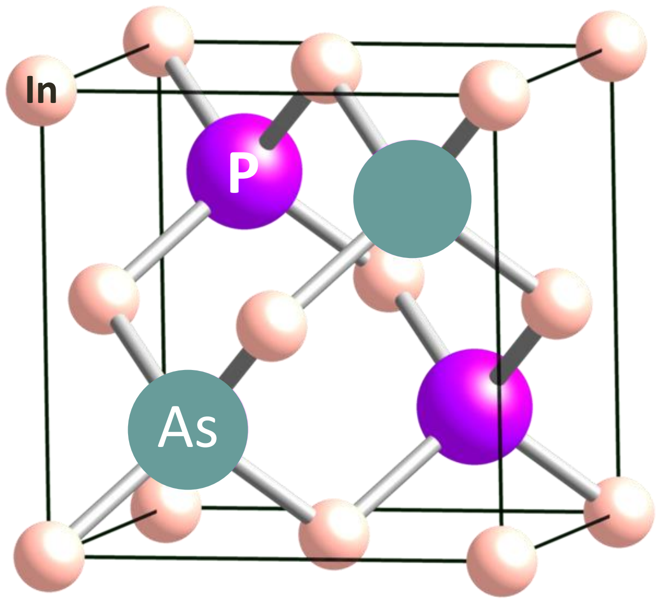


Unintentionally (UID doped InAsP



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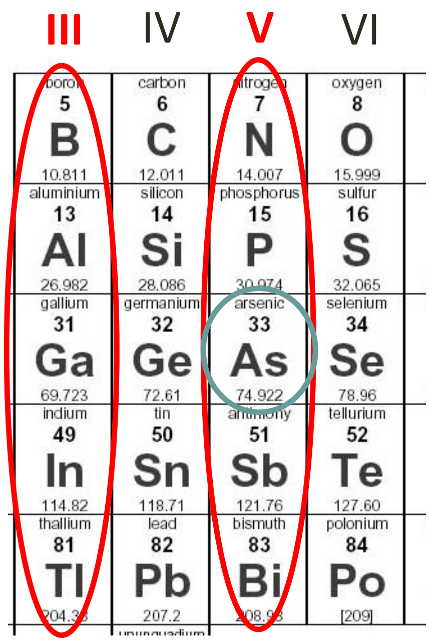

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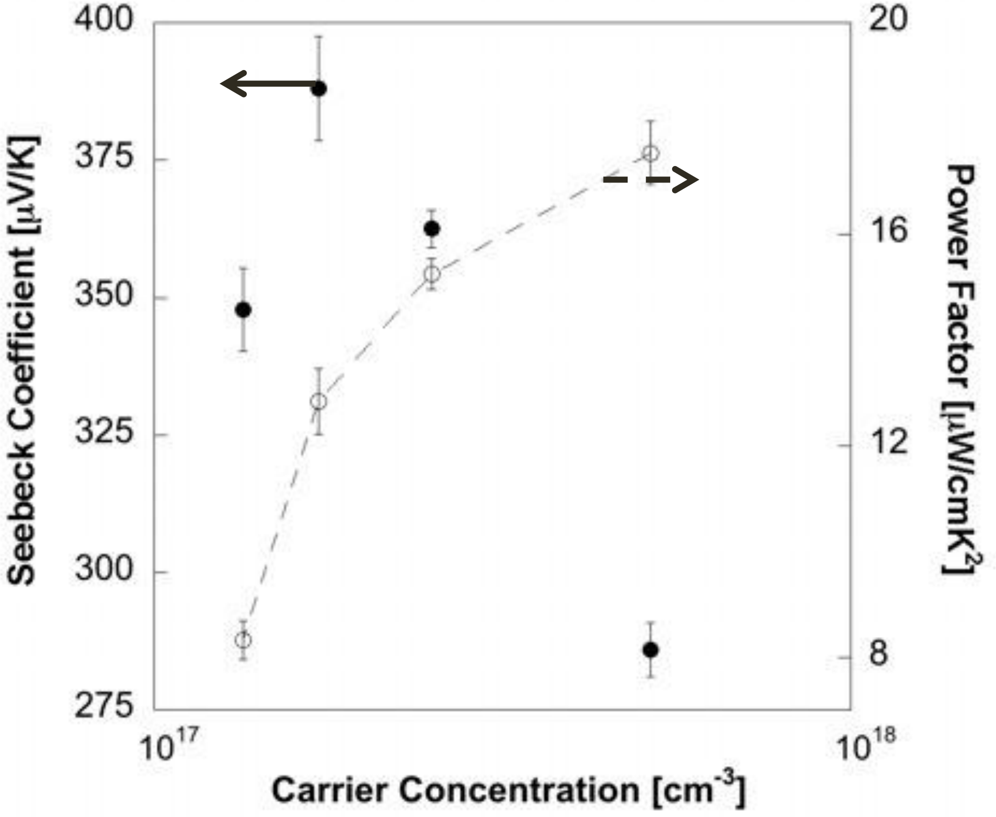
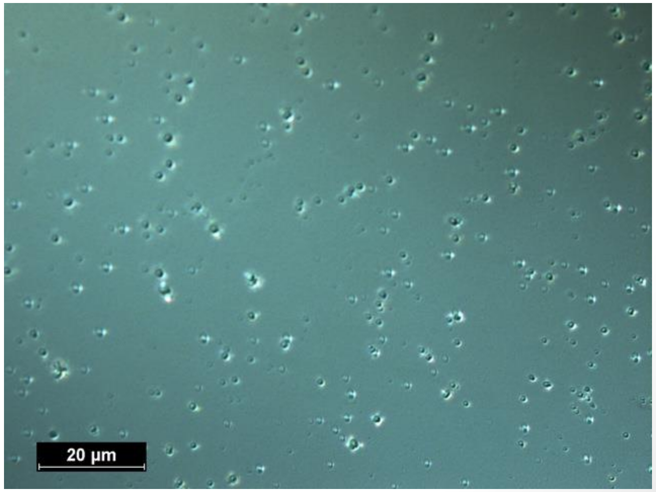
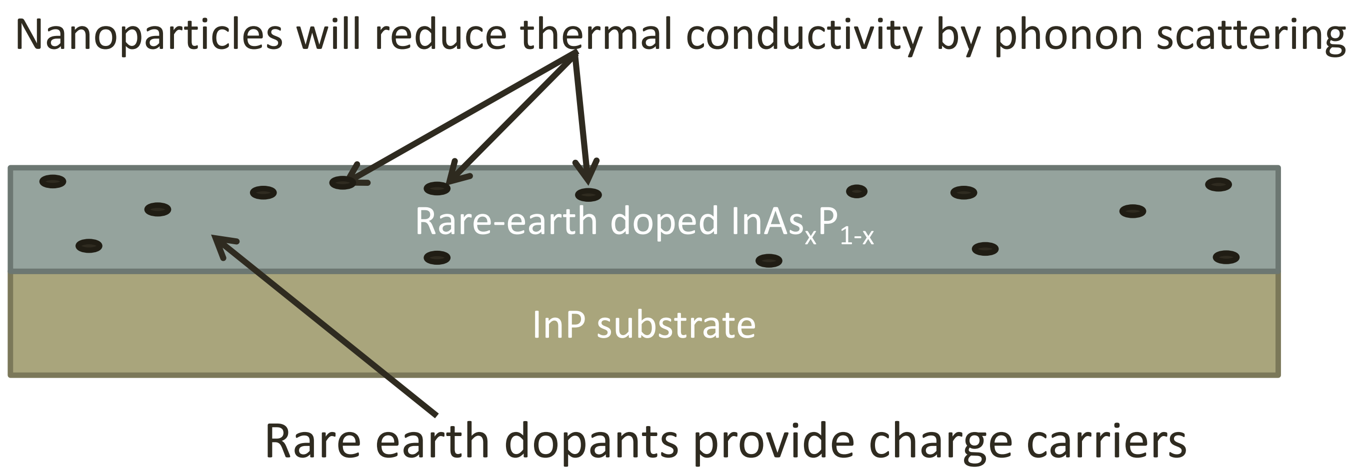


III/V ratio too high → Indium droplets



Future Goals

	InP - - - - - - - -	- - - - $InAs_xP_{1-x}$ - - - -	- - - - - - - - InAs
Si	✓		
UID		✓	
Er			



- Explore other rare earth elements (e.g. lanthanum) to compare with erbium- and conventionally-doped samples

Acknowledgements

UC SANTA BARBARA engineering

Palmstrøm RESEARCH GROUP

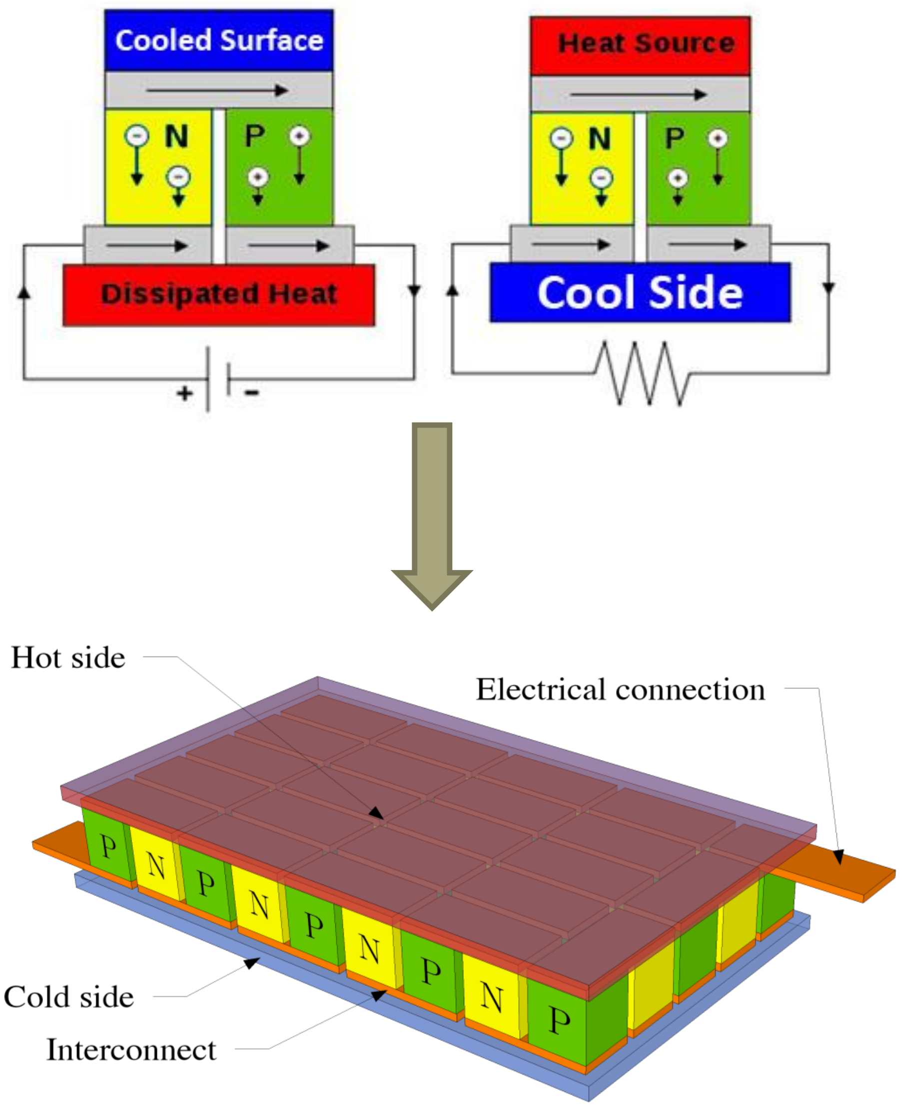
EUREKA!

CSEP

Ryan Need

Christopher Palmstrøm

The Thermoelectric Effect



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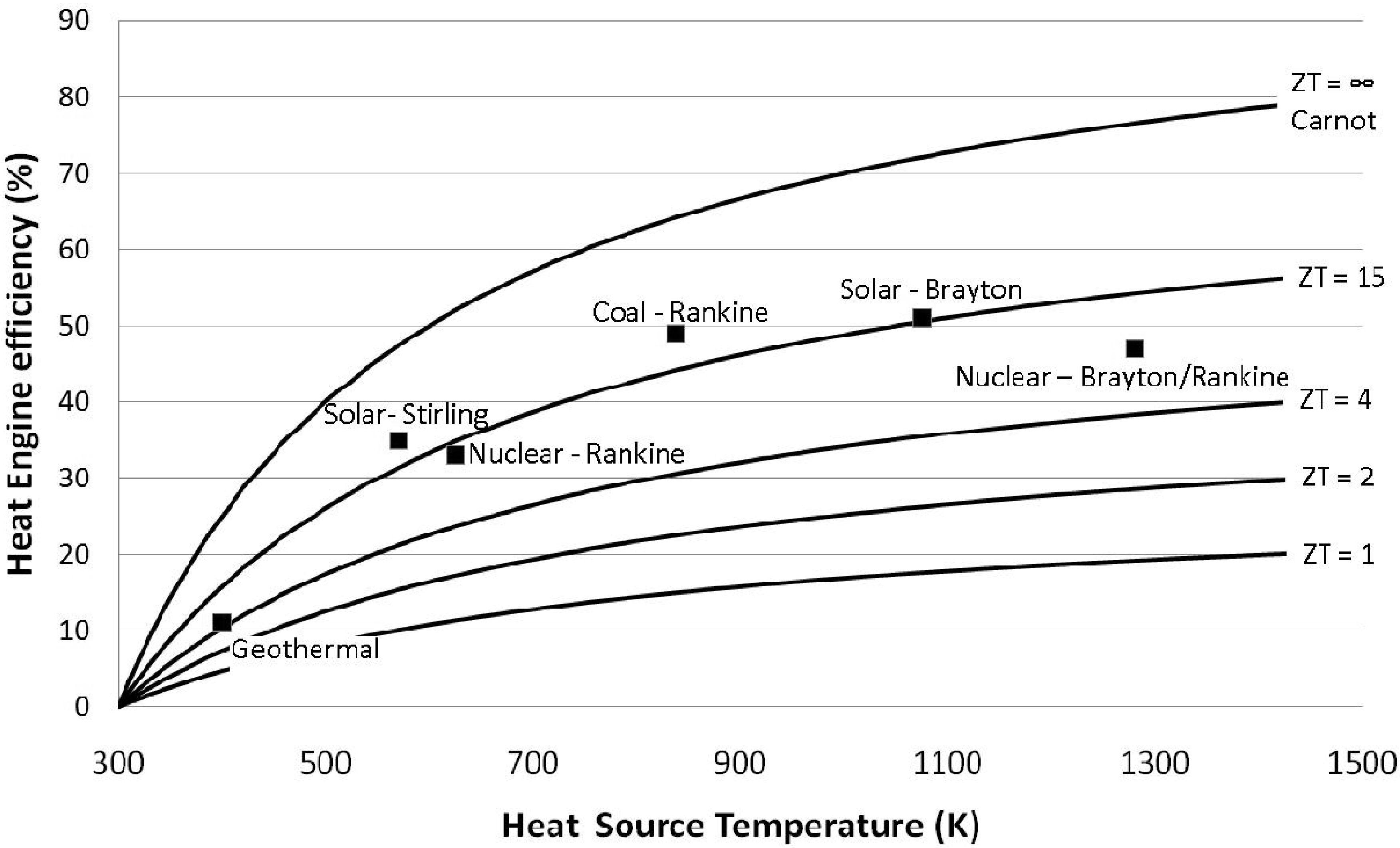
Thermoelectric Efficiency



C. B. Vining, "An Inconvenient Truth About Thermoelectrics," Nature Materials **8**, 83 (2009).