Semiconductor Nanowires for Thermoelectrics

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Outline

- Motivation
- Semiconductor nanowires
- Measurements technique
- Thermal conductivity of InSb nanowires
- Conclusions and outlook
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Motivation

2/3 energy lost as heat

70% energy wasted as heat

Power generation

Car industry

Heat dissipation

*https://www.comsol.com/model/power-transistor-8577
Motivation
Motivation

\[ ZT = \frac{\sigma \cdot S^2}{\kappa_e + \kappa_L} \cdot T \]

- Seebeck coefficient
- Temperature
- Thermal conductivity
- Conductivity

Efficiency up to ~ 12%
(400-600 °C)

http://thermoelectric-generator.com/

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Semiconductor Nanowires

\[ ZT = \frac{\sigma \cdot S^2}{\kappa_L \cdot T} \]

Temperature dependence of \( ZT \) obtained by experiment for a Te-doped InSb bulk single crystal

\[ \eta = \eta_c \frac{\sqrt{1 + ZT} - 1}{\sqrt{1 + ZT} + T_c/T_h} \]

\[ \eta_c = \frac{T_h - T_c}{T_h} \]

\( ZT \sim 3 \rightarrow \eta \approx 41\% \)


Semiconductor Nanowires

Difficulties in increasing ZT in bulk materials:

- A limit to ZT is rapidly obtained in conventional materials
- So far, the best bulk materials have ZT~ 1 at 300K

Low-dimensionaletal physics gives additional control:

- Enhanced density of states due to quantum confinement effect
- Increase S without reducing σ
- Boundary scattering at interfaces can reduce κ more than σ
- Possibility of materials engineering to further improve ZT

\[
\sigma = \int \sigma(E) \left( -\frac{\partial f_{eq}}{\partial E} \right) dE,
\]

\[
S \equiv \frac{k_B}{q} \frac{\int \sigma(E) \frac{(E-E_p)}{k_BT} \left( -\frac{\partial f_{eq}}{\partial E} \right) dE}{\int \sigma(E) \left( -\frac{\partial f_{eq}}{\partial E} \right) dE} \propto (E - E_f),
\]
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Measurements set-up

Pt/C contacts
NanoWire

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Measurements set-up

\[ \kappa = G_s \frac{4L}{\pi d^2} \]  

where \( G_s \) – nanowire (NW) thermal conductance, 
\( L \) – NW length, \( d \) – NW diameter
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InSb Nanowires

- InSb NWs grows in $<111>$ direction and has six $\{110\}$ side facets
- Diameter of NWs does not change along the nanowire length
- InSb $\rightarrow$ zinc blend single crystalline structure, Sb-polar
  $\rightarrow$ binary InSb (no P or As incorporated)

*TEM by Jordi Arbiol & Maria de la Mata, Institut de Ciència de Materials de Barcelona*
InSb Nanowires

300K

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• Semiconductor nanowires are very promising for thermoelectrics

• Low values of thermal conductivity of InSb nanowires were observed

• Surface scattering has to be considered

- Perform Seebeck coefficient and electrical conductivity measurements on InSb nanowires

- Thin InSb nanowires are good candidates for thermoelectric application
Thank you for your attention!