Organic Electronic Devices

Week 5: Organic Light-Emitting Devices and Emerging Technologies
Lecture 5.3: Introduction to Polymer Thermoelectric Devices

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Lecture Overview and Learning Objectives

• Concepts to be Covered in this Lecture Segment

  • Discussion with Respect to the Need to Create Devices that Convert Waste Heat into Electricity
  • Introduction to Thermoelectric Devices, the Figure of Merit, and the Conversion Efficiency
  • Explanation of the Key Differences in the Operation of Inorganic and Organic Thermoelectric Devices

• Learning Objectives
  By the Conclusion of this Presentation, You Should be Able to:

1. Describe what is meant by the figure of merit for thermoelectric devices and how this relates to efficiency.
2. Explain the interplay between electrical conductivity and the Seebeck coefficient in traditional semiconducting materials.
3. Justify why organic thermoelectric materials are promising with respect to performance and cost.
A Lot of Energy is Converted to Waste Heat Currently

Recovery of 16% of the Rejected Energy Would Cover the Commercial Sector
Thermoelectric Materials Convert Heat to Electricity

Thermoelectric Device Schematic  Figure of Merit for Properties of Materials

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

Efficiency Increases with Increasing \( ZT \)

Defining the Terms of the Figure of Merit

<table>
<thead>
<tr>
<th>Seebeck Coefficient ((S))</th>
<th>Electrical Conductivity ((\sigma))</th>
<th>Thermal Conductivity ((\kappa))</th>
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<tbody>
<tr>
<td>Describes how much energy the electrons that carry heat have</td>
<td>Describes how easily electrons can move in the material</td>
<td>Describes how easily the flux of heat can move in the material</td>
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</table>

Goal is to MAXIMIZE Electrical Conductivity \((\sigma)\) and Thermopower \((S)\) while MINIMIZING Thermal Conductivity \((\kappa)\)
Thermoelectric Devices Emerging Today

Multiple Devices Make a Module

Modules Can Be Used in Automobiles


Concept Images by: BMW, Ford, and BSST
Certain Materials Have Better Thermoelectric Properties Than Others

Predict Which One of These Materials Will Be The Best Thermoelectric

| Material | Material type | \(|S|\) (µV K\(^{-1}\)) | \(\sigma\) (S cm\(^{-1}\)) | \(k\) (W m\(^{-1}\) K\(^{-1}\)) | ZT (T = 298 K) |
|----------|---------------|-----------------|-----------------|-----------------|----------------|
| ZnO      | Insulator     | 350             | \(10^1\)        | 50              | \(\approx 10^{-3}\) |
| Bi\(_2\)Te\(_3\) | Semiconductor | 200             | \(10^4\)        | 1               | \(\approx 1\)   |
| Cu       | Metal         | 7.6             | \(10^7\)        | 400             | \(\approx 10^{-3}\) |
ZT is Tied to the Overall Device Efficiency

\[
\eta_{\text{max}} = \frac{T_{\text{HOT}} - T_{\text{COLD}}}{T_{\text{HOT}}} \frac{\sqrt{1+ZT} - 1}{\sqrt{1+ZT} + \frac{T_{\text{COLD}}}{T_{\text{HOT}}}}
\]

\[T_{\text{cold}} = 273 \text{ K}\]

Carnot \(T_{\text{hot}} = 900 \text{ K}\)

Carnot \(T_{\text{hot}} = 700 \text{ K}\)

Carnot \(T_{\text{hot}} = 500 \text{ K}\)

Carnot \(T_{\text{hot}} = 300 \text{ K}\)
Thermoelectric Properties Are Linked in Traditional Semiconductors

For Traditional Metals and Heavily Doped Semiconductors, The Seebeck Coefficient Can Be Written As:

\[ S = \frac{8\pi^2 k^2}{3e} m_e T \left( \frac{\pi}{3n} \right)^{2/3} \]

The Electrical Conductivity is Just:

\[ \sigma = e n \mu_e \]

Therefore, There Is An Inherent Tradeoff Meeting Conductivity and the Seebeck Coefficient with Respect to Doping in Traditional Thermoelectric Materials.

Polymer Thermoelectric Materials Can Overcome This Limitation

Further Reading: Shakouri, A.; Li, S. IEEE 18th International Conference on Thermoelectrics 1999.

The Upper Bound for Organic Thermoelectrics Has Not Been Found
The Cost of Polymer Materials is Much Lower Than Inorganic Materials

The recovery of waste heat could have a huge impact on the energy landscape of the United States. Thermoelectric devices are a means to provide a silent, long-lasting conversion solution that requires no moving parts. Currently, the conversion efficiency and expensive of traditional thermoelectric modules make them not feasible from an economic perspective in most cases. As such, there is a need to push to new materials and device architectures.

Thermoelectric devices are composed of a p-type (hole-transporting) and n-type (electron-transporting) leg. These legs are wired together electrically in parallel and thermally in series. Organic thermoelectric materials have the potential to play a unique role due to their lightweight, low-cost, and high-throughput fabrication schemes.