Thermoelectric Figure of Merit (ZT)

- Provides a measure of the thermoelectric performance of the TE material

\[ ZT = \frac{\alpha^2 \kappa}{\rho} \]

\[ \alpha = \text{Seebeck coefficient} \]
\[ \kappa = \text{thermal conductivity} \]
\[ \rho = \text{electrical conductivity} \]
\[ \Delta V = \text{Seebeck voltage} \]
\[ \Delta T = \text{temperature difference} \]

Efficiency
- Percent energy output from TE device

\[ \eta = \frac{\text{Power Output}}{\text{Heat Input}} \]

\[ \eta_{\text{max}} = \frac{T_{\text{hot}} - T_{\text{cold}}}{T_{\text{hot}}} \left( 1 + \frac{ZT_{\text{max}}}{T_{\text{cold}} / T_{\text{hot}}} \right) \]

Seebbeck Effect
- Applied temperature difference creates a current
- Temperature gradient across the TE material causes higher energy charge carriers to diffuse toward colder side
- Continuously applied heat keeps charge carriers moving

Pelletier Effect
- Applied current causes a temperature difference
- Charge carriers have different heat carrying capacities in different materials
- Charge carriers moving between materials cause heat to be absorbed or rejected

Fabrication Objectives
- Strong bond between half-Heusler and conducting material
- Consistent braze joints
- Desired electrical and thermal properties of braze
- High efficiency uniconductive devices
- Low thermal conductivity

Materials Selection
- Half-Heusler compound
- Nanostuctured alloys increase ZT
- Braze alloy
- Diffusion bonding influences joint strength
- Similar thermal expansion coefficients are ideal
- Braze foil thickness changes joint properties
- Conductive material
- Copper provides high conductivity electrical connection
- Direct Bonded Copper (DBC) provides insulation

Assembly and Joint Brazing Procedure
- Sand parts to appropriate size (approximately 2×2×3 mm)
- Clean components in sonication process
- Assemble half-Heusler legs, braze foil, and direct bonded copper (DBC); or copper, braze foil, and copper in brazing fixture
- Brazes and components in vacuum furnace (approximately 0.01-0.06 mbar at highest vacuum)

Results
- a) Tensile stress test results from Copper – Incoloy™-ABA – Copper joints brazed at 825°C for 5 minutes with various pressures applied to legs; and b) completely reversed bending test results from Copper – Cusil™ – Copper and Copper – Cusil™-ABA – Copper joints brazed at 825°C for 5 minutes (samples from data points marked red can be seen below)
- Copper leg braze interface after c) tensile; and d) bending tests for various numbered samples shown in red on graphs above (leg dimensions ~2×3 mm)
- e) SEM images of Copper – Cusil™ – Copper braze joint interface; and f) GM2 Energy example voltage measurement across braze joint to measure contact resistance

Future Directions
- Increase material uniformity to create more consistent devices
- Decrease variability in part sizes during fabrication
- Increase braze consistency to overall leg performance
- Improve braze fixtures to streamline braze process
- Apply pressure uniformly throughout braze cycle
- Higher quantity fabrication yield
- Develop better tensile testing apparatus to attach TE legs for testing
- Improve resistance measurement technique across joint
- Test material limits with current fixtures and fabrication techniques
- Implement efficiency measurements, thermal cycling tests, and thermoelectric generator (TEG) testing to determine power output and lifetime of TE device for various applications

Fabrication Issues
- Increase in global energy usage has created a growing need for new, efficient energy technologies
- Thermal energy losses pose many problems in current technologies
- Thermoelectric (TE) materials provide a method to convert waste heat directly into energy, making them a strong contender for energy production
- Most current TE generators and materials are costly and inefficient
- In order to improve feasibility of thermoelectric energy generation we need to improve modules
- Optimizing fabrication methods will help improve TE module efficiency

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References
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2. GM2 Energy, Inc., Voltage Measurement