Thermoelectric Modules for Space Exploration Applications

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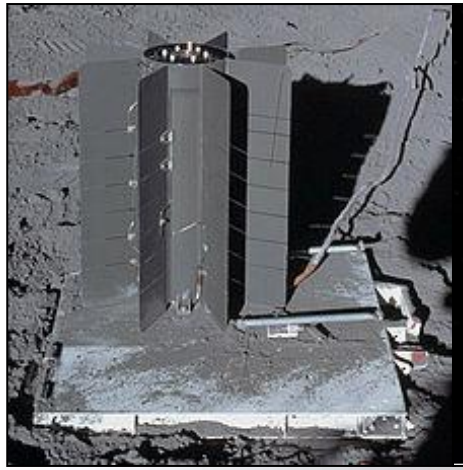
Background

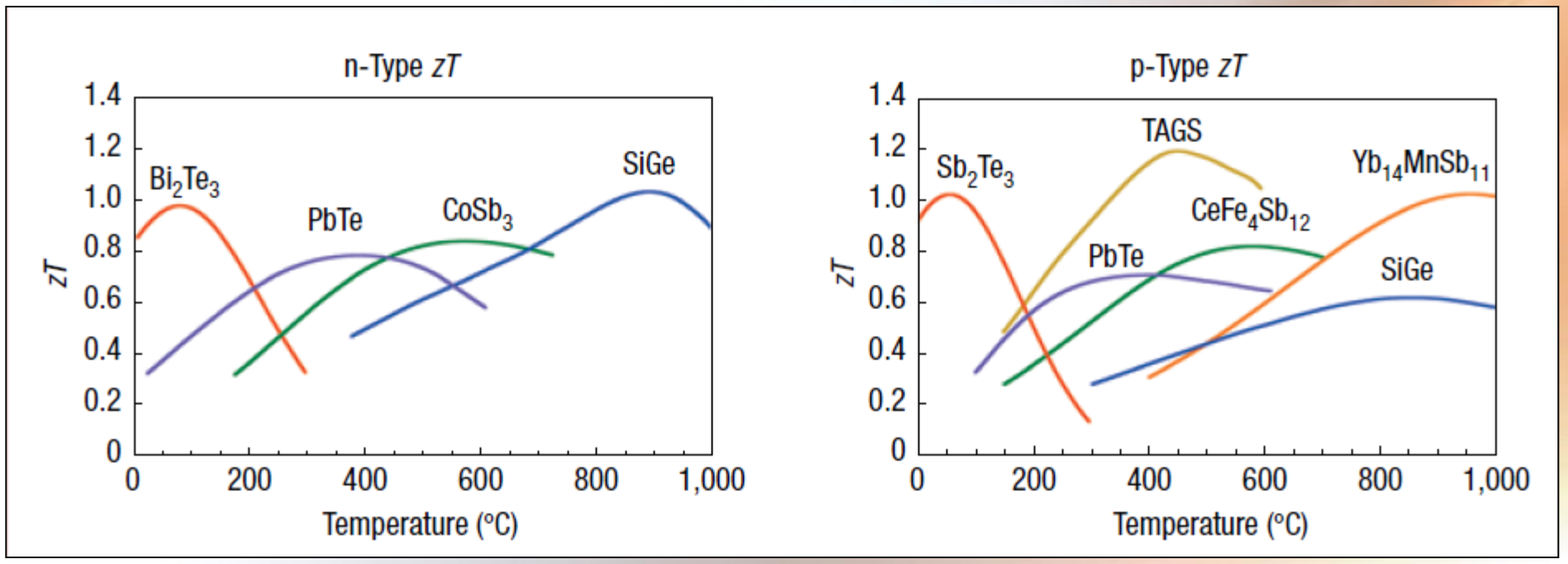
- Designed for long missions where solar tech cannot power the craft reliably.

- SNAP (NASA) models were first RTGs to be launched using Plutonium238 and Uranium235 heat sources.
  - Silicon-germanium, lead telluride and tellurides of antimony, germanium and silver (TAGS).
  - High energy density heat sources.
  - Cassini (Saturn), Voyager (Outer Planets), Curiosity…



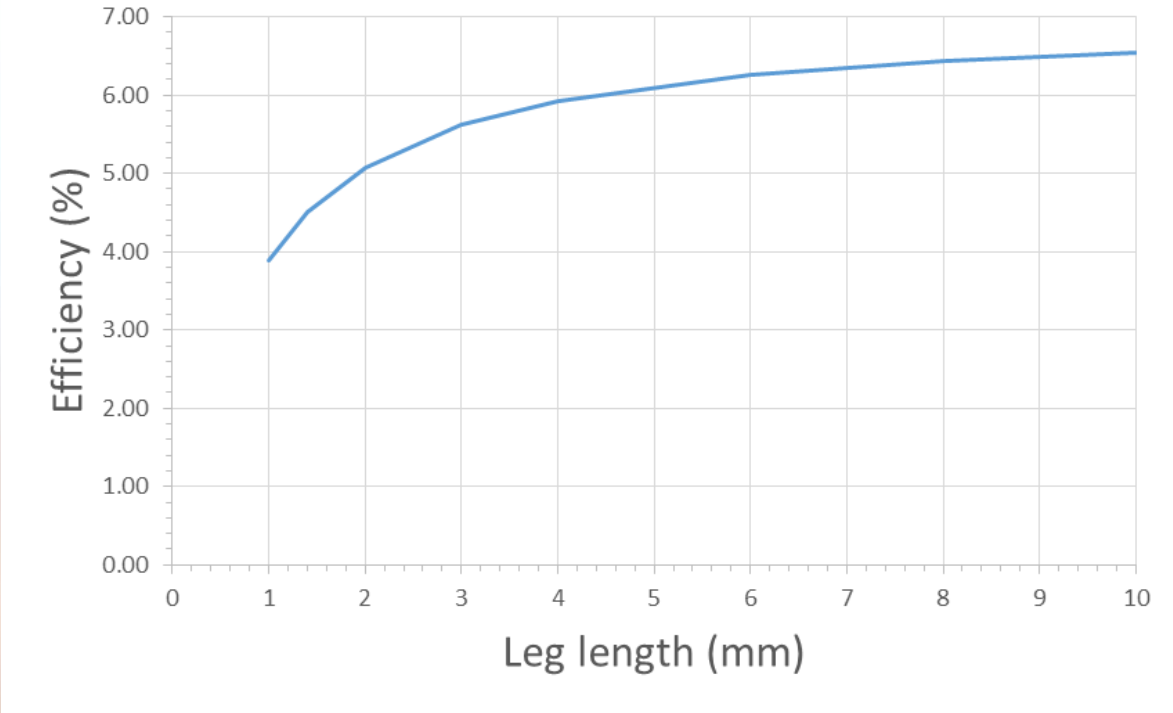
Background

- ESA system to use Americium241.
  - 80W thermal power.
  - With 5% system efficiency => 4W electrical.



Module Requirements

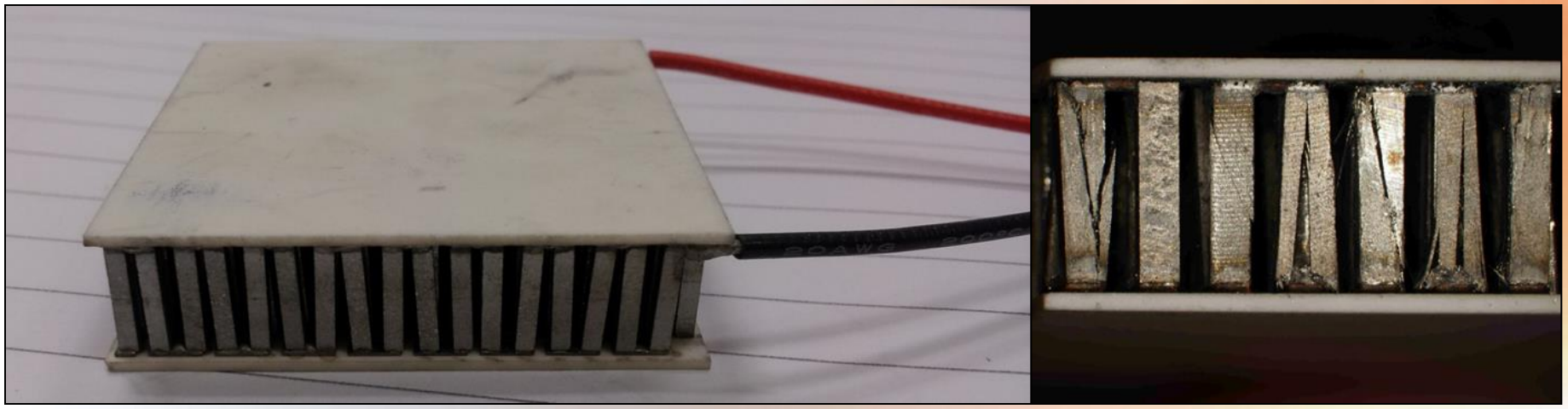
- High efficiency.
- Many couples.
- Robust.
- Requires lower hot side temperature energy harvesting.
- Very low module thermal conductivity to maintain hot side temperature.



Challenges in Manufacture

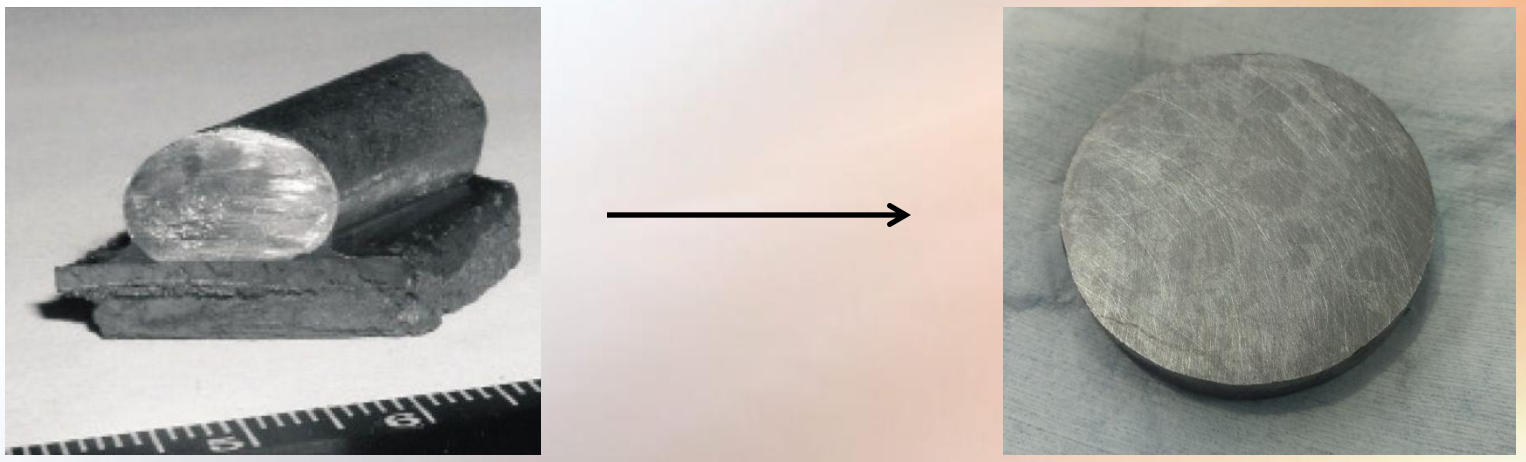
- Taller legs and more couples = more difficult to build.

- Bismuth telluride is brittle.
  - Further complexity in build.
  - Structural strength could be an issue.



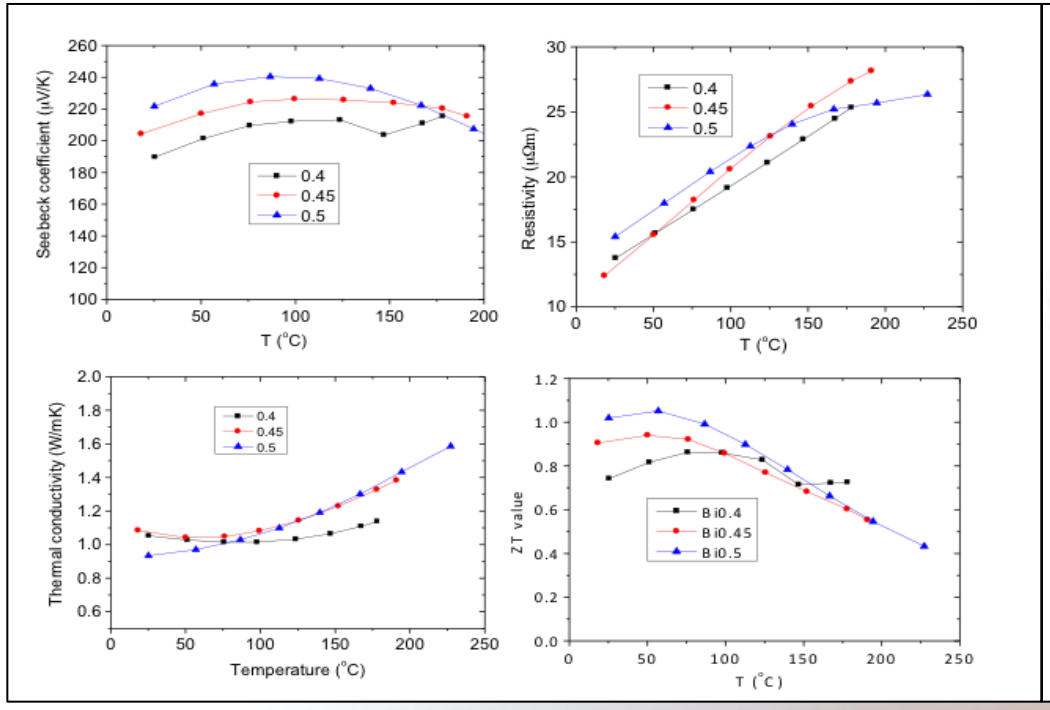
Materials and Manufacture

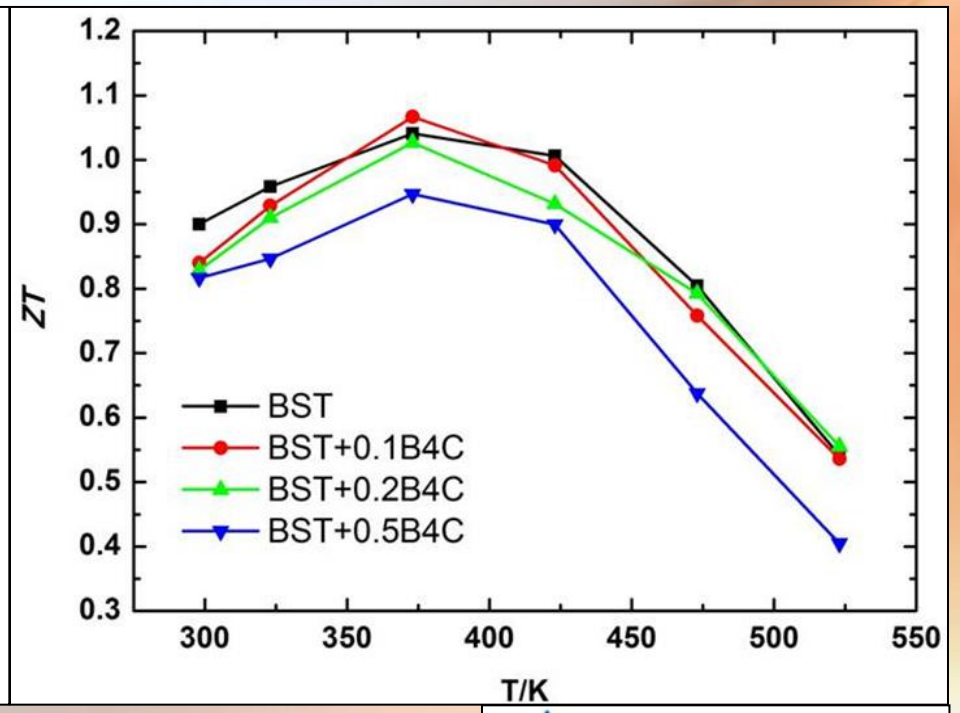
- To improve mechanical properties of bismuth telluride, three routes are compared:
  - Commercial zone melted.
  - SPS from nanopowders.
  - SPS from nanopowder with addition of boron carbide (B4C).



Materials and Manufacture

- P-type made by SPS manufacturing route.
- Addition of B4C to increase mechanical properties.

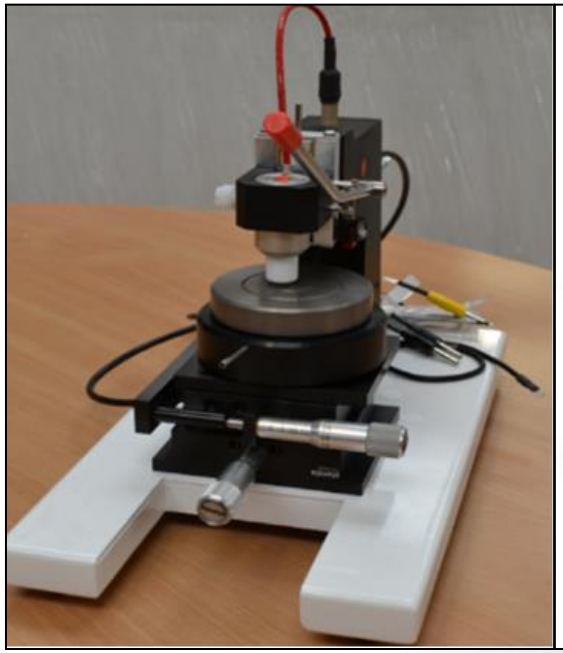


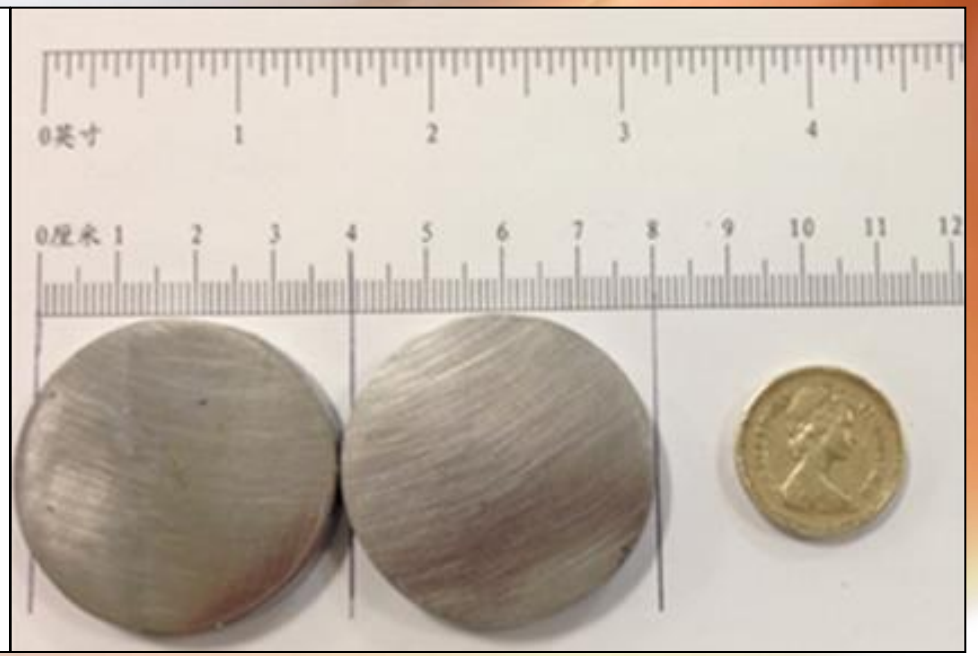


Queen Mary University of London

Puck Electrical Resistivity Mapping

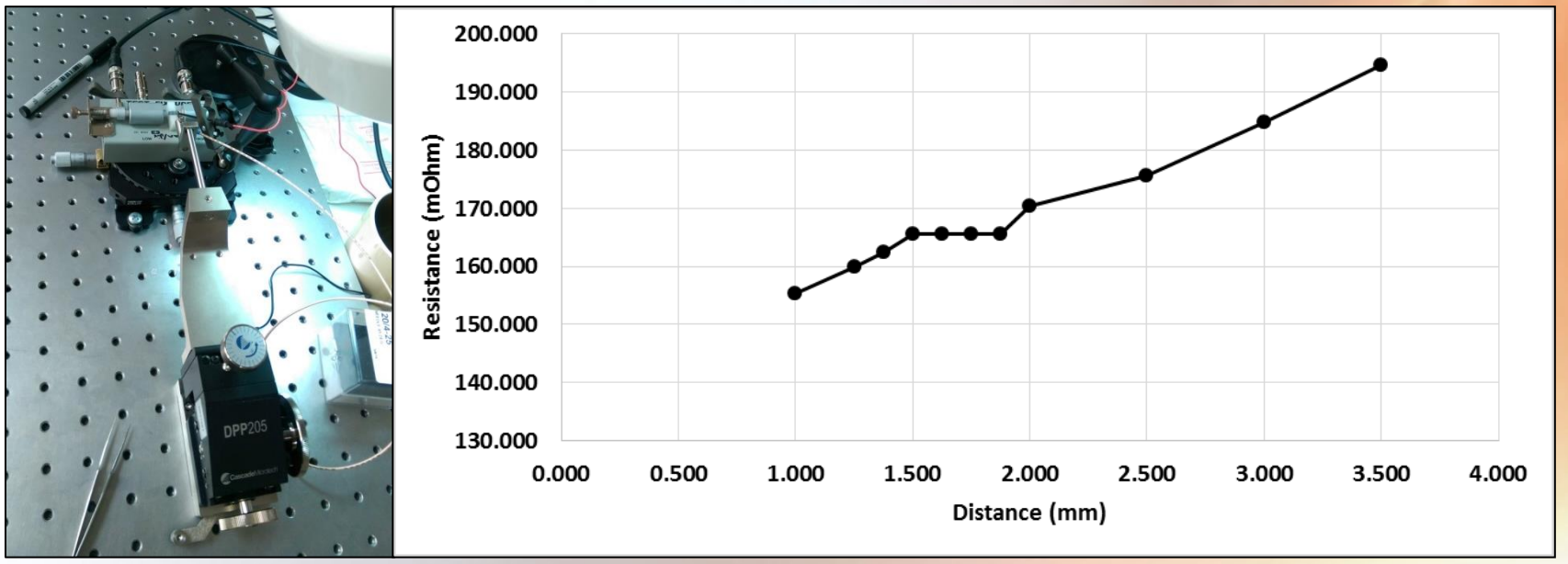
- Room temperature measurements.
  - Quality and uniformity.



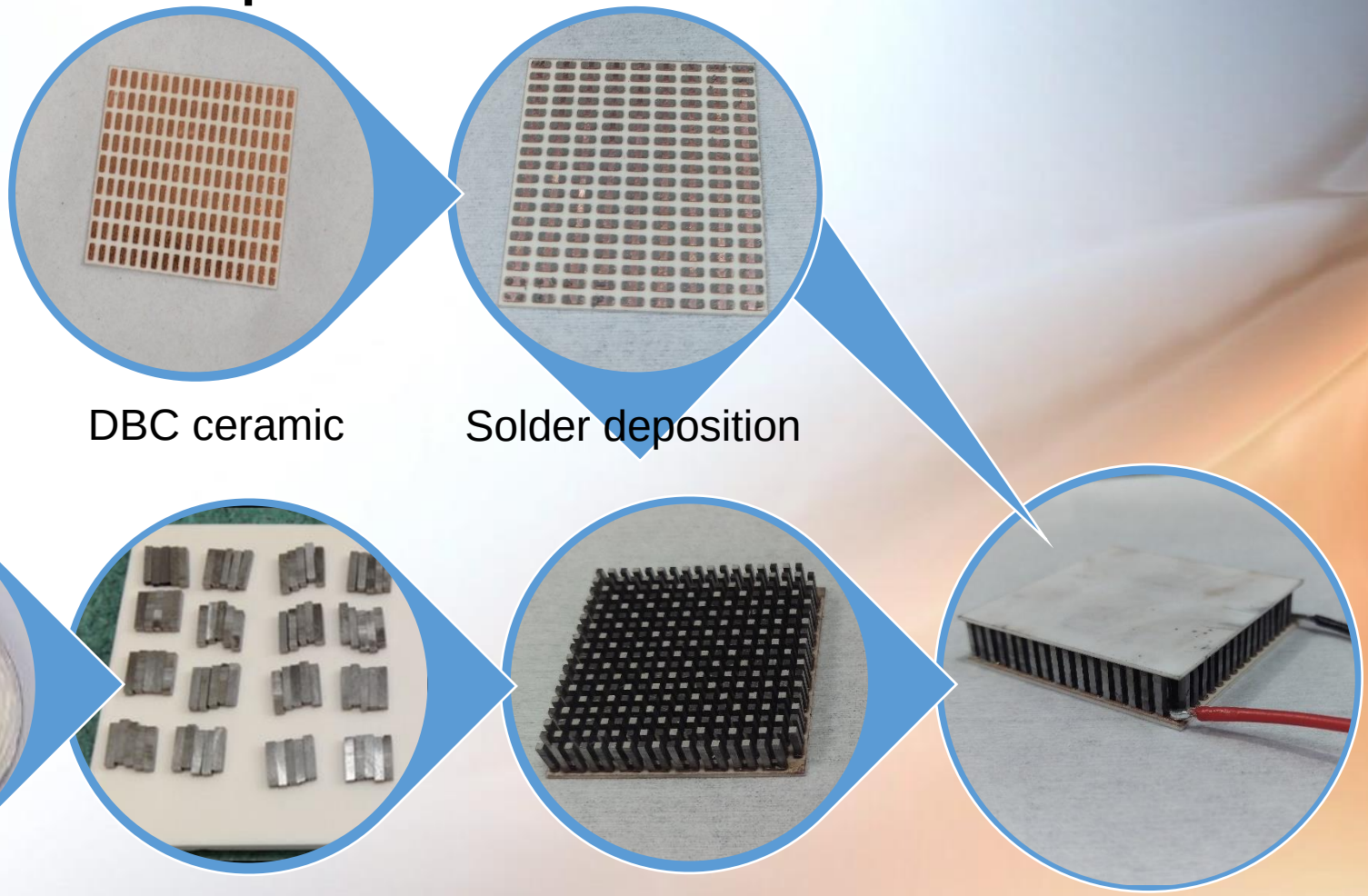


Joining Tests

- Contact resistance $<10^{-5}$ $\Omega.cm^2$.
- Represents <5% of total resistance.



Production process



DBC ceramic

Solder deposition

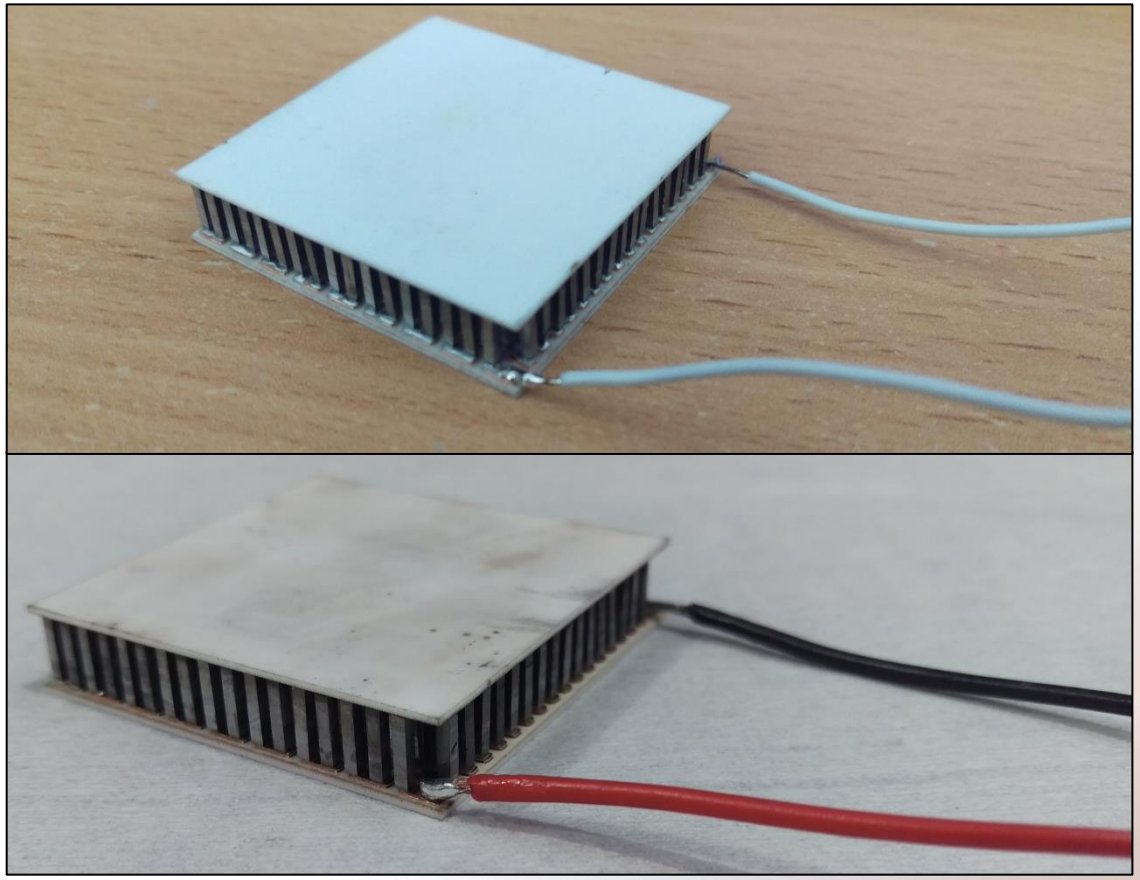
Material formulation and consolidation

Grind, Metallisation and cutting

Add pellets

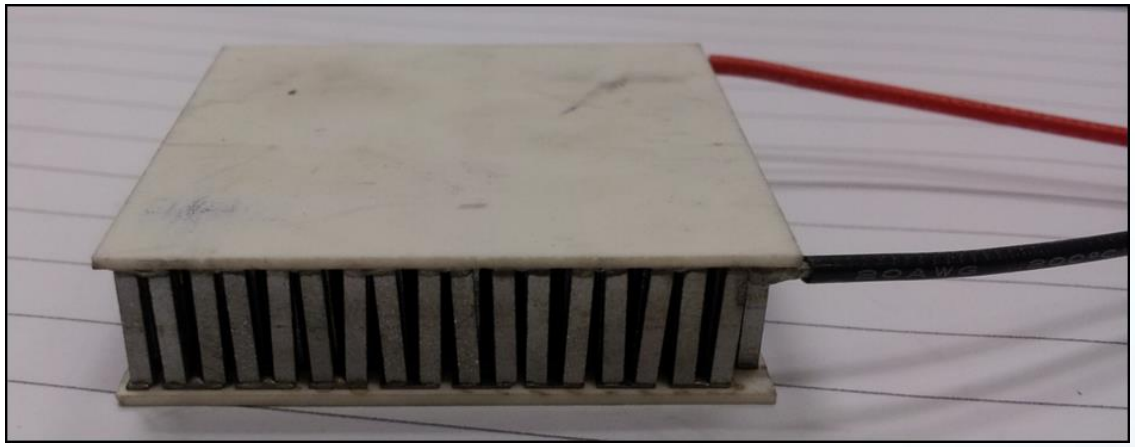
Add top ceramic and wires

Modules for Space Exploration



- 161 couple devices.
- Pellet size: 1.2mm x 1.2mm x 6mm (l,w,h).
- 250^{o}C hot side rating.
- 150^{o}C cold side rating.
- UK manufactured.
- SPS material provided by Queen Mary University of London.

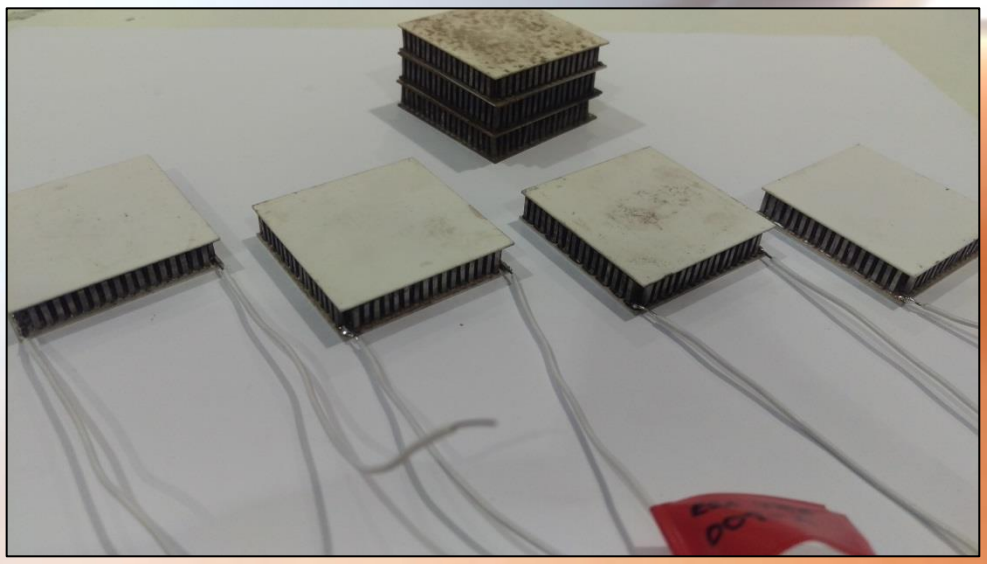
Custom Manufacturing for High AR



- Hard to maintain alignment with high aspect ratio pellets.
- Improvement of custom manufacturing methods.
- Commercial process to custom process shows improvement in pellet alignment.
- Improves:
  - Mechanically.
  - Electrically.
  - Thermally.

Module Manufacturing Quality

- Commercial n-type & SPS p-type Modules:
  - Average resistance = 17.44 Ω.
  - Standard Deviation = 2.50 Ω.



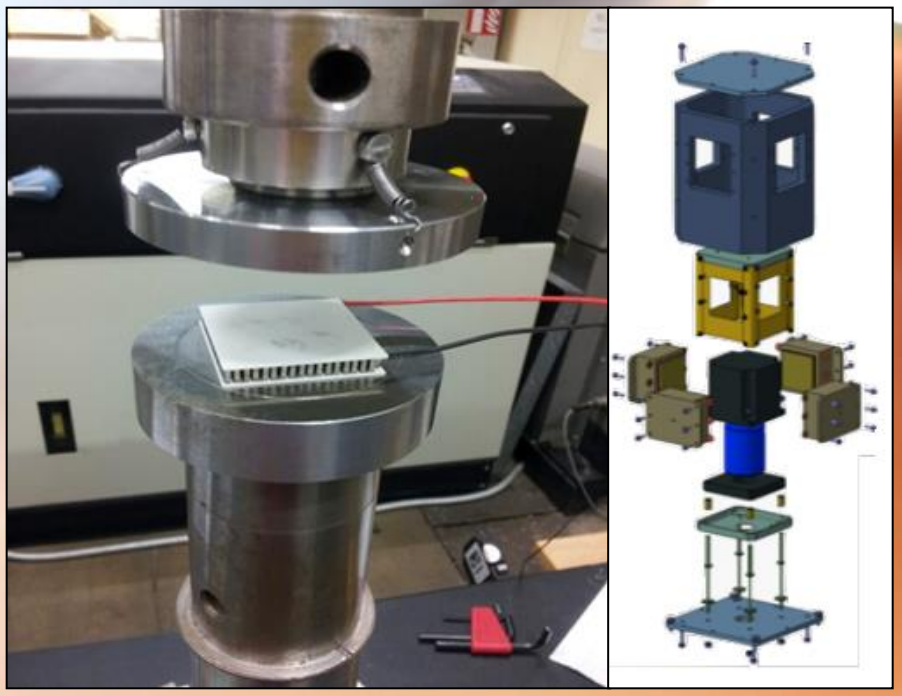
- SPS n-type & p-type:
  - Average resistance = 20.91 Ω.
  - Standard deviation = 0.89 Ω.

- Performance loss from n-type.

- Module manufacture is still challenging but build yield is at 75%.

Next Steps

- Modules are now with Leicester University.
- Mechanical testing and comparison to previous module builds.
- Thermoelectric generation performance testing on breadboard system.
- Explore routes for improving n-type ZT properties.

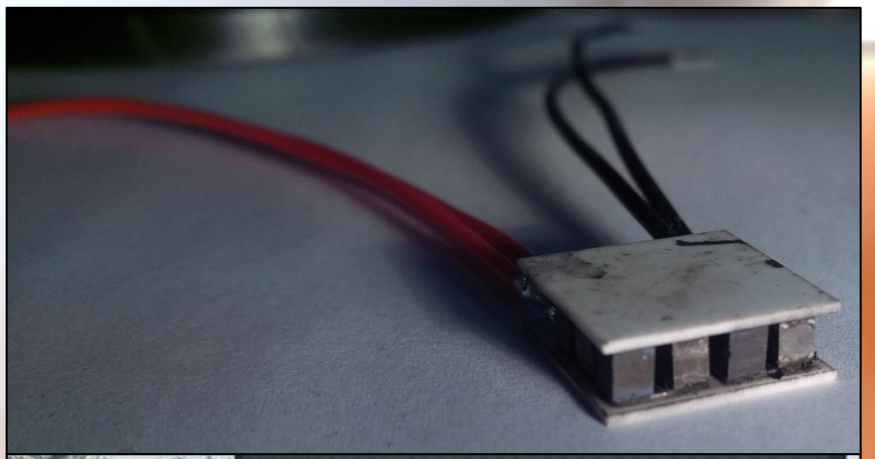


Research Update at ETL

- Currently concentrating on:
  - Skutterudite joining development and module manufacture.
  - Printed and flexible thermoelectrics.
  - PRINTEG pilot line for advanced module manufacture.
  - Silicide module development.

Research Update at ETL: Silicides

- Prototype silicide based modules manufactured.
  - 7-couple device.
  - Module XSec - 260mW/cm2 @ dT =380K
  - Pellets XSec - 760mW/cm2 @ dT =380K.
  - Estimated efficiency 2.8%.
- Current characterisation:
  - Performance data.
  - Reproducibility.
- Ongoing and into the future:
  - Lifetime testing and scalability.
  - Further testing in automotive system.
- More information to come at ECT 2017.



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