European Thermodynamics Limited

Intelligent Thermal Management

TE Modules Production and Control: Present and Future

Kevin Simpson

European Thermodynamics Ltd: an introduction

- Founded in 2001. Private Ltd Co.
- Bespoke thermal management
- 26 full and part-time staff

R&D department (6 Researchers) &

Engineering (8 Engineers and 2 Technicians)

- €5m annual turnover
- R&D projects part-funded by:

BESPOKE DEVELOPMENT FOR THERMAL MANAGEMENT

Mechanical and electronic design

Thermal and stress analysis

Prototyping

Production

LEADING SECTORS


Telecomm


Automotive

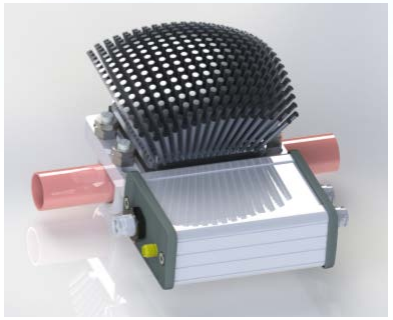

TV & Broadcast


Industrial

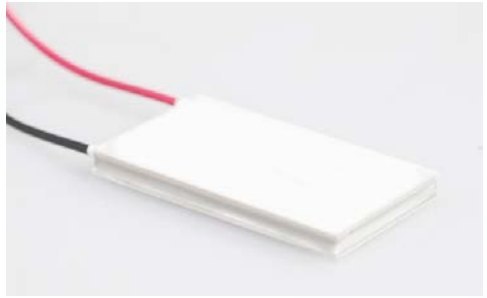

Lab & Medical


Military

New products



Wireless energy harvesting kit

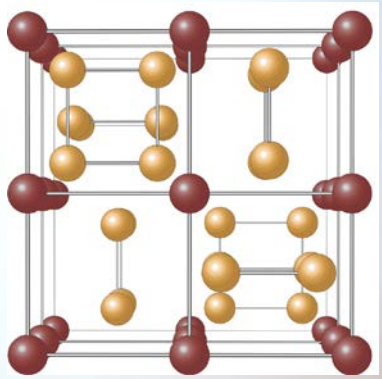


New thermoelectric cooler modules

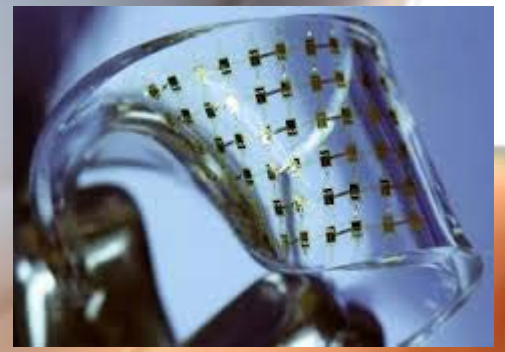
Temperature controller

Thermoelectric assembly

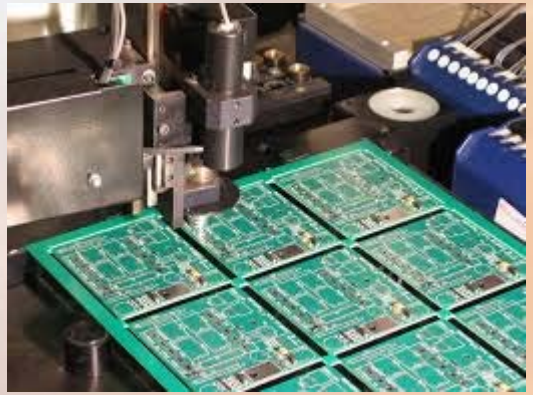
R&D



Novel thermoelectric materials



Flexible TEGs

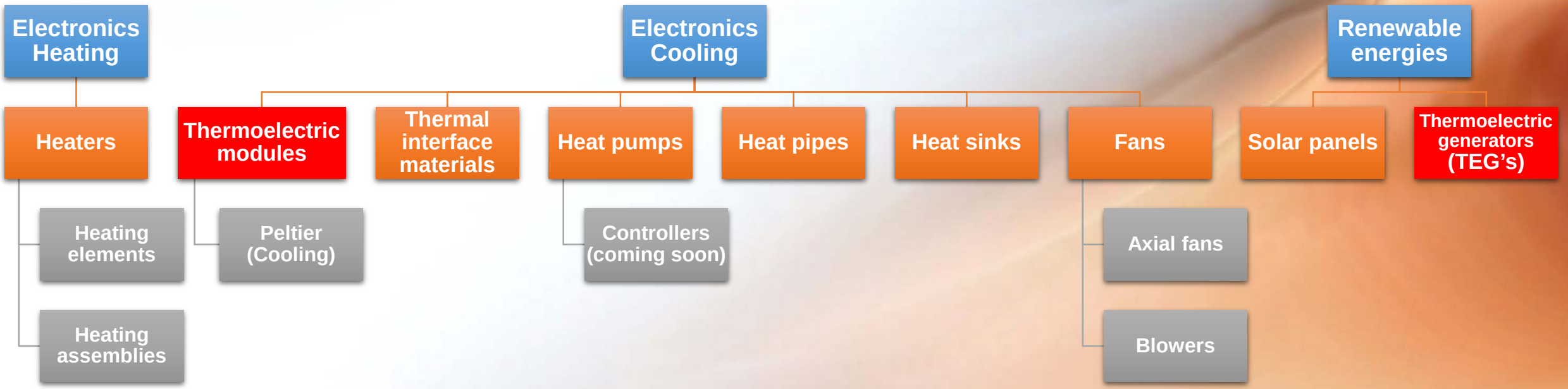


PCB/TEG fabrication

TEG reliability analysis

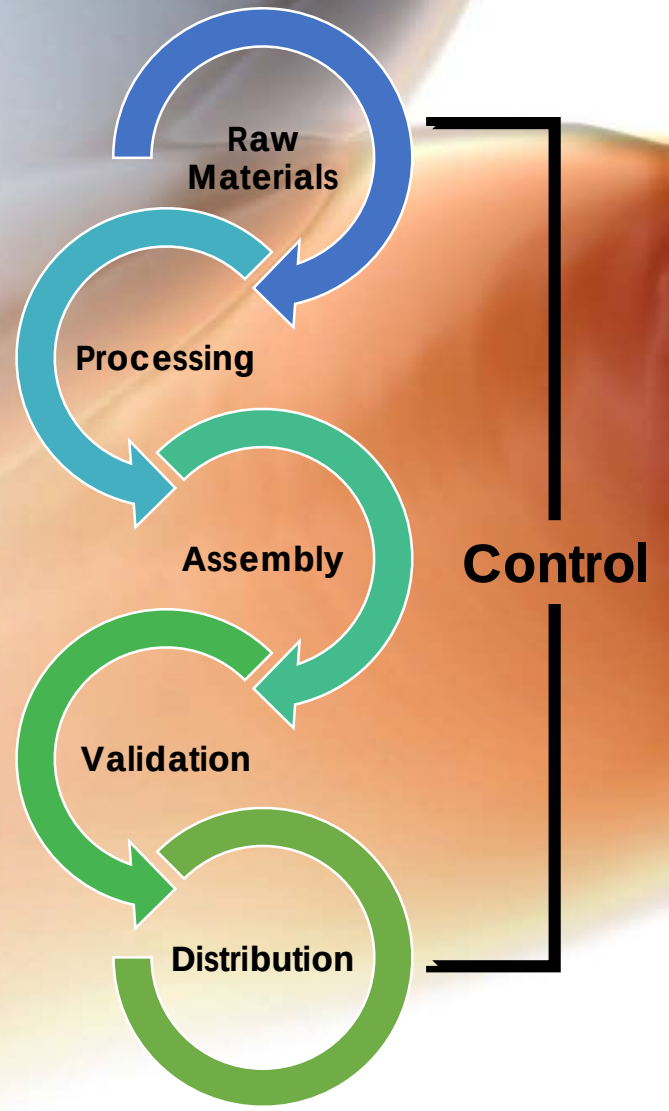
Adaptive™ Thermal Management

Products

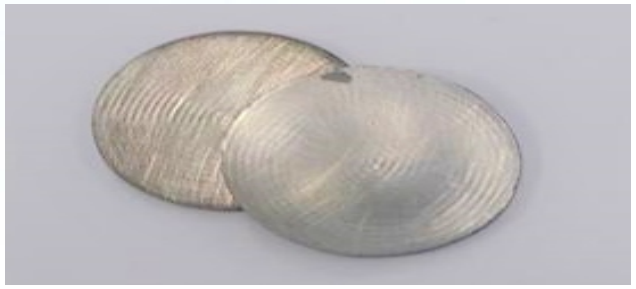

Electronics Heating
Electronics Cooling
Renewable energies
Heaters
Thermoelectric modules
Thermal interface materials
Heat pumps
Heat pipes
Heat sinks
Fans
Solar panels
Thermoelectric generators (TEG's)
Heating elements
Heating assemblies
Peltier (Cooling)
Controllers (coming soon)
Axial fans
Blowers

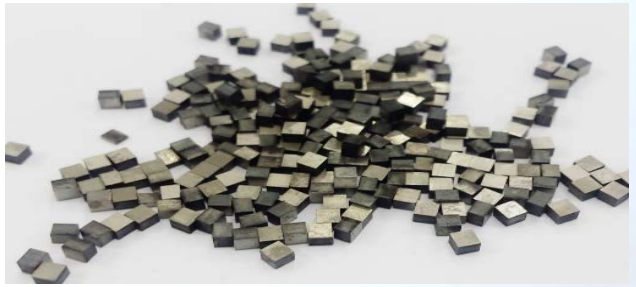
Current Research into Manufacturing

- Aims:
  - Establish a UK supply chain for Thermoelectric module manufacture
  - Bespoke and unique module design and fabrication
  - Increase material efficiency and production autonomy
  - Novel thermoelectric materials to exploit alternative markets through USPs
    - Powder formulation, Sintering Process, Metallisation, Cutting, Joining and module assembly
  - Design and manufacture high reliability devices
- Projects:
  - PrinTEG-Automated production line for TEGs
  - ElectroTEG-Electrodeposition of TE material to increase efficiency of manufacture
  - Prestege-Screen printing of thermoelectric pastes. Flexible substrates
  - Enhanced-Ink jet printing of TE inks. Complex module designs on flexible substrates



Control Stages





Material Consolidation

- Seebeck
- Thermal Conductivity
- Electrical Resistivity
- Mechanical Testing

Thermoelectric Pellets Machining

- Dimensional Control
- Contact Resistance
- Metallisation Barriers

Thermoelectric Device Assembling

- Harman Method
- AC Resistance
- Module Performance Test Rig

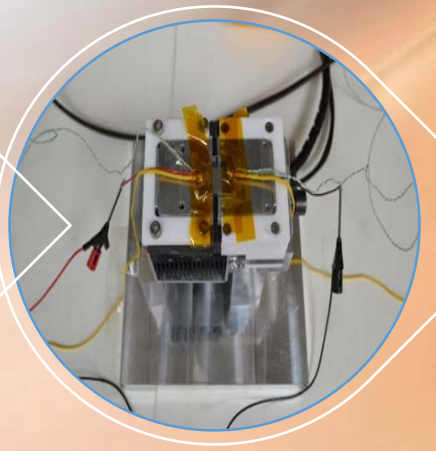
Control Methods →

Prestege & Enhanced Screen/Ink-Jet Printed TEGs

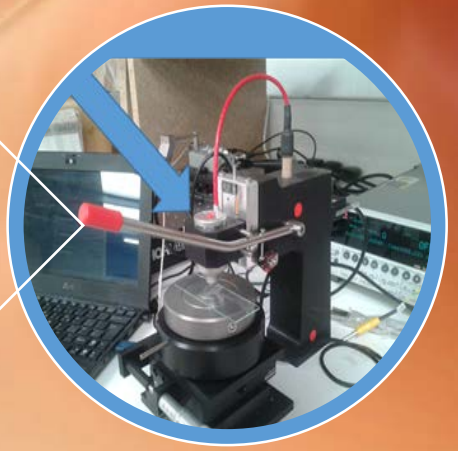
- Utilising established manufacturing techniques applied into reproducible/scalable TEG manufacture
- Reduced material wastage
- Validation of controlled characteristics:
  - Bespoke Seebeck test rig
  - 4 point probe sheet electrical resistivity

Silk Screen Printing

Firing/Sintering



Seebeck Characterisation



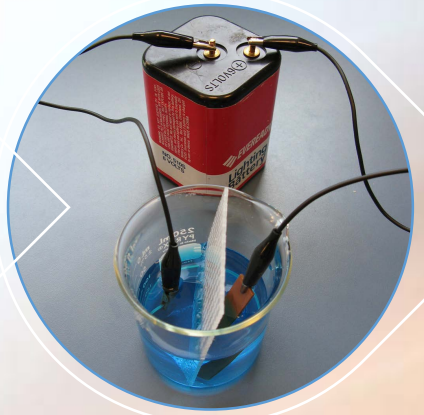
Electrical Characterisation

Ink-Jet Printing

ElectroTEG
Electrodeposited TEGs

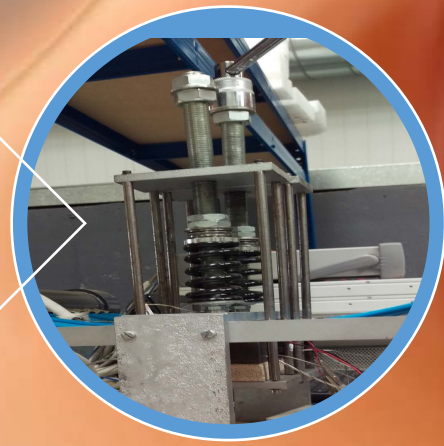
- Developing novel plating formulation
- Low cost and scalable process
- Reduced material wastage
- Full prototype module characterisation:
  - AC resistance
  - Power performance
  - Harman measurements
  - Hall measurements

Solution Formulation



TE Electroplating

Material joining



Performance Characterisation

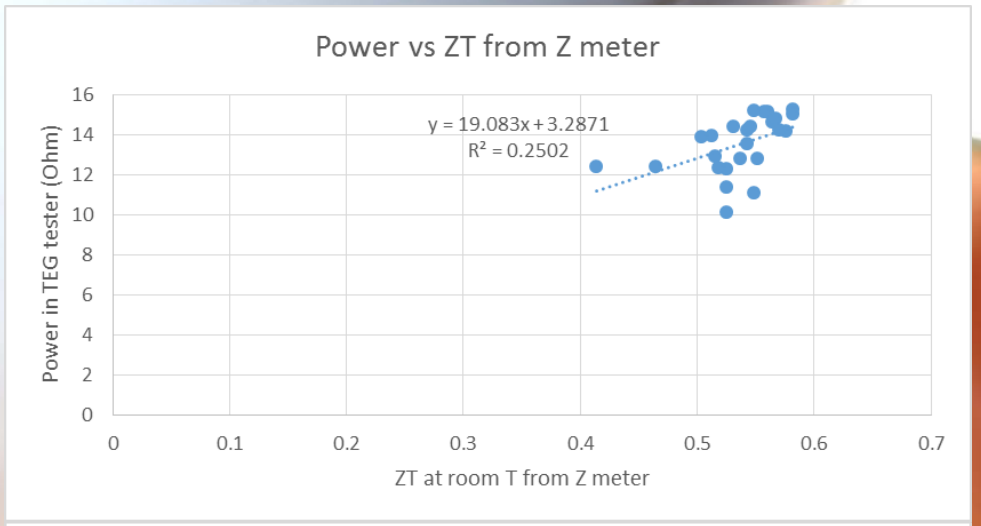
PrinTEG:
Control Within Fabrication Process

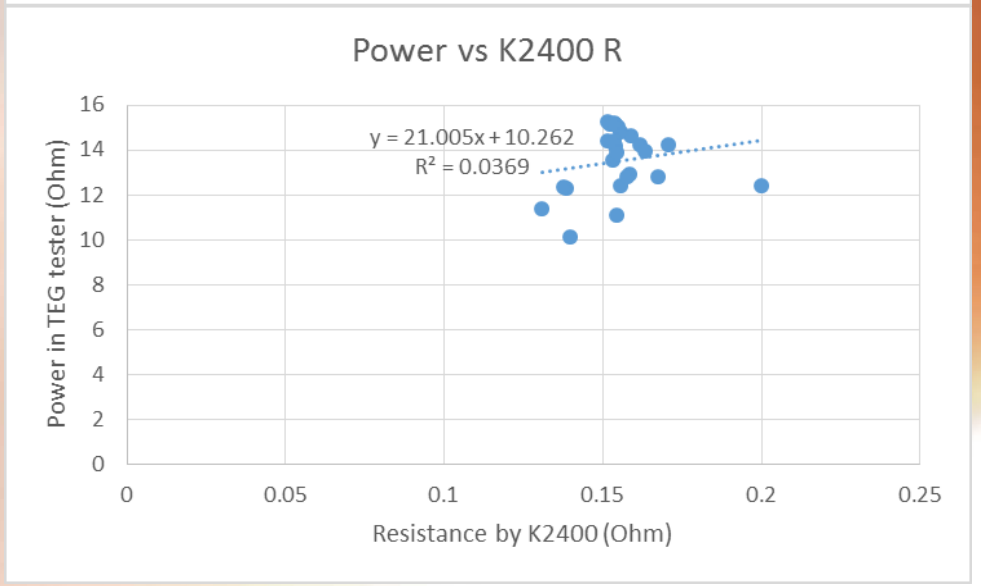
- Accuracy and reliability:
  - Placement accuracy to approximately ±20µm.
  - Minimum spacing 100µm.
  - Higher: Voltage, fill-factor/power density.
  - 200 pellets placed accurately.
  - Minimal human interaction.
  - Continuous production process.
  - Approximately 4 minutes to accurately position pellets for a module.
- Validation:
  - Pickup inspection-Single pellets.
  - Cyberoptics, optical inspection-macroscopic inspection.

**Equipment running at 30% speed for purpose of video.*

PrinTEG: Control Within Fabrication Process

- For industrial production levels, inline characterisation techniques must be developed for quality control
- Necessary requirements:
  - Quick measurement
  - Non-destructive
  - Accurate
  - Able to extrapolate from measurement
- Current issues arise with correlation between different measurement techniques e.g.:
  - TEG matched power point value (slow/offline)
  - Z-meter/Harman measurement (quick/inline)
  - 4-point probe resistance (quick/inline)
  - AC Resistance (quick/inline)





Device Performance

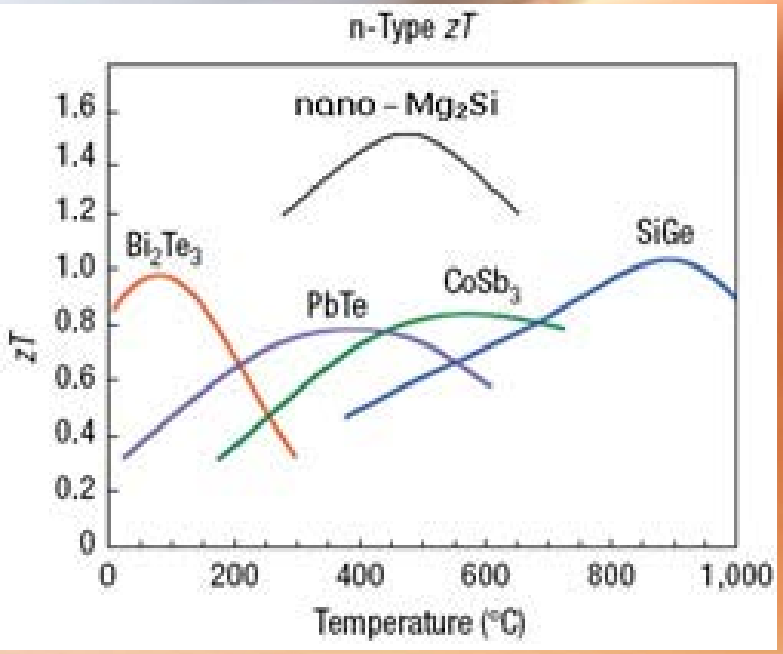
- ETL has carried out a literature review on module characterisation techniques used by manufacturing companies worldwide
- There is no standard method for accelerated lifetime tests
  - The variation in test methods lead to non comparable data
- Many follow a variety of military standards designed for general electrical systems
- The difficulty in unifying lifecycle testing is that there are a multitude of applications that thermoelectric modules are used for
- We propose defining a set of lifecycle testing methods which are compatible for a variety of general applications
- This will benefit end users and material developers

- Non-unified test categories:
  - Mechanical shock
  - Vibration
  - Shear force
  - High temperature soak
  - Thermal cycling
  - Thermal shock
  - Temperature gradient

Thermal cycling test rig developed to assess reliability

Desirable Material Characteristics

- Characteristics for determining suitability of new materials to realise material-prototype and prototype-mass production transition:
  - Material abundance and low toxicity
  - Estimated cost of processing and manufacturing route
  - Average ZT or peak ZT
  - Thermal stability > Ease of joining
  - Ease of metallisation
  - Mechanical characteristics (as a structural component)
  - Tailoring properties based on proposed use
    - E.g. Balancing power factor with thermal conductivity based on heat source and sink properties



Problems to Overcome

- Directions for determining performance of new materials
  - Estimated cost of processing and manufacturing route
  - Average ZT or peak ZT
  - Consider feedback from **module** lifetime cycling
- Inline characterisation issues: Devising a method which can take a quick measurement that accurately represents quality of a device
- Standardising methods for characterisation throughout supply chain and manufacturing
  - Promote accurate comparisons for a range of general systems/applications
  - Continuity/traceability
- **End user confidence in UK supplied thermoelectric modules**

Challenges

- Oxidation
- Metallisation
- BiTe replacement
- Mechanical strength
- Brazing formulations
- N and P type performance matching
- Thermal stress problem
- Low cost process development
- Module reliability/material stability
- Interfacing (materials or direct application)