The University of Manchester

Graphene Engineering Innovation Centre

Graphene & 2D Materials In Thermal Management Systems

5th May 2026

Graphene@Manchester

The world's leading Graphene & 2D Materials research and commercialisation centre



National Graphene Institute (NGI)

NGI vision: Use various 2DMs as building blocks for advancing functional materials by smart design

NGI operates between technology readiness level (TRL) 1- 3

The NGI positions Manchester as the global home of graphene, recognised for leading scientific output and high-impact breakthroughs

Who are we?

Graphene Engineering Innovation Centre



The GEIC has delivered over 700 projects to **more than 500 companies** working on proof-of-concept to prototype developments (TRL 3 to 6).

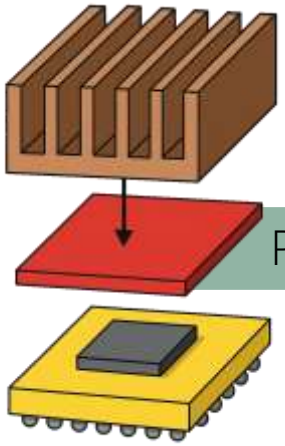
Creating and optimising products.

Scale-up and supply chain integration.

“Bridging the gap between research and industry”

Information Classification: General

Design, Make, Evaluate, Repeat



Problem

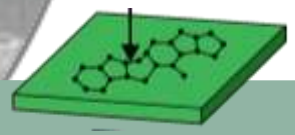
Research & Design

Make Prototype

Developing a 2DM-enhanced demonstrator

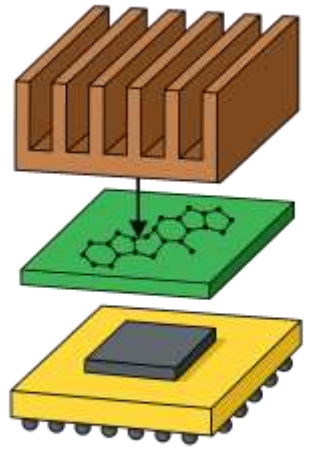
Test "Make or Break"

Improve or Fail Fast



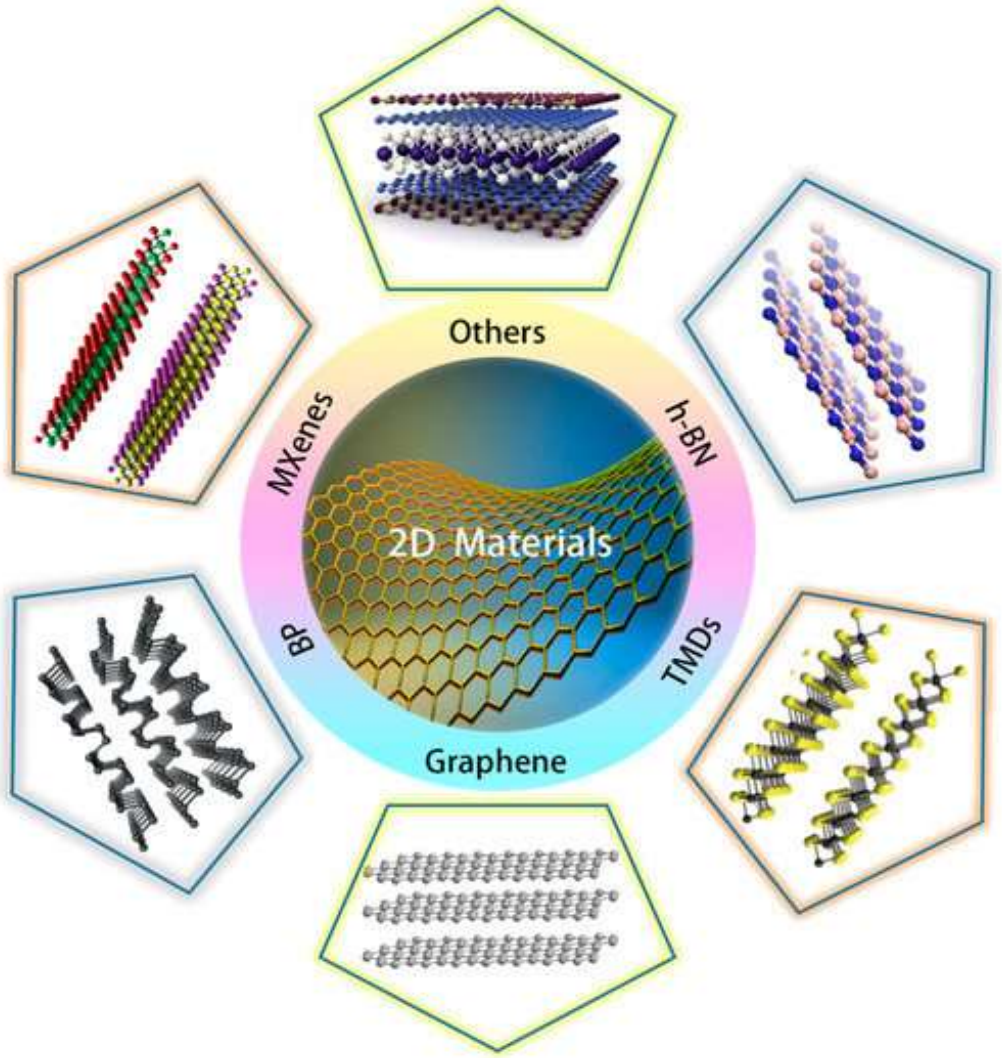
Validation of upstream partners and markets

Rapid material tailoring with downstream partners



Information Classification: General

Graphene and Other 2D Materials



A host of 2D materials each with unique thermal, electrical, and mechanical properties.

Graphene, h-BN, MXenes, MoS_2, WS_2 and hybrids drive next generation thermal solutions.

Different types and functionality - application dependent

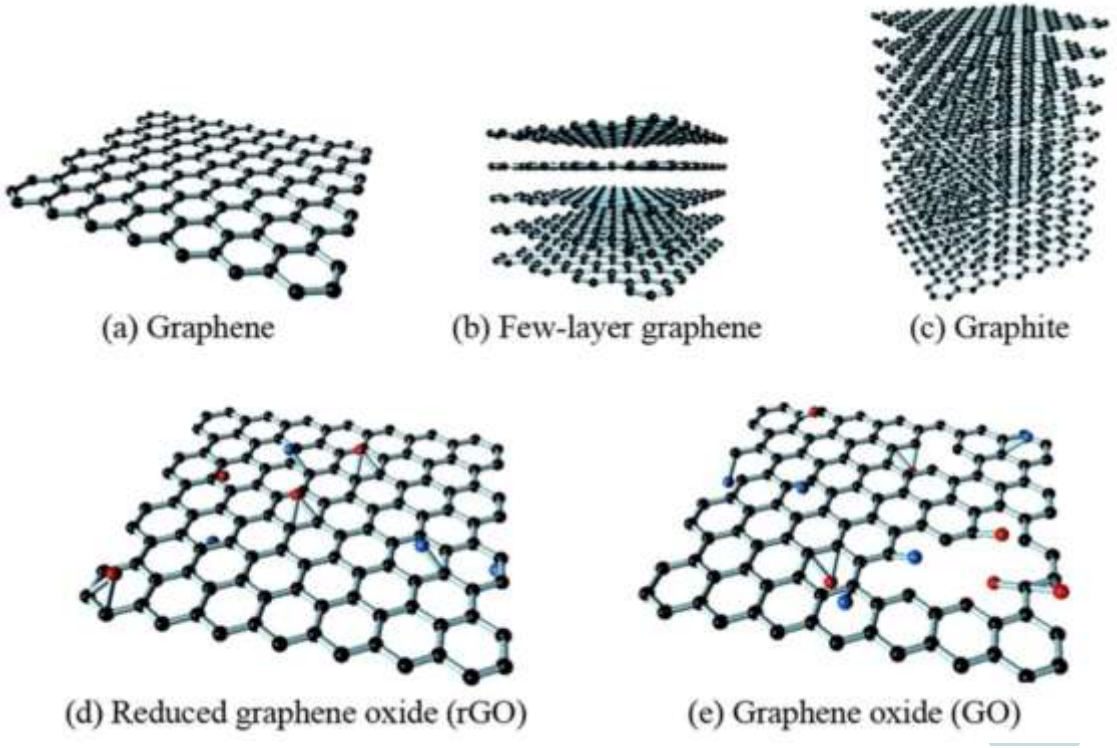
$M_{n+1}X_nT_x$, Where M - early transition metal (Ti, V, Nb, Mo etc) , X- Carbon/Nitrogen , T_x- surface terminations formed during etching (-O, -OH, -Cl etc.)

https://doi.org/10.3390/molecules24010088

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Graphene and 2D Materials

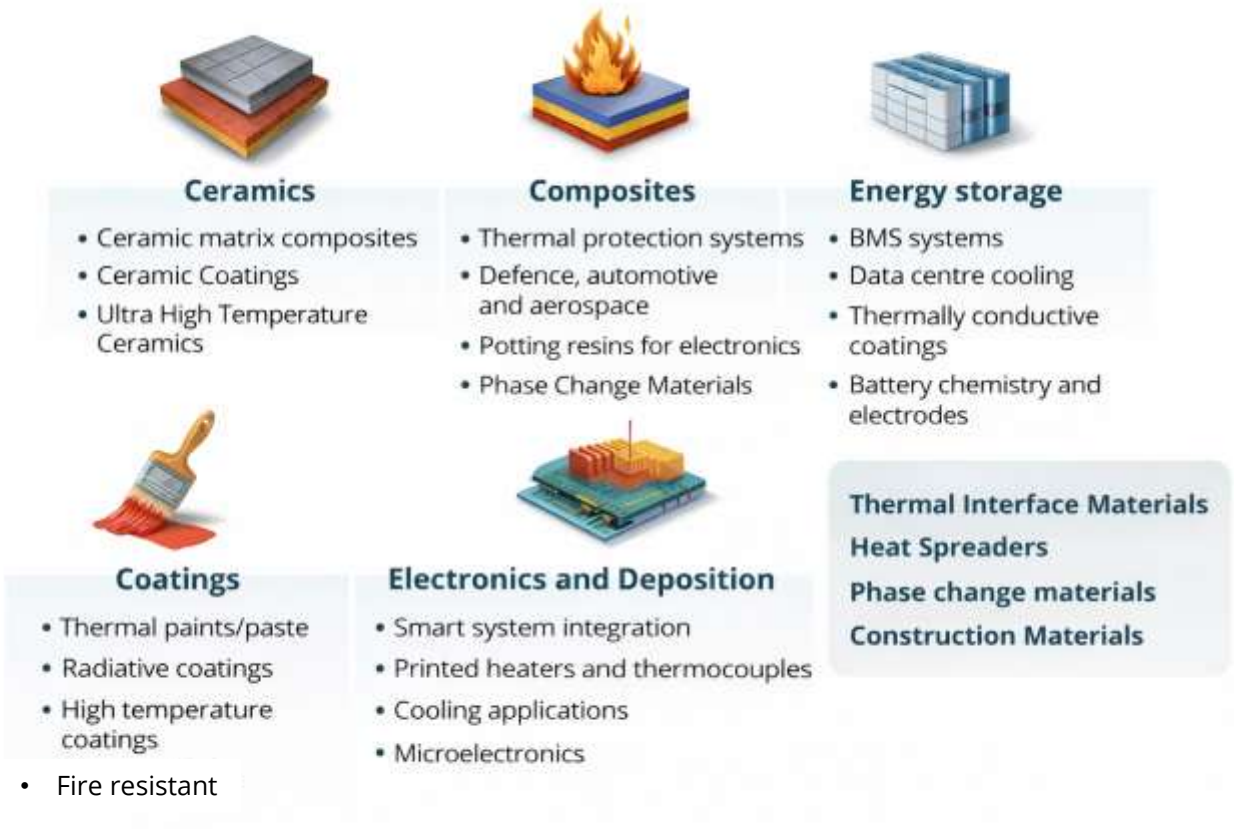
Feature	Single-Layer (SLG)	Few-Layer (FLG)	Graphite/Multi-Layer
Strength	Highest (Theoretical)	Excellent	Moderate
Dispersibility	Very Difficult	Manageable	Easy
Cost	Prohibitive	Moderate	Low
Best For	Sensors and Electronics	Structural Composites	Lubricants and Batteries



Information Classification: General

Application Areas for Thermal Management

Exceptional in-plane heat conduction ; Electrical insulation with strong heat flow; Interface engineering; Ultra-thin and lightweight



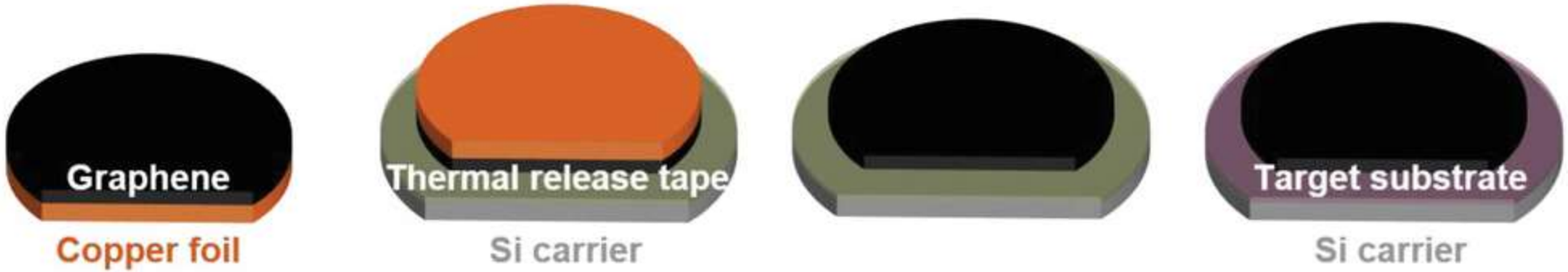
- Multifunctional Materials
- Key bottlenecks: Large area production and integration into existing manufacturing lines and cost
- **Application dependent**

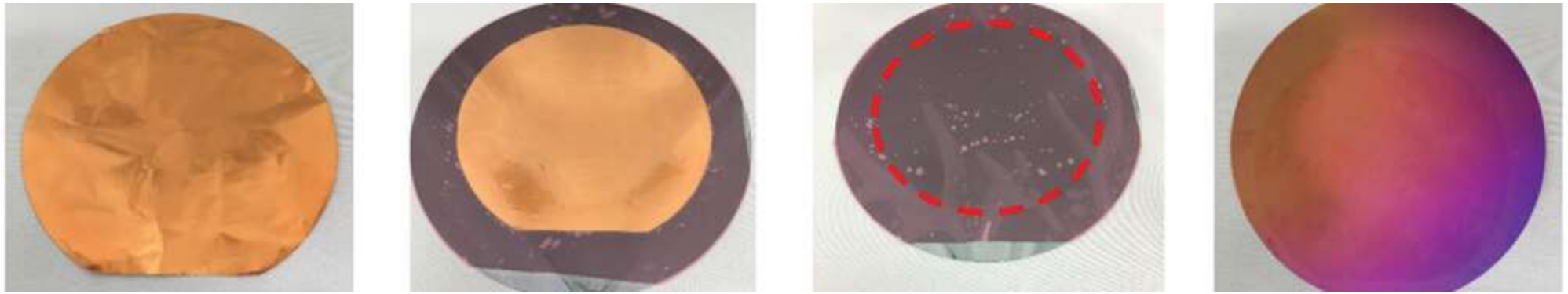
Information Classification: General

TIMs - Heat Spreaders in microelectronics

For developing processes from scratch:

CVD Growth | Transfer mechanism | Graphene-embedded electronics





10.1002/admt.202201587

Applications: High speed transistors, low resistance contacts, conductive electrodes, Chip cooling

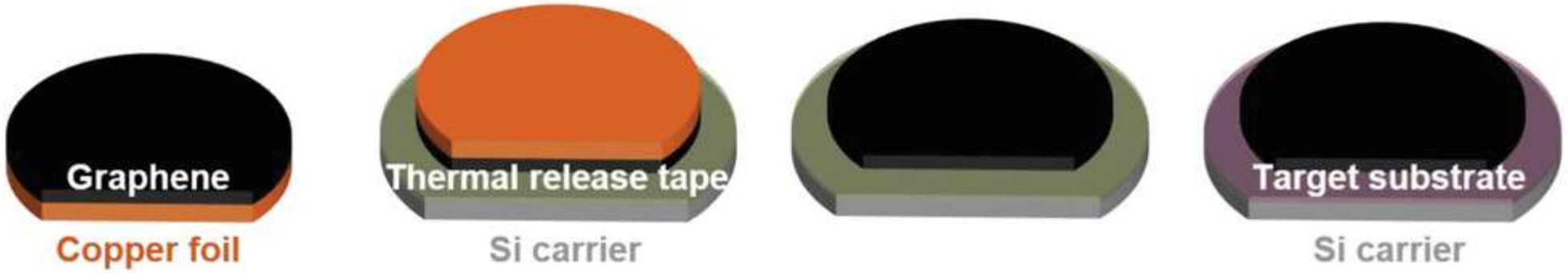
TIMs - Heat Spreaders in microelectronics

Utilising Graphene@Manchester:

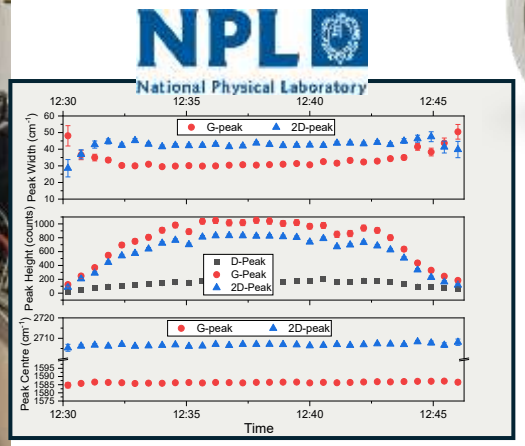
CVD Growth

Transfer mechanism

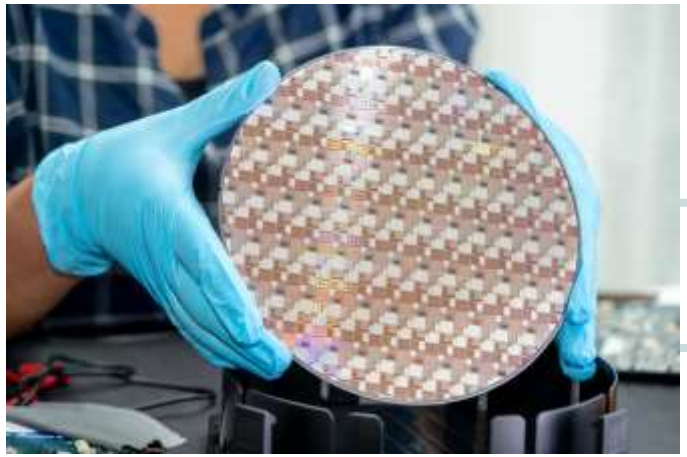
Graphene-embedded electronics







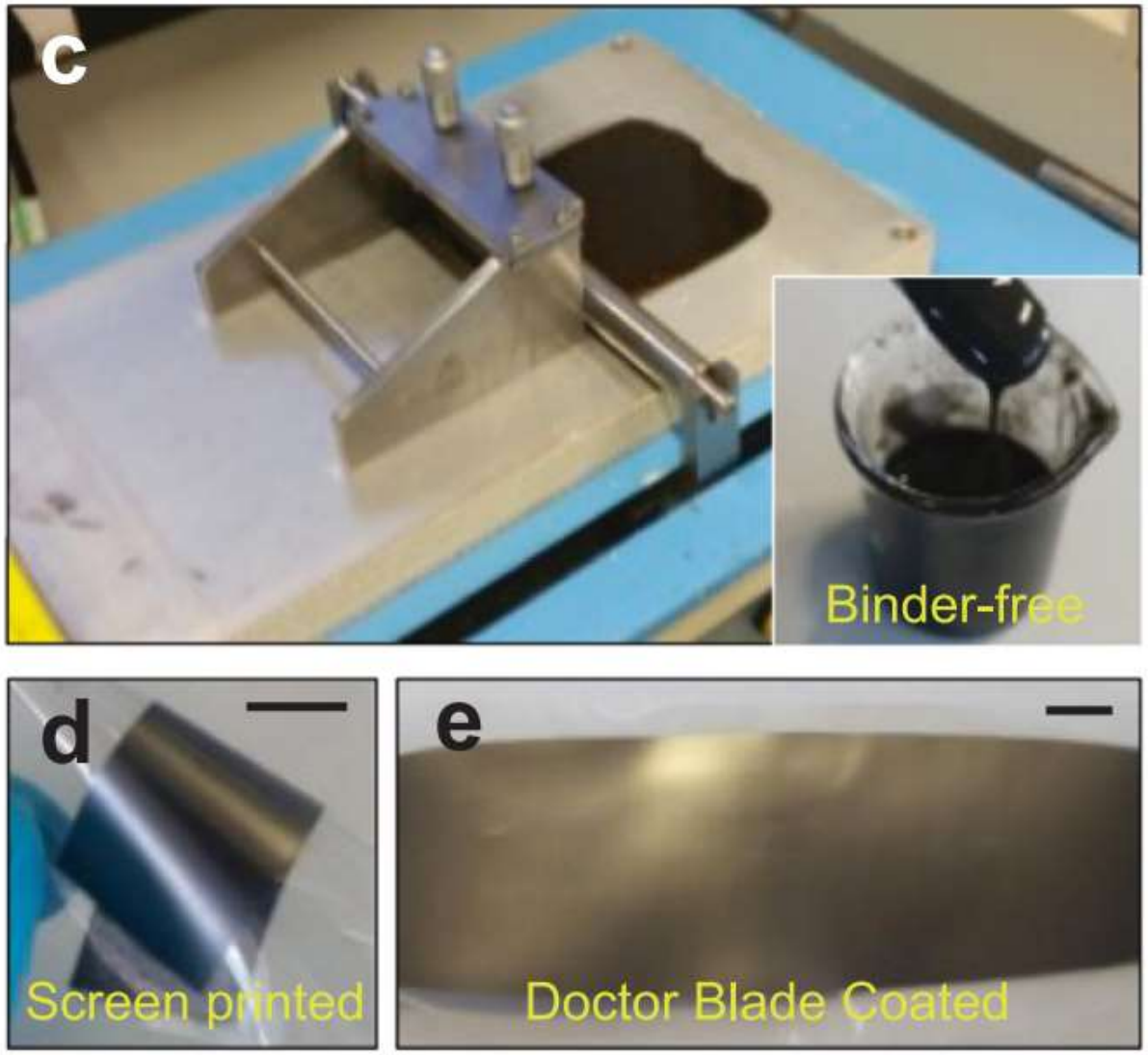




Information Classification: General

TIMs - Heat Spreaders (Top Down)

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Benchmarking and characterisation

Feasibility and scalability assessments

Graphene, h-BN and MOS_2 laminates (10 – 20 µm)

- High electrical conductivity (3100 ± 250 S/cm) for microwave shielding.
- Dielectric h-BN laminates with high resistivity (10^{14} Ohm cm)
- Mobile phone chip cooling applications

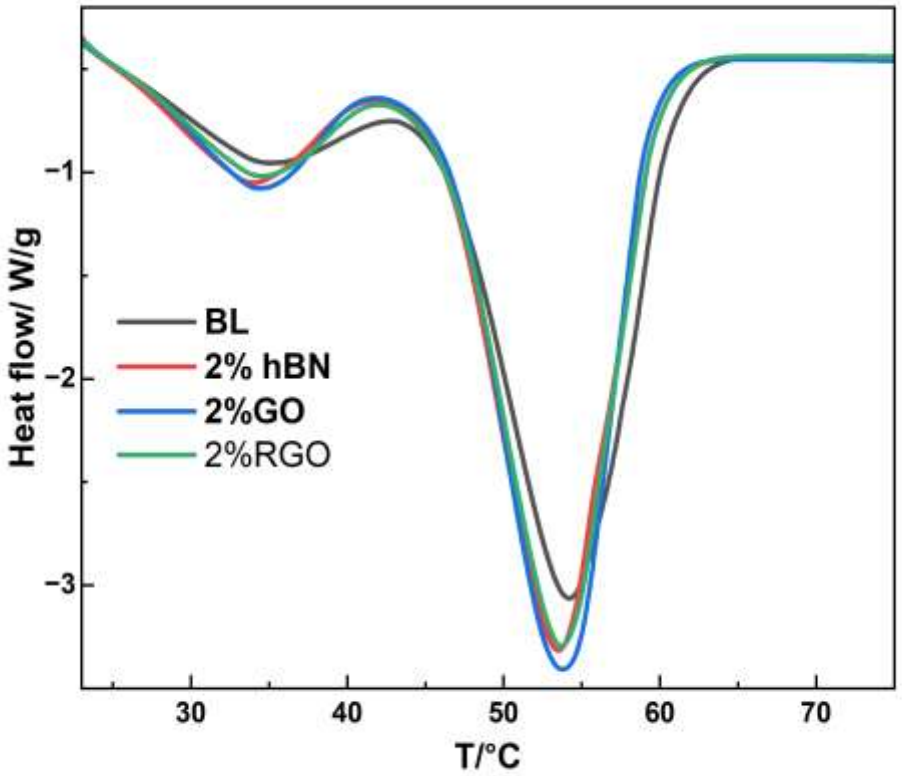
Information Classification: General

Moazzami G. et al. 2021. https://doi.org/10.1038/s41699-021-00215-2

TIMs – Phase Change Materials

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2DM can transform phase change applications

Balance between conductivity and latent heat storage capacity

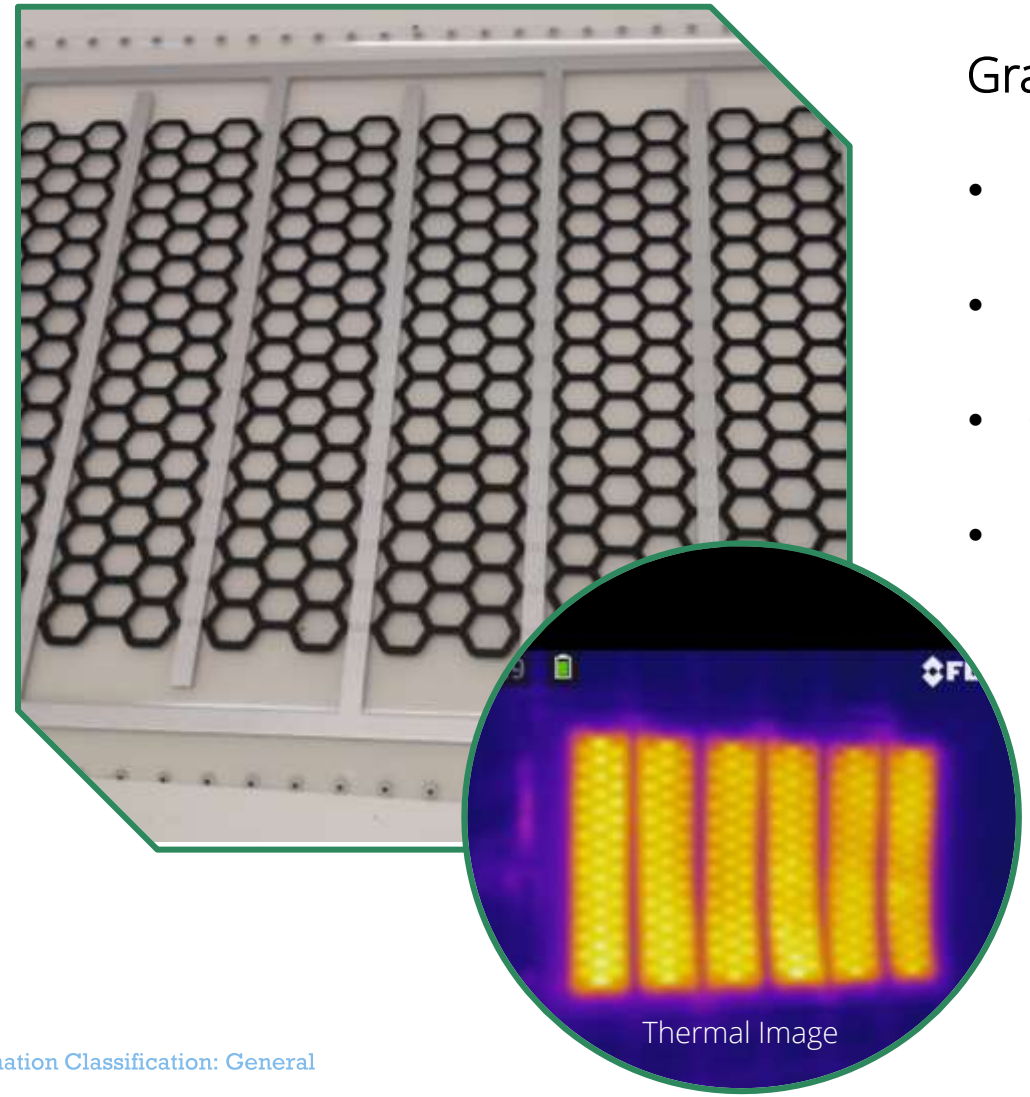
Material and loading optimisation, application dependent

DSC curve: Filler dispersion and interfacial bonding affect heat flow and phase transition behaviour

Information Classification: General

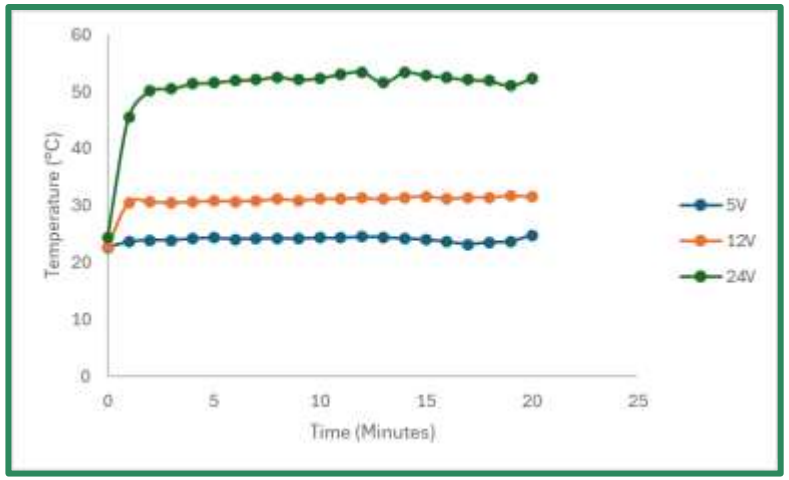
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Printed Electronics



Graphene heating panel with silver bus-bars

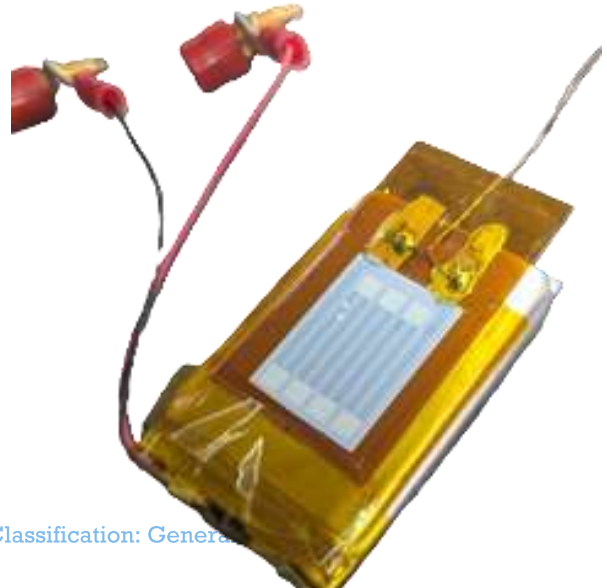
- Large print area (up to 750 mm x 750 mm)
- Printing on various substrates (e.g., PET, fabric)
- Can be embedded into carbon fibre composite panels
- Uniform heat spreading

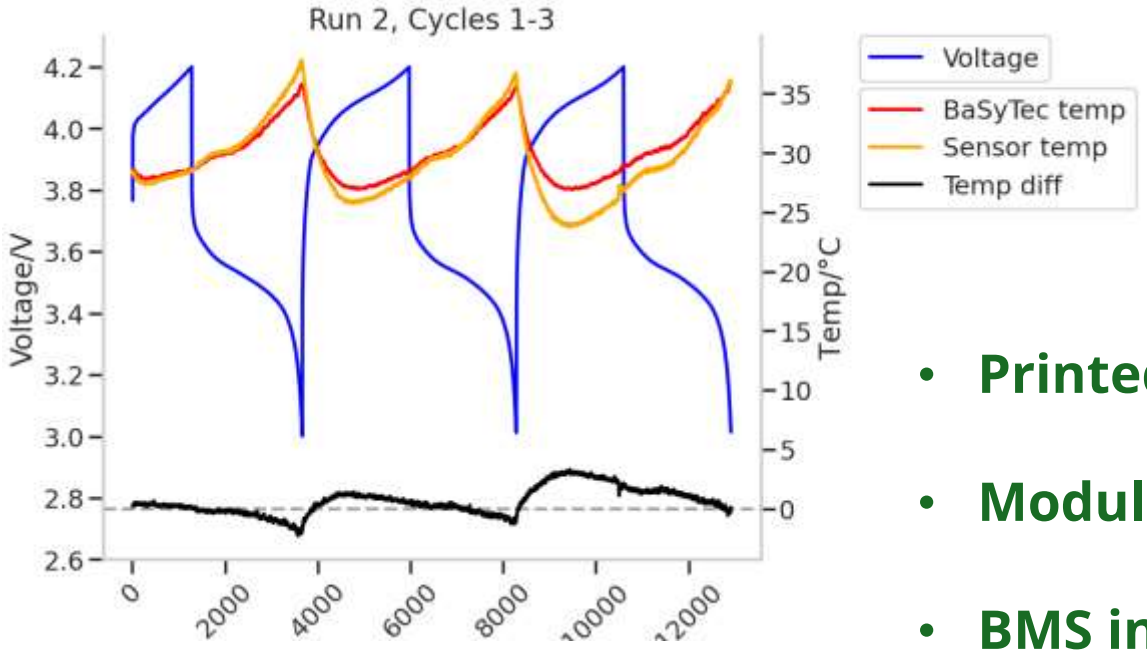


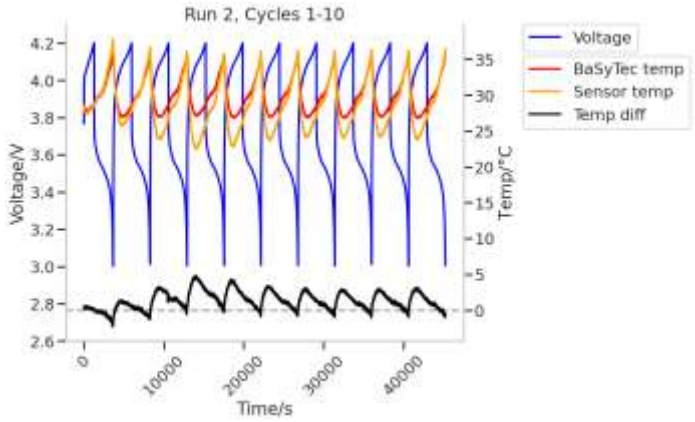
Information Classification: General

Printed Electronics / Battery Temperature Monitoring

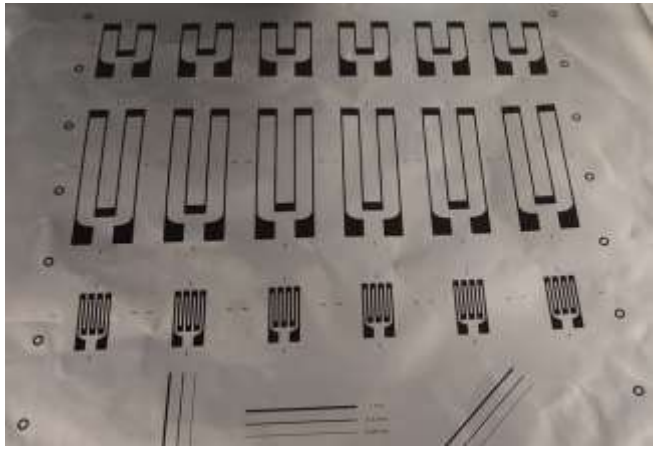
- Sensor printed onto Kapton support
- Thermocouple from cell test system (BasyTec) also attached to pouch for comparison
- High temp peaks seem to have good correlation with thermocouple
- Some low temperature hysteresis with cycles - Resolve with a finer calibration







- **Printed Thermopiles**
- **Module Assembly**
- **BMS integration**



Information Classification: General

2DM in Defence Applications

- Ultra high electrical conductivity enables exceptional EMI shielding efficiency (reflection + absorption).
- Layered MXene structures form continuous conductive networks ideal for blocking electromagnetic interference
- Tunable surface chemistry enables camouflage and stealth
- Supports next-gen defence platforms requiring high-performance, low-weight, multifunctional materials.

Multifunctional composites combining EMI shielding, heat spreading, and structural strength

GEIC Partners – Space



Adaptive Thermal Control System

SMARTIR

The harsh environment of space:

- Extreme temperature fluctuations (±100 °C)
- Vacuum (5 atoms per cm^3)
- Radiative cooling
- Extreme radiation

Design constraints:

- Survive the Launch
- Lightweight
- Low power consumption

The thermal control system is inefficient:

As effective as regulating the temperature of your home, with a hole on the roof.

Over 50% of the total satellite power can be used by the TCS



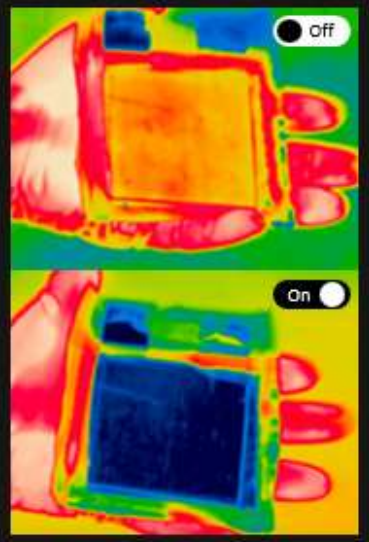
TCS Components:

- Radiator
- Heaters
- Heat spread/ thermal medium

Information Clas

GEIC Partners – Space

The SmartIR Radiator :



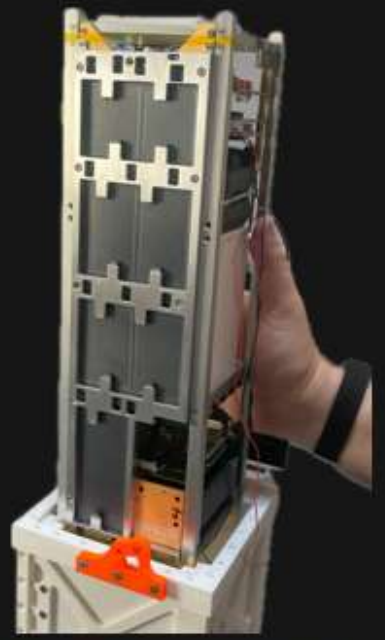
Dissipate the heat only when necessary:

Power Saving: up to 40%

Mass saving: up to 10%

Unique adaptation of the superior optical thermal properties of 2D materials:

- Lightweight
- Stronger than steel
- thermal conductivity





Supported by Bridging the Gap funding through GEIC, accelerated scale demonstration for TRL6+ evaluation

SMARTIR

Revolutionary adaptive thermal & signature management

February 2025. Confidential

Information Clas

2DM Enhanced Ceramics









SiC/2DM Hybrid – 99+ % relative density

Ceramic/metallic powders

- High shear mixing ; Acoustic mixer; Ball milling

- Sample size – 20 and 50mm pellets
- SPS Sintering @GEIC (Up to 2000 ^{o}C)

- HIP, Cold pressing @UoM Facilities
- High temperature tube furnaces (1200 - 1700 ^{o}C).



- ❑ Thermal shock resistance and high thermal conductivity
- ❑ Increased toughness and stiffness @elevated temperatures
- ❑ Enhances wear resistance(lower CoF) during high temperature applications
- ❑ Enhanced densification and sintering

Information Classification: General

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Graphene and 2D Materials

GEIC Composites Capabilities:

- **Processing Equipment:** Twin screw extruder, Single screw extruder, Injection Moulder, Internal Mixer, Hot Press, Autoclave, 1.8m^3 oven and Spark Plasma Sintering











Full suite of equipment across the lab areas, -40°C dew point dry room, automated battery cell stackers, coin and pouch cell production, characterisation equipment's etc.

Information Classification: General

Composites - Thermoplastics Processed at the GEIC

- HDPE
- LDPE
- PP
- PC
- PA6
- PA66
- SBS

- **TPU**
- PET
- PET-G
- PEEK
- ABS
- PBT
- **PVC**

Recycled

- **Recycled PET**
- Recycled PP
- Recycled HDPE
- Recycled LDPE

- PLA
- Bio-mass materials
- EBA
- PCL
- Acrylic

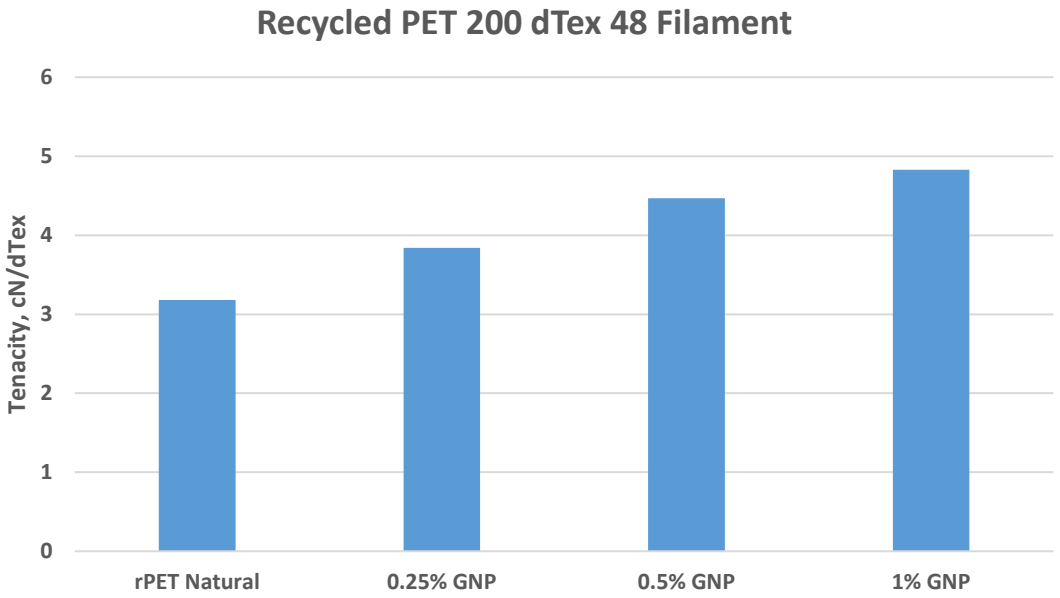
Filled Systems

- PP Talc Filled
- PP Glass Filled
- PA6 Glass Filled
- PA66 Glass Filled
- PEEK Glass Filled



Information Classification: General

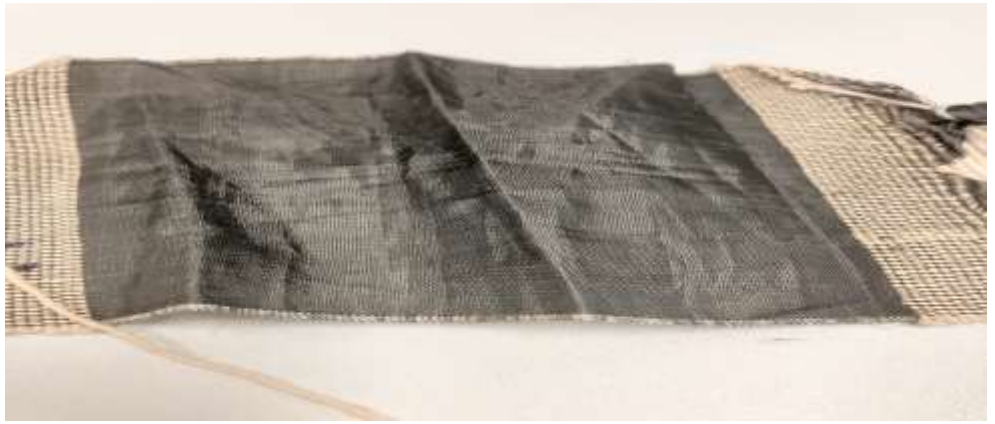
Graphene - Enhanced Recycled PET 200 d/tex 48-Filaments



	Tenacity (cN/dTex)	% Difference
rPET Natural	3.18	N/A
0.25% GNP	3.84	20.75
0.5% GNP	4.47	40.57
1% GNP	4.83	51.89



Thermal Performance – Woven Sample Heat Pressed		
	W/mK	Seconds
Natural rPET	0.293	3
rPET 1% Graphene	0.346	1.7
% Improvement	18.36%	-43.33%

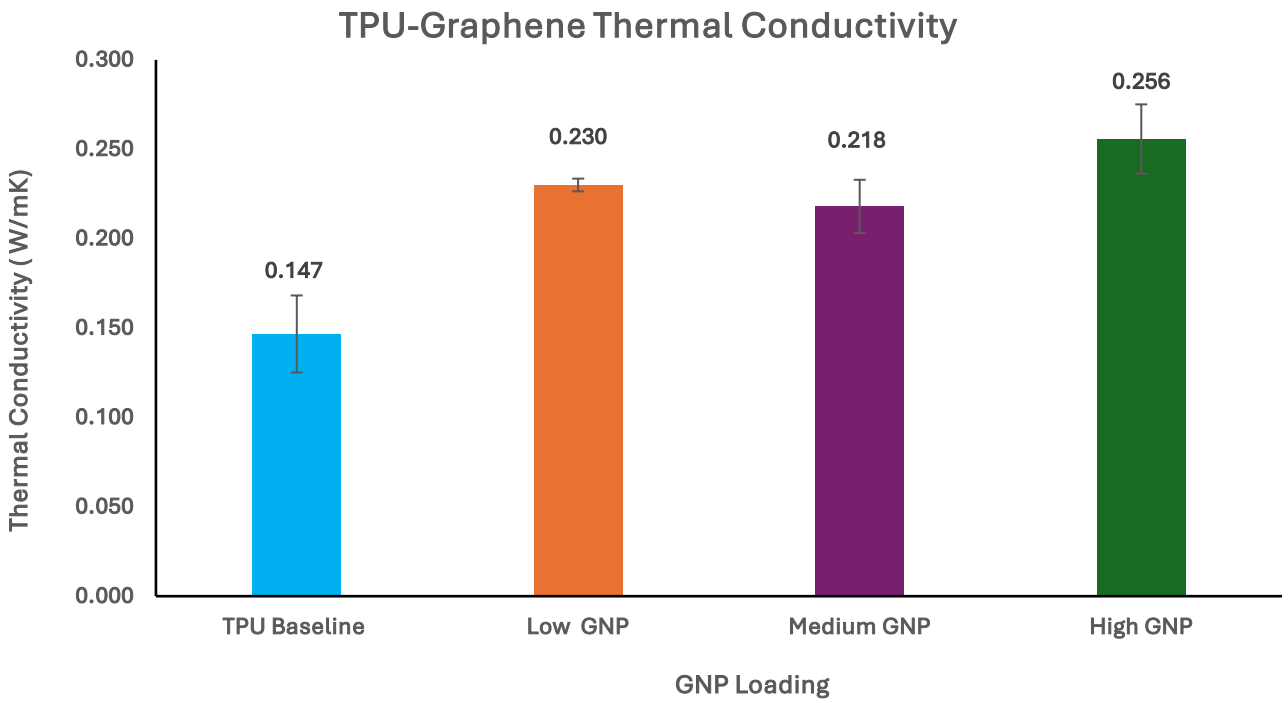


Applications: Sports wear, textiles, chemical resistant fabrics and composites

Information Classification: General

Composites: Graphene- Enhanced TPU





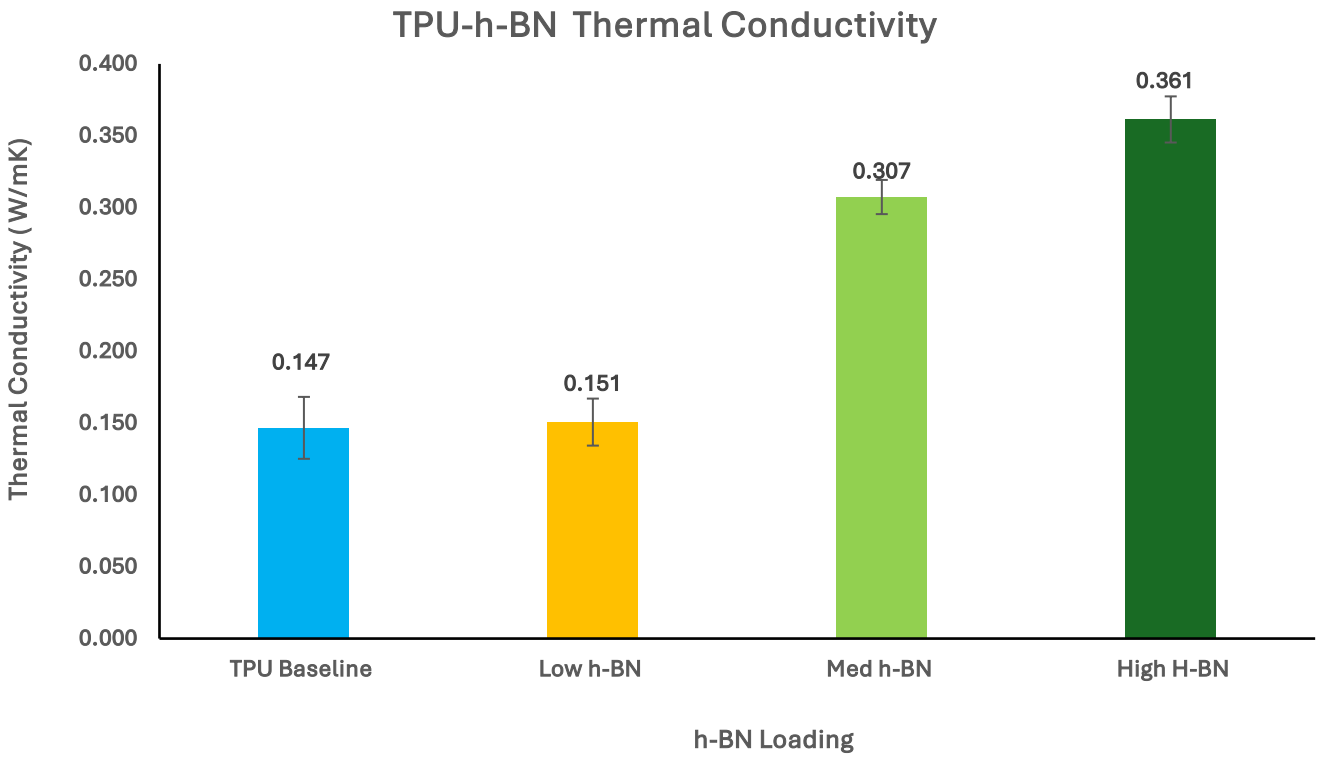
	Young' s Modulus, Mpa	% Difference
TPU Natural	4.25	N/A
Low GNP	7.01	67.28
Med GNP	8.10	90.64
High GNP	8.89	109.181

- TC Improvement : 56, 48 and 74 %
- Varies with the type of graphene and loading

- Emphasis on Multifunctionality: Mechanical robustness, heat dissipation, barrier properties
- Application dependent
- Trade-off with loading levels and cost implications

Application : Automotive components, footwear, medical devices

Composites: h-BN-Enhanced TPU



	Young's Modulus, Mpa	% Difference
TPU Natural	4.25	N/A
Low h-BN	6.48	52.68
Med h-BN	6.68	57.35
High h-BN	10.33	143.29

TC Improvement : 2.7, 110 and 146 %

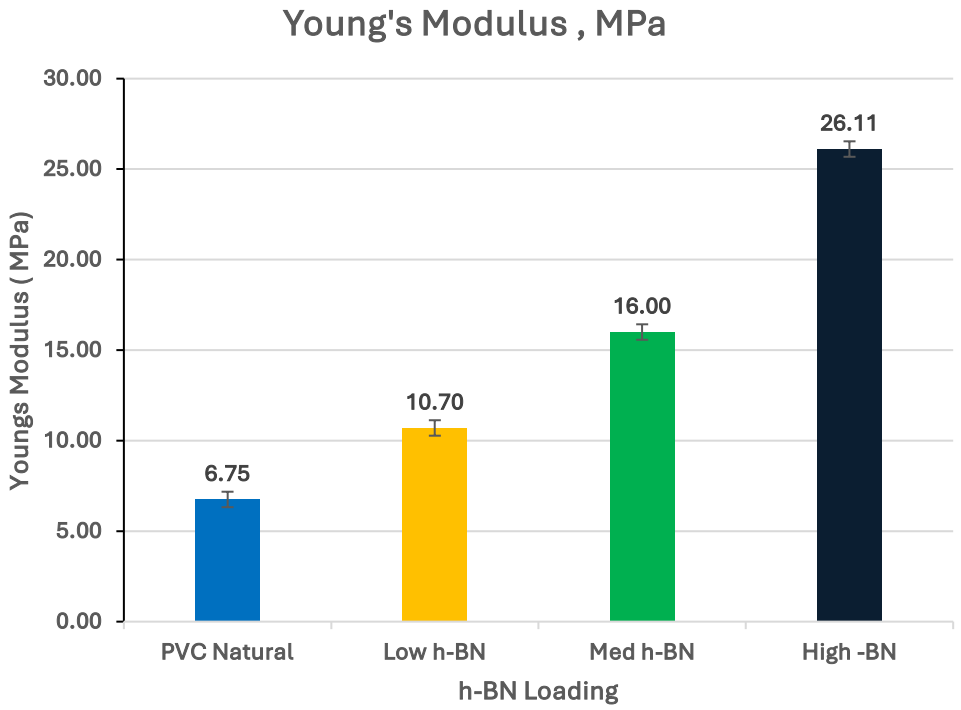
Minimum loading level required for thermal performance

Trade-offs (Mechanical /Thermal)

Information Classification: General

Composites: h-BN-Enhanced PVC

Applications: Flexible cable insulation, Inflatable fabrics for heat dissipation, acid and solvent resistant linings (subject to testing), construction materials



	Thermal Conductivity, W/mk	% Difference
PVC Natural	0.211	N/A
Low h-BN	0.317	50.24
Med h-BN	0.412	95.26
High h-BN	0.517	145.02
Low -GNP	0.316	
Med GNP	0.352	

	% Difference in Young's Modulus
PVC Natural	N/A
Low h-BN	58.52
Med h-BN	137.04
High h-BN	286.81

- Dispersion key to good properties.
- h-BN high-aspect-ratio, provides physical interlocking

Information Classification: General

Composites: Thermosets





Graphene and h-BN enhanced – Improvement in TC

Thermal Insulators

Material	Thermal Conductivity W/mK	Maximum stress to 25% strain (N)
Baseline PU	0.15	200
PU+ hBN(2%)+ HTM (30%)	0.13	289
PU+GNP(2%)+ HTM (30%)	0.14	293

- The 2DM fillers reinforce the polymer matrix, enhancing load transfer and stiffness.
- Drop in TC is expected - HTMs trap air, improving insulation.
- The combined structure yields lightweight yet mechanically robust and thermally efficient foams

Information Classification: General

Strategic Drivers and Challenges

- Reduce reliance on scarce materials like indium, gallium, cobalt, and rare-earth elements in thermal systems
- Stable global supply of carbon, boron , silicon, transition metal precursors
- Lateral size, flake thickness/layers, functionalisation
- source, quality , production capacity and price
- Manufacturing integration (Utilising knowhow)

Information Classification: General

Engagement Options
Projects or GEIC Membership







A typical pathway:

- Feasibility (Pathfinder)
"Can 2DM be used to make improvement?"

- Development project
Formulation + processing trials
Prototype parts

- Scale-up & validation
Pilot production
Performance validation

- Industrial transfer
Manufacturing partner integration
Supply chain readiness

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