Keep Cool – How Graphene-Enhanced Thermal Management Solutions Are Changing the Game
• Thermal management is a challenge for many products, including consumer electronics, batteries, LED lighting and more.
• Global Graphene Group (G³) is a leader in the graphene industry, developing and manufacturing game-changing graphene-enhanced products. G³ was the world’s first company to mass-manufacture graphene-enhanced thermal management materials.
• In this webinar, the experts from Global Graphene Group will discuss:
  • How graphene-enhanced thermal management solutions allow for heat dissipation
  • Specific thermal management products available today, including graphene-based heat spreaders, compressible graphene foams, etc.
  • Case studies on applications for these thermal management solutions and outcomes
Our Presenters

• **Matthew Wang, PhD – Product Development Manager**
  Dr. Wang has over 10 years of experience in developing graphene-based products for different applications. He gained his Ph.D Degree in Materials Science from Peking University in 2010 and joined Global Graphene Group right after graduation. He currently manages a product development team in G³ to support customers with their needs on graphene technologies and graphene solutions. Graphene for thermal management is one of his focused area in the past years and two key products have been successfully developed from his team, AT1500 heat spreader with superior in-plane thermal conductivity and AT1100 thermal interface materials with excellent compressibility.

• **Nathan Holliday – Technical Sales Manager**
  Holliday has over 7 years of experience in composites and coatings. He holds a Master’s degree in Materials Engineering from the Georgetown College of Chemistry. Holliday joined Global Graphene Group in 2017 and specializes in sales of our thermal management solutions.
Introduction to Global Graphene Group

**First Graphene Patent**
Dr. Jang filed the very first graphene patent in 2002, two years before Nobel laureates Dr. Giem and Dr. Novoselov’s discovery.

**Angstrom Materials Founded**
Dr. Jang and Zhamu founded Angstrom Materials in 2007, and a few short months later filed US patent No. 7,745,047—key IP for AEC’s graphene-silicon anode technology.

**ISO Certification**
Angstrom Materials implemented Quality Management System requirements and was ISO 9001:2008 certified.

**What’s Next.**

- **2002**
  - October 21, 2002
    - First Graphene Patent
  - September 23, 2007
    - Angstrom Materials Founded

- **2007**

- **2012**
  - World’s First Graphene Mass Production Begins
    - Drs. Jang and Zhamu filed the “Mass Production of Pristine Graphene Materials” patent on July 27, 2009. It was granted in 2012 positioning Angstrom to become the world’s leading producer of graphene.

- **2014**
  - October 29, 2015
    - Large Scale Production of Graphene

- **2015**
  - Transition to Holding Company Structure
    - The new holding company, Global Graphene Group, encompasses four divisions in energy storage and graphene production, aiming to accelerate business growth.

- **2016**
  - June 17, 2016
    - Graphene-Silicon Anode Production

- **2017**
  - December 13, 2017
    - R&D 100 Award Winner

- **2018**
  - December 9, 2014
    - ISO Certification

- **2019**
  - 2019
    - R&D 100 Award Winner
      - G’s battery technology recognized by R&D as one of the top 100 products of the year

- **2020**
  - Joined Eu Reach Consortium
    - Member of the graphene consortium with REACH, helping to shape the trajectory of the graphene industry

- **2021**
  - 2020
    - What’s Next.
G³ is a Leading Materials Science Technology Company

<table>
<thead>
<tr>
<th>By the Numbers</th>
<th>G³ Key Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Holds 438+ issued and pending U.S. patents and 100+ PCTs</td>
<td><strong>Most Important Patents</strong>&lt;br&gt;Covers the core and most significant patents in graphene and graphene-related areas</td>
</tr>
<tr>
<td>• G³ has 48% of employees with graduate degrees of Masters or higher for which 20 are PhD level</td>
<td><strong>Leader in Manufacturing Scale</strong>&lt;br&gt;Largest manufacturing capacity globally at 200 MT / year of single-layer graphene</td>
</tr>
<tr>
<td>• ~90 employees currently</td>
<td><strong>Wide Variety of Product Offerings</strong>&lt;br&gt;Broad portfolio of products that solve today’s most pressing problems in battery, thermal management markets and more</td>
</tr>
<tr>
<td>• 100,000+ square feet of research, production and office space</td>
<td><strong>Many Potential Areas of Focus</strong>&lt;br&gt;Solutions-based approach applicable to disruption of variety of end markets</td>
</tr>
<tr>
<td>• Produces 200 MT per year of single-layer graphene – enough to circle the Earth’s circumference 13,150 times</td>
<td><strong>Key People</strong>&lt;br&gt;Founders are pioneers in field of graphene, supported by a management team with experience scaling up businesses</td>
</tr>
<tr>
<td>• Formed 6 Joint Development Agreements (“JDAs”) with 5 partners in the last 12 months</td>
<td><strong>Industry Leading Customer Base</strong>&lt;br&gt;Large, blue-chip, industry leading customers who are actively using G³ offerings</td>
</tr>
<tr>
<td>• 5 additional JDAs under active discussion / negotiation</td>
<td></td>
</tr>
<tr>
<td>• 1 location with 3 facilities in the U.S.</td>
<td></td>
</tr>
<tr>
<td>• 6 locations with 7 facilities in Asia</td>
<td></td>
</tr>
</tbody>
</table>
G3’s Mission: Solving Tomorrow’s Problems Today

Battery Technologies for a Greener Earth
- Improved battery life
- Improved storage capacity
- Improved EV driving range
- Fast charge capability

Enhancing Products with Graphene
- Desalination
- Thermal interface materials
- Coating materials
- Conductive materials
- Biomaterials
Thermal management challenges

- Consumer electronics, LED lighting, batteries, electrical vehicles and more have a need to keep cool to optimize their operations:
  - Cell phones catching on fire due to hot batteries
  - Consumer electronics shutting down due to heat problems
  - 5G technology require more efficient heat dissipation solutions
  - EV safety issues
G$^3$ Graphene Types

(a) Graphene
(b) Few-layer graphene 
<10 layers
(c) Graphite

(d) Reduced graphene oxide (rGO)
(e) Graphene oxide (GO)

Thickness: 0.34 nm
The Theory of Graphene as Heat Conductor

X-Y plane: Strong covalent bonding
- *Highest tested value*: 5,300 W/m.K

Z direction: Weak Van der Waals bonding
- *Normally in 2-3 W/m.K range*

Copper: 400 W/m.K at RT
- *Phonons*: limited to 1-2% of the total.
- *Electrons*: >98% of the total.

Pristine -Graphene: 5,300 W/m.K (single layer)
- *Electrons*: relatively rare
- *Phonons*: Dominant of the total, due to its in-plane ideal structure

Graphene: ~2000 W/m.K (multi-layer)
- *Dependence of vacancy and defect concentration when bulk*
- *Variations of graphene quality and process conditions*
Thermal Management Solutions

- Thermal paste
- Graphene/Copper foil
- AT1500
- AT1100
- Graphene thermal paint
- Graphene Composite
Graphene-Based Heat Spreader (AT1500)

G3’s thermal heat spreader offers superior thermal conductivity for a range of electronic applications.

- G3’s graphene thermal heat spreader provides superior thermal management in the form of high thermal conductivity films / sheets
- Enhanced heat dissipation in a lightweight and non-combustible film
- The thermal heat spreader can be easily cut and laminated, making it compatible as a drop in solution for a variety of electronic applications
- The AT 1500 series of heat spreaders come in a variety of thickness options ranging from 20 – 300 um
- The heat spreader is currently in mass-production in the capacity-expanding phase

**Applications**: 3C industry, large screen displays, LED lighting
Graphene-Based Heat Spreader (AT1500)

G³'s thermal heat spreader offers superior thermal conductivity for a range of electronic applications.

**Performance**

- G³'s graphene heat spreader offers substantially higher thermal conductivity than competing materials such as copper, aluminum and magnesium alloys.

- G³'s graphene heat spreader dissipates heat quicker and more efficiently than other materials, able to maintain a temperature of 74.1°C compared to the heat source at >150°C.

**Key Advantages**

- **Lightweight**
  Can be used in applications where weight reduction is critical.

- **Thermal Conductivity**
  Superior heat transfer from components to keep electronics cool and avoid overheating failure.

- **Versatile and Efficient**
  Low maintenance and simple procedure for installation.

- **Conformability**
  Flexible and bendable, the heat spreader is capable of conforming to all uneven surfaces.
Graphene-Based Heat Spreader

The importance of a heat spreader
Graphene-Based Heat Spreader

Without AT1500

With AT1500
Graphene Film (AT1100)

G³’s thermal heat spreader AT1100 offers superior compressibility and thermal conductivity for power modules, LED lighting, and other electronic and electrical devices.

**Thermal Heat Spreader Overview and Value**

- AT1100 is made of single layer graphene and is highly engineered to achieve required thickness for different applications, standard thickness are 70um, 100um, 200um and 300um.
- It is soft and compressible, with a maximum of 90% thickness compressibility and excellent performance as thermal interface material.
- Easy to handle and die cut into many shapes, a nice replacement of thermal paste product to avoid messiness and improve process convenience.
- Durable and stable, long-lasting at temperature range of -40 to 400°C.
Graphene Film (AT1100)

G³’s thermal heat spreader AT1100 offers superior compressibility and thermal conductivity for power modules, LED lighting, and other electronic and electrical devices.

**Key Advantages**

- **Lightweight**
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  Low maintenance and simple procedure for installation

- **Conformability**
  Flexible and bendable, the heat spreader is capable of conforming to all uneven surfaces

**Performance**

- **Through Plane Thermal Conductivity (W/mK)**
  - 100 KPa
  - 200 KPa
  - 600 KPa

- **AT1100-70**
  
<table>
<thead>
<tr>
<th>Pressure (KPa)</th>
<th>Through Plane Thermal Conductivity (W/mK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>3.5</td>
</tr>
<tr>
<td>200</td>
<td>4.0</td>
</tr>
<tr>
<td>600</td>
<td>2.5</td>
</tr>
</tbody>
</table>

G³'s thermal heat spreader AT1100 offers superior compressibility and thermal conductivity for power modules, LED lighting, and other electronic and electrical devices.
Graphene Thermal Paste

$G^3$’s thermal paste uses graphene as filler; it has high thermal conductivity, is non-metallic. Ge-TH-G Series has very high thermal stability. It can withstand extreme environments, from $-40 \, ^\circ C$ to $150 \, ^\circ C$.

### General specifications

<table>
<thead>
<tr>
<th>Properties</th>
<th>Typical Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>Black or Grey</td>
</tr>
<tr>
<td>Thermal Conductivity (W/mK)</td>
<td>2–10</td>
</tr>
<tr>
<td>Viscosity (m · pas)</td>
<td>50,000–90,000</td>
</tr>
<tr>
<td>Specific Gravity (g/cm$^3$)</td>
<td>2.0–3.0</td>
</tr>
<tr>
<td>Working Temperature ($^\circ C$)</td>
<td>-50 ~ 160</td>
</tr>
<tr>
<td>Weight Loss (%) (96hr@100 $^\circ C$)</td>
<td>$\leq 1.0$</td>
</tr>
</tbody>
</table>

### Packaging

| Syringes                                        | 1.5g 3.0g 10.0g         |
| Bottle                                          | 100g 500g 1Kg 5kg       |
| Storage Conditions                              | 25 ~ 30 $^\circ C$      |

RoHS PASSED  
GRAPHENE INSIDE  
SILICONE FREE
Graphene Thermal Paste

G³’s thermal paste uses graphene as filler; it has high thermal conductivity, is non-metallic. Ge-TH-G Series has very high thermal stability. It can withstand extreme environments, from -40 °C to 150 °C.

- As TIM: can be used in computer heat conduction and cooling, electronic devices, large screen display, LED lighting, and any needs for thermal management products.
- It can be deployed as electromagnetic shielding material.

<table>
<thead>
<tr>
<th>TEMPERATURE</th>
<th>MANUFACTURER</th>
<th>PRODUCT NUMBER</th>
<th>T1</th>
<th>T2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient</td>
<td>TGC</td>
<td>Ge-TH-G042</td>
<td>68.68</td>
<td>60.26</td>
</tr>
<tr>
<td>N2 (Liquid) &lt; -40°C</td>
<td>TGC</td>
<td>Ge-TH-G042</td>
<td>68.65</td>
<td>60.08</td>
</tr>
</tbody>
</table>
Graphene thermal coating material has many beneficial characteristics:

- High temperature resistance
- Fast rate of heat spreading
- High thermal conductivity
- High heat radiation
- Insulate
- Corrosion resistance
- Resistance to strong acids and alkalis. It is the best choice for thermal management

G³’s graphene thermal coatings are specifically designed for use with radiant, bulk heat source. And, with its adhesion and processing properties, it is found in and suitable for a wide range of applications.

### Case I

**IR camera**

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>(A) Standard</th>
<th>(B) Ge-TH-P010</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature(°C) @ Edge of Blub</td>
<td>102.6851</td>
<td>87.7587</td>
<td>Sample A on the right, Sample B on the right</td>
</tr>
<tr>
<td>dT (°C)</td>
<td>-</td>
<td>14.9264</td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td>-</td>
<td>14.54%</td>
<td></td>
</tr>
</tbody>
</table>
# Graphene Thermal Paint

## Thermal Heat Spreader Overview and Value Proposition

### General properties

<table>
<thead>
<tr>
<th>Properties</th>
<th>Typical Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>Black</td>
</tr>
<tr>
<td>Surface resistance (Ohm/sq)</td>
<td>$&gt; 10^6$</td>
</tr>
<tr>
<td>Viscosity (m • pas)</td>
<td>50~200</td>
</tr>
<tr>
<td>Specific Gravity (g/cm³)</td>
<td>0.8~0.9</td>
</tr>
<tr>
<td>Coating method (°C)</td>
<td>Spray/Dip coating</td>
</tr>
<tr>
<td>Curing process (two steps)</td>
<td>5 min@70°C, 10 min@150°C</td>
</tr>
</tbody>
</table>

### Packaging

<table>
<thead>
<tr>
<th>Bulk</th>
<th>1Kg 5kg 25Kg 100Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage Conditions</td>
<td>25 ~30 °C</td>
</tr>
</tbody>
</table>
Graphene Composites

- G³ developed a series of graphene-based composites for heat dissipation purposes; The trends showed that both tensile strength and thermal conductivity improved as the concentration of graphene in the composite increases; It is a perfect solution for casing applications to housing power modules and batter packs.
- G³ will prepare a master-batch for customers with maximum graphene concentration.

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>SIZE</th>
<th>COLOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>PURE ABS/PC</td>
<td>40 X 25 X 2 mm</td>
</tr>
<tr>
<td>B</td>
<td>ABS/PC + 5% Graphene</td>
<td>40 X 25 X 2 mm</td>
</tr>
<tr>
<td>C</td>
<td>ABS/PC + 10% Graphene</td>
<td>40 X 25 X 2 mm</td>
</tr>
<tr>
<td>D</td>
<td>ABS/PC + 20% Graphene</td>
<td>40 X 25 X 2 mm</td>
</tr>
</tbody>
</table>
Graphene Composites

Graphene/ABS/PC composites with improved thermal conductivity

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>NOTE</th>
<th>TEST_P N</th>
<th>HEATER</th>
<th>AVE</th>
<th>dT</th>
<th>Eff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>PURE</td>
<td>B000</td>
<td>83.21</td>
<td>83.60</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B100</td>
<td>83.99</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>5%</td>
<td>B001</td>
<td>78.05</td>
<td>78.41</td>
<td>-5.24</td>
<td>6.26%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B101</td>
<td>78.77</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>10%</td>
<td>A001</td>
<td>74.12</td>
<td>73.47</td>
<td>-10.18</td>
<td>12.17%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A101</td>
<td>72.81</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>20%</td>
<td>A002</td>
<td>66.18</td>
<td>65.69</td>
<td>-17.96</td>
<td>21.47%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A102</td>
<td>65.20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Graphene Composite as Enclosures

- Reduce temperature
- Extend life time
- Increase safety
- Light weight

Dissipation

- VR
- LED light
- Lampshade
- Battery shell
- NB
- Heat dissipation/reinforced polymer composites
- Motor coil bobbin
- Electrical tools
Graphene Composite for Tires

Structure of Graphene-Based Tires

**Air Barrier:** Good air barrier of graphene reduces the chance of flat tire.

**Mechanical Strength:** Graphene enhances the strength of rubber to prevent friction.

**Thermal Conductivity:** Graphene increases the heat distribution rate when braking.

**Anti-Static:** Graphene is an effective electric conductive material for grounding static electricity of a vehicle.
Graphene increases thermal conductivity of SBR rubber by 3 folds, compared with the same amount of carbon black.
Graphene Composite for Tires

**Anti-Static**
Electric resistance of rubber can reach $10^3-10^5 \, \Omega/\square$ with different amount of graphene (5-45 phr).

**Air Barrier**
With 0.3 wt% graphene, the low permeable rubber can effectively reduce 48% of air penetration.

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**Air Penetration**

- No Graphene: 74%
- Graphene 0.3 wt%: 26% (↓48%)
Graphene as Transparent Conductive Film

- High transparency (absorbing only 2.3% of light per single layer of graphene) and high electrical conductivity.
- A layer of liquid crystals placed between graphene filled electrodes as well as a transparent polymer, could allow windows to restrict light.

- Conductive networks
- Much lower loading of Ag NWs
- Water/oxygen barriers: preventing oxidation of Ag NWs layer
- High transmittance over a wide range of wavelengths
- Low surface resistivity
- Flexible (bendable)
- Simple processing (at low temp.)
Thermal Heat Spreader in Action

- https://youtu.be/cICfMfU8eN4
Any Questions?
Thank you!

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