The Miracle of New Material: GRAPHENE

STANDARD GRAPHENE

CEO
Joung-Hoon Lee
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2. Company Overview
3. Standard Graphene
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Investment Status

1. USA: NSF (National Science Foundation) $2,800,000,000 (2008~2012)
2. EU: Flagship Program (17 countries and 60 organizations) $1,200,000,000 (2013~2023)
3. China: Government $1,000,000,000 (2011~2015)
4. Korea: Ministry of Science, ICT and Future Planning $175,000,000 (2012~2018)

(Source: HelloDD.com (2012))
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Company Overview

- Graphene technology R&D and manufacturing company
- Core competency in high quality graphene products and production process
- Leader in graphene technology with 17 years of carbon nano technology experience
- Leading company of Korean government’s graphene initiatives

<table>
<thead>
<tr>
<th>Main Product Name</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graphene (rGO)</td>
<td>Rechargeable battery, Supercapacitor, Radiation material, Coating material, etc.</td>
</tr>
<tr>
<td>Graphene Oxide (GO)</td>
<td>Polymer composite materials, etc.</td>
</tr>
</tbody>
</table>

Company
- Standard Graphene

CEO
- Lee Joung-Hoon

Established
- 2012. 02. 09.

Address
- 413 Fine Chemical industry center Jongga-ro 15, Jung-gu, Ulsan, S. Korea
Extensive graphene research history
- 7+ years of carbon material research
- 5+ years of graphene dedicated R&D

18 graphene related patents holding
10 graphene specific scientific papers published

Chemical exfoliation and reduction method development

Leadership in government initiative:
The leading company of New Science Material Development initiative

So far
- 17+ years of Carbon research
- 6+ years of graphene Massive production

Graphene synthesis started
“High Quality Graphene Manufacturing” project funded by UNIST, U of Ulsan and UST of Hong Kong

Process optimization

Nonoxidative exfoliation method development

Note: 1 reduced Graphene Oxide
Partnership (1)

3D printing market leader LOCAL MOTORS (USA) signed Technical cooperation MOU.

Strategic Partnership with Ulsan Techno-Park.
Partnership (II)

Joint research and development for development of multi-functional graphene and coating steel sheet
- POSCO, Hanwha Chemical, EXA E&C, Adesso, Hain Technology, XG Sciences.
- RIST, KIMS, Chonnam National University, Kyungpook National University.

Korea Automobile Parts Association (KAPA) signed MOU for heat radiation materials and lightweight components.

AVDOME AVIATION (USA): Lightweight/Strong cargo container for airplane under discussion.
What is Graphene?

Graphene Property Value

Single layer graphene: high surface area, Transparency, strength, thermal and electrical conductivity, etc.

- **Electrical Conductivity**
  - Graphene is 100 times higher than copper wire

- **Transparency**
  - It is amazingly transparent, absorbing just 2.3 percent of light that lands on it
  - More transparent than ITO, 97% /1layer

- **High Thermal Conductivity**
  - 5,000 W/mK
  - 2 times higher than Diamond

- **High Strength**
  - Breaking strength is 200 times larger than steel

- **Flexibility / Elasticity**
  - Tensile strength: 20 GPa
  - Flexibility Failure strain > 20%

- **High specific surface area** 2,630 m²/g
  - 1g of graphene can cover entire football field

Construction completed in 2009.

- Built from ground-up by Standard Graphene
- Automated from production to packing for easy scaling
- Modular design for versatile production

“Companies like Standard Graphene that invest in the improvements in processing are crucial for the future of graphene.”
– Dr. Chiu, Brussels, Belgium, April 2012
Advantages of Technology

▶ Continuous Exfoliation Process
▶ Continuous Thermal Reduction Process
▶ Mass Production

- 700 ton/year graphene oxide slurry
- 4.4 ton/year GO (graphene oxide) powder
- 1.1 ton/year rGO (graphene) powder

▶ Various Product Lines

: GO powder, GO slurry, rGO powder, GP powder and so on

▶ The Leading Company for the Development of Production Technology for High Quality of Graphene

- Principal Company of the “Graphene Project for Large-Scale Production” Funded by Korean Government (2009 ~ 2012)
<table>
<thead>
<tr>
<th>TITLE</th>
<th>Registration NO.</th>
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<tr>
<td>Method and apparatus for producing a nanoscale material having a graphene structure</td>
<td>10-1053933 2011-07-28</td>
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<td>Washing method of mixture comprising graphite oxide</td>
<td>10-1095584 2011-12-12</td>
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<tr>
<td>Apparatus for manufacturing nano-size graphite-structured material</td>
<td>10-1265712 2013-05-13</td>
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<tr>
<td>Method and apparatus for producing a nanoscale material having a graphene structure</td>
<td>10-1337970 2013-12-02</td>
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<tr>
<td>Mixture of multi-layered graphene for adsorbing organic material</td>
<td>10-1337969 2013-12-02</td>
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<td>Preparing method of graphite oxide</td>
<td>10-1409278 2014-06-12</td>
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<tr>
<td>A method and apparatus for manufacturing graphite oxide</td>
<td>10-1500692 2015-03-03</td>
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<tr>
<td>A method and apparatus for manufacturing graphite oxide</td>
<td>PCT</td>
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<tr>
<td>Method for manufacturing graphite oxide and graphene structured material</td>
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<tr>
<td>Method and apparatus for producing a nanoscale material having a graphene structure</td>
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<tr>
<td>A method of producing nano-size graphene-based material And an equipment for producing the same</td>
<td>EU</td>
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<td>A method of producing nano-size graphene-based material And an equipment for producing the same</td>
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Main Products (Oxidative Exfoliation Graphene)

- **FT-IR Data (GO)**
  - GO-V20-100
  - GO-V30-100
  - rGO-V20-100
  - rGO-V20-100

- **Raman spectrum**
  - GO-V20-100
  - GO-V30-100
  - rGO-V20-100
  - rGO-V20-100

FT-IR Graphene Oxide

Raman Shift (cm⁻¹): 26, 28, 30, 32, 34, 36, 38

Transmittance (%): 26, 28, 30, 32, 34, 36, 38

Wavenumbers (cm⁻¹): 4000, 3500, 3000, 2500, 2000, 1500, 1000, 500

GO/rGO Raman Data

Intensity: 0, 100, 200, 300, 400, 500

Raman Shift (cm⁻¹): 500, 1000, 1500, 2000, 2500, 3000, 3500

FT-IR Graphene Oxide

Transmittance (%): 26, 28, 30, 32, 34, 36, 38

Wavenumbers (cm⁻¹): 4000, 3500, 3000, 2500, 2000, 1500, 1000, 500

GO/rGO Raman Data

Intensity: 0, 100, 200, 300, 400, 500

Raman Shift (cm⁻¹): 500, 1000, 1500, 2000, 2500, 3000, 3500
## Specifications (Oxidative Exfoliation Graphene)

### Specifications

<table>
<thead>
<tr>
<th></th>
<th>Graphene (rGO)</th>
<th>Graphene Oxide (GO)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>rGO-V20-100</td>
<td>rGO-V21-100</td>
</tr>
<tr>
<td>Surface Area (m²/g)</td>
<td>280 ~ 330</td>
<td>250 ~ 300</td>
</tr>
<tr>
<td>Thickness (AFM, nm)</td>
<td>&lt;5</td>
<td>&lt;5</td>
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<tr>
<td>Carbon Content (%)</td>
<td>88 ~ 90</td>
<td>93 ~ 96</td>
</tr>
<tr>
<td>Oxygen Content (%)</td>
<td>4 ~ 8</td>
<td>0.8 ~ 1.5</td>
</tr>
<tr>
<td>Lateral Size (㎛)</td>
<td>&gt;7</td>
<td>&gt;7</td>
</tr>
</tbody>
</table>

### New Products

- **rGO-V21-100 & rGO-V31-100:** Carbon content ↑ & Oxygen content ↓
  Also, impurities decrease. *(especially, S : Non-Detectable)*
  - Launching date: October, 2015

- **rGO-V22-100 & rGO-V32-100:** Carbon content & Oxygen content same as ER4400-1 & ER4401-1
  - K & Mn contents ↓
  - K: 250ppm → 5ppm  Mn: 550ppm → 15ppm
  - Launching date: December, 2015
Exfoliation (Oxidative Exfoliation Graphene)

Measurement of number of layer (GO)

Contrast
- Monolayer: 0.09
- Bilayer: 0.18

※ Most of GO are Monolayer.

(Source: KIMS (Korea Institute of Materials Science))
Shape Control (Oxidative Exfoliation Graphene)

Graphite / x5,000

GO (Graphene Oxide) / x10,000

Shape Control Technology

Graphene / x100,000

Graphene / x100,000
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Potential Applications

Energy
(GO and rGO)
- Super-Capacitor electrodes
- 2nd Battery Electrode
- Dye-Sensitized Solar Cell Electrode
- Bistable Memory
- Resonator
- Semi Conductor
- Veselago Lesns

Electronic Devices
(rGO, CVD graphene)
- FET
- Pseudospintronics

Composite
(GO and rGO)
- Corrosion-resisting coating
- Lightweight materials

Biotech
(GO and rGO)

Display
(rGO, CVD graphene)

※ GO (graphene oxide), rGO (reduced graphene oxide)
World Market Forecasts (1)

Annual average growth rate 22.1%

(Unit: one hundred million US $)

(*Source: Strategies Unlimited, Prismark report, GFK, FUJI economy report, IDTechEx etc)
## World Market Forecasts (II)

(Unit: one hundred million US $)

<table>
<thead>
<tr>
<th>Product</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025</th>
</tr>
</thead>
<tbody>
<tr>
<td>Touch Panel Module</td>
<td>278.2</td>
<td>306.4</td>
<td>337.4</td>
<td>371.7</td>
<td>409.3</td>
<td>450.6</td>
<td>496.3</td>
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<tr>
<td>OLED Panel</td>
<td>109.4</td>
<td>163.2</td>
<td>215.8</td>
<td>285.4</td>
<td>377.6</td>
<td>499.4</td>
<td>660.6</td>
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<tr>
<td>Smart Window Passive</td>
<td>37.8</td>
<td>42.7</td>
<td>48.2</td>
<td>54.4</td>
<td>61.3</td>
<td>69.1</td>
<td>77.9</td>
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<tr>
<td>Smart Window Active_BIPV</td>
<td>195.2</td>
<td>228.2</td>
<td>266.7</td>
<td>311.8</td>
<td>364.6</td>
<td>426.2</td>
<td>498.2</td>
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<tr>
<td>EV/ESS LIB ESS LIB</td>
<td>125.6</td>
<td>153.4</td>
<td>186.4</td>
<td>226.2</td>
<td>274.9</td>
<td>333.8</td>
<td>405.4</td>
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<td>EV/ESS LIB EV LIB</td>
<td>1,330.9</td>
<td>1,358.1</td>
<td>1,404.5</td>
<td>1,452.6</td>
<td>1,502.2</td>
<td>1,553.6</td>
<td>1,606.7</td>
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<tr>
<td>Supercapacitor</td>
<td>1.9</td>
<td>3.2</td>
<td>5.4</td>
<td>9.1</td>
<td>15.2</td>
<td>25.6</td>
<td>42.6</td>
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<tr>
<td>Lightweight High Strength Composite</td>
<td>78.7</td>
<td>85.0</td>
<td>91.5</td>
<td>98.6</td>
<td>106.2</td>
<td>114.6</td>
<td>123.5</td>
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<td>High Barrier Film High Performance</td>
<td>149.4</td>
<td>154.9</td>
<td>160.5</td>
<td>166.2</td>
<td>172.2</td>
<td>178.4</td>
<td>185.0</td>
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<tr>
<td>EMI Shield Nano Coating</td>
<td>1.6</td>
<td>2.1</td>
<td>3.0</td>
<td>4.2</td>
<td>5.8</td>
<td>8.0</td>
<td>11.4</td>
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<td>EMI Shield EMI/RFI</td>
<td>54.4</td>
<td>55.8</td>
<td>57.4</td>
<td>59.2</td>
<td>60.8</td>
<td>62.6</td>
<td>64.3</td>
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<td>Corrosion-resisting Steel Korea Market</td>
<td>175.0</td>
<td>189.9</td>
<td>206.2</td>
<td>224.0</td>
<td>243.2</td>
<td>264.0</td>
<td>286.6</td>
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<td>Sum</td>
<td>2,538.2</td>
<td>2,742.9</td>
<td>2,983.2</td>
<td>3,263.4</td>
<td>3,593.1</td>
<td>3,985.8</td>
<td>4,458.6</td>
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</table>

(Source: Ministry of Science, ICT and Future Planning, Korea)