Unleashing the Power of Graphene

NanoXplore GmbH

Dr. Francis Nedvidek
## Introduction

- Few Layer Graphene (FLG) from natural flake graphite
  - Proprietary **environmentally friendly** exfoliation technology (4 patents)
  - 60 tonnes/year production capacity → 18 tonnes in place today

- heXo-G graphene based solutions
  - Powder for compounders
  - Pellets for masterbatch (PE, PP, PC, PET….)
  - Compounds for energy and industrial applications
  - Injection and blow molded plastic parts

- Target Markets:
  - Graphene-enhanced pellets for
    - thermoplastics, thermosets & resins for textiles
  - Specialized compounds for Li-ion electrodes
A Brief History

Birth: R&D services company focused on nanomaterials

Transformation:
- Graphene production
- Graphite applications

Mason Partnership:
Graphite Investment

Opening of St-Laurent
4 tonnes / year
German office & Two Carbon investment

Acquisition of
Capacity expansion
18T/Year graphene

Four Initial Patents:
Functional graphene, graphite-graphene composite, thin graphite

2011
2012
2013
2014
2015
2016
Today

2016
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Natural Graphite → Injection Molded Plastic

1. Mechanical exfoliation of natural graphite
2. Twin-screw compounding with resin and proprietary additives
3. Blow and injection molding

Major Graphite Producer Partners
NanoXplore has established a strong partnership with Colorplastic SA here in Switzerland.

With deep and broad knowledge of additives Colorplastic and NanoXplore together produce customized compounds and master batches covering the thermoplastic and surface technology sectors.
Own Formulation and Process Innovation

- Identify issues
- Propose improvements / innovations
- Share the Data

[Diagram showing the process of formulating and molding with Graphene, Raw Materials, Formulation, Customized Molding, and User Markets]

- Engineer solution(s)
- Provide improvements / changes
- Propose improvements / innovations

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Capture Broader Polymer Value Chain

**Raw Materials**
- Petro chemicals & distillates
- Ores and Processed metals & minerals
- Processed Bio Feed Stocks...

**Basic Ingredients**
- Basic chemicals
- Polymers
- Metals
- Processed Bio Feed Stocks...

**Specialty Chemicals**
- Formulations
- Additives
- Blending & Intermediaries
- Integrated Users

**Distribution**
- Logistics
- Direct to Users
- Specialty Distributors
- Users / OEMs...

**User Markets**
- Distributors
- Users
- OEMs
- Products
- Distribution

**Business Case** → \( \Delta \text{Value} > \Delta \text{Price} \)

Added Value
- Process Cost

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he-X-o G graphene → characteristics

- **Water-based** environmentally friendly exfoliation (4 patents)
- **Low surface defects;** 2-5 layers; 1 µm – 10 µm lateral
- **Ease of dispersion** → polymers & resins
- **Industrial scalable** & high quality
- Graphite flakes → Graphene / Masterbatch / Compound
- **Price points** → viable business case
- "Multifunctional" enhancement of polymers

1 µm
Multiple Enhancements

Performance $\uparrow\uparrow$

Cost $\approx$

Value $\uparrow$

Cost $\leftrightarrow =$

Value $\leftrightarrow =$

Cost $\downarrow$

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## Polymer performance enhancement examples

<table>
<thead>
<tr>
<th>Material</th>
<th>Impact</th>
<th>heXo-G wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>LLDPE</td>
<td>+10% in yield strength</td>
<td>2%</td>
</tr>
<tr>
<td>HDPE</td>
<td>+14% in yield strength</td>
<td>0.5%</td>
</tr>
<tr>
<td>PE</td>
<td>Conductivity $10^{-6}$ S/m</td>
<td>10-12%</td>
</tr>
<tr>
<td>PA 6-6 (nylon)</td>
<td>+10% in tensile strength</td>
<td>1%</td>
</tr>
<tr>
<td>Silicone-rubber</td>
<td>+10% in abrasion resistance</td>
<td>0.1%</td>
</tr>
<tr>
<td>ABS</td>
<td>4X thermal conductivity</td>
<td>0.2%</td>
</tr>
<tr>
<td>UHMWPE</td>
<td>+40% in fracture toughness</td>
<td>0.5%</td>
</tr>
<tr>
<td>HDPE</td>
<td>+22% in oxygen barrier</td>
<td>1%</td>
</tr>
</tbody>
</table>
Graphene-enhanced TPU

- Tensile Modulus
- Flexural Modulus

![Graphene-enhanced TPU Modulus Graph](image)
Graphene reduces shrinkage and increases dimensional stability of LDPE.

1 wt.% he-X-o G 4 reduces shrinkage by 35% vs raw LDPE

5 wt.% he-X-o G 4 reduces shrinkage by 44% vs raw LDPE
Graphene increases operating temperature

- Increases polymer thermal stability in LDPE (using heXo-G V20)
- Increased degradation temperatures
- Improvement of 56°C at 10 wt.% graphene (TGA curve shift)

### Shift in degradation T

<table>
<thead>
<tr>
<th>Graphene (wt.%)</th>
<th>50% weight loss</th>
<th>80% weight loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11 °C</td>
<td>3 °C</td>
</tr>
<tr>
<td>2</td>
<td>19 °C</td>
<td>11 °C</td>
</tr>
<tr>
<td>5</td>
<td>15 °C</td>
<td>28 °C</td>
</tr>
<tr>
<td>7</td>
<td>25 °C</td>
<td>37 °C</td>
</tr>
<tr>
<td>10</td>
<td>56 °C</td>
<td>56 °C</td>
</tr>
</tbody>
</table>
- Graphene he-X-o G disperses anisotropic in HDPE
- HDPE 1 wt.% graphene composite conductivity = vacuum dielectric
- HDPE 15 wt.% percolation threshold conductivity increases with graphene loading
- HDPE at 30 wt.% loading increases electrical conductivity $\times 10^{14}$
Thermal conductivity vs additive loading in epoxy resin

- **Weight and cost** reduction in transportation & aerospace

- **Thermally conductivity** polymers enabling electronics deployment

- **No degradation** → boron nitride (BN), aluminum nitride (ALN)... need high wt% concentrations but degrade mechanical properties

- heXo-G graphene provides higher thermal conductivity
  - Can complement and/or reduce the amount of additives used

Thermal Conductivity (W/K·m)
Measured out-of-plane thermal conductivity

- Initial slope is 0.02 W/K·m·% graphene he-X-o G V20
- Steeper slope of 0.04 W/K·m·% beyond 12% percolation threshold
- Thermal conductivity of 2.32 W/K·m reached for 50 wt.% graphene (factor of 10x)
**EMI shielding example**

- **Metal-base coatings** provide high conductivity, but are heavy, impacted by corrosion and complex to manufacture.
- Polymer composites with heXo-G V20 demonstrate >40dB X-Band
- High shielding effectiveness (>99% reduction for 8-12 GHz)
  - Lightweight and corrosion resistant
  - Static and UV protection
  - Increases strength + minimizes elongation

**Table: Shielding Effectiveness (SE)**

<table>
<thead>
<tr>
<th>Material</th>
<th>SE (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPU/CB (10 wt%)</td>
<td>12.2 dB*1</td>
</tr>
<tr>
<td>TPU/CNT (10 wt%)</td>
<td>21.8 dB*1</td>
</tr>
<tr>
<td>HDPE/CB (20 wt%)</td>
<td>16 dB*2</td>
</tr>
<tr>
<td>TPU/heXo-G (10 wt%)</td>
<td>29.6 dB</td>
</tr>
<tr>
<td>TPU/heXo-G (20 wt%)</td>
<td>40.0 dB</td>
</tr>
</tbody>
</table>

\[ SE (dB) = SE_A (dB) + SE_R (dB) \]

**References**
*2: Dinesh & al. ICEBEA’2012, Jan.7-8 2012, Dubai
He-X-o G in geothermal piping

- PE-100 base polymer
- Disperse graphene he-X-o G V4 @ 1 wt% loading
- Use grade he-X-o G V20 @ 8 wt% loading
- Doubles thermal conductivity (0.8 W/m·K)
- Increases tensile strength by 30% with minimal elongation compromise
- Retains high impact resistance and improve the flexural modulus
Other Applications

- Stronger + thermally conductive 3D printing materials
- Plastics with EMI shielding properties
- Antistatic and impermeable packaging
- Thermally conductive polymers / epoxies
- Tougher, abrasion resistant and hydrophobic yarns/textiles/rubbers
- Corrosion resistant paints / coatings
- Higher capacity battery electrodes / fuel cells
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BCR Plastics SA
# Two grades of graphene powder

<table>
<thead>
<tr>
<th>Properties</th>
<th>heXo-G V4</th>
<th>heXo-G V20</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average thickness</td>
<td>4-6</td>
<td>20</td>
<td>Carbon Content</td>
</tr>
<tr>
<td>Average flake size</td>
<td>3</td>
<td>50</td>
<td>&gt; 93 wt.%</td>
</tr>
<tr>
<td>Bulk density</td>
<td>0.13</td>
<td>0.24</td>
<td>&lt; 4 wt.%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Oxygen contact</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&gt; 92 wt.%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&lt; 5 wt.%</td>
</tr>
<tr>
<td><strong>Electrical Conductivity</strong></td>
<td>***</td>
<td>***</td>
<td><strong>Mechanical strengthening</strong></td>
</tr>
<tr>
<td><strong>Thermal Conductivity</strong></td>
<td>***</td>
<td>***</td>
<td><strong>Moisture and oxygen barrier</strong></td>
</tr>
<tr>
<td><strong>Liquid dispersion</strong></td>
<td>***</td>
<td>*</td>
<td><strong>Typical Applications</strong></td>
</tr>
<tr>
<td><strong>Typical Applications</strong></td>
<td>Coatings, antistatic and EMI shielding, sensors, thermal interface materials, UV resistance</td>
<td>Conductive/ESD composites, thermal conductivity, material strengthening, battery electrodes</td>
<td></td>
</tr>
</tbody>
</table>