CARBON AND GRAPHITE FOR PHOTOVOLTAIC INDUSTRY

Innovation & Efficiency for a competitive PV energy
Among all renewable energies photovoltaic benefits from many environment and economic advantages:
• Unlimited renewable source of energy
• Increasingly cost competitive
• Decentralized power source
• Peak power at peak time of usage
• Environment friendly

The sun, an energy available for free...

Photovoltaic systems use cells to convert sunlight directly into electricity. When sunlight strikes a PV cell, electrons are dislodged, creating an electrical current. The most common semiconductor material used in photovoltaic cell is silicon, an element most commonly found in sand. The crystalline silicon technology, which distinguishes monocrystalline, multicrystalline and ribbon sheets processes, represents approx. 90% of the market today.

Thanks to its outstanding properties graphite is the unique and only material to withstand high temperature, corrosion and the severe conditions on the silicon production process.

Other photovoltaic processes are now available on the market such as the thin film technology where modules are constructed by depositing extremely thin layers of photosensitive materials onto glass, plastic or stainless steel.

“Photovoltaic” is the combination of two words: “photo”, from Greek origin, which means light, and “voltaic”, from “volt”, the unit used to measure electricity.

Carbone Lorraine is a world leader in isostatic graphite production, and proposes proven solutions to each step of the photovoltaic production chain, from polysilicon feedstock to cells antireflective coating via thin film process. Its range of materials covers graphite, Carbon/Carbon composite as well as insulation materials.

Benefits of Carbone Lorraine materials:
• Grade consistency (inert and non-wetting to most chemicals)
• Large diameters available up to 1.5 m in graphite and 2.2 m in Carbon/Carbon composites for the whole range of products
• High purity (less than 5 ppm), which avoids contamination and allows high quality products
• Dedicated high performance solutions to increase lifetime and efficiency
• Carbone Lorraine materials offer strong benefits...
Isostatic graphite grade 2191 UHP5
The best combination with high thermal conductivity, high strength & high purity!

- Large size rounds up to dia. 1500 mm in isostatic graphite 2020.
- Trays or tubes up to dia. 2200 mm in Carbon/Carbon composite AM252
- Rigid carbon thermal insulation CALCARB® and ISOLOR®
- Machining capacity and purification capabilities for large dimensions
- Dedicated solutions to reduce chemical reaction with molten silicon

Silica → Metallurgical silicon → TCS Siemens reactor & converter → Polysilicon

- Purified graphite grades 2123PT, 2450PT, 2020PT
- SiC coating
- Rigid carbon thermal insulation CALCARB® and ISOLOR®
- Heat shields AM252
- Stable properties and excellent wear performance vs. silicon environment

Carbone Lorraine all along the photovoltaic production chain
Photovoltaic production chain —

- 2020 graphite crucibles, holders, heaters
- Rigid carbon thermal insulation CALCARB® and ISOLOR®
- AM252 carbon/carbon bolts & nuts
- Large sizes
- Excellent price to performance

Multicrystalline silicon melting

Monocrystalline silicon pulling

Si - Ribbons process

Wafer slicing

Solar cell

Anti-reflective coating \( \text{Si}_3 \text{N}_4 \)

- 2020 graphite carriers
- AM252 carbon/carbon carriers
- Large sizes
- Mechanical stability
- Adapted CTE

Isostatic graphite grades 2124 UHP5, 2450 UHP5
- Rigid carbon thermal insulation CALCARB® and ISOLOR®
- Ultra high precision machining to ensure process stability
- Non wetting to silicon
MATERIALS

Graphite grades

<table>
<thead>
<tr>
<th>Grade</th>
<th>Density</th>
<th>FS (MPa)</th>
<th>CTE (10⁻⁶/°C)</th>
<th>Resistivity (μΩcm)</th>
<th>Thermal conductivity (W/m°C)</th>
<th>Permeability (cm²/s)</th>
<th>Standard sizes (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2191</td>
<td>1.75</td>
<td>44</td>
<td>4.2</td>
<td>1,000</td>
<td>116</td>
<td>0.5</td>
<td>540x540x1,830</td>
</tr>
<tr>
<td>2020</td>
<td>1.77</td>
<td>45</td>
<td>4.3</td>
<td>1,550</td>
<td>85</td>
<td>0.4</td>
<td>530x635x1,830</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,030x1080x325</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,500x1,830</td>
</tr>
<tr>
<td>2123</td>
<td>1.84</td>
<td>58</td>
<td>5.5</td>
<td>1,140</td>
<td>112</td>
<td>0.3</td>
<td>305x620x915</td>
</tr>
<tr>
<td>2160</td>
<td>1.86</td>
<td>76</td>
<td>6.0</td>
<td>1,270</td>
<td>102</td>
<td>0.2</td>
<td>305x305x915</td>
</tr>
<tr>
<td>2450</td>
<td>1.86</td>
<td>45</td>
<td>4.5</td>
<td>1,550</td>
<td>85</td>
<td>0.04</td>
<td>On request</td>
</tr>
<tr>
<td>6503</td>
<td>1.74</td>
<td>23</td>
<td>3.3</td>
<td>800</td>
<td>200</td>
<td>1</td>
<td>550x550x1,830</td>
</tr>
</tbody>
</table>

Purity

<table>
<thead>
<tr>
<th></th>
<th>Unpurified</th>
<th>Purified</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>290 ppm</td>
<td>PT : &lt; 20 ppm</td>
</tr>
</tbody>
</table>

SiC coating

<table>
<thead>
<tr>
<th>T max</th>
<th>Density</th>
<th>Open porosity</th>
<th>RF (MPa)</th>
<th>CTE (10⁻⁶/°C)</th>
<th>Coating thickness</th>
<th>Hardness</th>
<th>Young modulus (GPa)</th>
<th>Permeability (cm²/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1700°C</td>
<td>3.2</td>
<td>Impervious to most gases (H₂) and liquids</td>
<td>350</td>
<td>4.8</td>
<td>50-250 μm</td>
<td>2280</td>
<td>2950 Knoop</td>
<td>63</td>
</tr>
</tbody>
</table>

Rigid carbon insulation

<table>
<thead>
<tr>
<th></th>
<th>Density</th>
<th>Thermal conductivity at 400°C (W/m°C)</th>
<th>Thermal conductivity at 2,200°C (W/m°C)</th>
<th>Standard Dimensions (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISOLOR® S10</td>
<td>0.1</td>
<td>2.4</td>
<td>2.2</td>
<td>1,500x1000x40</td>
</tr>
<tr>
<td>CALCARB® CBCF 18-2000</td>
<td>0.18</td>
<td>0.1</td>
<td>1.0</td>
<td>Rounds &amp; special sizes on request</td>
</tr>
</tbody>
</table>

Carbon/Carbon composite

<table>
<thead>
<tr>
<th>AM252</th>
<th>Density</th>
<th>FS (MPa)</th>
<th>Flexural modulus (GPa)</th>
<th>Max sizes (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.70</td>
<td>100</td>
<td>10</td>
<td>Ring Ø 2,200</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tube length 3,000</td>
</tr>
</tbody>
</table>
CARBONE LORRAINE harnesses prime expertise in industrial applications to deliver innovative solutions – involving graphite, other high-performance materials, and key components for electric motors and electronic equipment – for many high-technology markets.

As world number-one in its main business specialities, Carbone Lorraine fields an extensive industrial and commercial network covering around 40 countries, working hand in hand with its clients to pursue permanent innovation through a broad range of top-class products and services.

Contact in North America
CARBONE OF AMERICA
Ultra Carbon Division
900 Harrison Street
Bay City, MI 48708
USA
Tel.: +1 989 894 29 11
Fax: +1 989 895 77 40
solar.us@carbonelorraine.com

Contact for Europe
CARBONE LORRAINE COMPOSANTS
41 rue Jean Jaurès - BP 148
F-92231 GENNEVILLYERS CEDEX
FRANCE
Tel.: +33 (0)1 41 85 45 14
Fax: +33 (0)1 41 85 43 53
solar.fr@carbonelorraine.com

Contact for Asia
Le Carbone Advanced Graphite Co., Ltd
#29 South Tahu Road,
Kunshan Development Zone,
Kunshan, Jiangsu Province,
215334, PR China
Tel.: +86 512 5763 9808
Fax: +86 512 5763 9811
www.carbonelorraine-hc.cn