e-Mobility Applications of Nanocrystalline (NC) Materials

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Materials & Components
VAC: Global leader in magnetic materials

Who we are

- VAC’s portfolio of magnetic materials consists of more than 120 different alloys and materials
- VAC produces the full range of magnetic materials of soft, semihard and permanent magnetic materials
- Several key materials are developed by VAC
- VAC has production know how for all important key production technologies used for magnetic materials
  - Rapid solidification technology for amorphous and nanocrystalline materials
  - Melting and hot & cold rolling of crystalline materials
  - Powder technology for permanent magnets

VITROPERM® → Nanocrystalline alloy → High saturation polarization & low coercivity
Collaborative design process with clients to develop customized products specified to their long-term needs

VAC features a close-knit and client-focused design and production process
Production Process of Amorphous Foils at
Impact of Productions Steps on Quality

**Melting:**
- Homogeneous chemical composition → saturation flux density Bs
- Vacuum treatment → high purity & consistent composition

**Casting:**
- uniform thickness
- high surface quality
- excellent ductility

**Testing**
- Testing of magnetic properties for each batch: Bs and permeability μ
- Testing of width, thickness, ductility & surface quality for each coil
- High quality ensures reliable and consistent material supply for wireless power transfer (WPT) applications
Nanocrystalline Material is VITROPERM®
Nanocrystalline VITROPERM®

Unique combination of material properties

- VAC was one of the first companies in the world starting mass production of nanocrystalline VITROPERM® in 1992
- More than 25 years experience in the production of amorphous and nanocrystalline materials
- VAC developed VITROPERM® to a widely diversified Nanocrystalline material family covering a wide range of properties and requirements
- VAC is under development of nanocrystalline materials of the next generation with
  - Higher saturation flux density
  - Lower losses
  - Thinner ribbon thickness

<table>
<thead>
<tr>
<th>Key properties</th>
<th>VITROPERM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material base</td>
<td>≈ 70 % Fe</td>
</tr>
<tr>
<td>Saturation flux density $B_s [T]$</td>
<td>&gt; 1.2</td>
</tr>
<tr>
<td>Adjustable permeability $\mu_i$</td>
<td>4,000 – 200,000 (F), 1,000,000 (Z), Max. 600,000 (R)</td>
</tr>
<tr>
<td>Coercivity $H_c [A/m]$</td>
<td>0,5</td>
</tr>
<tr>
<td>Losses $P_{Fe} [W/kg]$ (100 kHz/300mT/100 °C)</td>
<td>&lt; 80</td>
</tr>
<tr>
<td>Saturation magnetostriction $\lambda_s$</td>
<td>0 (10⁻⁹ – 10⁻⁶)</td>
</tr>
<tr>
<td>Max. operation temperature $T_{op}$</td>
<td>&gt; 150°C (180°C)</td>
</tr>
</tbody>
</table>

VITROPERM® → High saturation flux density → High permeability → Lowest magnetic losses
## Nanocrystalline VITROPERM® 800

### Key properties vs. other materials

<table>
<thead>
<tr>
<th></th>
<th>Nanocrystalline VITROPERM 800</th>
<th>Amorphous FeSiB (85-90 wt.% Fe)</th>
<th>NiZn</th>
<th>MnZn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main composition</td>
<td>FeCuNbSiB (83 wt.% Fe)</td>
<td>Fe(SiB)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saturation flux density $B_s$ [T]</td>
<td>&gt; 1.2</td>
<td>1.4 – 1.6</td>
<td>&lt; 0.35</td>
<td>&lt; 0.45</td>
</tr>
<tr>
<td>Saturation magnetostriction $\lambda_s$ [$10^{-6}$]</td>
<td>≈ 0</td>
<td>25 - 35</td>
<td>20 - 40</td>
<td>20 - 40</td>
</tr>
<tr>
<td>Coercivity $H_c$ [A/m]</td>
<td>0.5 - 1</td>
<td>4 - 10</td>
<td>5 - 15</td>
<td>5 – 15</td>
</tr>
<tr>
<td>Thermal conductivity [Wm/K]</td>
<td>10</td>
<td>12</td>
<td>1 - 3</td>
<td>1 - 3</td>
</tr>
<tr>
<td>Losses $P_{Fe,typ}$ [W/kg] (100 kHz, 200 mT)</td>
<td>&lt; 35</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. operation temperature $T_{op}$</td>
<td>&gt; 150°C</td>
<td>&lt; 120°C</td>
<td>&lt; 120°C</td>
<td>&lt; 120°C</td>
</tr>
</tbody>
</table>

**VITROPERM®**

- High saturation flux density
- High permeability
- Lowest magnetic losses
### VITROPERM® 800 Foil Grades

For cores & components, EMI shielding and Wireless Power Transfer (WPT) applications

<table>
<thead>
<tr>
<th>Foil thickness:</th>
<th>19 µm</th>
<th>18 µm</th>
<th>17 µm</th>
<th>16 µm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness tolerance (µm)</td>
<td>± 2</td>
<td>± 3</td>
<td>± 2</td>
<td>± 2</td>
</tr>
<tr>
<td>Foil width „as cast“ (mm)</td>
<td>25 – 60</td>
<td>25 - 66</td>
<td>60</td>
<td>25 - 108</td>
</tr>
<tr>
<td>„as cast“ width tolerance (mm)</td>
<td></td>
<td></td>
<td>± 0.5 / ± 1.0</td>
<td></td>
</tr>
<tr>
<td>Foil width „slit“ (mm)</td>
<td>3 - 56</td>
<td>3 - 56</td>
<td>-</td>
<td>3 - 102</td>
</tr>
<tr>
<td>„slit“ width tolerance (mm)</td>
<td></td>
<td></td>
<td>± 0.10 / ± 0.15</td>
<td></td>
</tr>
</tbody>
</table>

- VAC standard VITROPERM® grade - 18 µm - is used for WPT application, too
- Fulfillment of WPT quality requirements are confirmed by several customers
- VAC has best long-term experience of high volume deliveries for WPT applications (since 2014 more than 600 t)
- VAC produces and sells wide ribbons (66 mm and more) since 2013
Benefits of VITROPERM® 800
vs. competitor materials

<table>
<thead>
<tr>
<th>Typical values for some key features</th>
<th>VAC</th>
<th>Competitor A</th>
<th>Competitor B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Britteness of foil Ribbon breaks per 100 km</td>
<td>&lt; 3</td>
<td>&gt;100</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Holes (size) Diameter in mm</td>
<td>&lt; 0.3</td>
<td>&lt; 0.3</td>
<td>1-5</td>
</tr>
<tr>
<td>Holes (amount) Counts per km ribbon</td>
<td>&lt; 100</td>
<td>&gt; 1000</td>
<td>&gt; 10000</td>
</tr>
<tr>
<td>Surface roughness Ra (air side)</td>
<td>0.7</td>
<td>0.7</td>
<td>1.1</td>
</tr>
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</table>

VITROPERM® is best in class material
- Highest surface quality
- Lowest size and amount of holes
- Best in class consistency of mechanical properties
- Best homogeneity of chemical composition

Surface structure of as cast nano foils
3D laser scanning microscopy images
Typical air side surface of nano ribbon
WPT Applications
Wireless charging is a method for transferring electrical energy from a charger to a device without the need for a physical wire connection.

- Requires coupling of wireless charging pad with compatible device with built-in receiver.
- Provides convenience by removing need to physically plug-in device to cable.

Wireless Charging Applications:

- Consumer electronics
- Medical devices
- Electric vehicle charging
- Household appliances
- Military/Aviation
Wireless Charging: Product Differentiation

**Special requirements**
- High ductility in amorphous state
  - Leads to higher yield in processing
- Excellent surface quality
  - No holes or pimples
  - No scratches or splits
  - No wavy surface or rippled edges
- Consistent thickness
  - No wedge shape or thicker edges
- Low stacking thickness
  - High filling factor
  - Trend goes to thinner material
- Flat winding condition of coil
  - No damaged ribbon edges
- Greater foil width
  - 60 mm → 66 mm → 100 mm

**VITROPERM® 800 unique selling points**
- Outstanding ductility
- Highest surface quality
  - Lowest size and amount of holes
- Best in class consistency of mechanical properties
- Highest filling factor
- Best homogeneity of chemical composition

**VITROPERM® 800**
- Best-in-class WPT properties are confirmed by customers
- VAC delivered more than 600 t into WPT applications since 2014
Wireless EV Charging

**Special requirements (additional)**
- Consistent magnetic properties over a broad temperature range (for Rx)
  - -40 ... 85 (120) °C
- High mechanical stability
  - Resistant to shocks and vibrations
- High WPT efficiency
  - Short charging times
- Low losses at high power levels
  - No heating up of WPT system
- Easy assembly and low weight
  - No ‘chess board’ assembly
  - Low total thickness of Rx

**VITROPERM® 800 unique selling points**
- High thermal stability and wide range of operating temperature
  - Curie temperature $T_c \approx 600$ °C
- Multilayer lamination of VITROPERM 800
  - Unbreakable
- WPT system with VITROPERM 800 has same or higher WPT efficiency like ferrite systems
- Higher permeabilities of VITROPERM 800 (1,000 – 3,000 @ 85...125 kHz) lead to higher coupling factors vs. ferrite systems
- Multilayer lamination of VITROPERM 800
  - Wider due to its robustness
  - Thinner due to its robustness vs. ferrite systems

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<th>Mode</th>
<th>Inductive charging</th>
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<tr>
<td>Standard</td>
<td>IEC 61980-3</td>
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<tr>
<td>Power class</td>
<td>2...5.5 kW</td>
</tr>
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<td></td>
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<td>Connection</td>
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<td>Communication</td>
<td>Wireless</td>
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**Inductive charging**
- Standard IEC 61980-3
- Power class 2...5.5 kW, 11...22 kW
- Connection Schuko / CCE
- Communication Wireless
Key Take Aways
Key Take Aways VITROPERM®

- Nanocrystalline VITROPERM® 800 has unique and outstanding combination of properties vs. other technical solutions:
  - Outstanding shielding performance
  - Excellent power transfer efficiency
  - Better thermal conductivity and stability than ferrite solutions
- Consistent material properties & excellent ductility in amorphous state = high yield in processing
- Over 600 mT of VITROPERM® 800 shipped to market since 2014 for WPT and shielding applications
- VITROPERM® 800 is preferred and benchmark material for WPT applications