



# e-Mobility Applications of Nanocrystalline (NC) Materials

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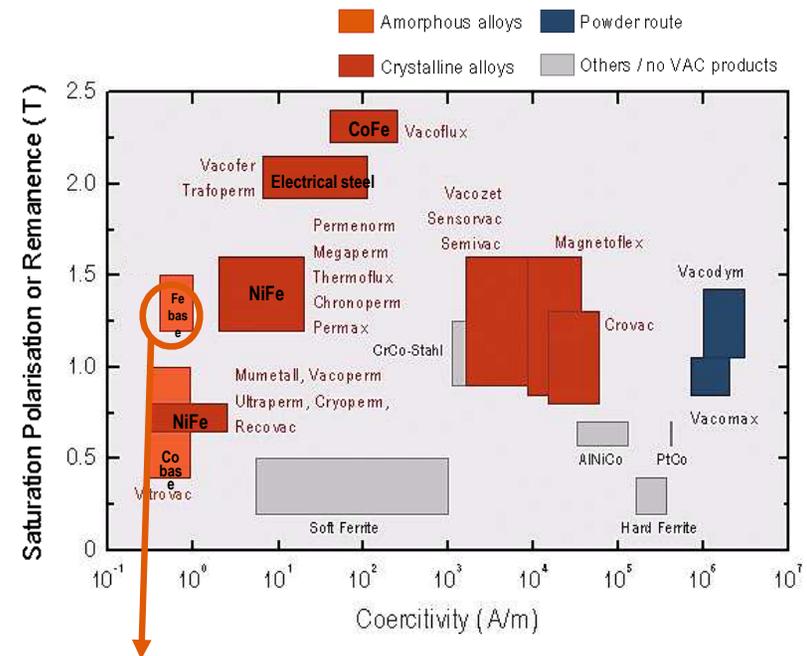
Materials & Components

# VAC: Global leader in magnetic materials



## Who we are

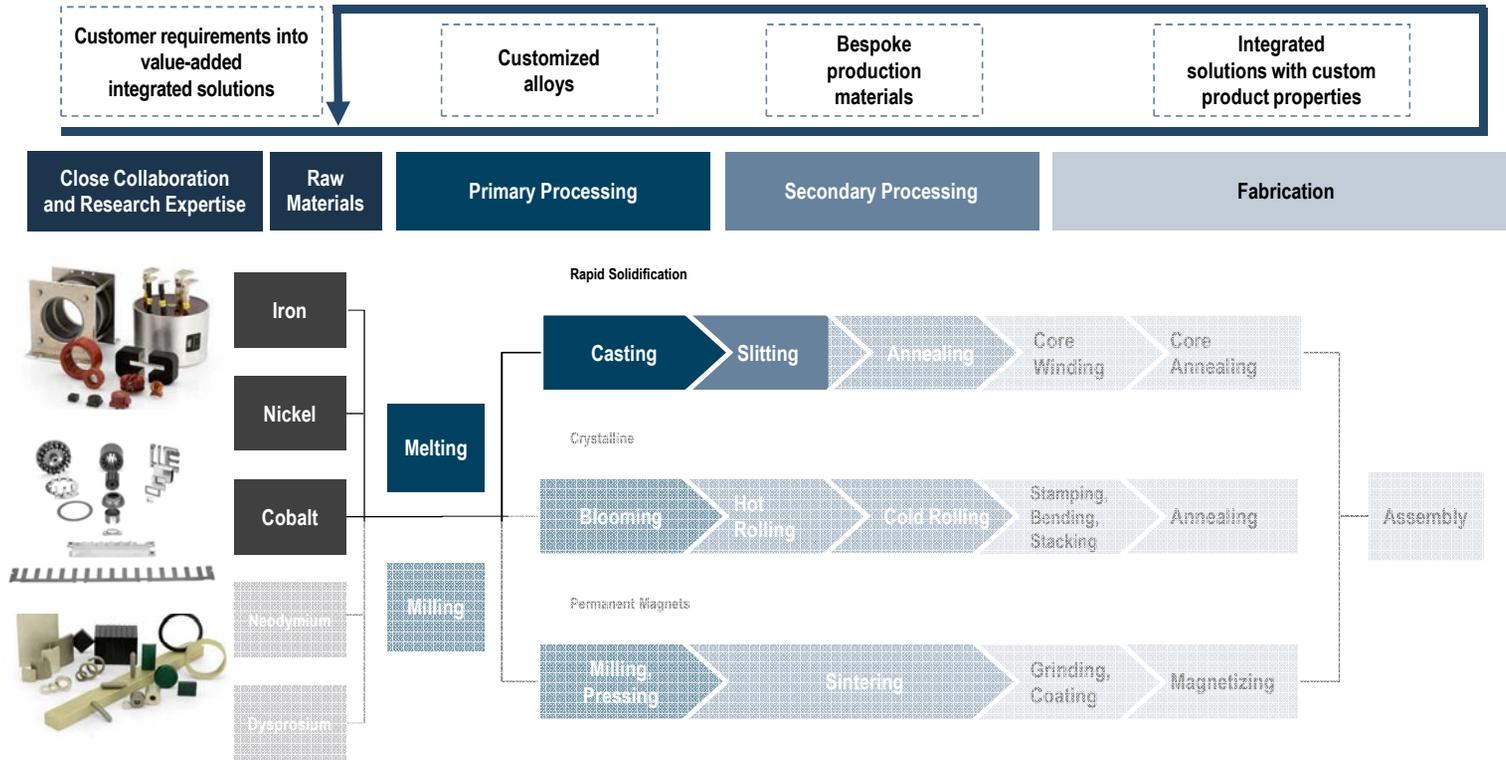
- VAC's portfolio of magnetic materials consists of more than 120 different alloys and materials
- VAC produces the full range of magnetic materials of soft, semihard and permanent magnetic materials
- Several key materials are developed by VAC
- VAC has production know how for all important key production 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<sup>®</sup>** → Nanocrystalline alloy  
 → High saturation polarization & low coercivity

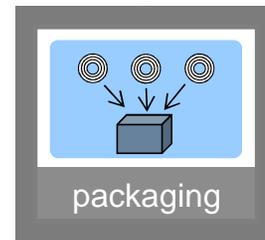
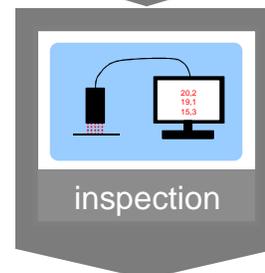
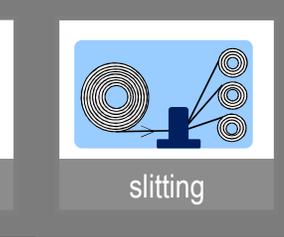
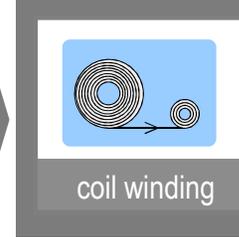
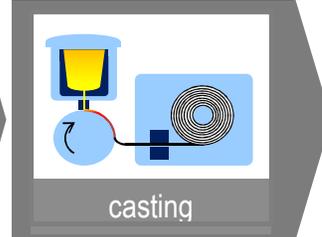
# VAC Value Chain Integration

- 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

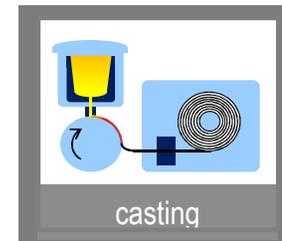
## Melting:

- Homogeneous chemical composition → saturation flux density  $B_s$
- Vacuum treatment → high purity & consistent composition



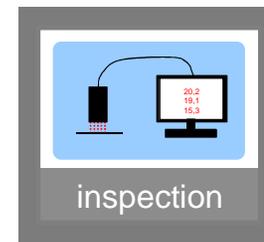
## Casting:

- uniform thickness
- high surface quality
- excellent ductility



## Testing

- Testing of magnetic properties for each batch:  $B_s$  and permeability  $\mu$
- 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<sup>®</sup>



# Nanocrystalline VITROPERM<sup>®</sup>



## Unique combination of material properties

- VAC was one of the **first companies in the world** starting mass production of nanocrystalline VITROPERM<sup>®</sup> in 1992
- More than **25 years experience** in the production of amorphous and nanocrystalline materials
- VAC developed **VITROPERM<sup>®</sup>** 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



| Key properties                                | VITROPERM  |
|---|--|
| Material base                                 | ≈ 70 % Fe  |
| Saturation flux density $B_s$ [T]             | > 1.2  |
| Adjustable permeability $\mu_i$               | 4,000 – 200,000 (F),<br>1,000,000 (Z),<br>Max. 600,000 (R) |
| Coercivity $H_c$ [A/m]                        | 0,5  |
| Losses $P_{Fe}$ [W/kg] (100 kHz/300mT/100 °C) | < 80   |
| Saturation magnetostriction $\lambda_s$       | ≈ 0 ( $10^{-8}$ – $10^{-6}$ )                              |
| Max. operation temperature $T_{op}$           | > 150°C (180°C)  |

**VITROPERM<sup>®</sup>** → High saturation flux density  
→ High permeability  
→ Lowest magnetic losses

# Nanocrystalline VITROPERM<sup>®</sup> 800

## Key properties vs. other materials

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

### VITROPERM<sup>®</sup>

- High saturation flux density
- High permeability
- Lowest magnetic losses



# VITROPERM<sup>®</sup> 800 Foil Grades

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



| Foil thickness:           |                   | 19 $\mu\text{m}$      | 18 $\mu\text{m}$ | 17 $\mu\text{m}$ | 16 $\mu\text{m}$ |
|---------------------------|-------------------|-----------------------|------------------|------------------|------------------|
| Thickness tolerance       | ( $\mu\text{m}$ ) | $\pm 2$               | $\pm 3$          | $\pm 2$          | $\pm 2$          |
| Foil width „as cast“      | (mm)              | 25 - 60               | 25 - 66          | 60               | 25 - 108         |
| „as cast“ width tolerance | (mm)              | $\pm 0.5 / \pm 1.0$   |                  |                  |                  |
| Foil width „slit“         | (mm)              | 3 - 56                | 3 - 56           | -                | 3 - 102          |
| „slit“ width tolerance    | (mm)              | $\pm 0.10 / \pm 0.15$ |                  |                  |                  |

- VAC standard VITROPERM<sup>®</sup> grade - 18  $\mu\text{m}$  - 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<sup>®</sup> 800

vs. competitor materials

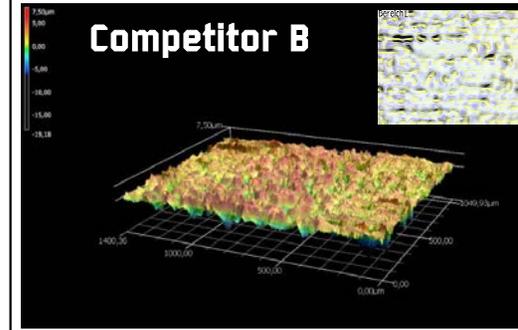
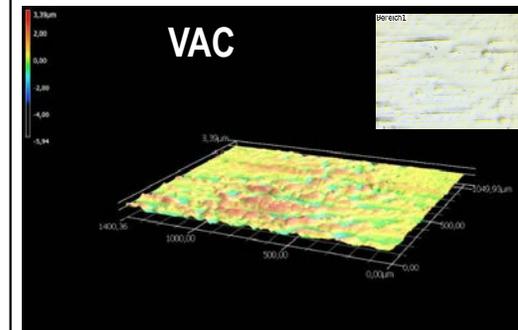
| Typical values for some key features |                          | VAC             | Competitor A | Competitor B |
|--------------------------------------|--------------------------|-----------------|--------------|--------------|
| <b>Brittleness of foil</b>           | Ribbon breaks per 100 km | 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

**VITROPERM<sup>®</sup> 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 microscope images  
Typical air side surface of nano ribbon



# WPT Applications

# Wireless charging – Applications / Markets

## Wireless Charging Technology



- 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<sup>®</sup> 800 unique selling points

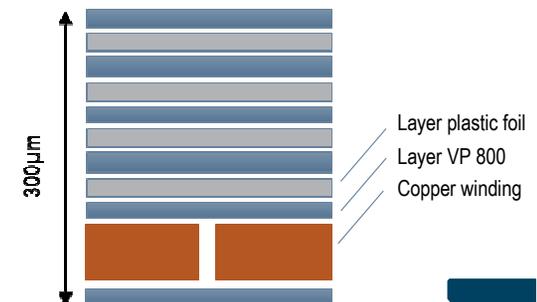
- Outstanding ductility
- Highest surface quality
  - Lowest size and amount of holes
- Best in class consistency of mechanical properties
- Highest filling factor
- Best homogeneity of chemical composition

## VITROPERM<sup>®</sup> 800

- Best-in-class WPT properties are confirmed by customers
- VAC delivered more than 600 t into WPT applications since 2014



qi WIRELESS POWER  
CONSORTIUM



# 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

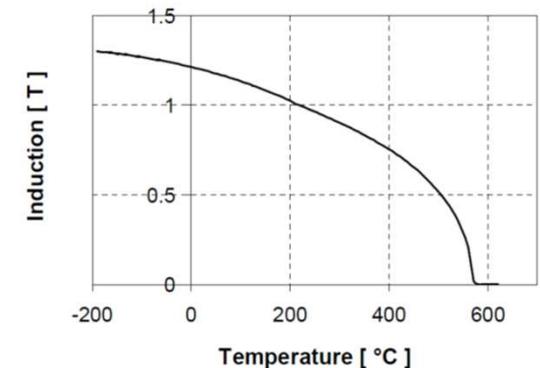
## VITROPERM® 800 unique selling points

- 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



**VAC**<sup>®</sup>  
VACUUMSCHMELZE

|               |                          |
|---------------|--------------------------|
|               | Inductive charging       |
| <b>Mode</b>   | -                        |
| Standard      | IEC 61980-3              |
| Power class   | 2...5.5 kW<br>11...22 kW |
| Connection    | Schuko / CCE             |
| Communication | Wireless                 |



# Key Take Aways

# Key Take Aways VITROPERM<sup>®</sup>



- Nanocrystalline VITROPERM<sup>®</sup> 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<sup>®</sup> 800 shipped to market since 2014 for WPT and shielding applications
- VITROPERM<sup>®</sup> 800 is preferred and benchmark material for WPT applications

