SUPERCONDUCTOR INDUSTRIALIZATION

REALITY OR ROCKET SCIENCE?

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OVERVIEW

THEVA at a glance

Company  THEVA GmbH, HQ in Ismaning, Germany, established 1996
Product  high temperature superconducting wire
Investors  Target Partners, BayBG
Team  45 FTE (mostly engineers, technicians)
IP  38 patents (24 granted)

Timeline

1996 - 2012
May 2012
Jan 2015
Jan 2017

Development  Pilot plant setup  Product roll-out  Expansion
HTS conductor development
Operation:
- HTS coatings
- Equipment manufacturing
Samples available
Pilot plant running
Performance increase
Production cost down
Sales & projects
Prepare for expansion
Additional equipment
Accelerated production
Further cost reduction
**Unique Value Proposition**

- **Extremely high power density**
  800 A/mm² (@77K, sf) realized
  Current density 200+ times higher than copper

- **Inexpensive raw materials**
  < 5 €/kAm at high volume
  No supply constraints

- **High operating temperature**
  Liquid nitrogen cooling: 65 – 77 K
  unparalleled performance at lower temperature
**Drawbacks and Hurdles**

- Complexity of production
  predominant cost factor
- Conductor tape – no round wire
  restrictions for handling and component design
- Pilot production – scaling lies yet ahead
  matter of time and market pull

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*THEVA*

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**HTS Tape – Flexible Ceramics**

How do produce kilometer-long single crystals?

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Thin film coating on a flexible metal substrate!

A. Oriented substrate

B. Oriented nucleation layer by deposition engineering

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**RABiTS**
Rolling Aligned Bi-axially Textured Substrate

**IBAD**
Ion Beam Assisted Deposition

**ISD**
Inclined Substrate Deposition
Somehow looks like rocket science
KEY ASPECTS FOR PRODUCTION

- Can we control it?
  Yes.
  PVD coating with established technology, as demonstrated in: photovoltaics, semiconductors, hard coatings, optics, etc.

- Can we get the cost down?
  Yes.

- Better performance needed?
  Not really.
  Material is fine. No fundamental R&D necessary
CSD Wire Manufacturing

Substrate preparation
- Cold-rolling
- H₂ - Annealing
- E-polishing

CSD coating
- La₂Zr₂O₇ - buffer
- CeO₂ - buffer
- Cleaning
- YBa₂Cu₃O₇ Functional layer
- Silver Contact layer
- Oxygen Anneal

Customizing
- Slicing
- Electro-plating
- Quality control Marking

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Process technology

Chemical solution deposition (CSD)

Advantage
• High throughput (deposition rates)
• Low capex
• Lowest power consumption
• Inexpensive raw materials

⇒ Perfect fit for power engineering applications
Expanded pilot line

• EPL construction until end 2015
• Planned capacity > 200km technical HTS wire
• Start sampling for projects mid 2016
Performance

Development with industrial partners over nearly 10 years

Long lengths samples >20m
PVD - Wire Manufacturing Process

Substrate preparation
- De-greasing
- Electro-polishing
- Rinsing & Drying

PVD coating
- E-beam ISD-MgO Orientation
- E-beam MgO Cap layer
- E-beam HTS Functional layer
- E-beam Laser grading
- E-beam Silver Contact layer
- E-beam Oxygen Anneal
- Quality control (Tapestar)

Customizing
- Slicing
- Electro-plating
- Quality control Marking

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PRODUCTION TECHNOLOGY

Consistent PVD – coating (e-beam-evaporation)

Substrate
- Hastelloy C276, non-magnetic
- High mechanical strength > 500 MPa
- cleaning & electro-polishing

MgO-buffer layer
- Inclined substrate deposition (ISD)
- bi-axial orientation, FWHM < 10°
- 25° tilt, graded surface

GdBa$_2$Cu$_3$O$_7$-layer
- continuous e-beam evaporation
- high deposition speed
- no composition control necessary

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HTS – Production Line
Cutting edge production setting worldwide standards

Pilot line features
- Modular, fully-automated
- Continuous vacuum tape locking
- Inline quality control
- Production capacity: 150 km/yr (@ 12 mm-width)
- Max. tape length: 1,000 m
- Processing speed: 30+ m/h
- Yield: > 70%

Goals
- Cost efficient production
- Robust process allowing high yield
- Implementation of industrial standards
- Stringent quality management & continuous improvement process (CIP)

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HTS Wire Specs

Current carrying capacity (@ 12 mm)

- $I_{C,\text{min}}$ up to 600 A
- $I_{C,\text{avg}}$ up to 800 A
- $I_{C,\text{max}}$ up to 1200 A

Excellent magnetic field performance

Lift-factors:

- $I_C(30\,\text{K}, 2\,\text{T})/I_C(77\,\text{K}, \text{s.f.}) = 2$
- $I_C(4.2\,\text{K}, 10\,\text{T})/I_C(77\,\text{K}, \text{s.f.}) = 2$

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TECHNICAL CONDUCTORS FOR APPLICATIONS

Customizing & Coil winding

Elektrical stabilization

- Lamination:
  - 100 μm Cu-foil single sided TPL 12100 CU100
  - 50 μm Cu-foil double sided TPL 13100 CU2x50
- E-plating: 10-20 μm copper sheath TPL 12100 CU2x20

Coiling (EcoSwing wind turbine generator)

- Industrial coiling technique
- Low-resistance joints (< 10 nΩ)
- Impregnation for robust coils withstand strong forces

EcoSwing 2T-tests coil with voltage taps
KEY ISSUES
KEY ISSUE FOR MARKET DEVELOPMENT

Reducing production costs

- Process stability & reproducibility
  Yield

- Scalability, volume, speed
  Efficiency

- Procurement, alternative materials & suppliers
  Direct costs
RECENT ITEMS FROM OUR AGENDA

- Training schedule for new staff members
- Organization of 3-shift operation
- Work safety
- Second sources & supplier audits
- Commissioning of new equipment & processes in production
- Long-term operation, service life of components
- FMEA, risk mitigation, spare parts management
- Staying within set specs limits, achieving yield goals

It's just like any other producing business

If there is a need, we can make HTS wire a commodity product
THEVA Pro-Line
Superconducting wire

- Reliable  strict quality management
- Powerful  extremely high ampacity
- Competitive  cost-efficient production
Thank you!