Karlsruher Institut für Technologie

Supraleitung International
HTSL Materialien und Drähte für Energieanwendungen

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ZIEHL VIII, 4.4.2022

INSTITUTE FOR TECHNICAL PHYSICS

HTS Materialien und Drähte für Energieanwendungen

Grundlagen und Anwendungsfelder der Hochtemperatursupraleiter

HTS Leiter- und Kabelkonzepte

- Coated Conductor
- Hochstrom- und AC-Kabelkonzepte

Internationaler Stand und Entwicklungen

- Industrielle Leiterherstellung
- Aktuelle Entwicklungen

Low temperature (LT) superconductors

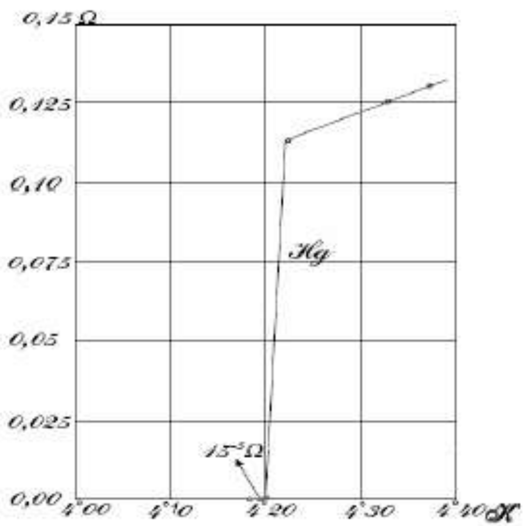
Liquification of He

H. Kamerlingh Onnes, Leiden (1908)

Discovery of „superconductivity“: ideal conductivity

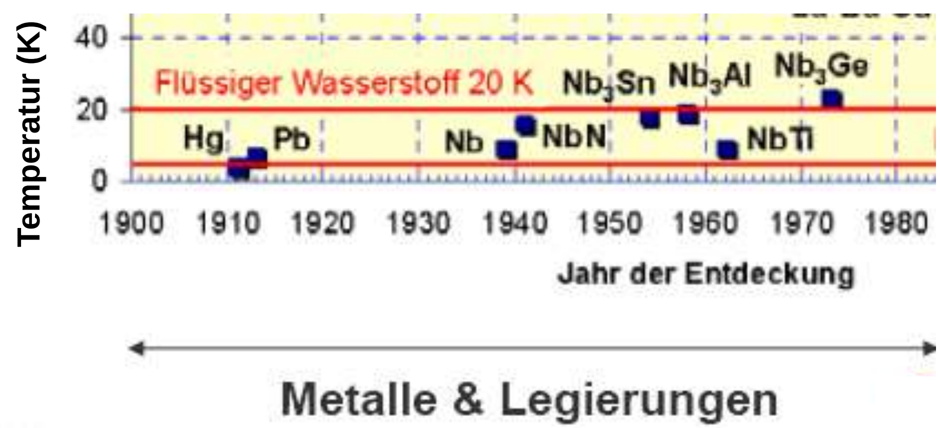
H. Kamerlingh Onnes, Leiden (1911)

Kamerlingh Onnes



Sprung im elektrischen Widerstand von Hg: critical temperature T_C

Many metals and alloys are superconductors



→ Current transport without losses (DC)

Conventional SC require cooling by liquid He

The critical current density $J_c(B,T)$

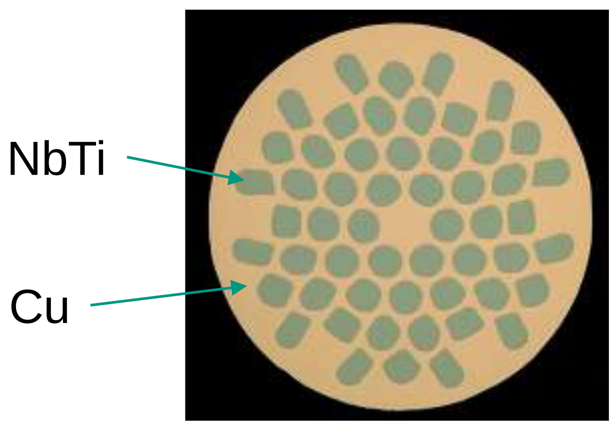
- Ideal conductor for dc, i.e. **no ohmic losses** at $T<T_c$
- R=0 limited by the critical current $I_c(B,T)$
- AC currents result in AC-losses

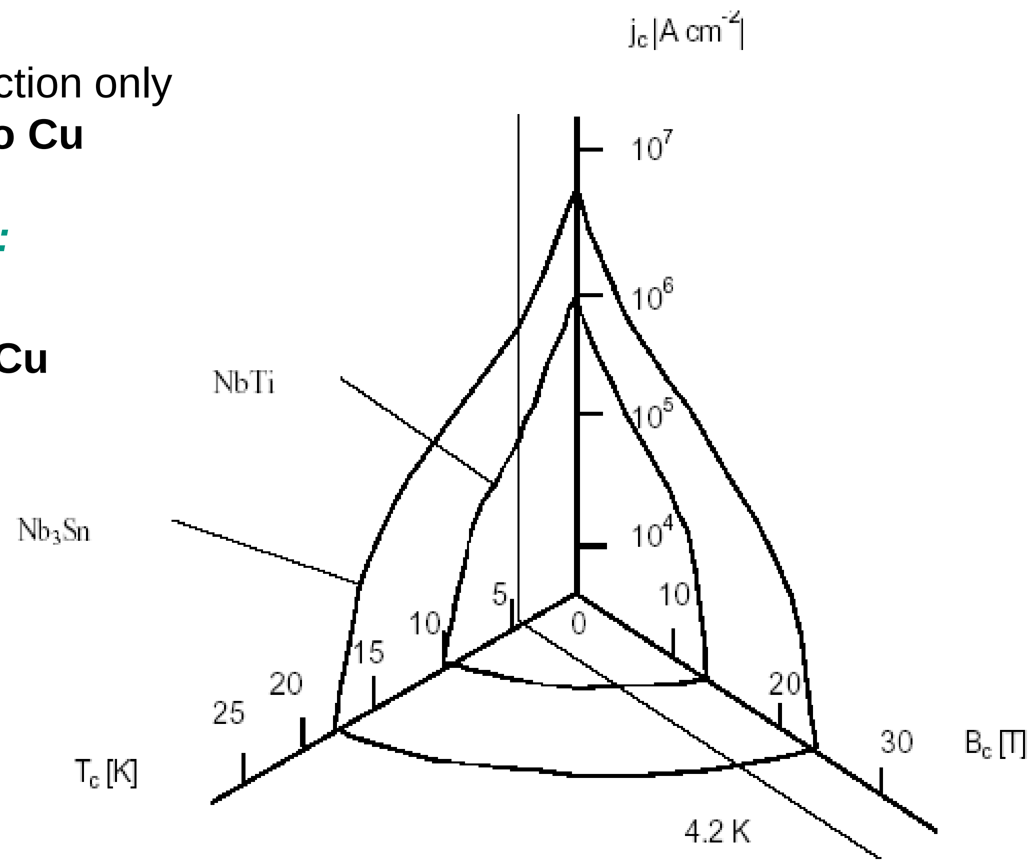
Critical current density J_c

I_c related to the superconductor cross section only
app. 1.000-time increased compared to Cu

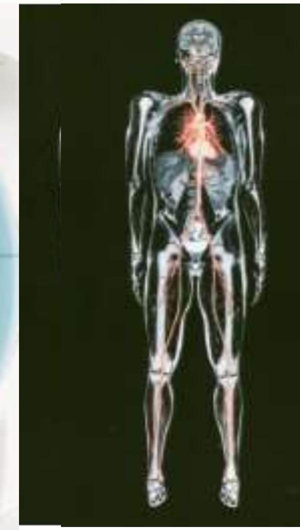
Engineering critical current density J_e:

I_c related to the whole wire cross section
app. 100-time increased compared to Cu





Applications of LT superconductors



Medizintechnik

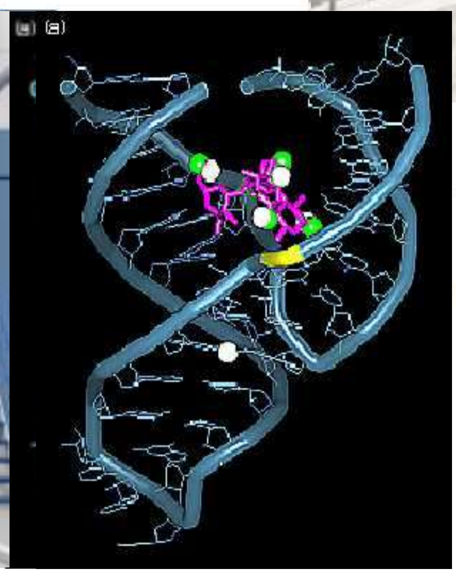
MRI Bildgebung

für weiches Gewebe

(Organe, Knorpel, Sehnen)

Weltmarkt > 3 Mrd € p.a.

> 3000 to NbTi p.a.



Analytik

NMR Spektroskopie

Weltmarkt > 500 M€ p.a.

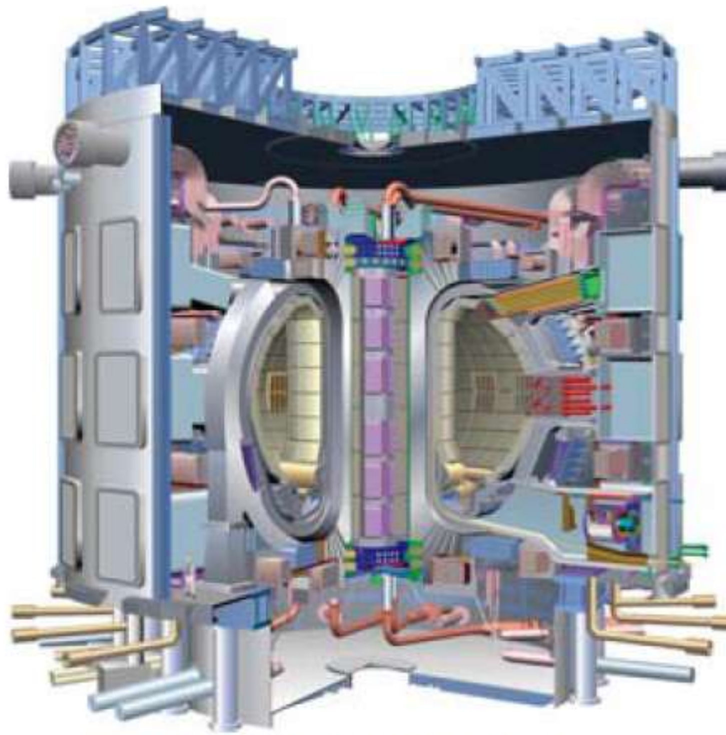
> 500 to Nb_3Sn p.a.

Applications of LT superconductors

Magnets for large scale experimente

- Particle accelerator (e.g. CERN)
- Fusion reactors (e.g. ITER)

Large Hadron Collider, LHC at CERN



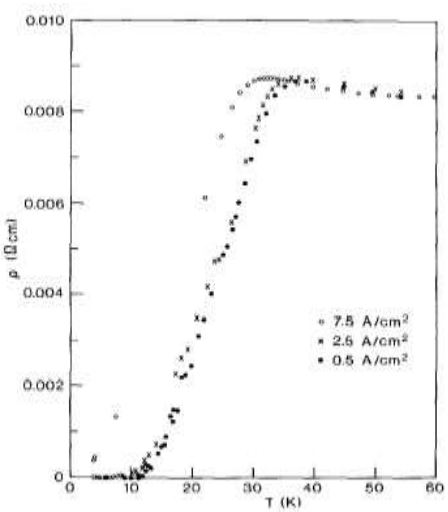
International Thermonuclear Experimental Reactor, ITER

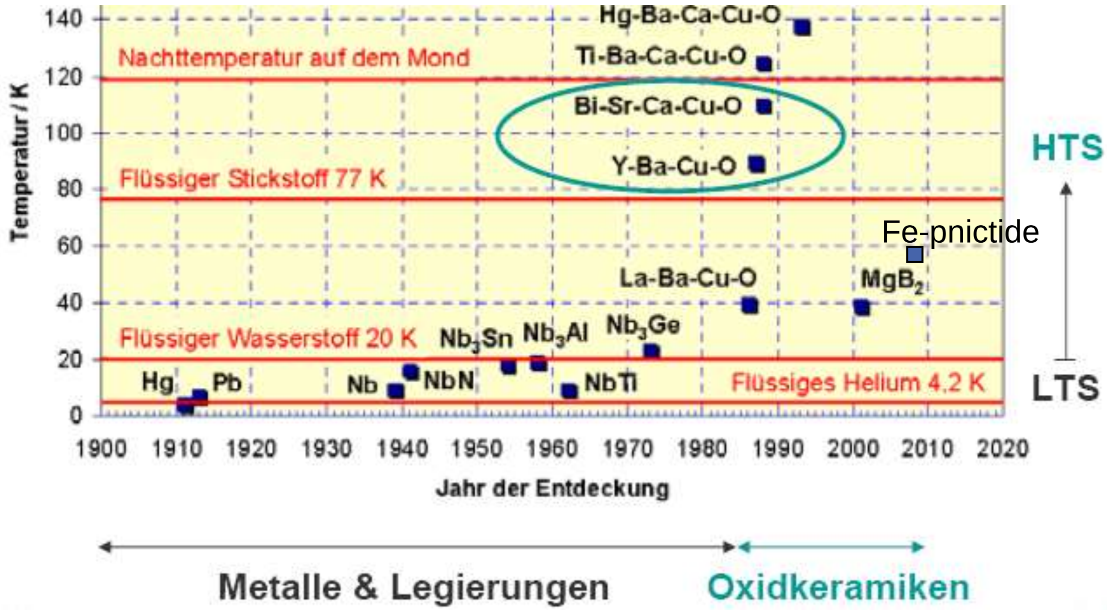
> 500 to Nb_3Sn

ITER Kabel

High temperature superconductors (HTS)

Ba-La-Cu-O:
J. G. Bednorz, K. A. Müller, Z. Physik, B 64 (1986) 189





Cooling with liquid nitrogen possible

Relevant for applications

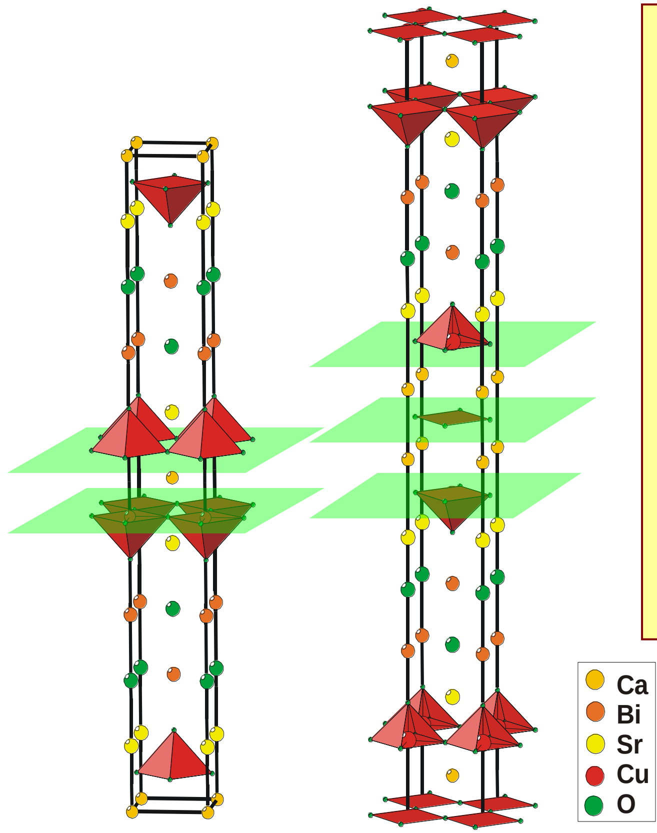
HTS phase		*T_C (K)*
$YBa_2Cu_3O_{7-\delta}$	Y-123	92
$Bi_2Sr_2CaCu_2O_8$	Bi-2212	84
$Bi_2Sr_2Ca_2Cu_3O_{10}$	Bi-2223	110
$TlBa_2Ca_2Cu_3O_{10}$	Tl-1223	125
$HgBa_2Ca_2Cu_3O_{10}$	Hg-1223	133

High temperature superconductors (HTS)

BiSCCO

Bi(Pb)-2212   Bi(Pb)-2223

2212 ≈ $(Bi,Pb)_2Sr_2CaCu_2O_x$ ($x \approx 8$)
2223 ≈ $(Bi,Pb)_2Sr_2Ca_2Cu_3O_x$ ($x \approx 10$)



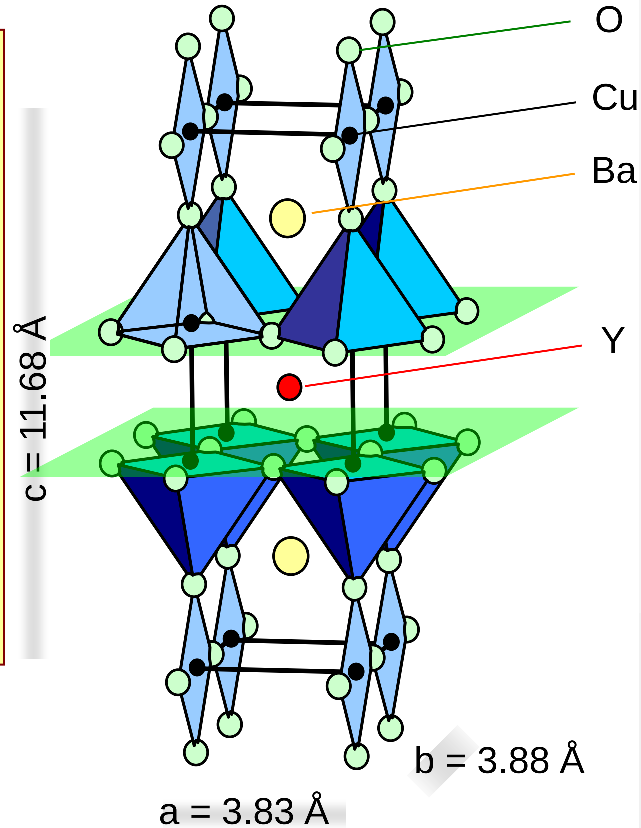
Ceramics with complex layered unit cell (2-dimensional)

CuO_2-layers responsible for superconductivity

Strong anisotropic properties

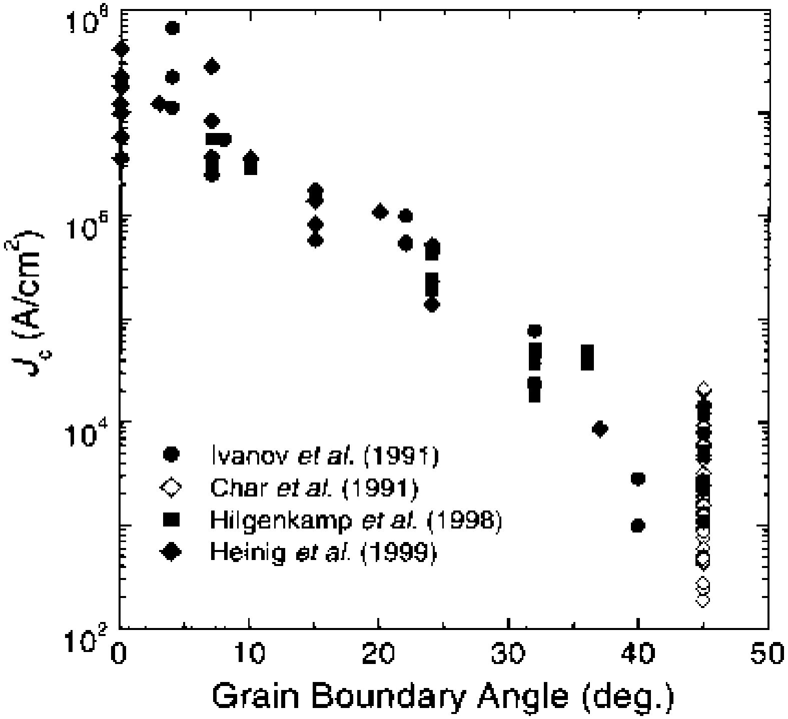
REBCO

$REBa_2Cu_3O_{7-x}$
RE: Y, Nd, Er, Gd, Eu…

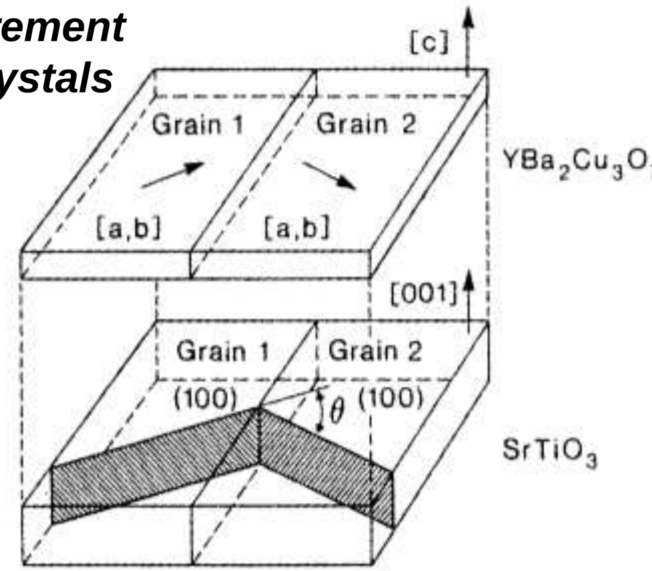


T_c = 85 K T_c = 110 K T_c = 92 K

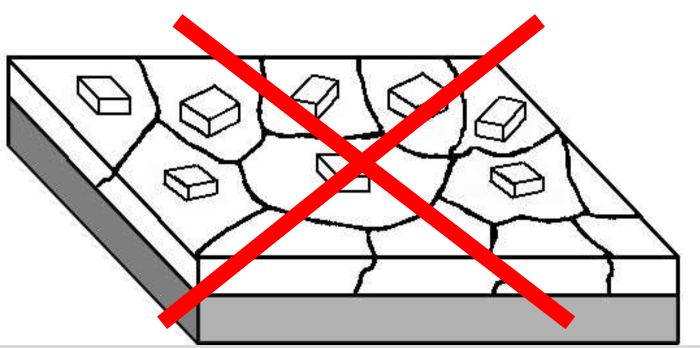
The grain boundary challenge of HTS

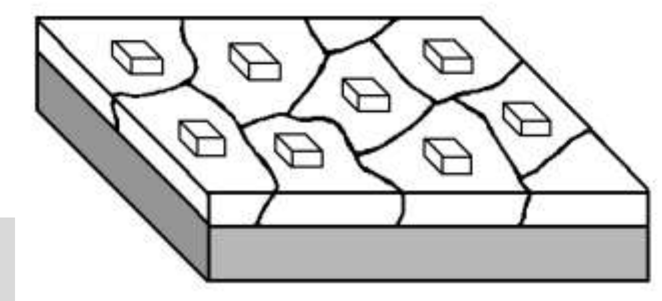


Measurement on bicrystals

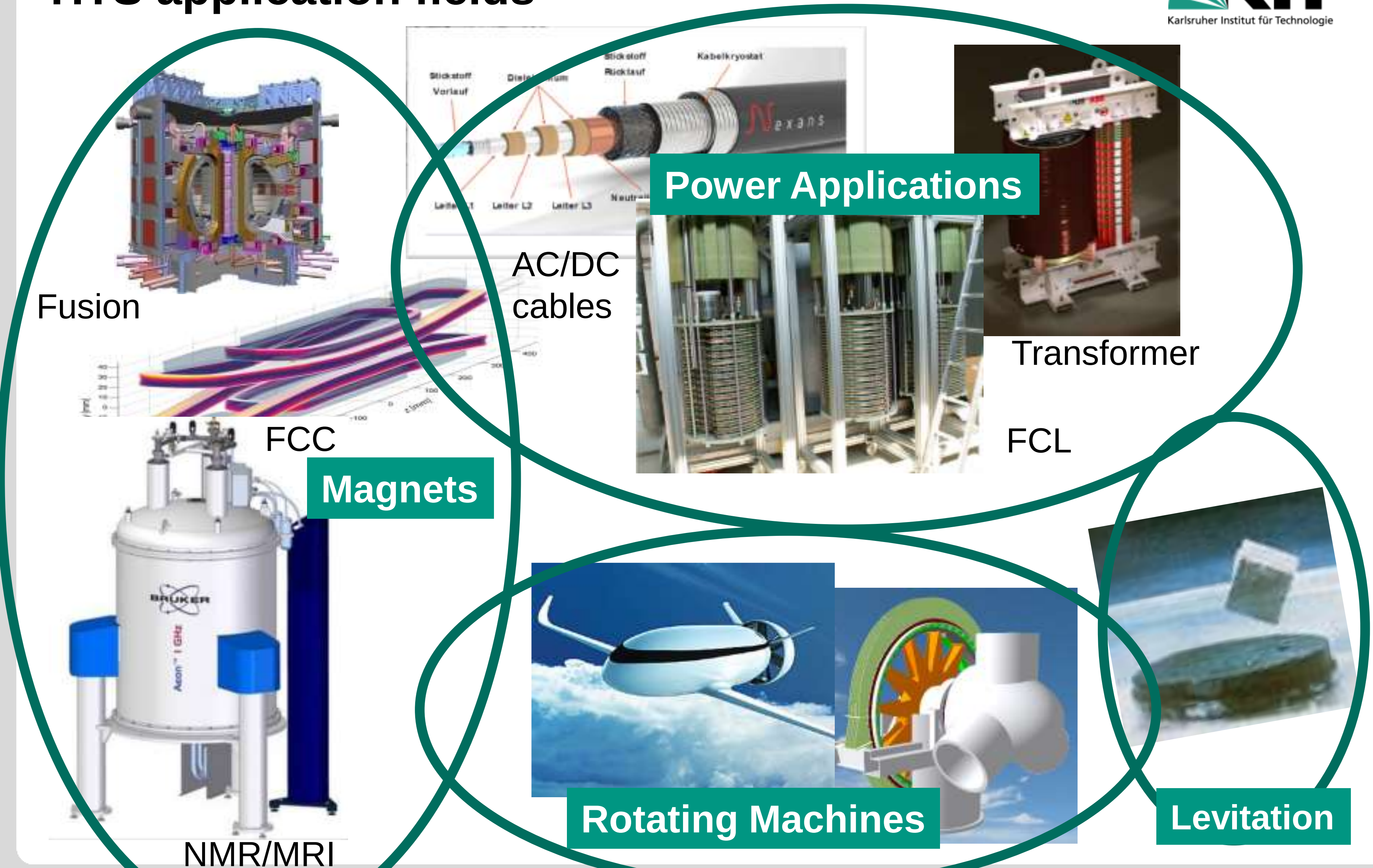


➯ High J_c in polycrystalline materials require strong biaxial texture





HTS application fields



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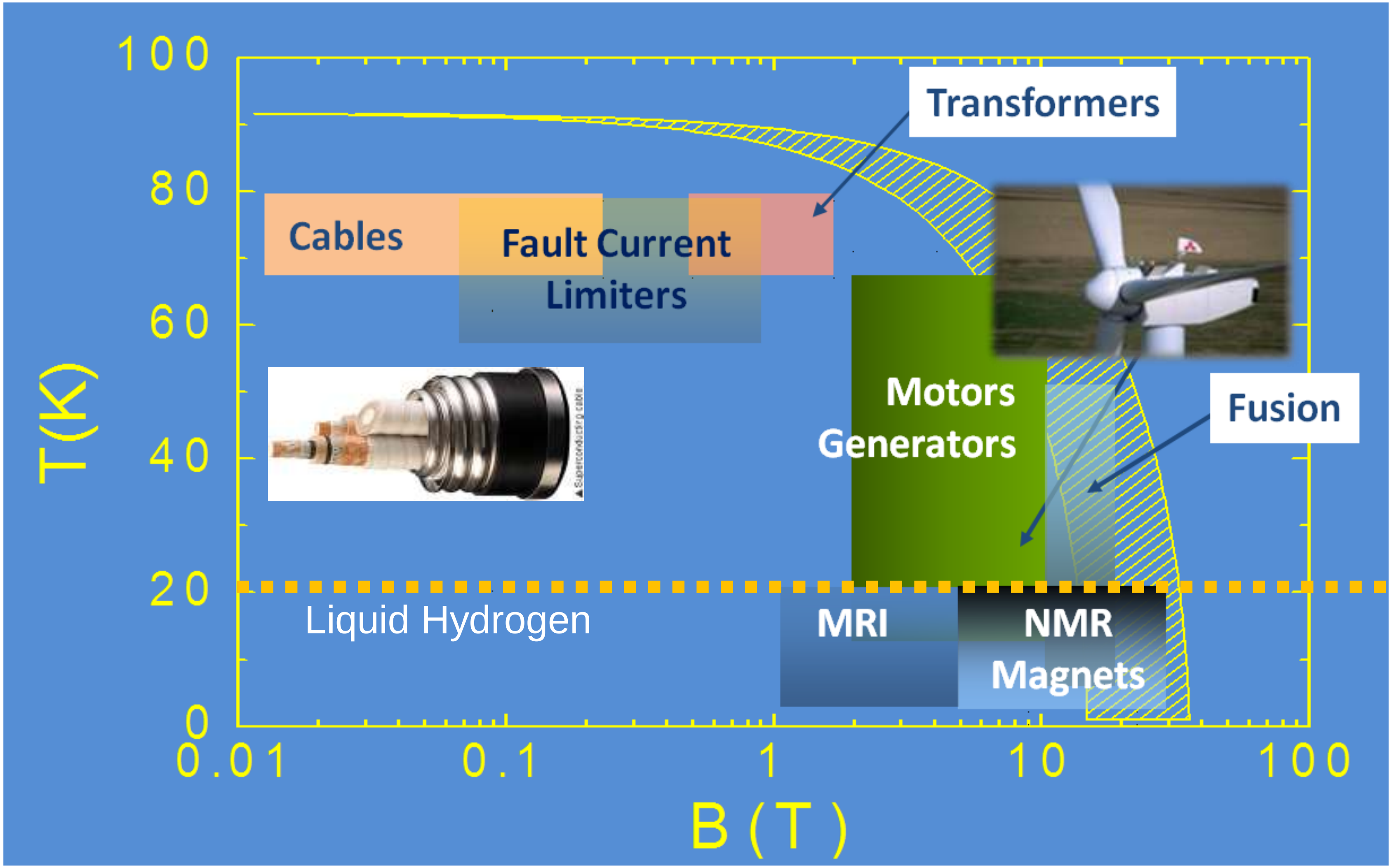

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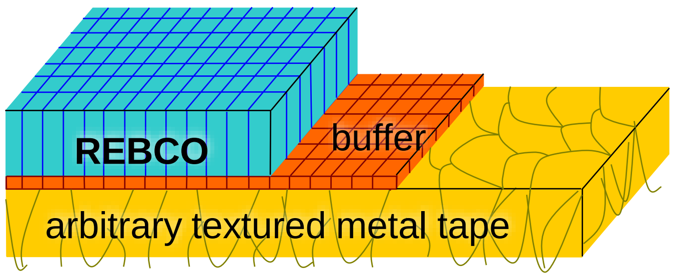
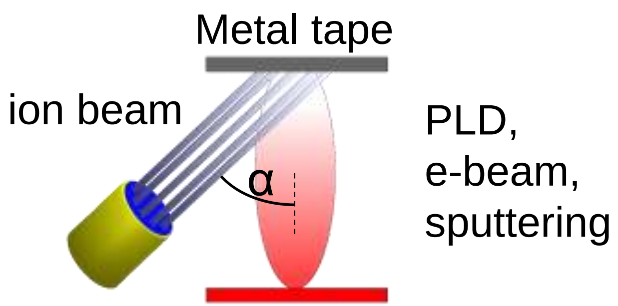
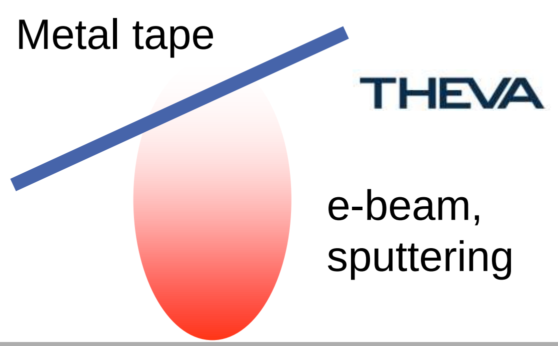
Coated Conductors – the HTS „Wire“



Coating of metal tapes with $REBa_2Cu_3O_x$ films

➯ Special buffer layers enable the required biaxial HTS film orientation

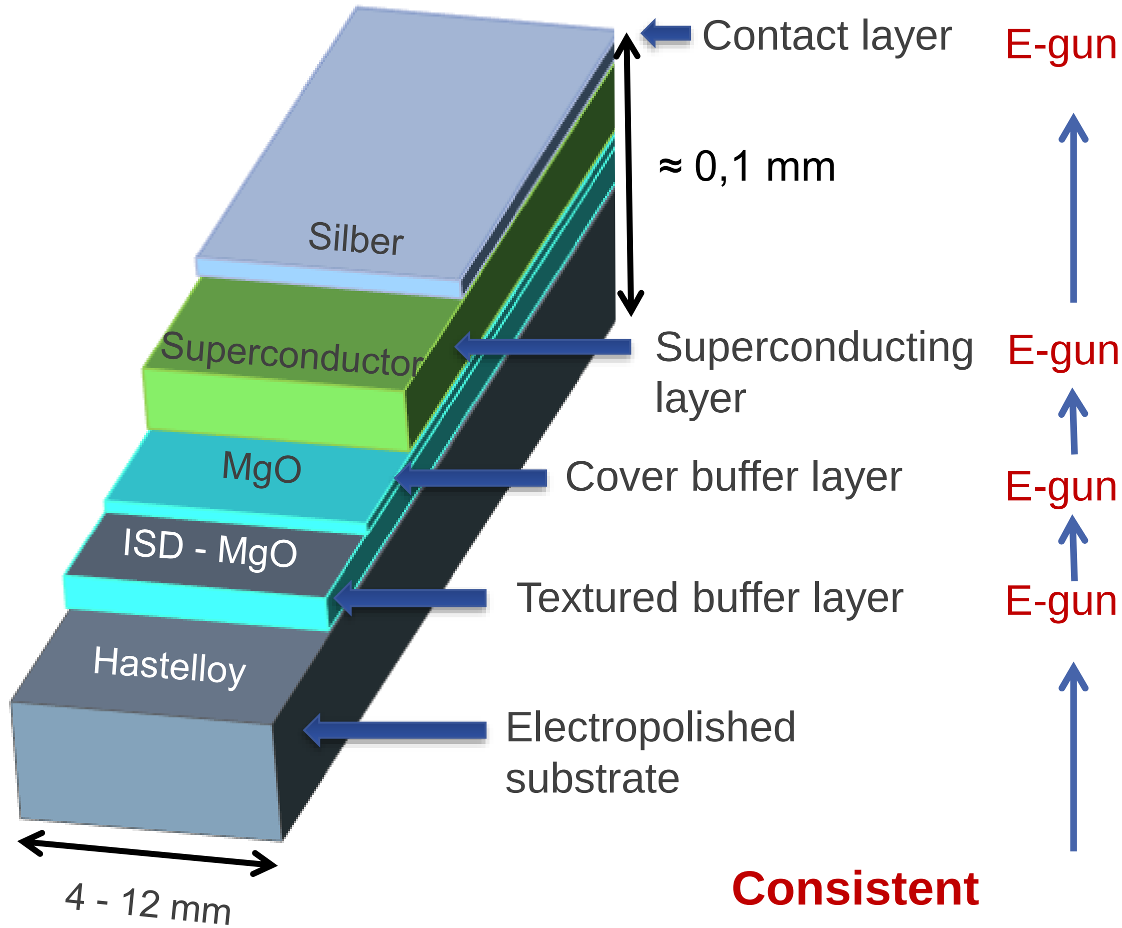




Ion Beam Assisted Deposition (IBAD)

Inclined Substrate Deposition (ISD)

THEVA - Coated Conductor



Non magnetic substrate

High yield strength

Low number of layers

Robust und scalable process

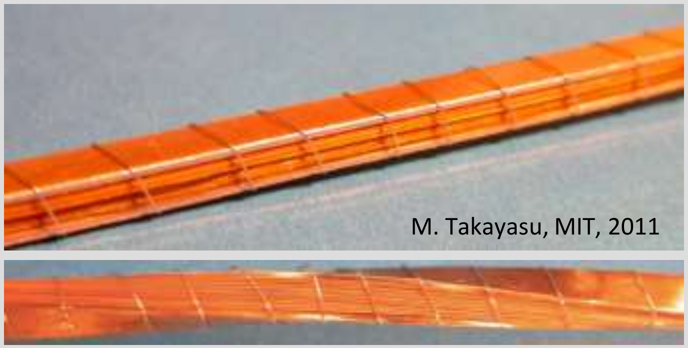
Up to 1000A/cm @ 77K

Consistent

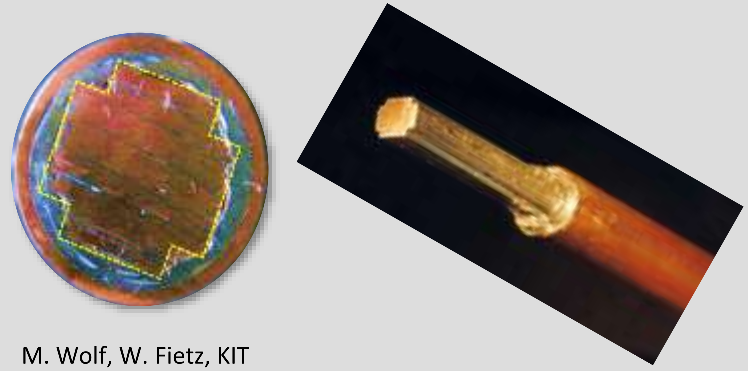
Process technology

HTS Hochstrom und AC-Kabelkonzepte

Stacks and Twisted Stacks



Cross Conductor - CroCo



M. Wolf, W. Fietz, KIT

AC

Roebel

Cable on Round Core

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Industrial Coated Conductor fabrication

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- 2022: 8 relevant CC companies worldwide
- Europa: THEVA (Germany), S-Innovation/SuperOx (Russia)
- USA: AMSC, SuperPower
- Asia: SuNAM (South Korea), Fujikura (Japan), SCST + Shanghai Superconductor (China)
- Wide variety of coating techniques used
  evaporation – CVD – Chemical Solution Deposition – PLD
- Variation in terms of conductor architecture, CC dimensions, HTS phases
- Currently continuous developments towards
  Higher CC quality (J_c(B,T), mechanical properties),
  Increased conductor output (single batch length + production capacity) and reduced costs (esp. production yield)

THEVA as example

THEVA

Proven HTS – Wire Production Technology

Features of production

- Operational since 2016
- Capacity: 120 km/yr
  @ 12 mm-width
- Production wire length:
  500 m – 600 m (1000 m possible)
- Physical vapor deposition using vacuum systems
- Integrated quality control in each step
- Stringent quality management

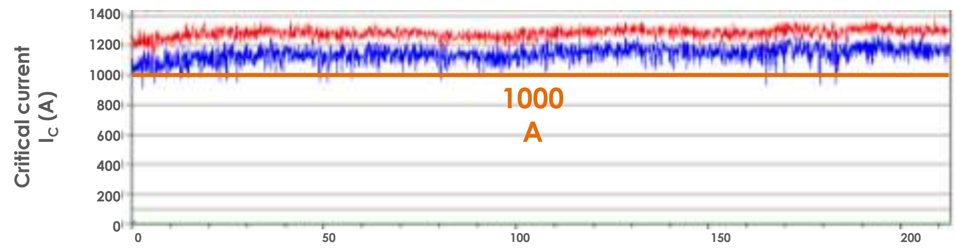
CURRENT STATUS – PRODUCTION OPTIMIZATION

High performance wire

Enhanced HTS thickness (4.5 µm)

$I_{C,min}$ (77K, s.f.) = 750 A – 1000 A

Piece length: 50 m – 200 m



Laser Slitting

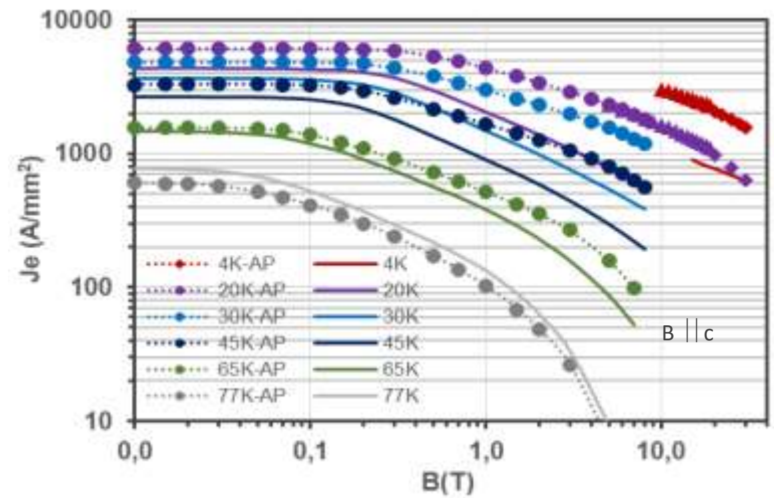
Clean, straight edge – no burr

Introduction of Artificial Pinning

Current density for B ||c of total 60 µm thick tape
(40 µm substrate and 5 µm surround Cu coating)

- 10 T: 3000 A/mm²
- 20 T: 2000 A/mm² **@ 4.2 K**
- 30 T: 1550 A/mm²

@ 20 K, 20 T: 800 - 900 A/mm²

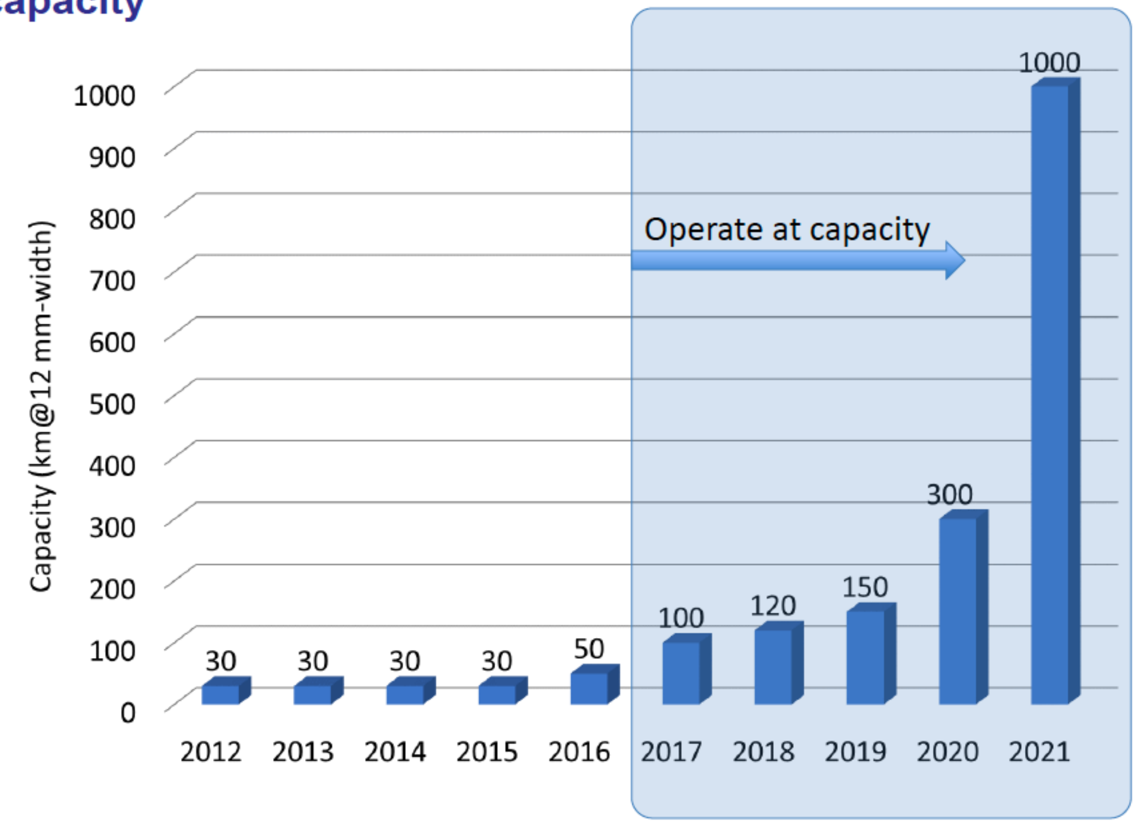


Below 50 K: **I_C(B) improvement by factor 2.5**

Industrial Production Ramps Up

SuperOx 2G HTS wire: Production capacity

- Strong market pull due to compact fusion programs
- Increase in production volume similar for other manufacturer
- Yield is steadily increasing
- Manufacturer need steady demand to bring down prices and improve production



Demand drives capacity scale-up

Recent developments
KC4: KIT-CERN Collaboration on Coated Conductor

- KIT and CERN will establish a **joint, open HTS CC synthesis Lab**, which will bridge the gap between small scale basic materials research on CC and larger scale component requirement of **tailored, high quality full Coated Conductor architectures** in sufficiently long length
- KC^4 is based on **established Bruker CC-technology for long CC and wide tapes**
- Focus on R&D of high J_c, longer length CC, not on low cost CC production
- Both **power applications** as well as **magnet applications** will be targeted
- Long length filamentization and ROEBEL cable fabrication will be feasible

BRUKER HTS R&D-line equipment

To be transferred to KIT….

- Tape processing equipment with different substrate handling concepts (batch and reel-to-reel R2R processes) including stabilization

PLD600
Batch vacuum coating

R2R electroplating

ABAD vacuum coater

PLD600
substrate drum

Timeline of KIT-CERN Collaboration

Karlsruher Institut für Technologie

HTS CC Open Lab/Foundry

KIT ITEP | CERN | Third Parties

Tailored R&D and demonstration operation

CERN | KIT/ITEP

Baseline R&D Operation

KIT/ITEP | CERN

I-A Installation | I-B Commissioning | I-C Performance demonstration | I-D Baseline R&D operation

t.b.c

1/2022 — 2022 — 2023 — 2024 — 2026

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ivSupra

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