Karlsruhe Institute of Technology

WP2.1 - R&D on accelerator grade HTS REBCO conductors

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Institute for Technical Physics

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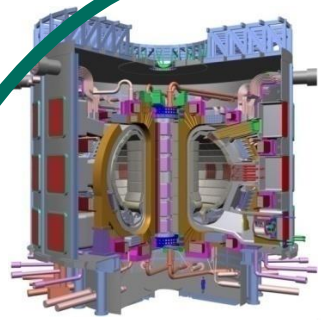
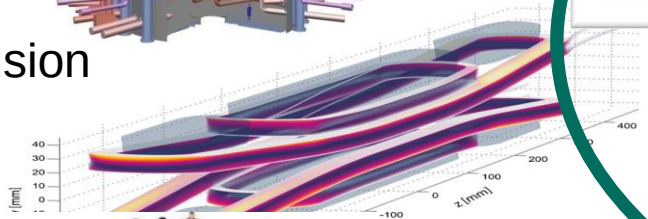
WP2.1- R&D on accelerator grade HTS REBCO conductors

- KC^4 Equipment Status
- First Coated Conductor Depositions and Characterization
- Next steps

REBCO Coated Conductor Application Areas



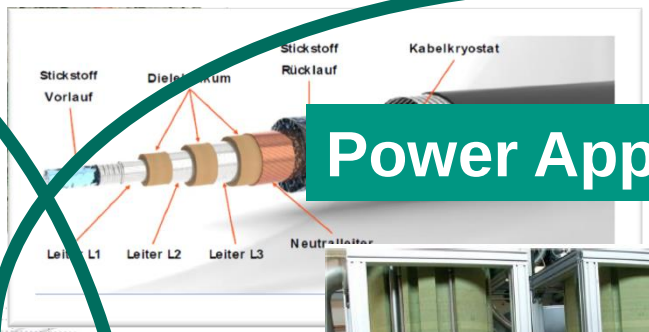
Fusion



FCC

NMR/MRI

Magnets



AC/DC cables

Power Applications

FCL

Transformer

Rotating Machines

Current Status and Challenges of Coated Conductors

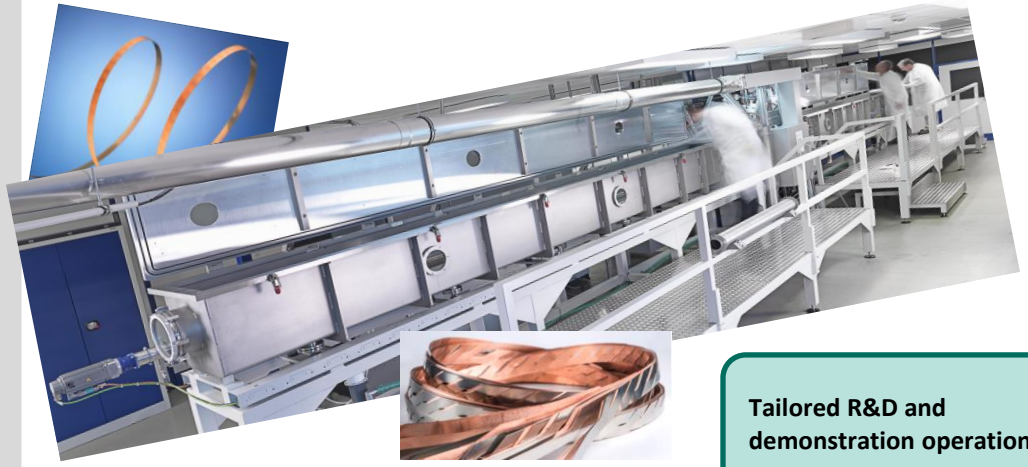
- Coated Conductors are available on an industrial scale, but costs remain an issue
- Beyond J_c there exist a number of open development areas, which need to be improved (yield, mechanical issues, thin conductors, electromechanical properties of full conductor, ac losses) and combined
- Each application requires different and specific CC properties/architectures (e.g. magnetic field, temperature, ac-properties, stabilization, mechanical properties, insulation)
- New scientific ideas often require just a few 100m of very specific CC, not easily available from commercial vendors, since industry needs to focus on just a few CC variants to enable economic production
- There exists currently no company independent public research institution in Europe, which is able to bridge the gap between small scale basic materials research on PLD-based CC and larger scale industrial synthesis, being able to deliver 100m+ class, tailored, high quality Coated Conductors on demand

KC^4: KIT-CERN Collaboration on Coated Conductor

KIT and CERN established a **joint, open HTS CC synthesis Lab**, which will bridge the gap between small scale materials research on CC and larger scale component requirement of **tailored, high quality full Coated Conductor architectures** in sufficiently long length

- Both **power applications** as well as **magnet applications** are targeted
- Focus on R&D CC issues, **not on low cost CC productio**n
- KC^4 is part of the Helmholtz R&D Programm „Materials and Technologies for the Energy Transition“ at KIT
- KC^4 is part of the High Field Accelerator Magnets R&D Programm at CERN
- Third party R&D projects towards tailored CC synthesis for specific applications will be become possible based on an HTS CC open foundry concept
- KC^4 is based on established Bruker CC-technology for long CC and wide tapes, but Bruker is not involved in KC^4- contract/operation
- Long length filamentization and ROEBEL cable fabrication will be feasible

Timeline of KIT-CERN Collaboration



HTS CC Open Lab/Foundry

KIT ITEP | CERN | Third Parties

Tailored R&D and demonstration operation — CERN | KIT/ITEP

KIT/ITEP

Baseline R&D Operation
(< 25% capacity use)

CERN

t.b.c

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

Intermediate 20m length scale

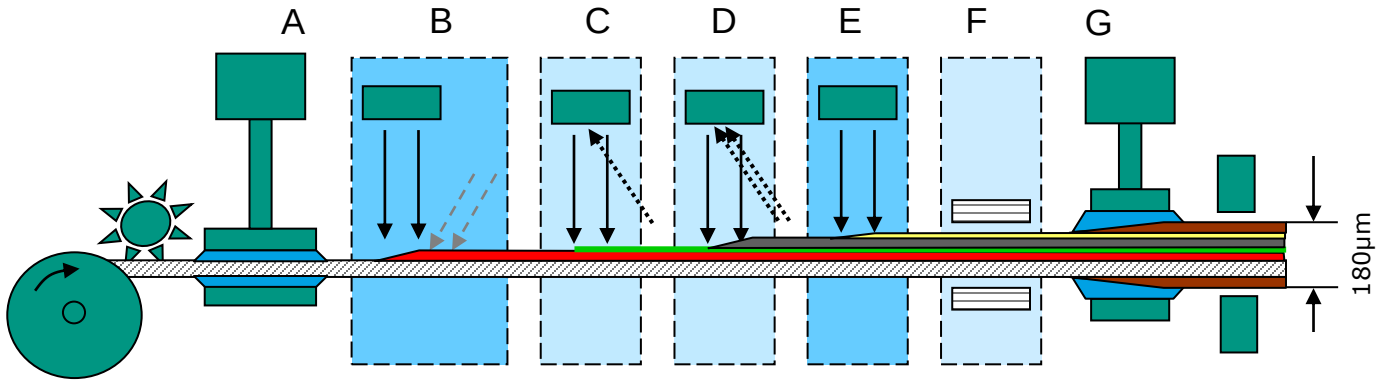
Extension to 100m+ length scale

2022 2023 2024 2027

KC^4: Baseline R&D Topics

- Investigate scaling laws to transfer small scale PLD materials development results towards larger scale Coated Conductor production systems
- Address specific Coated Conductor architectures needed for the R&D program at CERN and KIT
- Investigate and improve electromechanical properties of full coated conductor architectures (mechanical stability, interface resistance, thermal properties,….)
- Evaluate in-line quality control systems
- Establish accelerated materials development concepts
- ….

KC^4 Coated Conductor Synthesis Steps



b > 12mm (foils)

b < 12mm (tapes)

(A : substrate cleaning/polishing) — USP/USR-F/USR-B/POL
B : IBAD Puffer deposition — ABAD
C : PLD Puffer deposition — HEX600+PLD300/600
D : PLD SC deposition — HEX600+PLD300/600
E : Ag- coating — Tacoma–M/MET-F
F : O_2- loading — Tacoma-O/BEL-F
G : Cu-plating — PLA

+ characterization
(structural, electrical, mechanical) — e.g. TapeStar

BRUKER HTS R&D-line equipment

Transferred to KIT:

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

PLD600
Batch vacuum coating

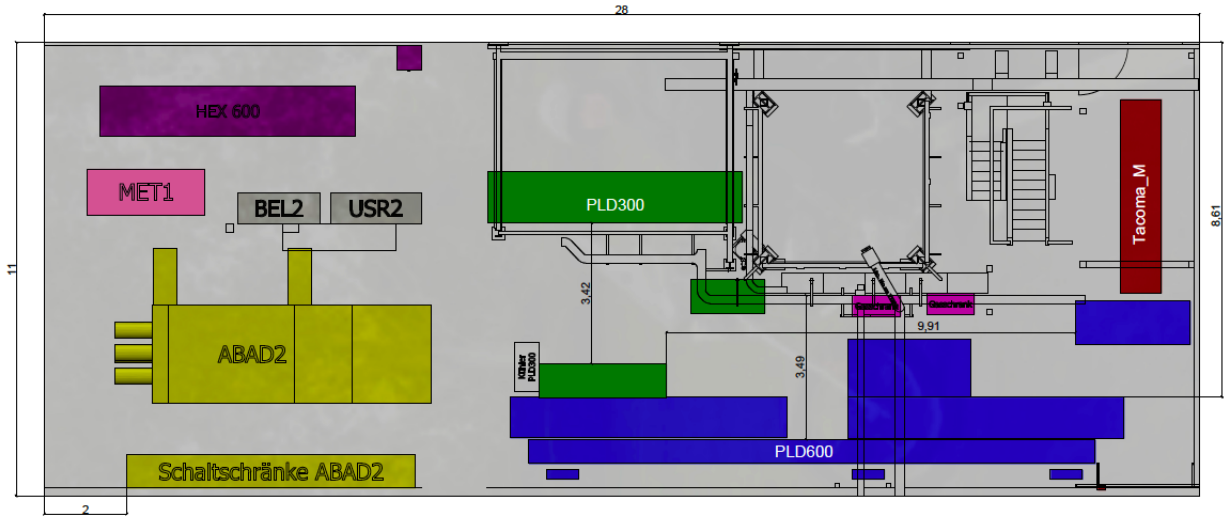
R2R electroplating

ABAD vacuum coater

PLD600
substrate drum

PLD

Core KC^4 Lab space



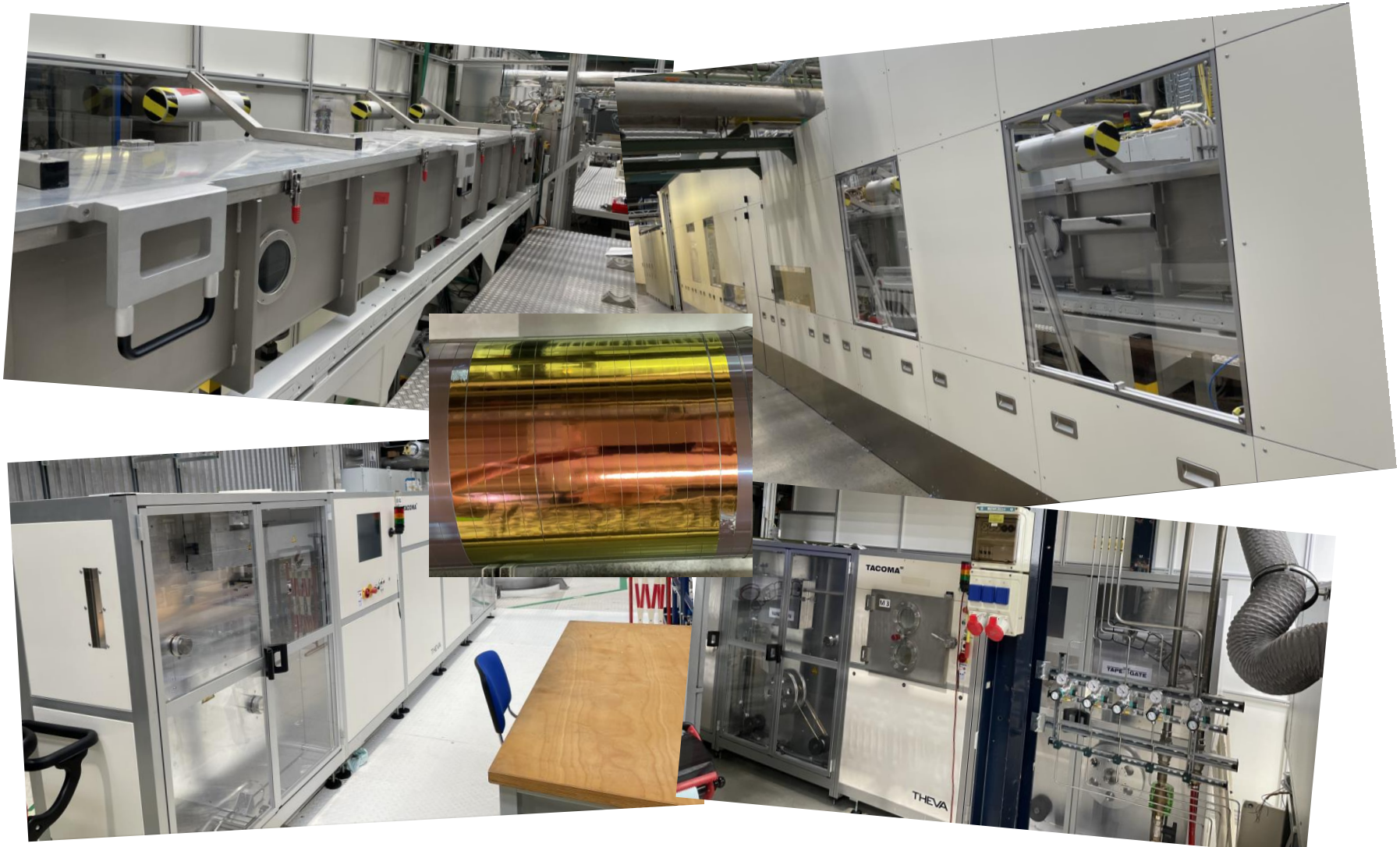
Transfered Bruker equipment list

USR-F*	substrate cleaning
USP*	tape spooling
USR-B*	reel-to-reel substrate cleaning
POL*	substrate polishing
ABAD	IBAD deposition
HEX 600	tape handling
PLD300	PLD
PLD600	long length PLD
Takoma-M	Ag-coating
Takoma-O	O-loading
MET-F	Ag-coating
BEL-F	O-loading
PLA*	Cu-plating
TapeStar*	J_c-characterization

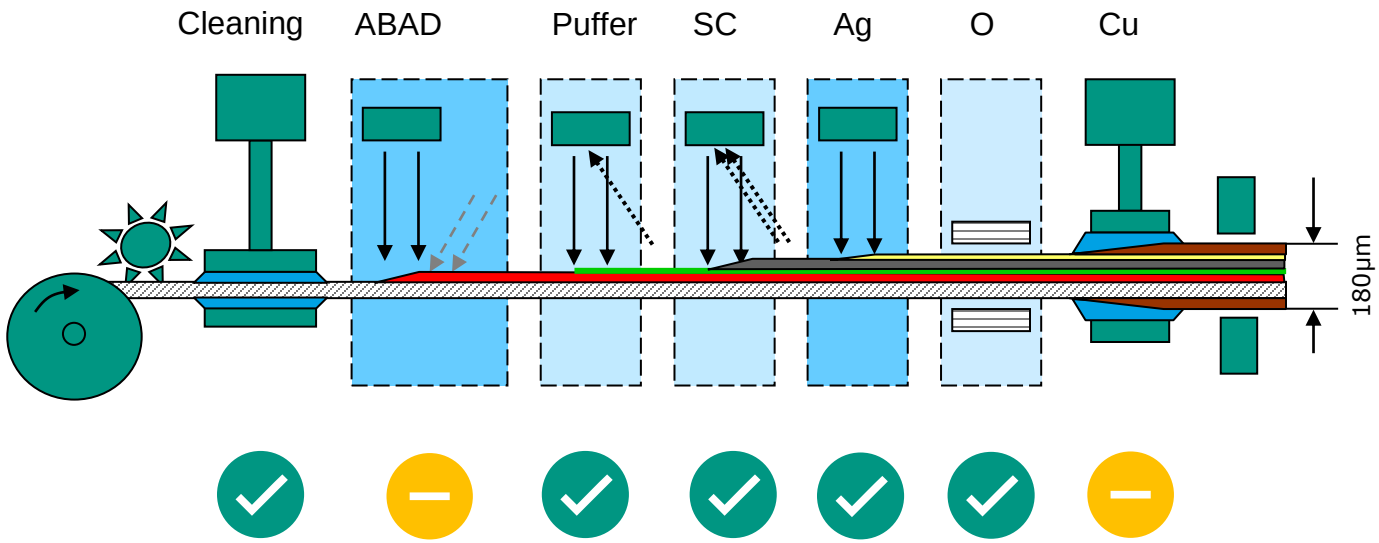
*: equipment located in other ITEP labs

ITEP wide > 500 m^2 lab space dedicated to KC^4

KC^4 Lab snapshots



Current Project Status
(intermediate 20m length scale)

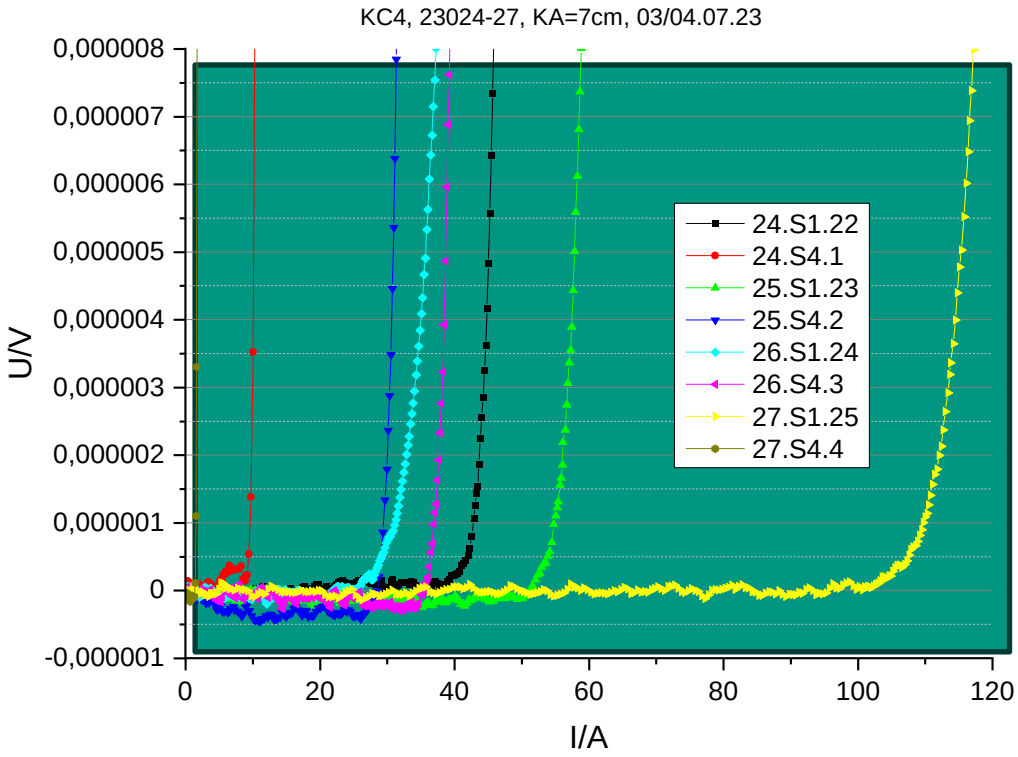


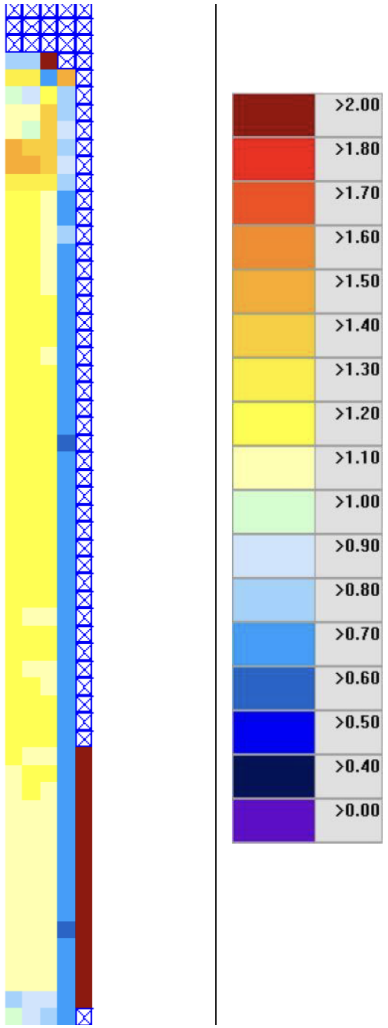
Status Deposition Runs

- Mostly short length (0,5m, 0,5µm) experiments to optimize/check deposition conditions for regular Y123 coatings
- IBAD MgO tapes from Faraday, SUNAM, HTS and Shanghai SC under investigation
  - LMO and CeO buffer layer termination of IBAD MgO tapes
- So far 35 full deposition runs
  (each 1 day PLD, 1 day silver coating, 1 day oxygenation)
- In total 46 tape pieces prepared
- 1 serious equipment failure (vacuum leak influencing deposition quality)
- Establishment of (routine) characterization procedures
  - 77 K, sf full width J_c characterization
  - CryoScan homogeneity check
  - Magnetooptic characterization ?
  - X-ray characterization (PhD Kai Walter)
  - fast LT, high field J_c measurement so far missing
    (request for collaboration)

77 K Characterization examples

- Full width transport and inductive Ic-measurement

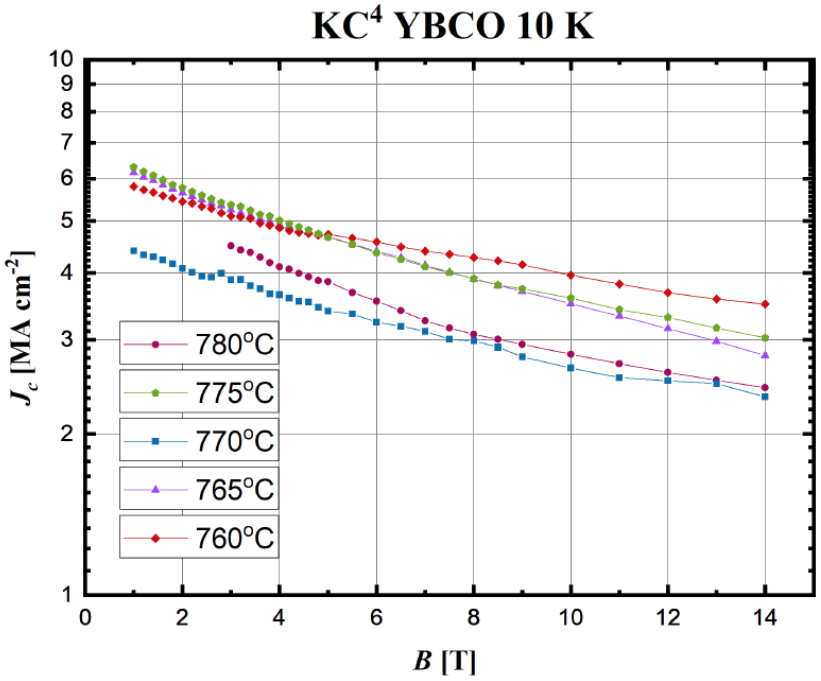


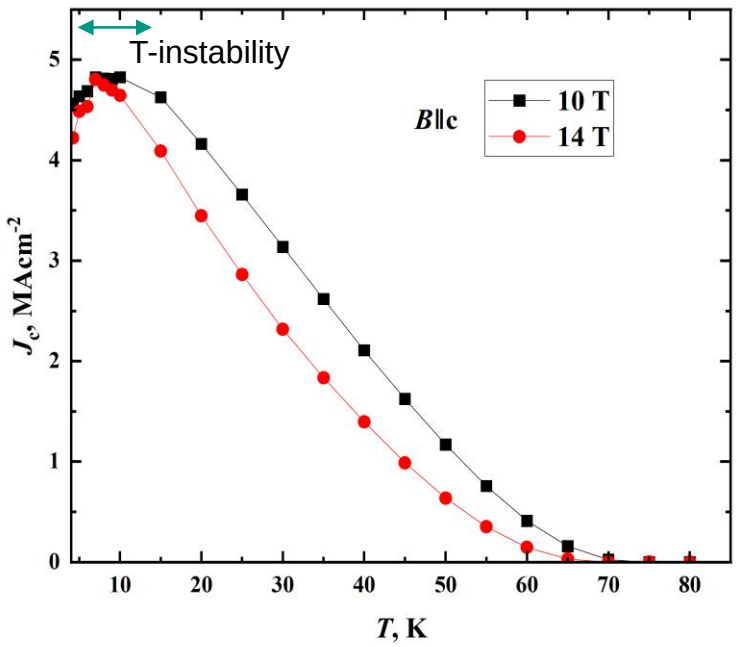


J_c (77 K, sf) > 1 MA/cm^2 and good homogeneity demonstrated

Characterization examples

- High field, low temperature J_c characterization tests
- So far only small patterned bridges for PPMS setup

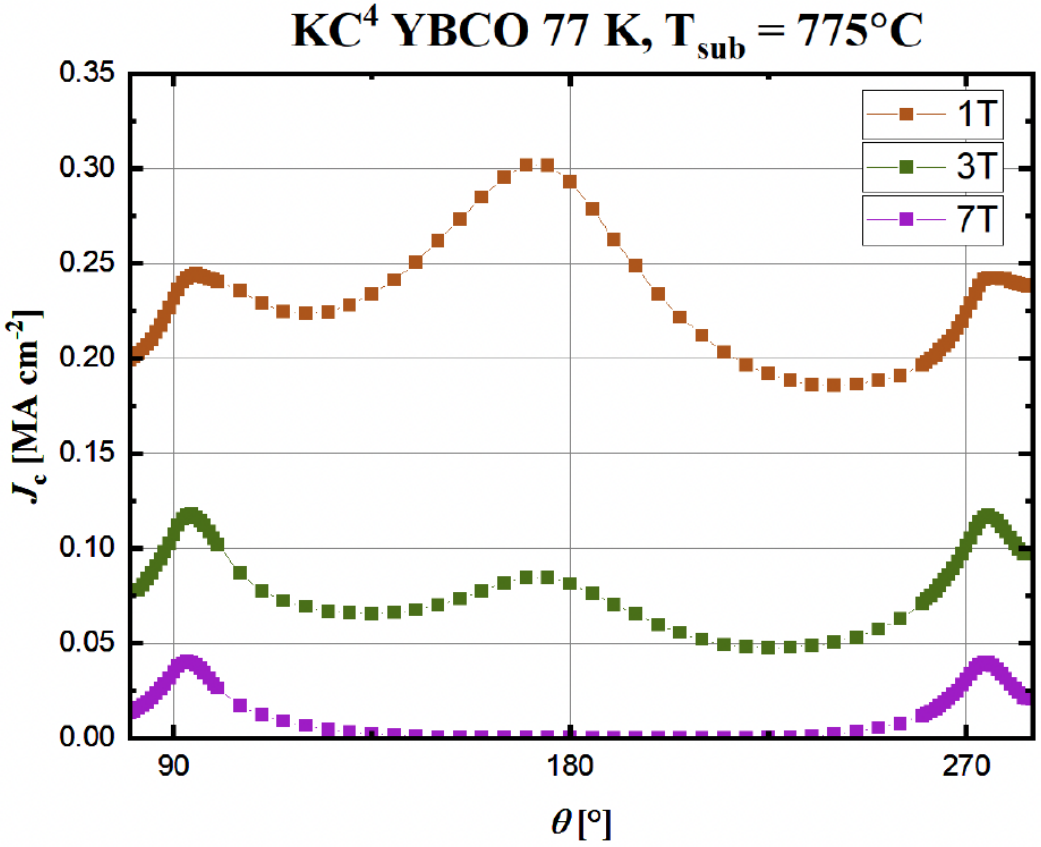




High field J_c-values meet expectations, more characterization needed

Characterization examples

- J_c anisotropy characterization



Characterization examples

- J_c after application of 0.1% tensile strain

J_c-values are measured on two short samples of same tape

Tensile strain of 0.1% applied at 77 K

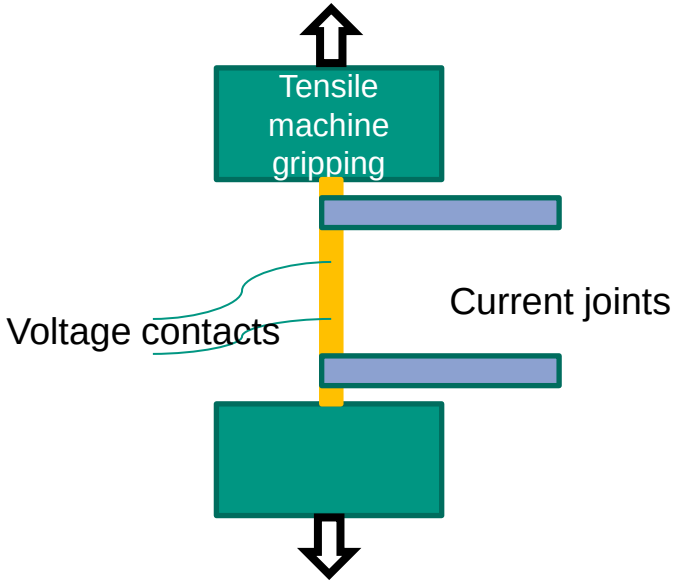
Samples are cut to remove damage from extensometer tips

J_c-values measurement repeated for shortened samples

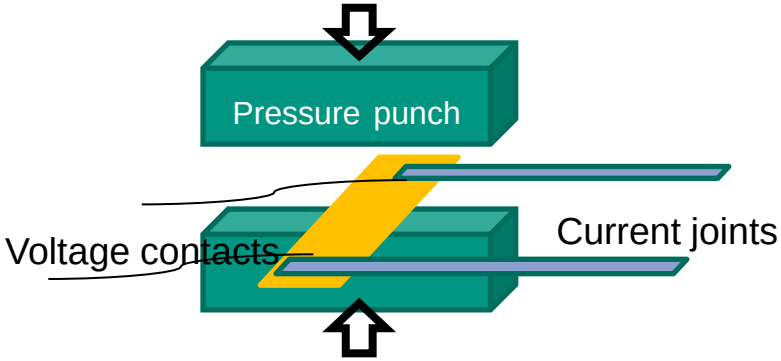
Result: J_c change is within 1%: 195.64 A to 194.68 A and 200.62 A to 198.8 A (that can be within measurement uncertainty and scattering along the length)

Further mechanical characterization steps:

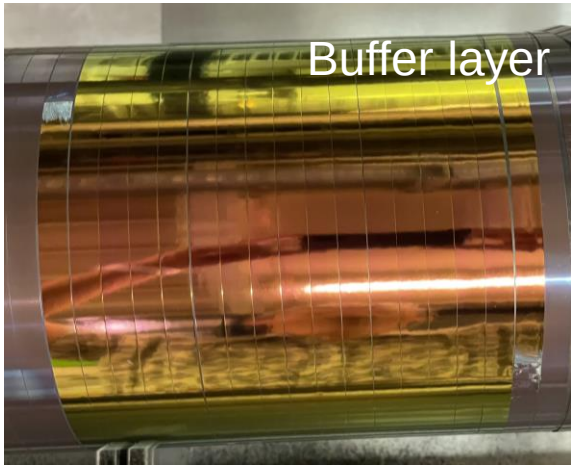
- J_c under tensile stress/strain

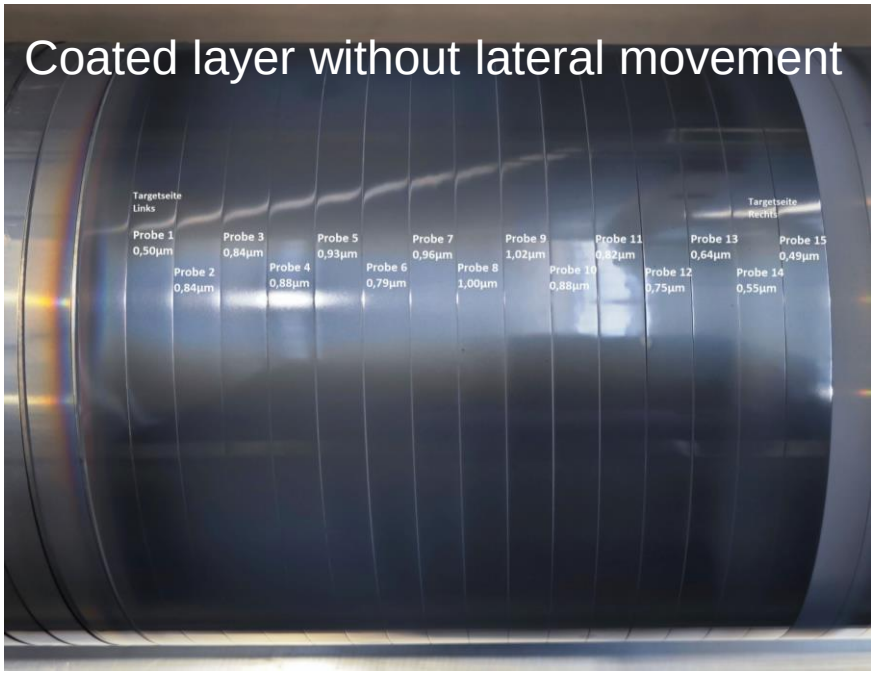


- J_c under compressive stress



Long(er) length deposition experiment





Next steps

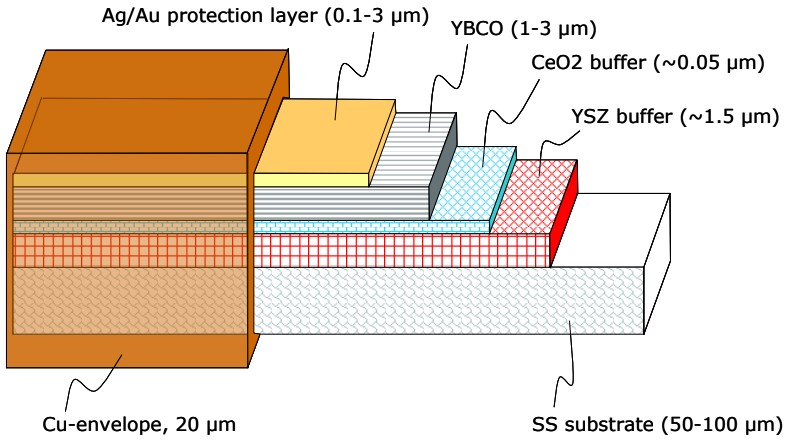
- Discussion and decision on first R&D campaigns
- Discussion and decision of joint characterization efforts
- Coming 6 month
  - required repeatment of deposition parameter overview tests for various buffers, SC stoichiometries
  - increasing film thicknesses to >2 µm, tape length >20m
  - more detailed analysis of mechanical properties
  - Establish RfO for second PLD system PLD300

- Coming 12 month
  - Correlation with small scale PLD experiments
  - homogeneity analysis
  - wider tapes
    (Joint CERN project „HIGHEST“ - I.FAST Innovative Fund)

BHTS's process chain

- The standard processing route for the BHTS coated conductors consists of …
  - … stainless steel substrate polishing and cleaning
  - … YSZ buffer layer coating by vacuum deposition (ABAD)
  - … Ceria and YBCO layer coating by vacuum deposition (PLD)
  - … Ag shunt layer coating by vacuum deposition (evaporation) and Ag layer annealing in O2 atmosphere
  - … Cu encapsulation by plating
  - … final inspection and quality check of the HTS tapes

Typical HTS layer stack



Idealized sketch of the BHTS process chain