



Scaling-up and R&D of 2G-HTS Tapes Fabricated by Ultra-fast PLD Process at Shanghai Superconductors Technology

Y Zhao, G-Y Jiang, Y Wu, J-M Zhu, Y. Yamada and Z-J Jin

**Shanghai Superconductor Technology Co., Ltd
Shanghai Jiao Tong University**

Shanghai Key Laboratory of High-Temperature Superconductor Materials and Applications,

Contact: yuezhao@shsctec.com

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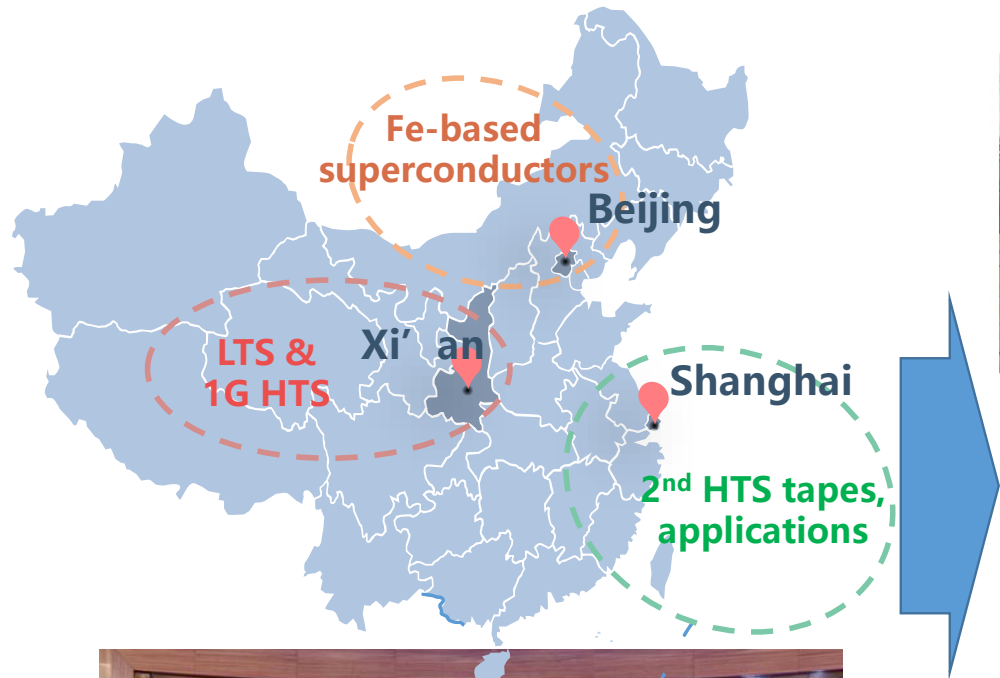
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Outlines

- **State-of-the-art of 2G-HTS in China**
- **What we did at Shanghai superconductor technology (SST)**
 - Mass product
 - R&D
 - Market
 - Applications
- **Conclusion and outlook**

State-of-the-art of 2G-HTS (projects) in China



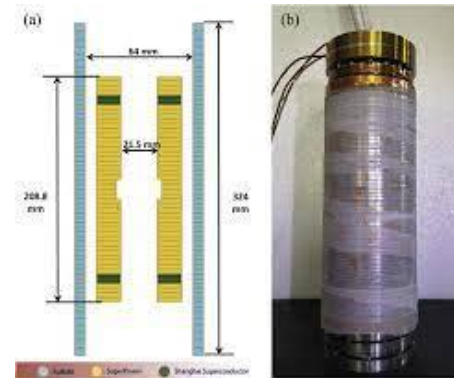
35 kV Shanghai HTS cable



the World's first 160kV DC SFCL



Yangtze River Delta superconducting industry chain alliance



World record 32.35 tesla DC all SC magnet



the world's first MW HTS induction heater

Introduction to SST



Establishment (2011)

- Private company funded by strategic investors
- Supported by Shanghai strategic emerging industries



Industry-Academia Cooperation

- Research Institute of Superconductivity
- Market/application-aligned R&D



Current Status

- Commercialized 2G-HTS conductors **since 2015**
- **70+ employees**
- Ability of design and manufacturing of production facilities
- Two main factory sites: Zhangjiang High-Tech Park for Vacuum deposition, Songjiang Park for other processes

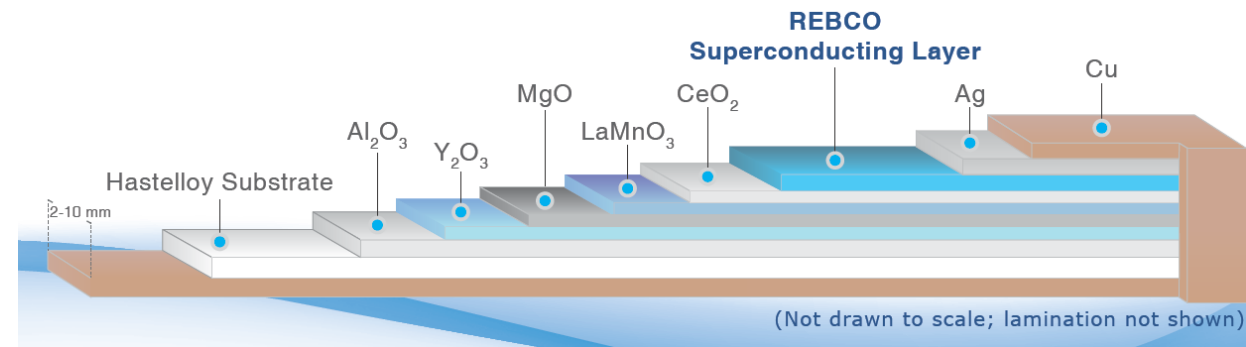


PLD+IBAD: One of the Most reliable techniques

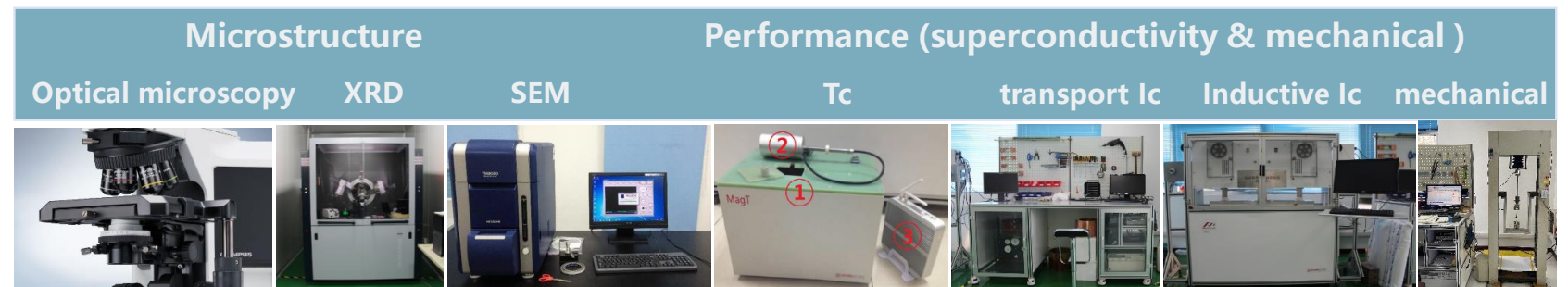


A reliable method

- High reproducibility
- Fast growth, high yield
- Tunable microstructure



Necessary QC process and equipment



Strategy at SST: High speed & Customer-friendly

Production(A*m)=production time(s) × deposition efficiency(A*m/s)

=production time(s) × deposition length(m) × growth rate(m/s) × current density(A/m²)

Production time

- Utilization
- Effective working hours of product line

Deposition length

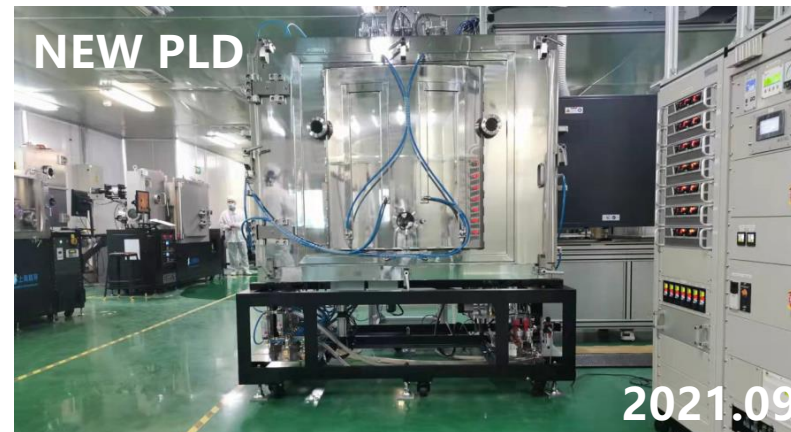
- Deposition area=length*1cm-w
- Enlarged by MPMT structure

Growth rate

- Dependent on laser power
- Limited by deposition kinetics process

Current density

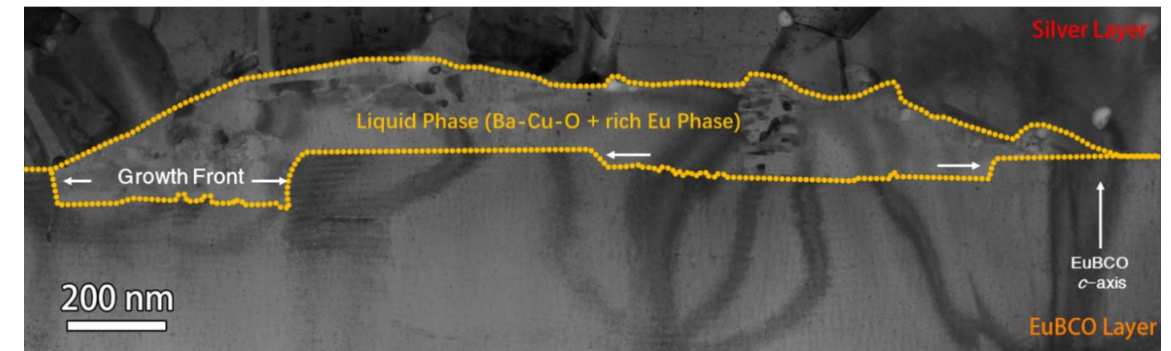
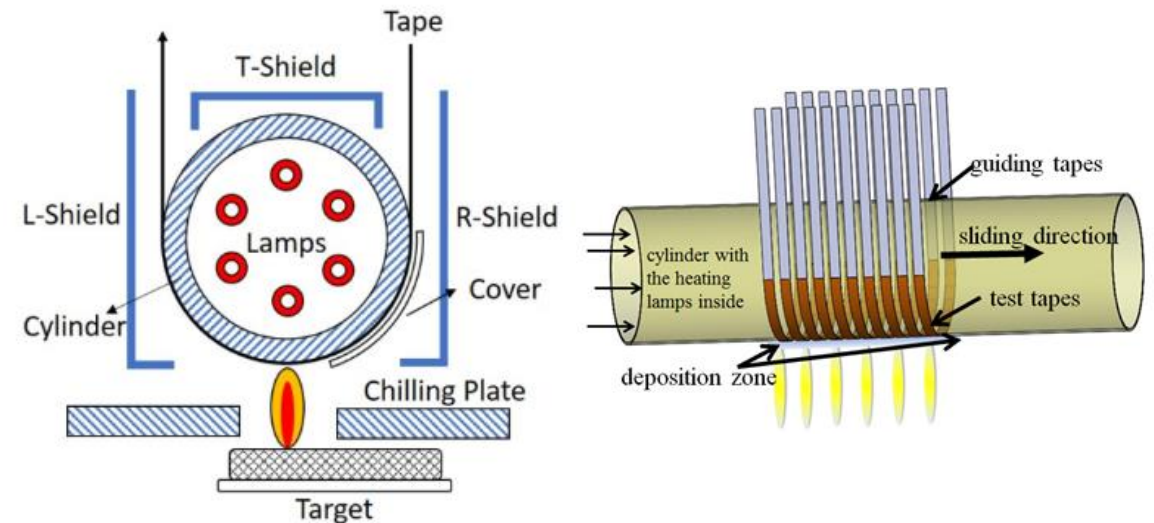
- Dependent on film quality
- Dependent on pinning centers



Other than more facilities (investments), what else can we do technically?

Strategy at SST: High speed PLD technique

- ❑ Radiation assisted conductive heating(RACH) system, leading to high temperature homogeneity under high travelling speed
- Effective heating technique for high throughput
- heating tapes from RT to ~ 900 °C in 3.5 seconds
- Temperature variation: ± 4 °C
- Tape speed: >100 m/h
- ❑ **Unique growth conditions:** local overheating \rightarrow transit liquid phase \rightarrow enhanced diffusion \rightarrow quenching

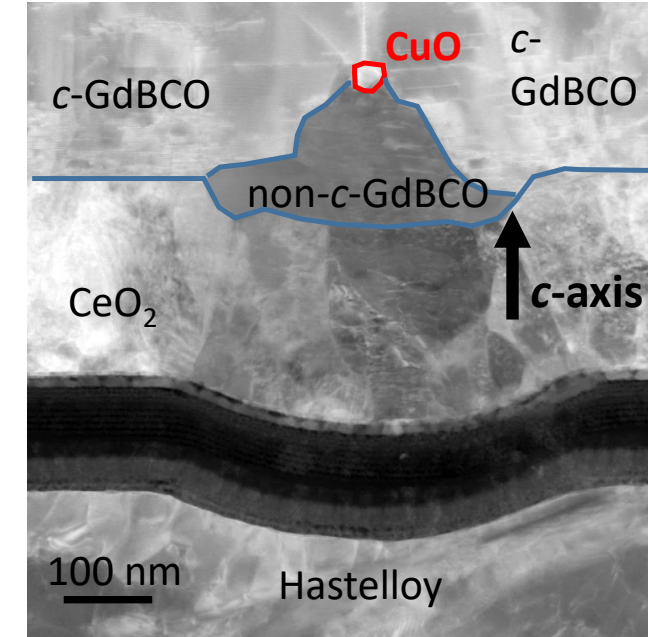
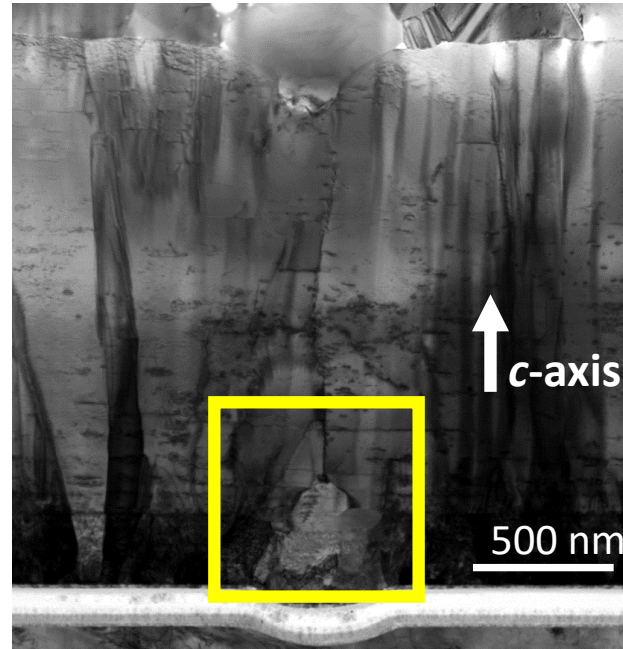
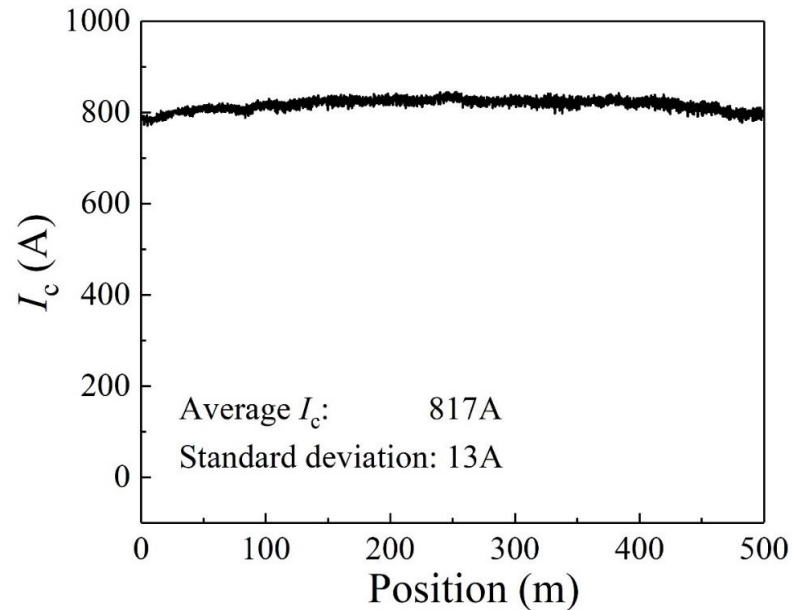


Ultra-high growth rate: > 100 nm/s

Zhao Y, et al. Supercond. Sci. Technol. 32 (2019) 044004;
Jiang G, et al. IEEE TAS, 2019, 29(5): 6600504.
Wu Y, et al. Supercond. Sci. Technol. 34 (2021) 05LT01 (5pp)
Wu Y, et al. Materials Today Physics 18 (2021) 100400

High performance GdBCO films with "robust" structure

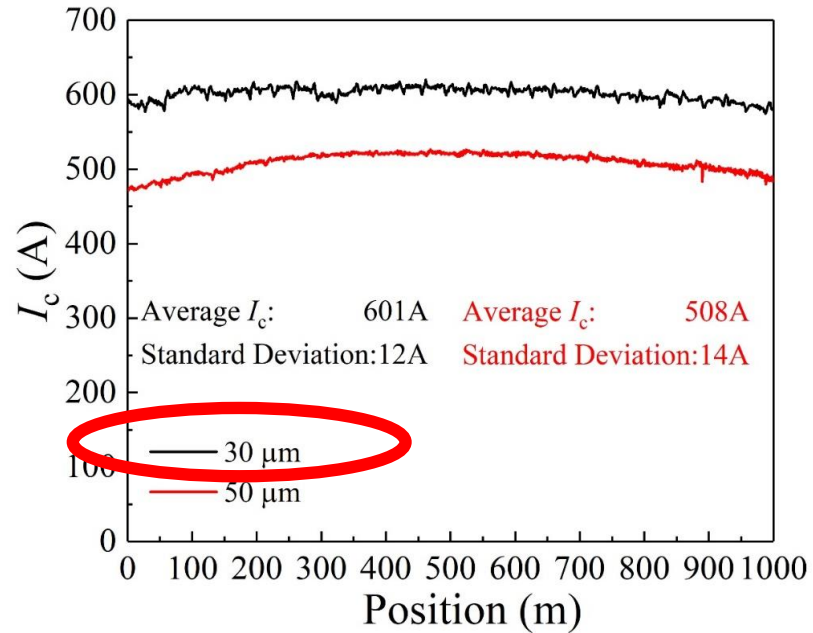
Defective region



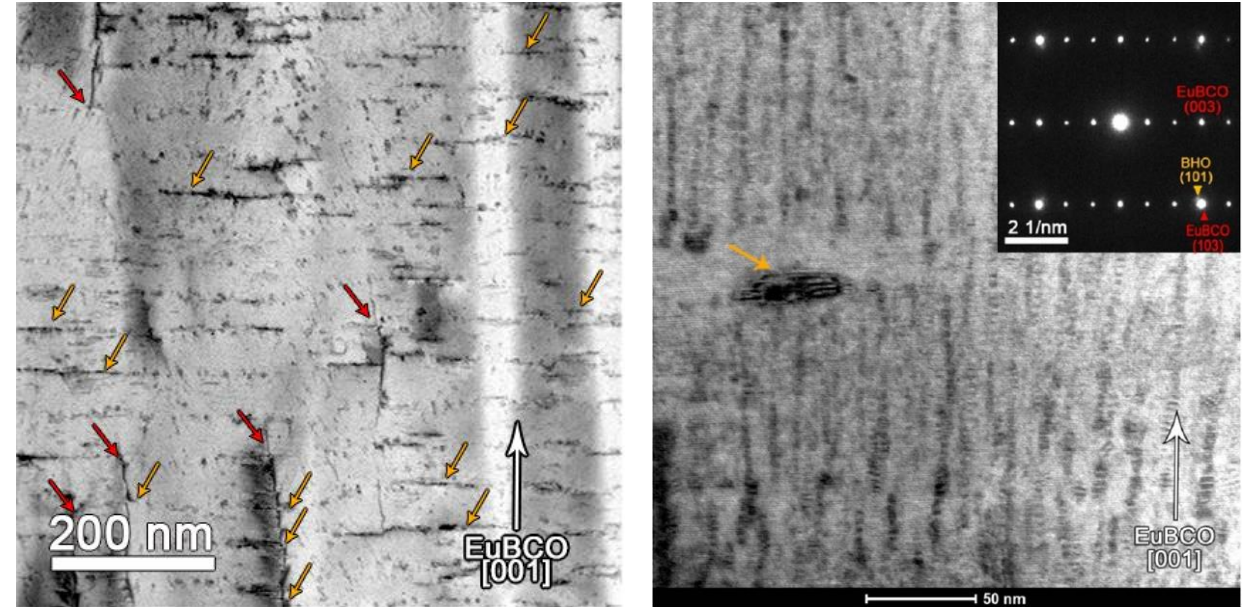
Annual production for a 300W
PLD: >150 km*500 A
i.e., in 2020, 300 + km (10 mm)
was produced;

High quality GdBCO film grown under
"overgrowth" mechanism

Mixed-landscape pinning centers in “fast grown” EuBCO films



KM-class long EuBCO tapes with high I_c achieved on **30** and 50 μm substrates

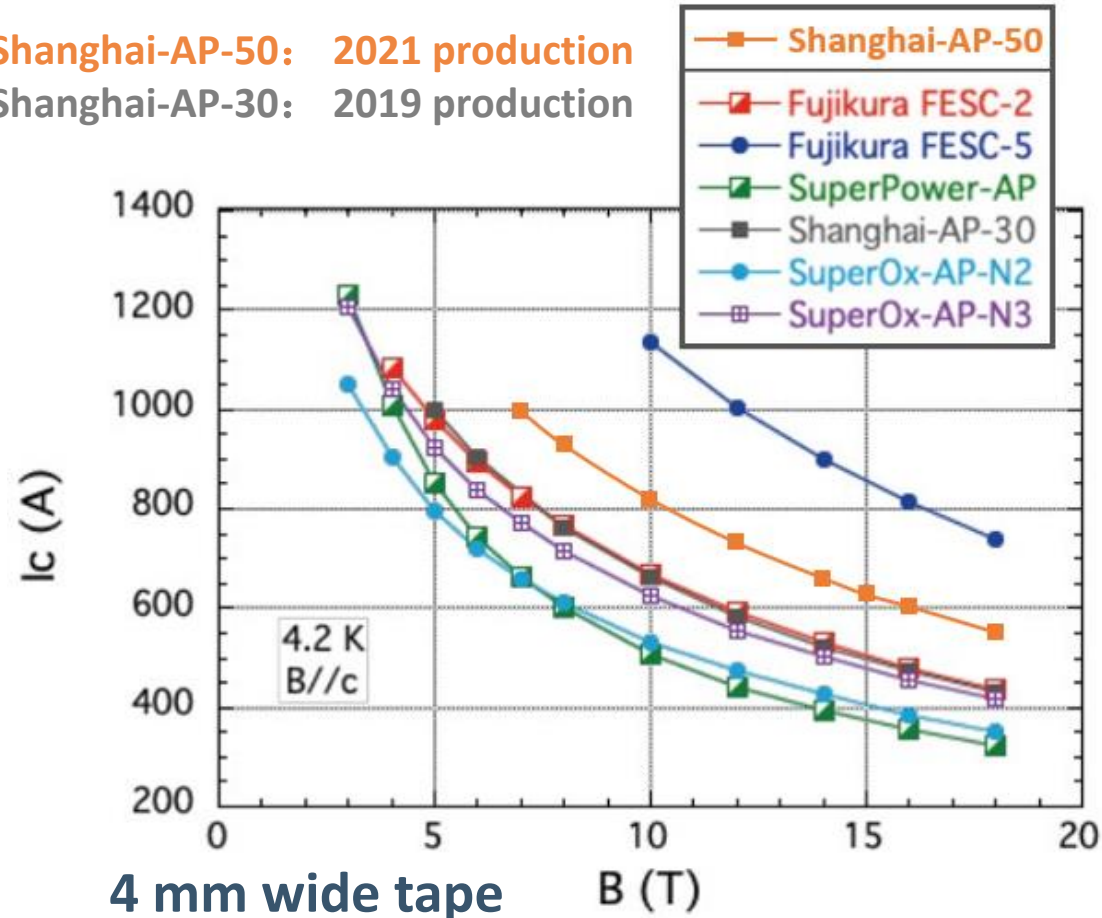


- ✓ Inclined nano-rods and high density of stacking faults co-exist throughout the film thickness
- ✓ Tunable defect landscapes under high growth rates

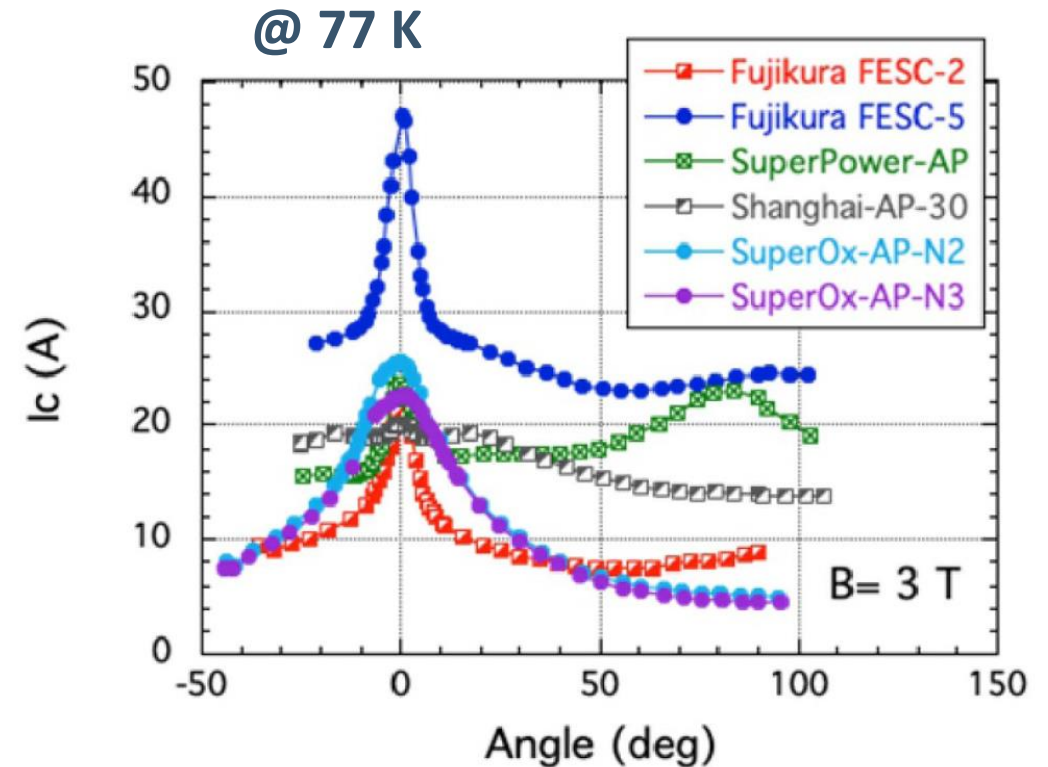
All the in-filed performance data available at <http://htsdb.wimbush.eu/>
Jiang G, Zhao Y, Zhu J, et al. *SuST*, 2020, 33(7): 074005.

Competitive performance on the mass produced APC tape

Shanghai-AP-50: 2021 production
Shanghai-AP-30: 2019 production

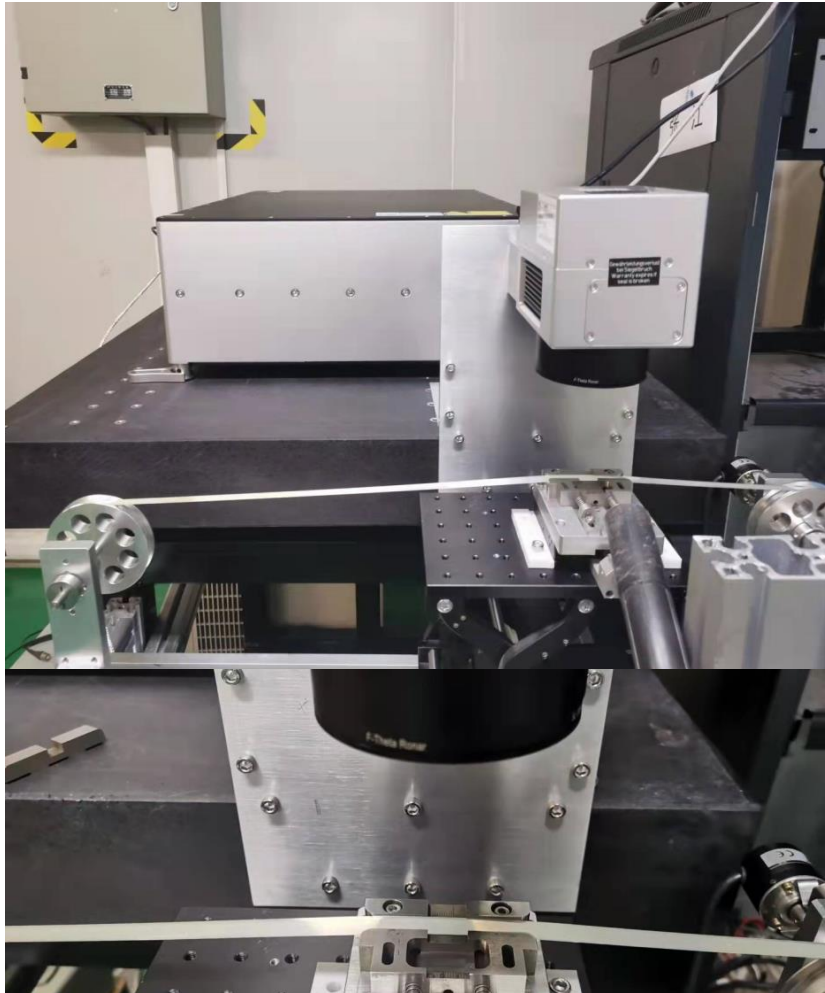


Superconducting properties of commercial REBCO-coated conductors with artificial pinning centers. Supercond. Sci. Technol. 34 (2021) 105005 (13pp)

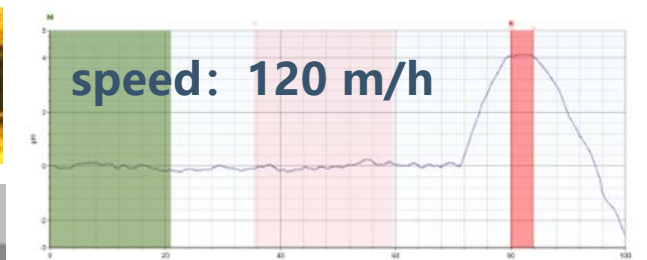
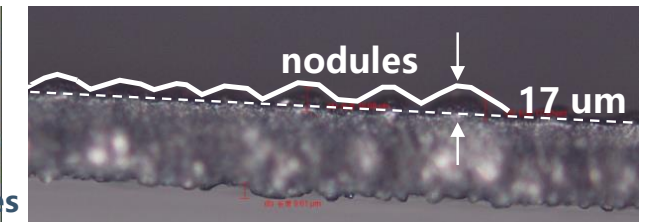
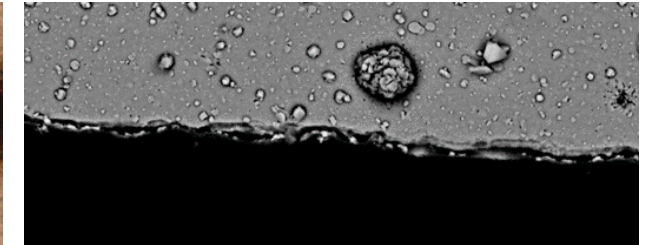
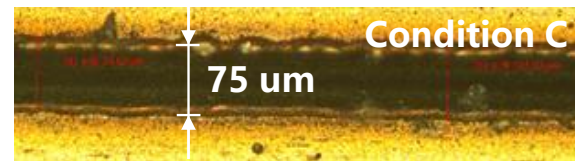
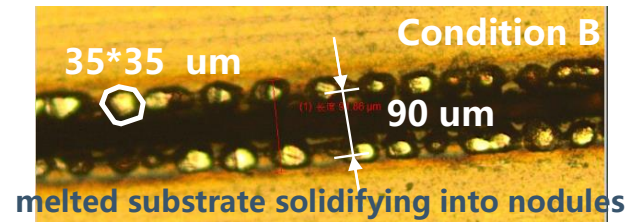
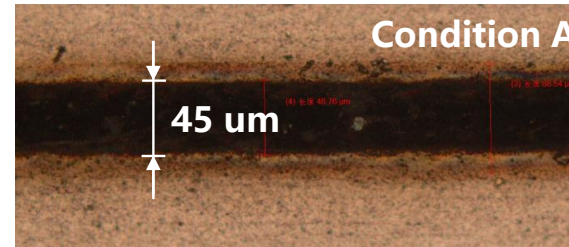


- ↖ Competitive I_c vs B ($//c$) at 4.2 K
- ↖ Continuous improvement of in-field I_c
- ↑ Weak anisotropy

R&D: Laser Slitting



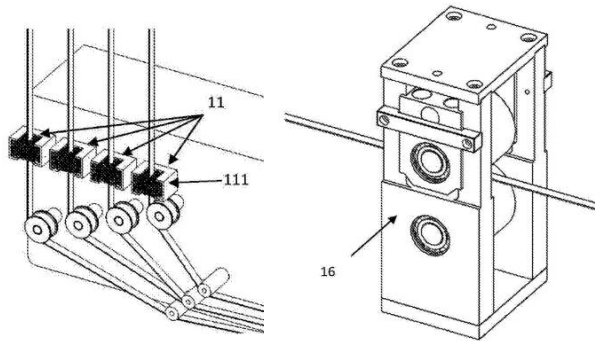
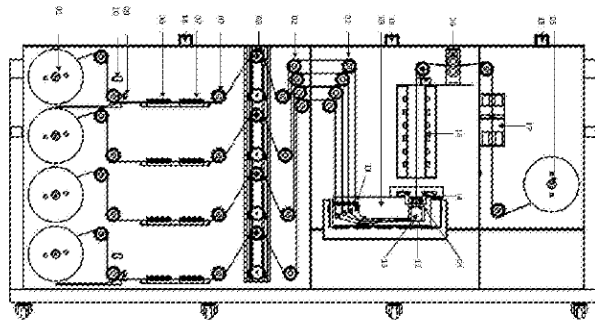
home-made R2R laser slitting setup



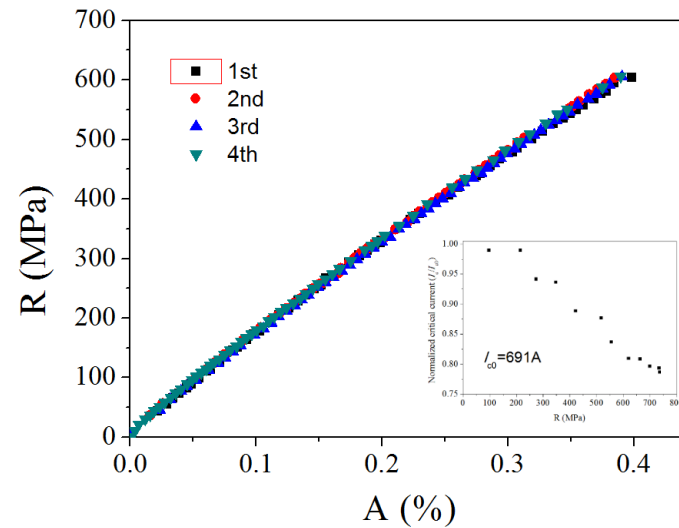
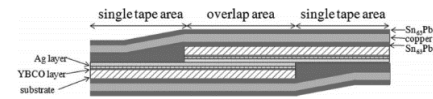
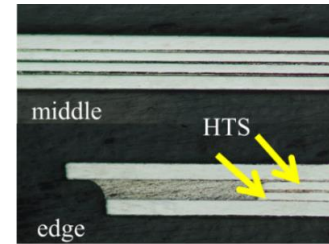
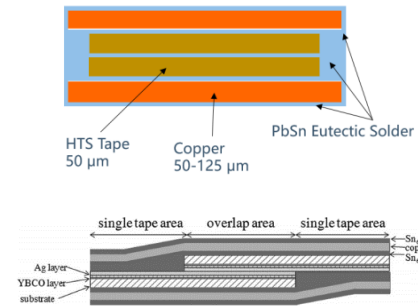
- ❑ Trade-off between speed and quality
- ❑ Appearance of nodules related to the thermal effect

Strategy at SST: Customization for Robust combined conductor

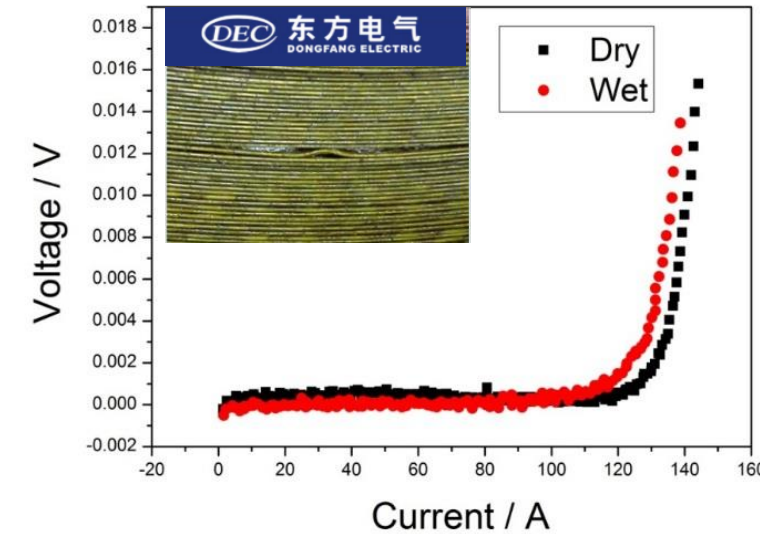
Lamination techniques for power applications



contactless low temperature
and rapid cooling package
techniques



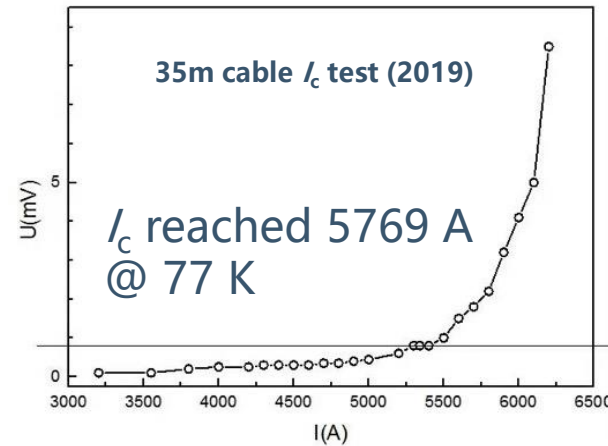
Double insert or optical fiber coupling
(For China Southern Power Grid SFCL project)



Minor I_c degradation after epoxy
impregnation

- ⊙ Automatic lamination equipment
- ⊙ Wire edge fully covered
- ⊙ Uniform and robust
- ⊙ Copper / Brass / Stainless Steel

Case1: Shanghai HTS Cable (three in one type)



Key Parameters

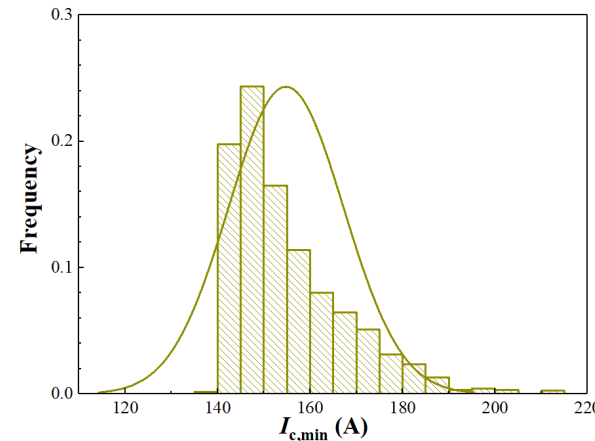
V Rated Voltage
35kV

A Rated Current
2200A

Length
1200m



the 3 in 1 type



- 170+km, avg. piece length 150m, for conductor layer;
- HTS tape supply completed within 5 months in 2020;

Partly courtesy of Dr. Zong Shanghai Electric cable research Institute & (new company) Shanghai International Superconducting Technology Co., Ltd.

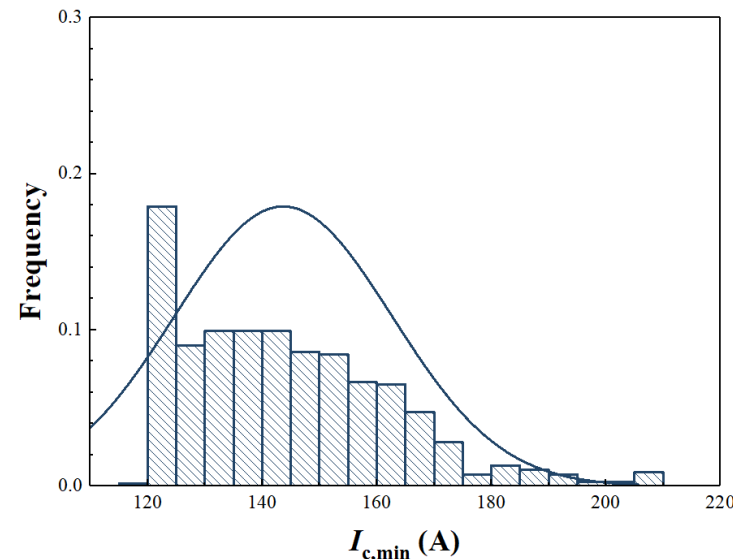
Case2: Shenzhen HTS cable (the tri-axial core type)



Project owner: Guangdong Electric Power Design
Designed by: Beijing Jiaotong University
Constructed by: Zhongtian Technology Group
Operated by: Shenzhen Power Supply Bureau
Cooling system by: CSIC Pride Cryogenic Technology Co., Ltd.

operation since late Sep 2021

- 500 m long HTS cable for Shenzhen Ping An Financial Center (height of 592.5 meters)
- Simplifying the power grid structure: reducing the construction of 110 kV substation, and save area of 500 m²



- 110 km, avg. piece length 150m
- HTS supply completed within 3 months

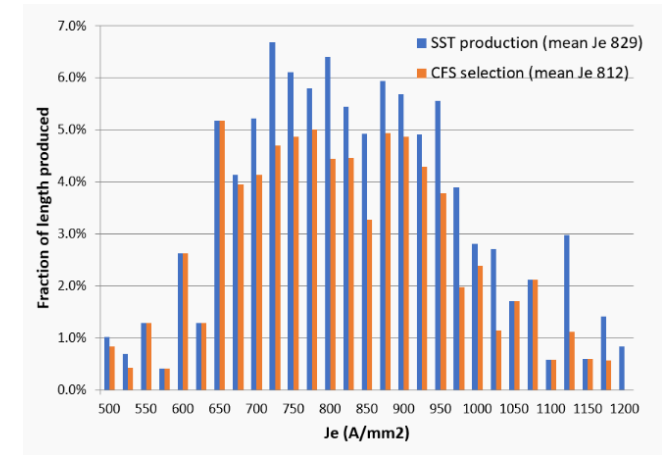
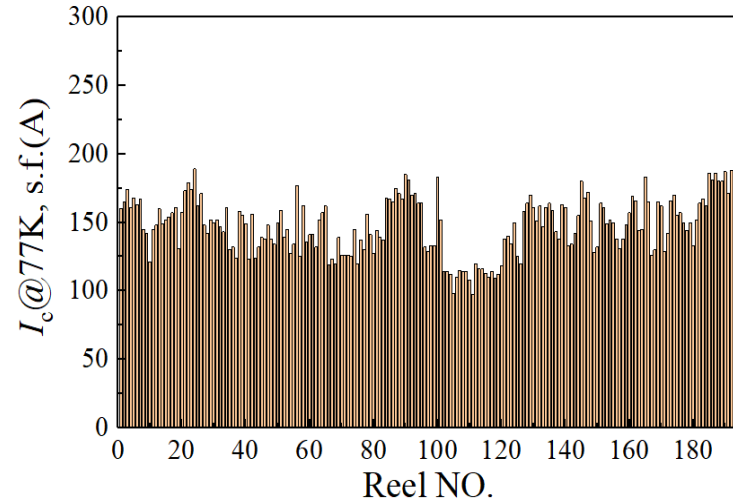
Case3: MIT-CFS, Tokamak Energy and SST

Compact Fusion/High-field Magnet

- MIT-CFS
- Tokamak Energy

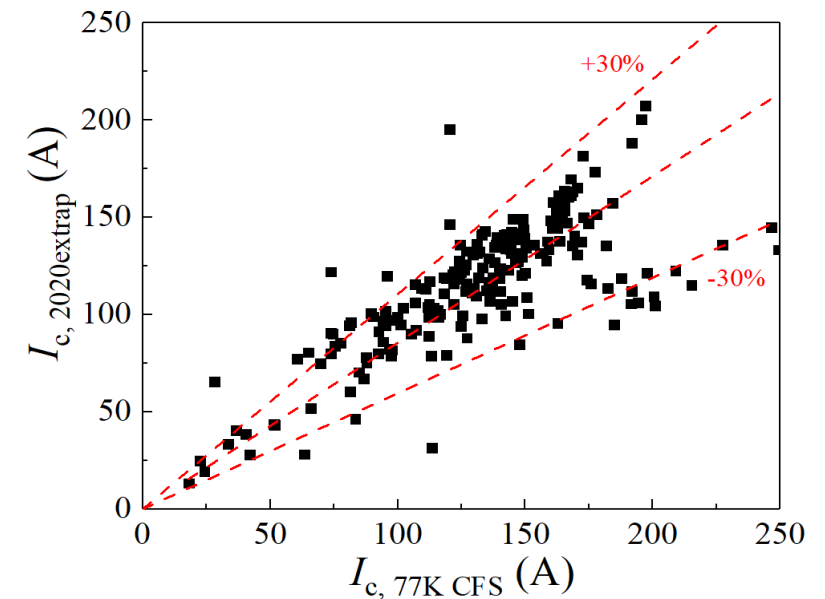
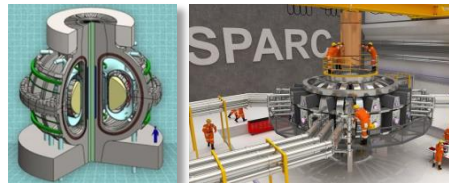
customers' feedback:

- Stable product
- low rejection;
- Ave. J_e exceeding 750 A/mm²
- Comparable lift factor variation as peers



120+ km in total
Complete delivery in 2020

Commonwealth Fusion System (US)
Compact Fusion using 2G-HTS



Summary

■ 2G-HTS Business Chance in China:

- Based on a large demand for electrical power, HTS business is close to commercialization in China
- Many demonstration projects, including power cable, FCL, high speed maglev train, magnets, are being conducted and planned.
- Commercial 2G-HTS tapes are highly anticipated, to be available at low price and well-customized properties.

■ Technological developments at SST:

- Large volume production by IBAD + high speed PLD,
annual production > 1000 km/4mm ($I_c=150-200A$) ;
- Low temperature, high field properties improved by advanced APC, composition,...
- Thin tape(high J_e): Now 30 μm in thickness available
- New slitting method: laser slitting without damage at the edges

Thank you!

Sales contact:

hanyin.deng@shsctec.com

bai.song@shsctec.com