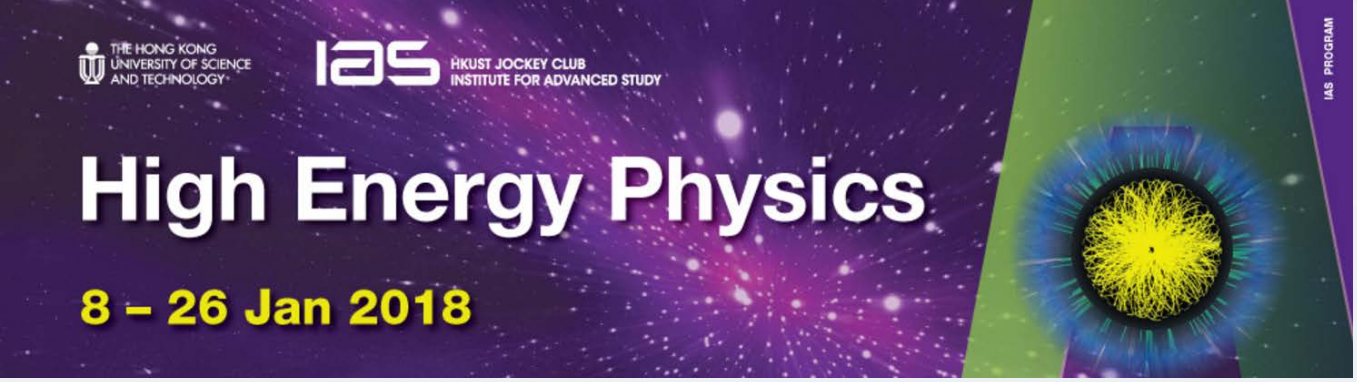

上海超导
Shanghai Superconductor

Progress of 2G HTS Wires Development in Shanghai Superconductor

Zhao Yue
Shanghai Superconductor Technology Co. Ltd., 200240 Shanghai
2018.01.18

Outline

上海超导
Shanghai Superconductor

- Overview of Shanghai Superconductor
- Production Line
- Wire Performance
- Applications
- Future Plan

OVERVIEW

上海超导
Shanghai Superconductor

Establishment (2011)

- Strategic high-tech enterprise
- Registered capital 500 million RMB
- Realized commercialization of 2G-HTS products in late 2014

Team Profile (100 employees, >20 PhDs)

- 40 with R&D, manufacturing, characterization and post processing
- 35 with facilities and equipment
- 25 with sales, marketing, administration, HR, operation, finance, purchasing etc.

Research Institute of Superconductivity (SJTU)

- Independent personnel authority, financial authority and PhD enrollment

Industry-Academia Cooperation

上海超导 Shanghai Superconductor

Research Institute of Superconductivity (RIS)

Operation Budget

Allocated by SSTC to RIS for R&D

Profit Feed Back

Feed back certain % of profit

To SJTU for continuous R&D

Assignment of Research Achievement

Intellectual properties owned by company

Honours owned by university

Our team

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Shanghai Superconductor

Materials

Professor Yutaka Yamada
- Former Leader at ISTEC Japan

Professor Yijie Li
- Shanghai 1000 Talents Program
- Former Researcher at SuperPower

Dr Yue Zhao
- Distinguished Research Fellow
- Researcher at Demark Tech. U.

Dr Wei Wu
- Research Fellow
- PhD of Qsing Hua U.

Dr Zhiwei Zhang
- Research Fellow
- PhD of Cambridge U.

Applications

Professor Zhijian Jin
- SJTU Smart-grid Center VP
- Ex-employee of CERN

Professor Zhiyong Hong
- Shanghai Oriental/Pujiang Scholar
- PhD of Cambridge U.

Dr Zhuyong Li
- Research post-doc
- PhD of Chonnam U.

Dr Linpeng Yao
- Research post-doc
- PhD of SJTU

Dr Zhen Huang
- Associate Research Fellow
- PhD of Cambridge U.

- 4 professors，5 post-docs，20+ PhDs
- Most projects involve collaboration between company and university
- 20+ full time technical engineers at SST for the development of research work

Production Line

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Shanghai Superconductor

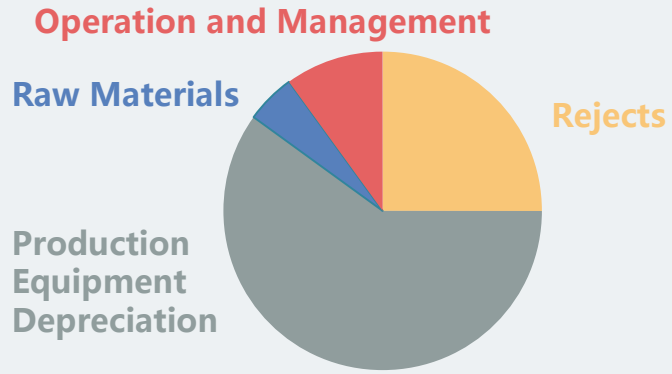
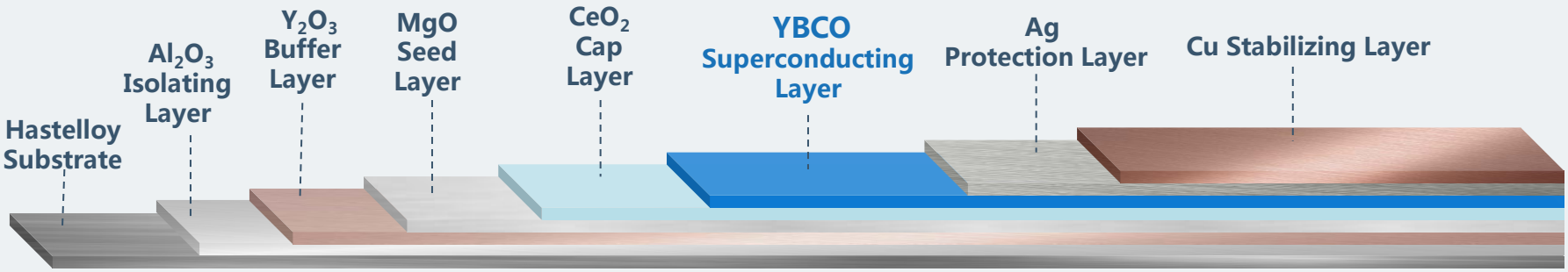


Chart: 2G HTS Wire Production Cost (Before 2014)

Independent Design and Manufacturing

- Substantial cost reduction (manufacturing/maintenance/upgrade)
- Improved yield (70%) through beneficial interactions between optimization of production process and equipment upgrades

Polishing	R2R RF Magnetron Sputtering	R2R IBAD	R2R HTRF Magnetron Sputtering	R2R PLD	R2R DC Magnetron Sputtering	Slitting Machine	Continuous Electroplating	Continuous Lamination



Product Specification

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Shanghai Superconductor

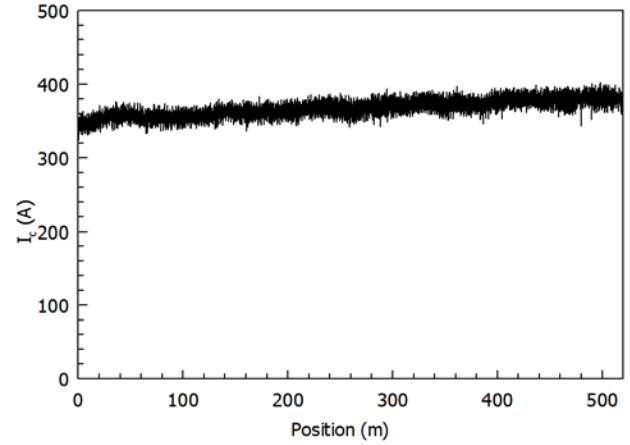
Series	ST-02-E	ST-03-E	ST-04-E	ST-05-L	ST-05-E	ST-06-L	ST-10-E	ST-12-L
Post-processing	Copper-plated	Copper-plated	Copper-plated	Laminated*	Copper-plated	Laminated*	Copper-plated	Laminated*
Average Ic (77K s.f.)**	45-60 A	75-100 A	80-120 A	45-120 A	120-160 A	120-160 A	200-350 A	200-350 A
Wire Width	2 mm	3/3.3 mm	4 mm	4.8 mm	5 mm	5.8 mm	10 mm	12 mm
Wire Thickness	55-95 μm	55-95 μm	55-95 μm	175-350 μm	55-95 μm	175-350 μm	55-95 μm	175-350 μm
Crit. Tensile Stress	>400 Mpa	>400 Mpa	>400 Mpa	>400 Mpa	>400 Mpa	>400 Mpa	>400 Mpa	>400 Mpa
Crit. Tensile Strain	0.4 %	0.4 %	0.4 %	0.4 %	0.4 %	0.4 %	0.4 %	0.4 %
Current Uniformity	±5-10 %	±5-10 %	±5-10 %	±5-10 %	±5-10 %	±5-10 %	±5-10%	±5-10 %
Min Bending Diameter	11-15 mm	11-15 mm	11-15 mm	15-20 mm	11-15 mm	15-20 mm	11-15 mm	15-20 mm

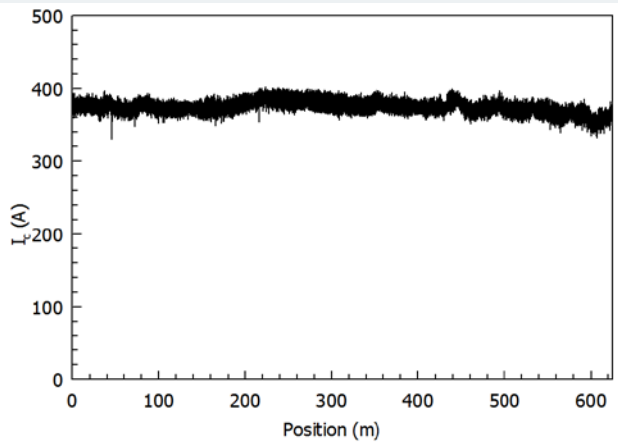
*Choices of Materials: copper, brass or stainless steel or insulation
**Higher Ic available upon request

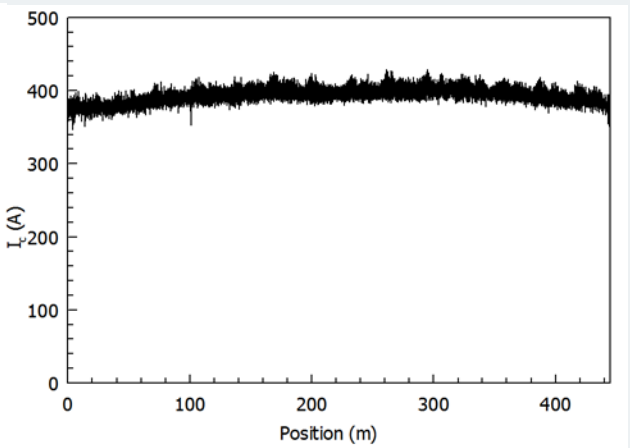
Max Width of ReBCO（current）= 10mm

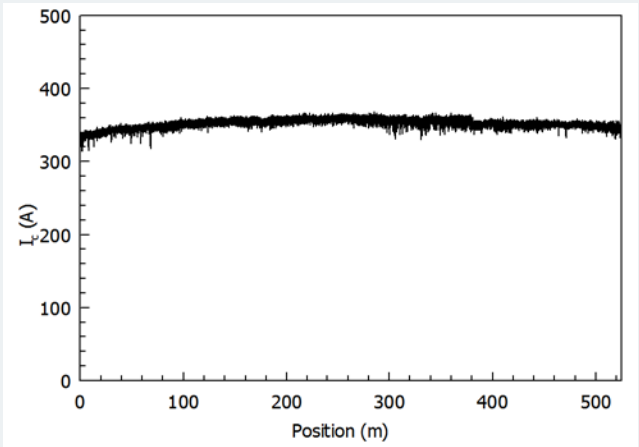
Long Tape Production

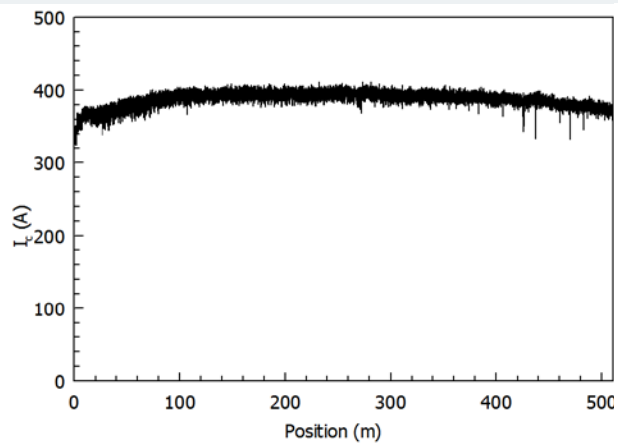
上海超导
Shanghai Superconductor

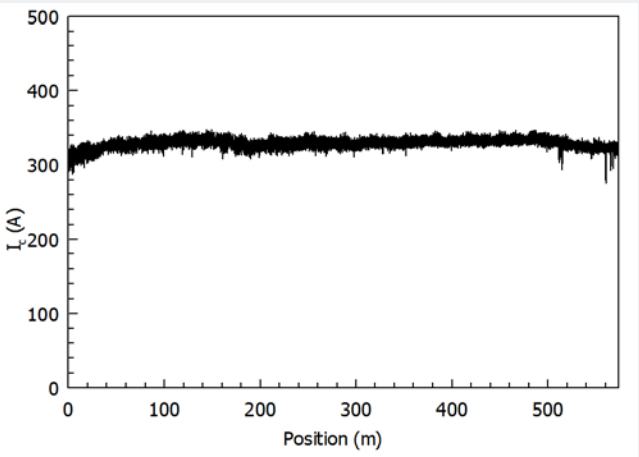












- Stable long tape production of 300 m piece length
- May require 1-3 low resistance joints in case of defects

Long Tape Production

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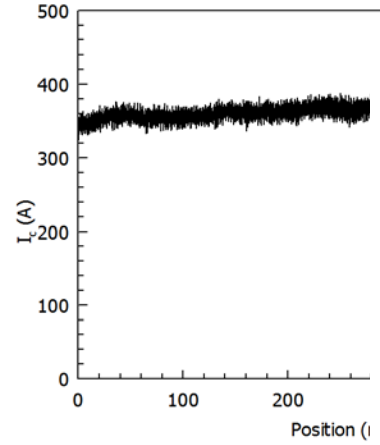
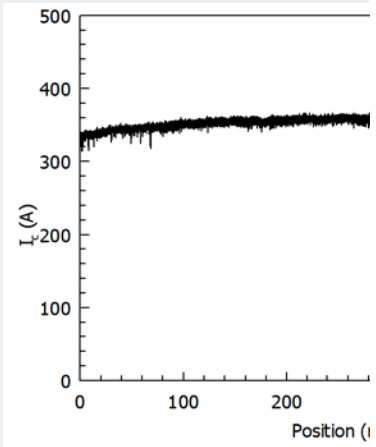
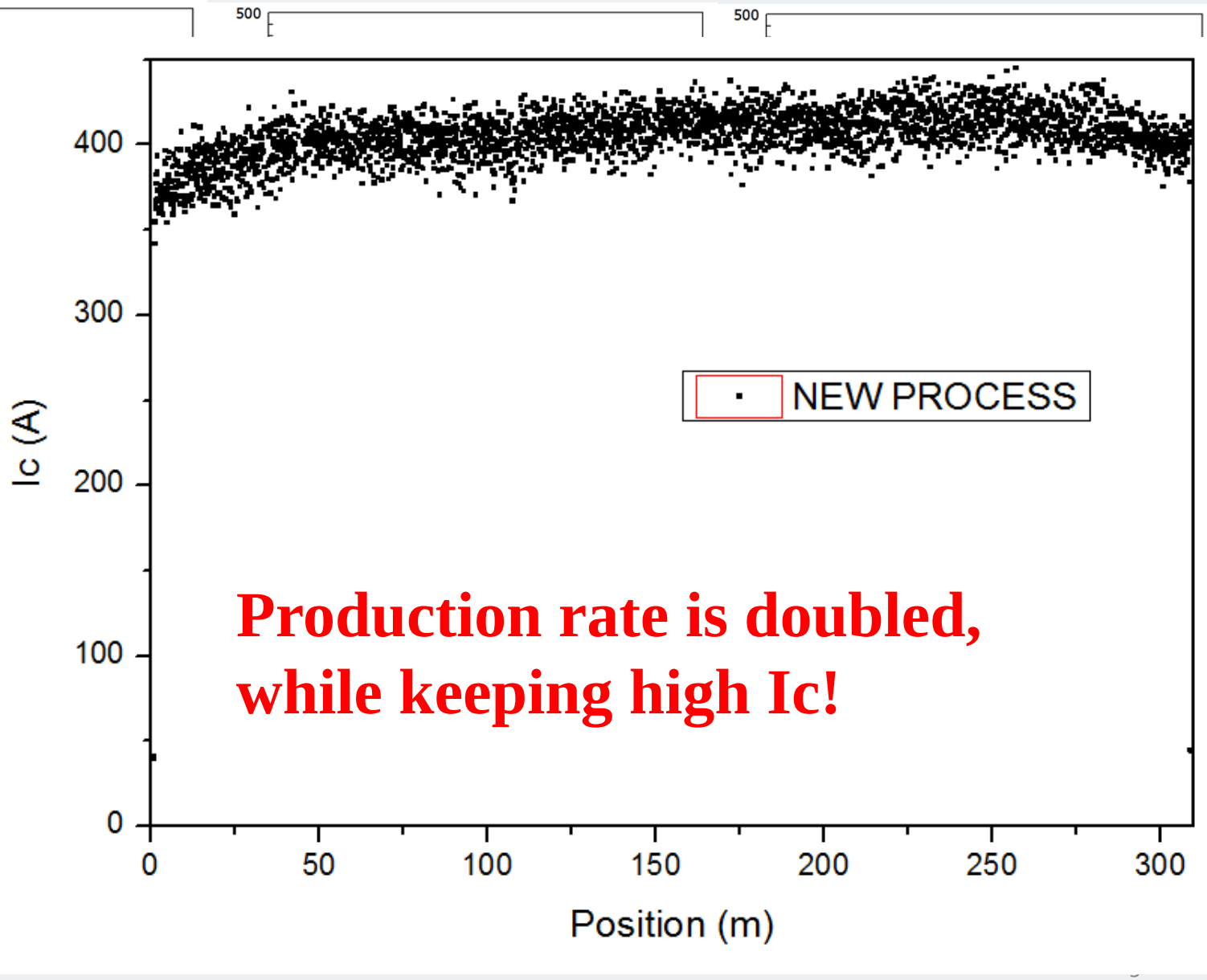
Shanghai Superconductor







- Stable
- May re

Ic Quality Control (@77K)

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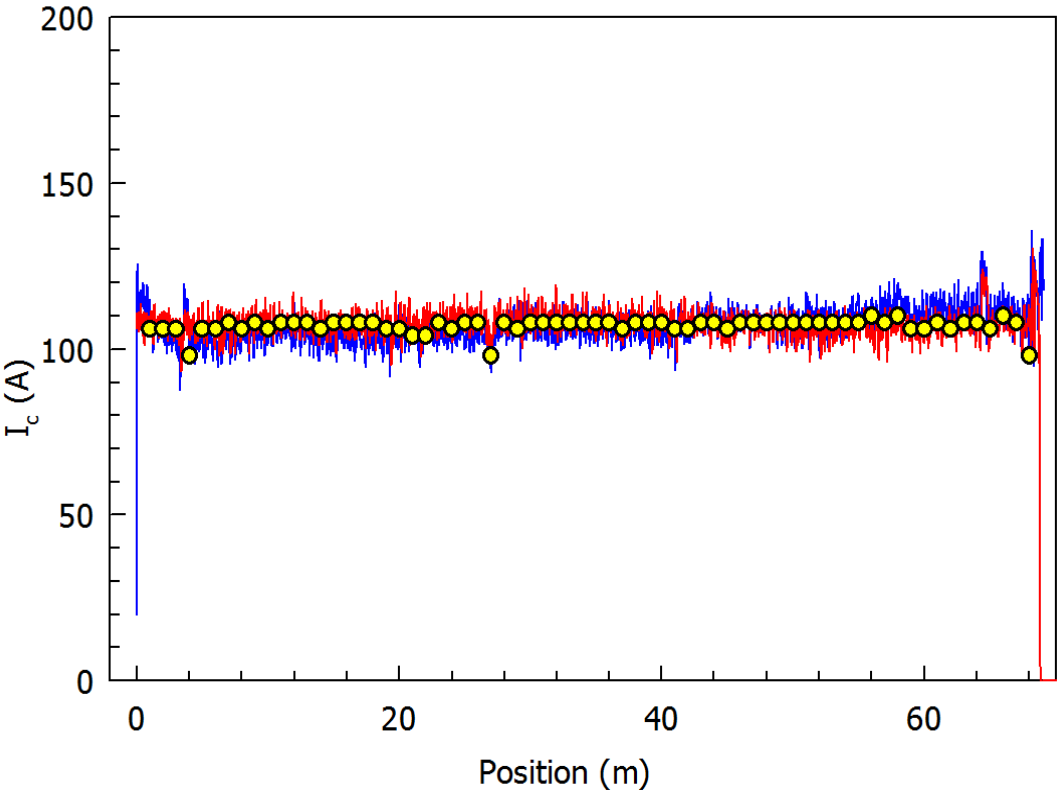
Shanghai Superconductor



Blue and red lines represent inductive measurements, respectively, and the yellow dots transport measurement.

High Field Low Temperature Performance (PSI)

上海超导
Shanghai Superconductor

Stacked Tape HTS Conductors for Fusion Magnets

(Davide Uglietti @ Swiss Plasma Center, EPFL)

For 60 kA cable at 4.2K and 12T

Tape Overview – Ic (B, θ) Nov 2016

manufacturer	*I_c (77 K, s.f.) on 4 mm*	*I_c (4.2 K, 12 T) A/cm width*	*J_e(nonCu) at 4.2 K, 12 T*
STI Conductus	130-180 A	**850-1200**	**1700-2400 A/mm²**
Shanghai Sup. Tech.	>180 A	**600-1000**	**1200-2000 A/mm²**
Superpower	80-120 A	**400-1000**	**800-2000 A/mm²**
Bruker	45 A	**>1500**	**>1500 A/mm²**
Fujikura	300 A	**1200**	**1600 A/mm²**
Superox	90-150 A	**420-520**	**700-870 A/mm²**
Theva	100-200 A	**500-1000**	**500-1000 A/mm²**
AMSC		**400 (1000 irr.)**	**500 (1300 irr.) A/mm²**
SuNAM	>300 A	**400**	**400 A/mm²**
D. Nanoschicht	100 A	**350**	**350 A/mm²**
SWCC	120 A		
Sumitomo, Metox, SAMRI/CAS, Shanghai Creative Sup. Tech., Oxolutia			

High Field Low Temperature Performance (PSI)

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AMSC		4(	
SuNAM	>300 A		
D. Nanoschicht	100 A		
SWCC	120 A		
Sumitomo, Metox, SAMRI/CAS, Shanghai C			

Shanghai Superconducting Technology was selected as supplier:

- **Narrow (3.3 mm) and wide tapes (4.8 mm) are available**
- **Fast delivery time**
- **Competitive high I_c over price ratio**
- **Curiosity to test one more supplier.**

High Field Low Temperature Performance (KEK@JPN)

上海超导 Shanghai Superconductor

Critical Current Measurement of Commercial ReBCO Conductors at 4.2K

K. Tsuchiya @ High Energy Accelerator Research Organization (KEK Japan)

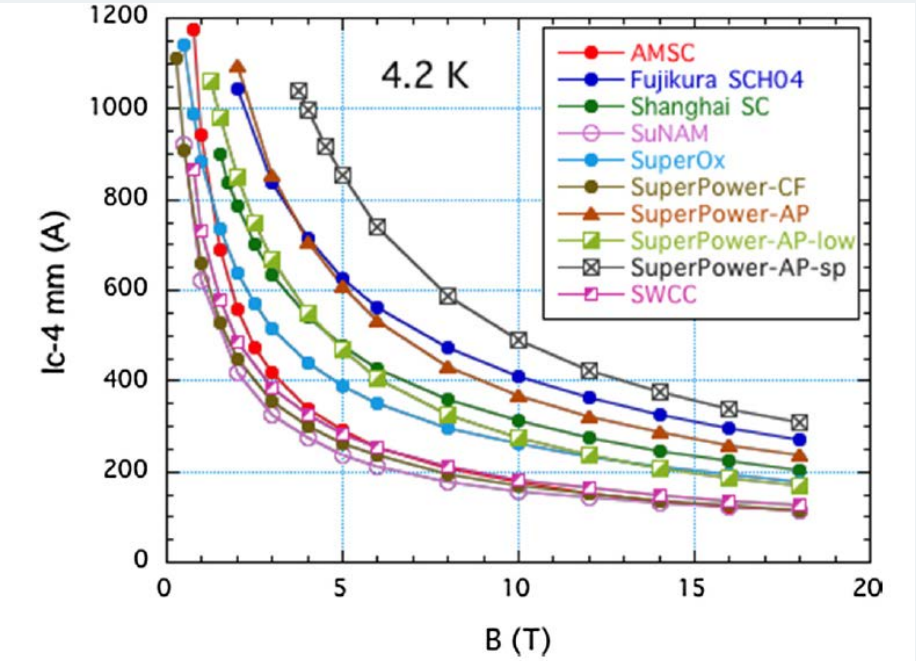

Fig. 5. Transport I_c for 4-mm-wide conductors versus B for commercial conductors in perpendicular fields at 4.2 K. The estimated errors of the I_c values are less than 2–3%.

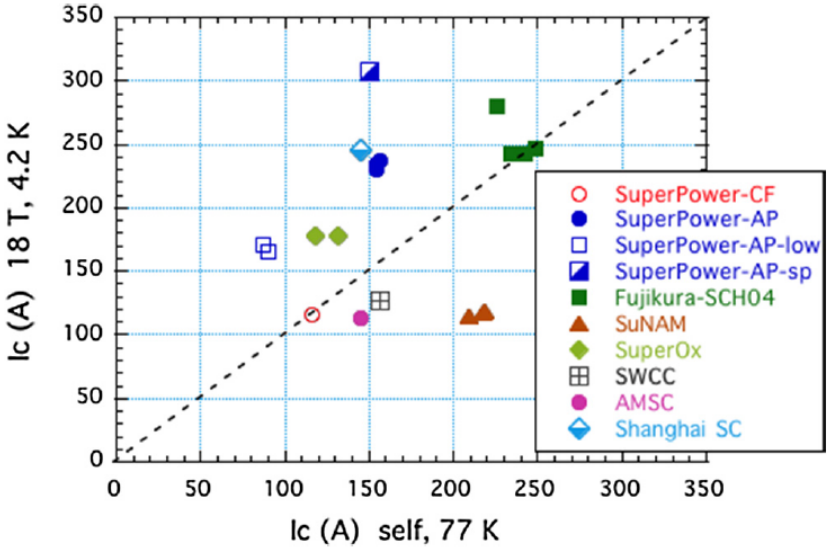

Fig. 6. I_c values of the REBCO conductors measured at 4.2 K and 18 T versus I_c of the same conductor measured at 77 K and under the self-field condition.

Tsuchiya K et al. Critical current measurement of commercial ReBCO conductors at 4.2K, Cryogenics 85 (2017) 1-7 May 2017

High Field Low Temperature Performance (KEK@JPN)

上海超导 Shanghai Superconductor

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K. Tsuchiya @ High Energy Accelerator Research Organization (KEK Japan)

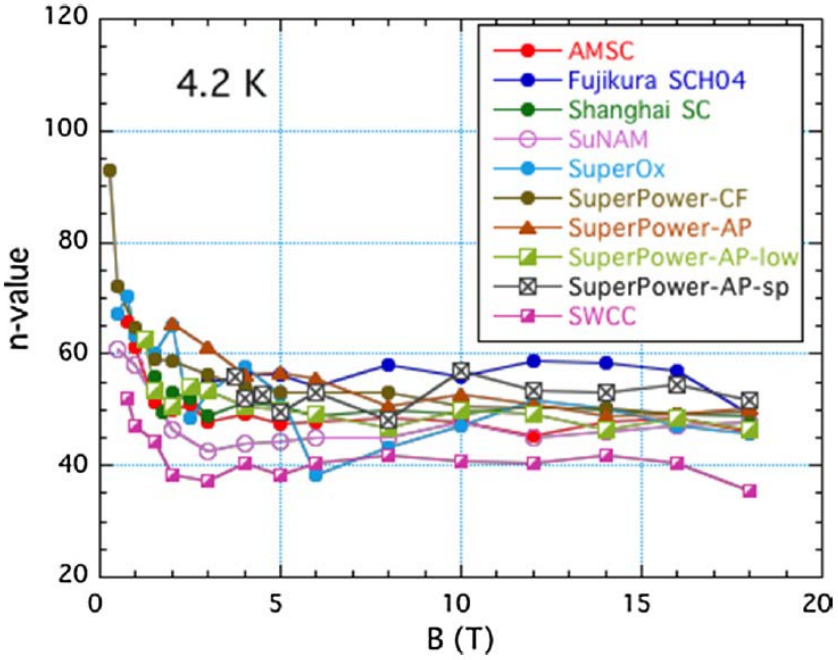


Fig. 7. n-Value versus *B* for commercial conductors in perpendicular fields at 4.2 K.

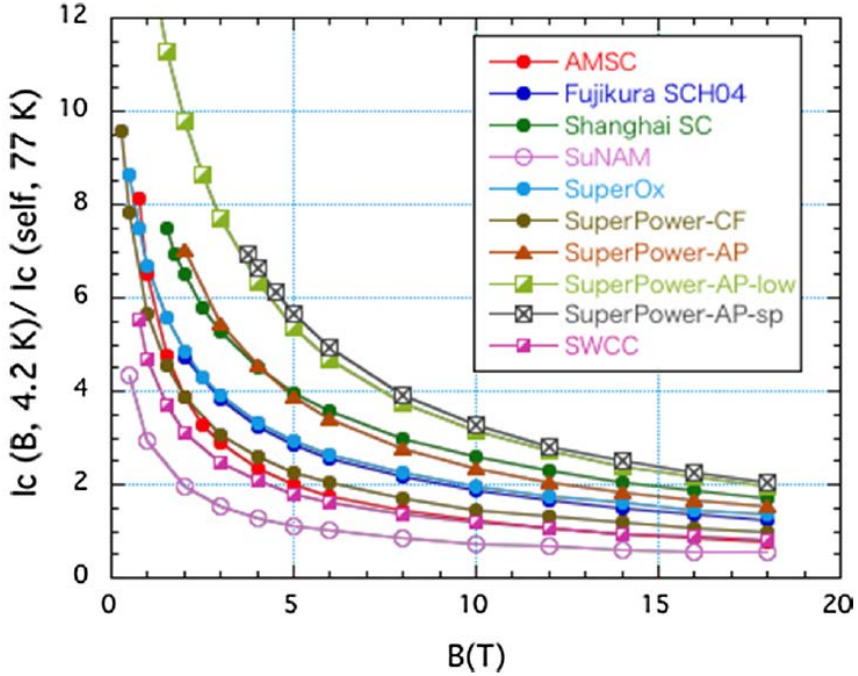
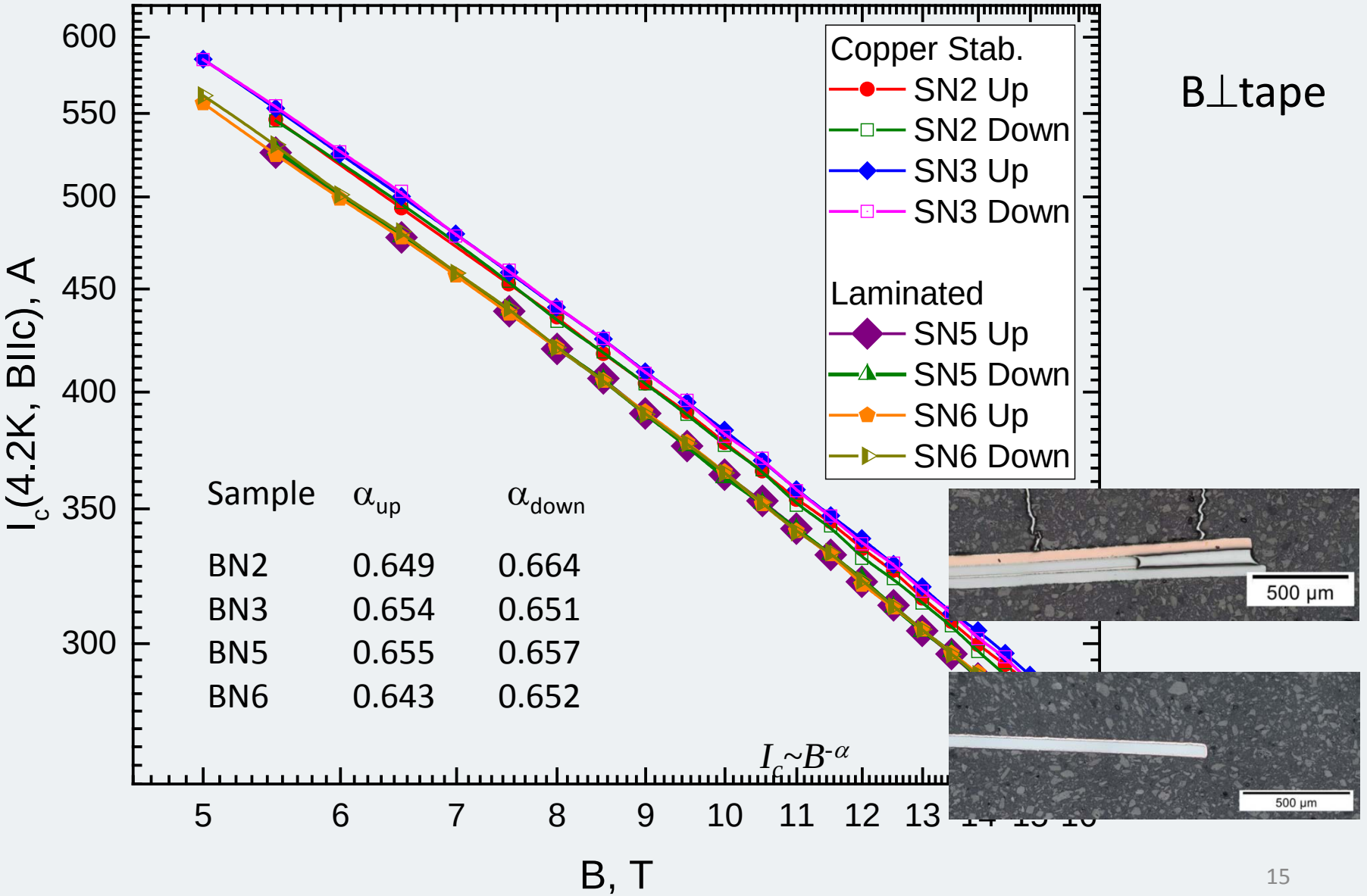


Fig. 8. *B* dependence of lift factor, I_c (*B*, 4.2 K)/I_c (self, 77 K), for various commercial REBCO conductors.

High Field Low Temperature Performance (NHML)

上海超导
Shanghai Superconductor



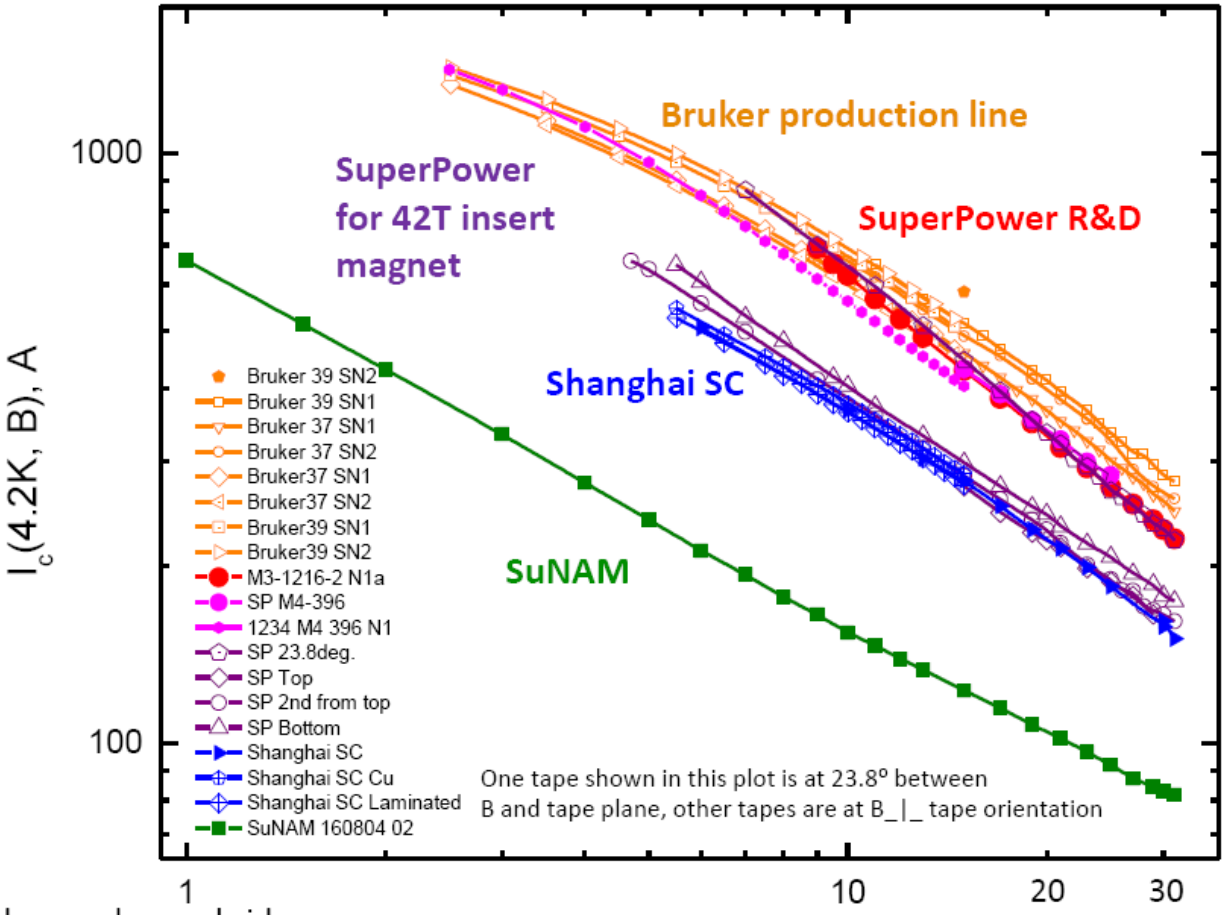
High Field Low Temperature Performance (NHML)

上海超导
Shanghai Superconductor

Comparison transport I_c(4.2K, B) for ReBCO tapes from different manufacturers

Bruker production line tapes show higher I_c(4K,B) then SuperPower R&D tapes

Shanghai SC tapes show I_c (4K,B) comparable to SP tapes used for 42T insert

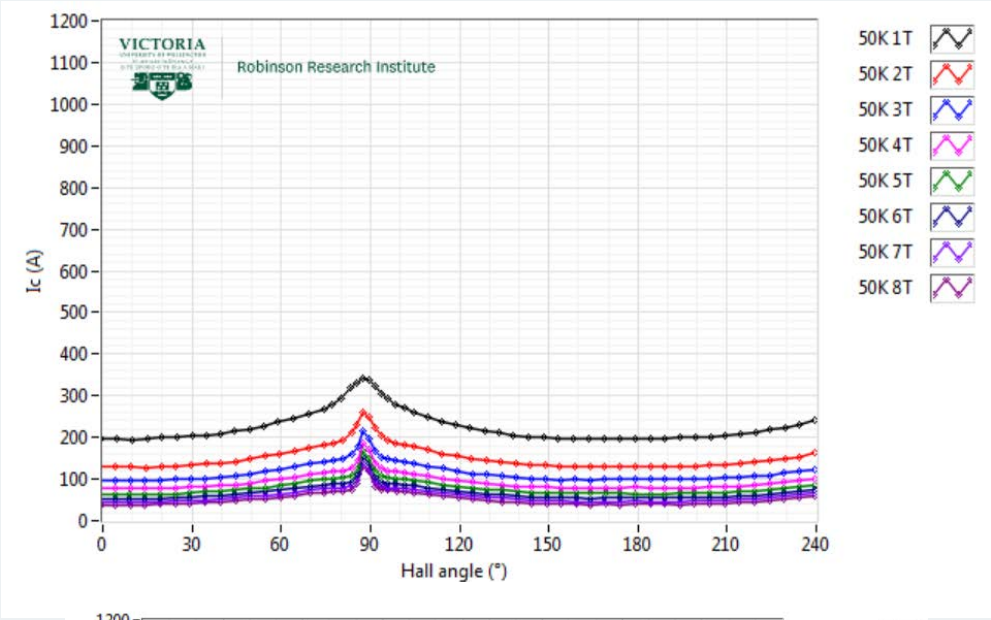


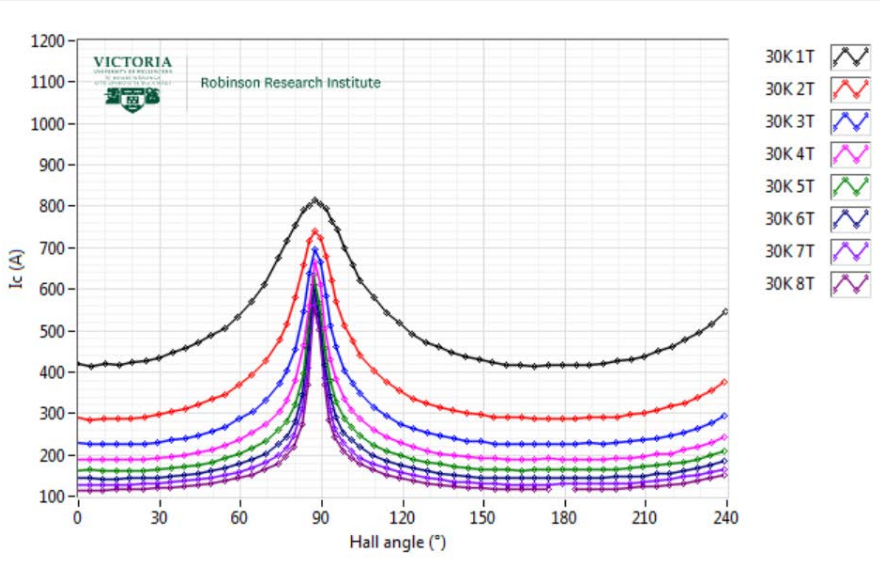
~4mm wide samples, no bridges

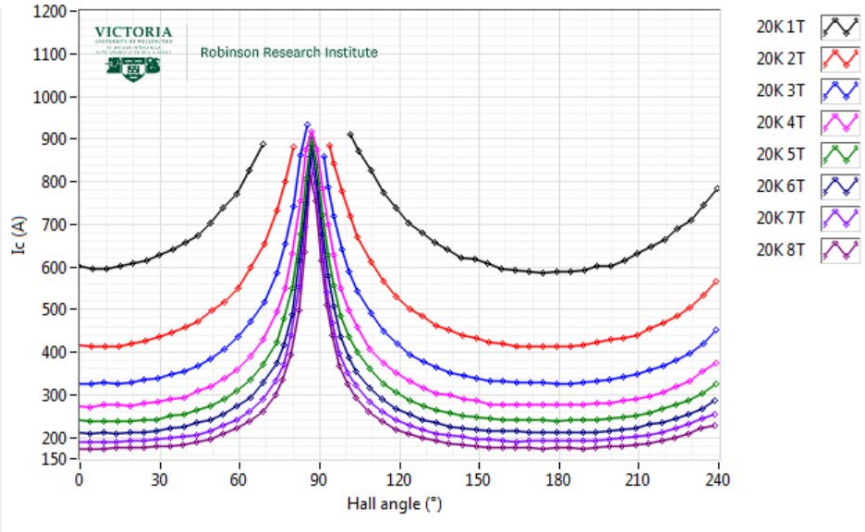
High field data from magnet time Jan. 18-20, 2017

Angular dependency of Ic

上海超导
Shanghai Superconductor







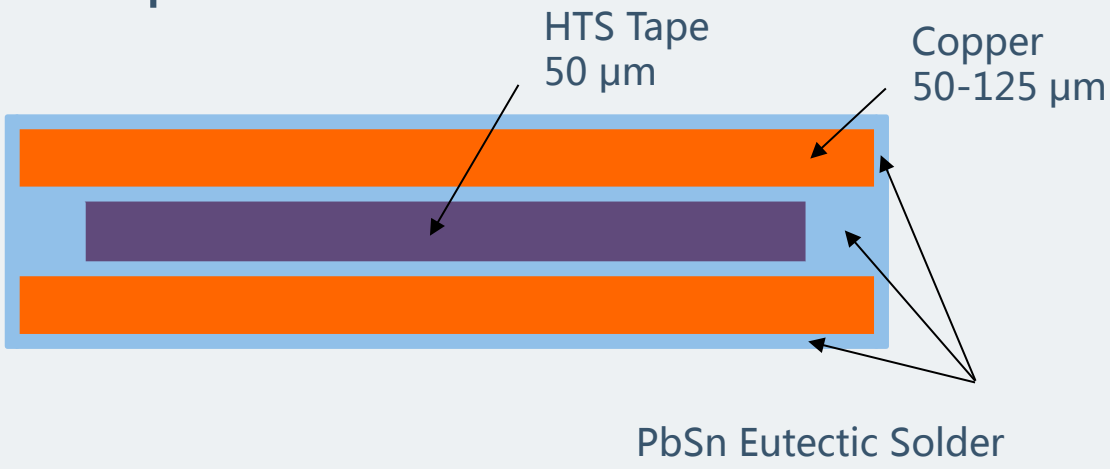
3.3 mm width tape

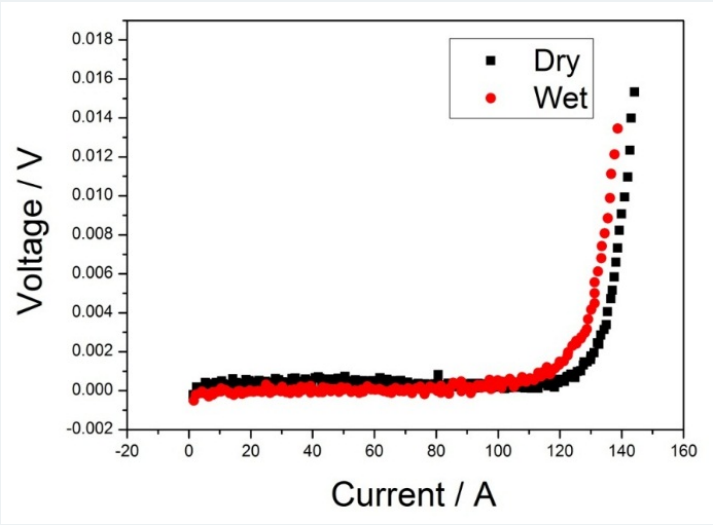
Measured by Robinson Research Institute

Lamination Technique

上海超导
Shanghai Superconductor

Improving Stability and Mechanical Properties





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

Little Ic degradation after epoxy impregnation

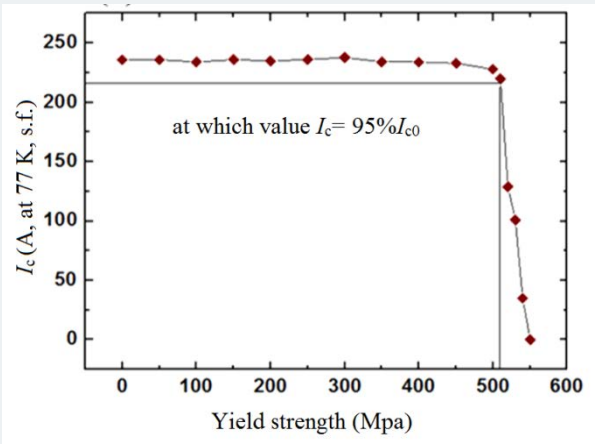
Lamination Technique

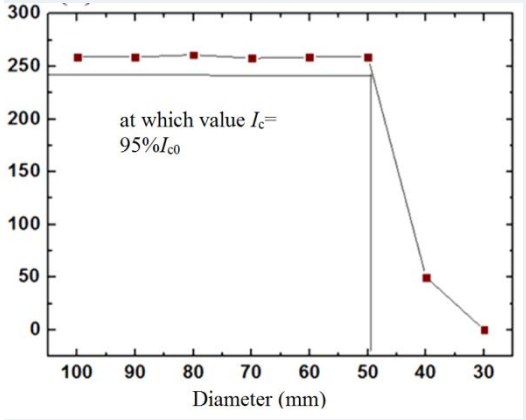
上海超导
Shanghai Superconductor

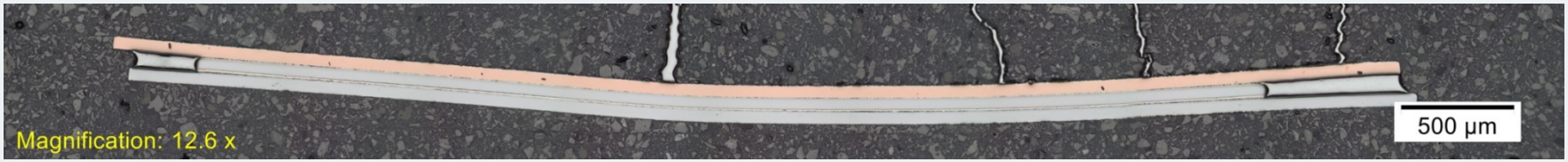
- ✓Superior delamination resistance
- ✓I_c loss after epoxy impregnation 10% in the worst case, no deterioration in most cases
- ✓Enhanced electro- mechanical performance

Critical tensile stress (77K)
>500 MPa

Critical bending diameter (77K)
<50 mm







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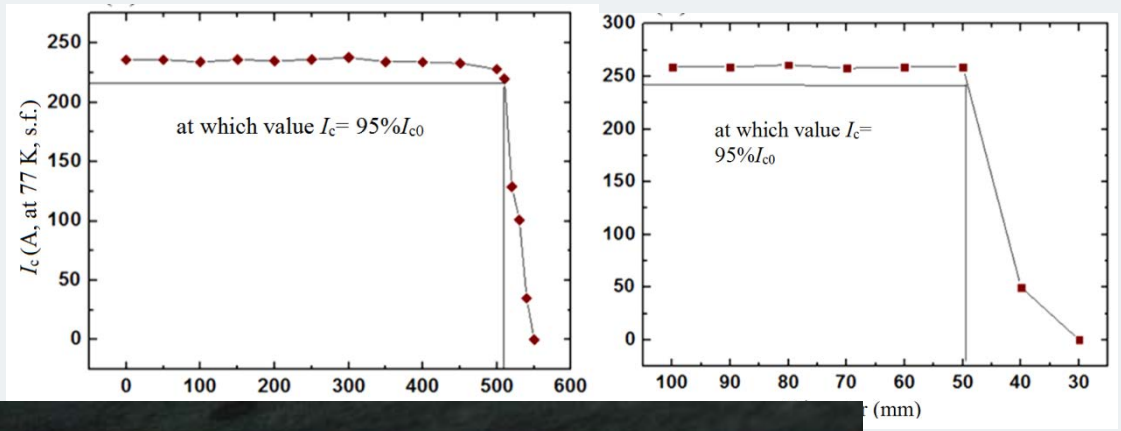
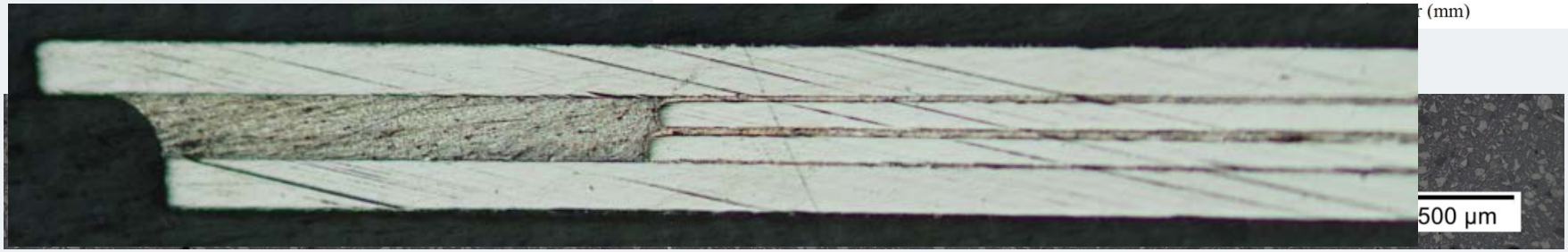




Jointing Technique

上海超导
Shanghai Superconductor

Type	Characteristics	Resistance	Status	Application
Soldered	Fast & Convenient	25nΩ•cm^2	Commercialized	Wide range of applications
1st Gen LRS	●Automated production ●Highly robust	2-150nΩ	Commercialized	●2G-HTS Cables ●Coils and magnets (Operated w power supply)
2nd Gen LRS	●Low resistivity ●Potential for higher Je	1-3nΩ	Technical Support	●Maglev
Resistance-free Joint	●Superconducting Joint ●Complex process	~ 0nΩ	R&D	●MRI ●NMR i.e. persistent current mode

1st Generation
Low resistance Splice

Soldered

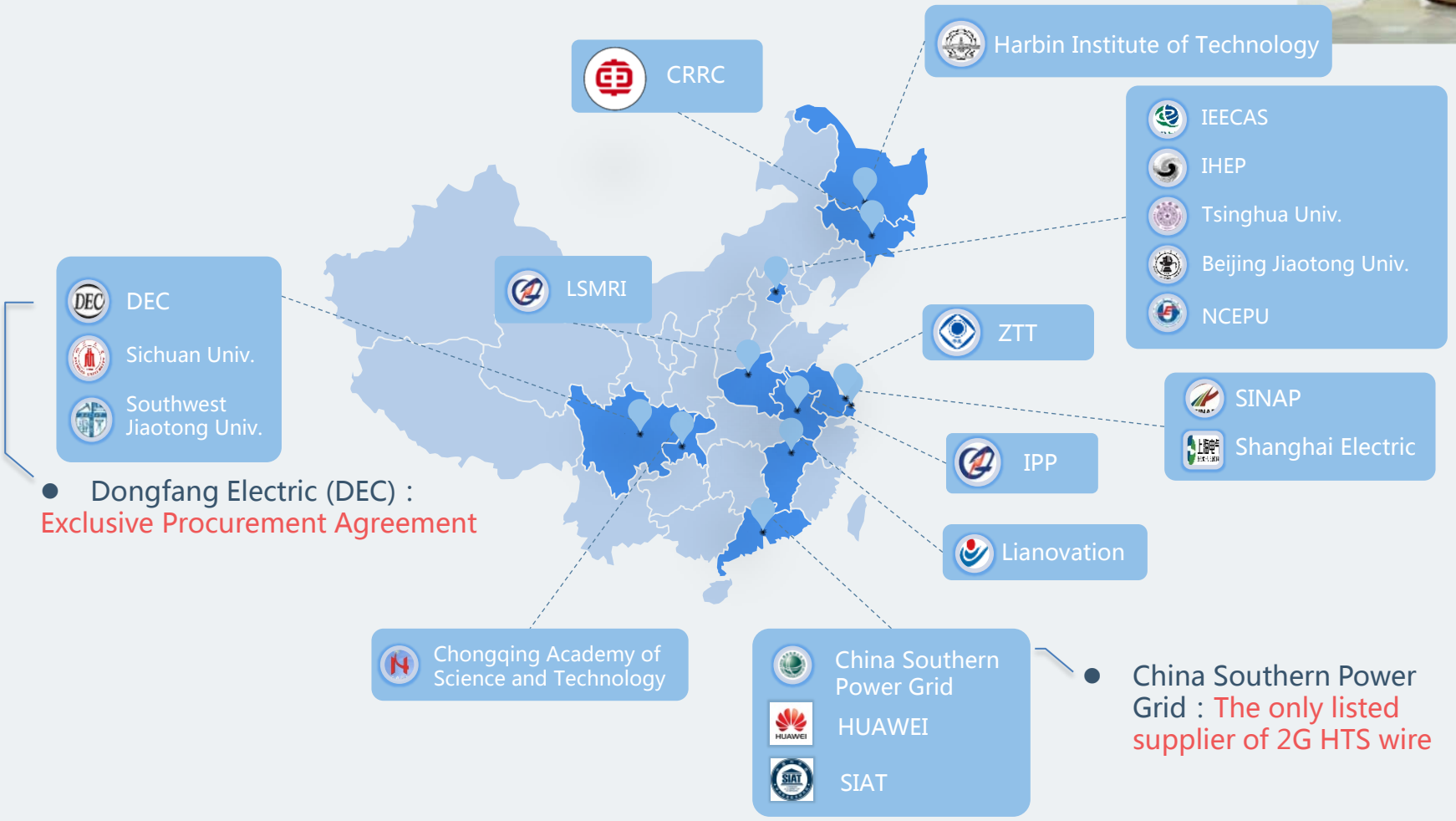
2nd Generation
Low resistance Splice

Diffusion Joint

Domestic Market

上海超导
Shanghai Superconductor

- Won ALL major public biddings in 2015 and 2016
- Best performance to price ratio and excellent customer service

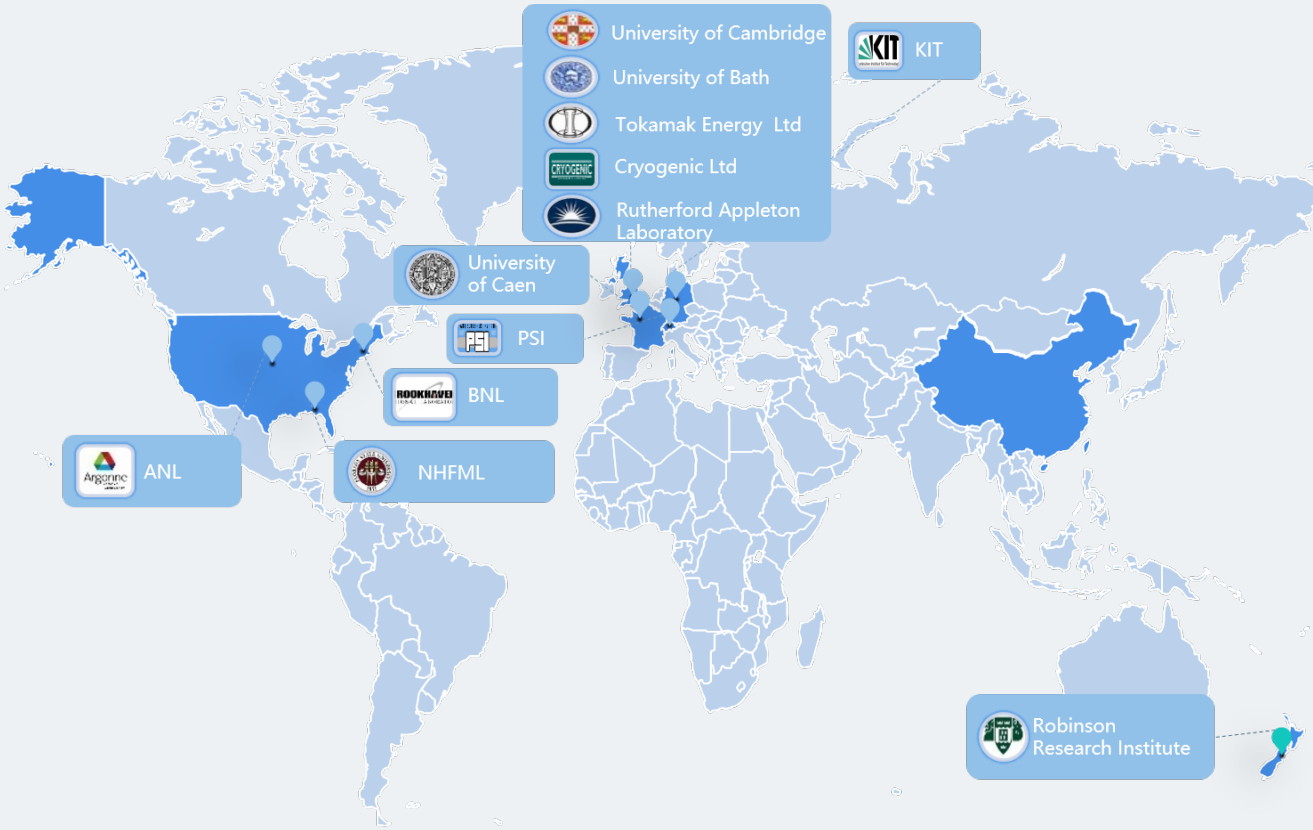


- Dongfang Electric (DEC) : Exclusive Procurement Agreement

- China Southern Power Grid : The only listed supplier of 2G HTS wire

International Market

上海超导
Shanghai Superconductor



- Expanded overseas since 2016

Institution (Field)	Test Data
PSI (Fusion)	Ic (4.2K, 12T) > 800 A/cm
TE (Fusion)	Ic (20K, 8T) > 540 A/cm
Cryogenics (Magnet)	Ic (4.2K, 12T) > 600 A/cm
NHFML (Magnet)	Ic (77K, 0.6T) > 70 A/cm
MIT (Fusion)	Ic (4.2K, 12T) > 750 A/cm
LBNL (Magnet)	Ic (77K, s.f.) > 400 A/cm
WANG NMR (MRI)	Ic (65K, 1.5T) > 160 A/cm
KEK (Magnet)	Ic (4.2K, 18T) > 500 A/cm
KIT (Cable)	Ic (77K, s.f.) > 330 A/cm
CRISMAT (Lift)	Ic (77K, s.f.) > 350 A/cm

2G-HTS power application (ongoing)

上海超导 Shanghai Superconductor

China Southern Power Grid
km-class 10kV/2kA 2G-HTS DC Cable

Approved Nov. 2017

中国南方电网 CHINA SOUTHERN POWER GRID

State Grid (@shanghai)
km-class 35kV/2kA 2G-HTS AC Cable
Budget: ~0.2 Billon CNY for 2 years

Approved Oct. 2017

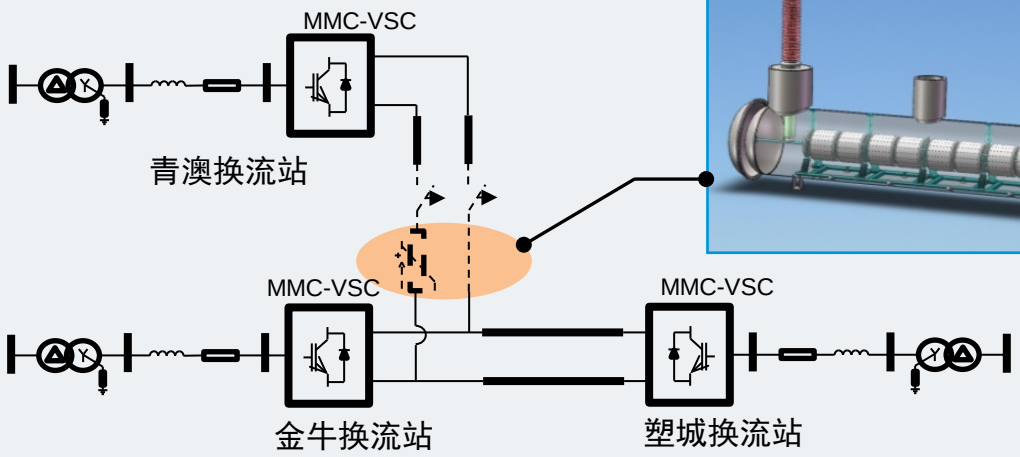
国家电网 STATE GRID
国网上海市电力公司 STATE GRID SHANGHAI MUNICIPAL ELECTRIC POWER COMPANY

China Southern Power Grid
160 kV / 2 kA SFCL
Budget: ~50 million CNY for 4 years

Project Approved

中国南方电网 CHINA SOUTHERN POWER GRID

Expected achievement : FCL prototype | grad connect operation



参量	指标
Rated voltage	≥160kV
Rated current	≥1kA
Response time	<1ms
SC inhibition rate	>35%
Operation term	≥6 mon.

2G-HTS magnets (ongoing)

上海超导
Shanghai Superconductor

for Particle Accelerator

- High Intensity heavy-ion Accelerator Facility (HIAF)
- Project in collaboration with CAS
- Total budget 6-8 billion RMB
- For heavy-ion cancer therapy and nuclear waste disposal (accelerator driven sub-critical system)

- CAS （Institute of modern physics）plans to replace all LTS magnets and copper coils with HTS ones


产学共赢

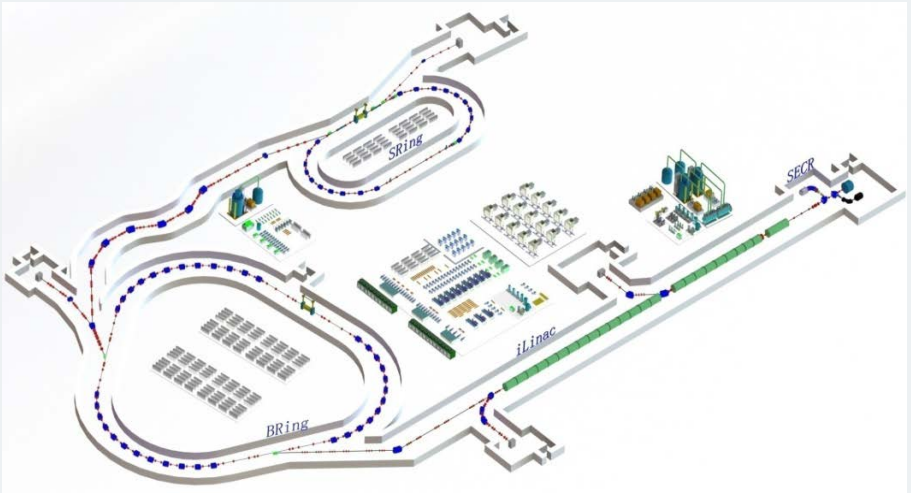
特09

上海交通大学教授、上海超导科技股份有限公司副总裁洪智勇：

全球领先超导技术将在惠州应用

发挥市场和资本优势　广东可集聚先进技术

依托大科学工程　惠州行业前景广阔



2G-HTS magnets (ongoing)

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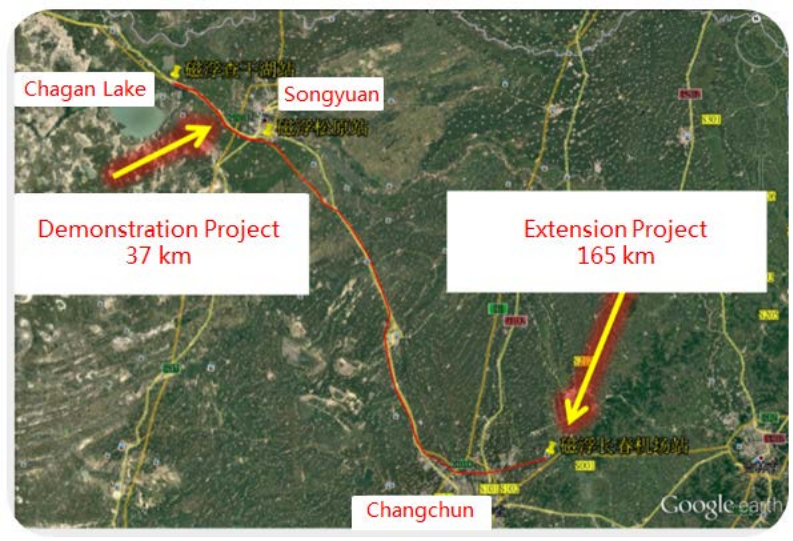
Shanghai Superconductor

for Maglev – Jilin, CRRC

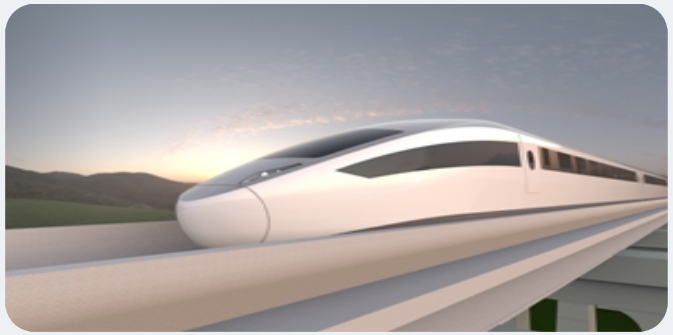
Songyuan City to Chagan Lake 37km 2G-HTS Maglev Tour Route

- Total investment 4.5 billion RMB, open to traffic in 2022
- 2G-HTS Electrodynamic Suspension
- Operation in Air - >400km/h



Medium Term Plan: Songyuan City to Changchun City (165km)

Long Term Plan: Songyuan – Harbin– Changchun (30 mins traffic circle and connection to the Belt and Road Initiative)



Future Plan

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Current:	2020:
1 PLDs 15km/month 70% yield	6 PLDs or more >120 km/month 80% yield
>120 km/year	>800 km/year

- Wider substrate (12 mm)
- Thinner substrate (20-30 μm)
- Ic (77K, s.f.) > 600-800 A/cm
- Ic (30K, 3T) > 2000 A/cm with APC
- Ic (4.2K, 12T) > 2000 A/cm with APC
- Soldered-Stacked-Square (3S) cabling technique – 1mm tapes stack
- Commercialised superconducting joint

Summary

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◆ 2G HTS wires in SSTC：

- Strong R&D backup from the university
- Homogeneity for the tapes up to 500 m；
- High performance at low temperature high magnetic field ；
- Advanced lamination processes ；
- Various of joint techniques

◆ Outlooks：

Higher Performance

Lower Price

Thanks for your attention !