IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), October 2015.
Plenary presentation PL4 given at EUCAS 2015; Lyon, France, September 6 – 10, 2015.
Not submitted to IEEE Trans. Appl. Supercond.

EUCAS 2015

12th EUropean Conference on Applied Superconductivity

Status of Superconducting Materials and Applications in China

P.X.Zhang

Northwest for Nonferrous Metal Research (NIN)

Western Superconducting Technologies Co., Ltd. (WST)

8th, Sep. 2015 Lyon France

IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), October 2015.
Plenary presentation PL4 given at EUCAS 2015; Lyon, France, September 6 – 10, 2015.
Not submitted to IEEE Trans. Appl. Supercond.

Outline

1. Overview of R&D programs for superconductivity in China
2. Progress of low Tc superconductors (LTS)
3. Progress of high Tc superconductors (HTS)
4. Progress of superconducting applications
   Magnet application /Electrical power application
5. Summary

1. Overview of R&D programs for superconductivity in China

A. National High Technology Research and Development Program (863 Program)

B. National Basic Research Program of China (973 Program)

C. National Fusion Research Program of China (ITER China)

D. National Natural Science Foundation of China (NSFC)

IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), October 2015.
Plenary presentation PL4 given at EUCAS 2015; Lyon, France, September 6 – 10, 2015.
Not submitted to IEEE Trans. Appl. Supercond.

The R&D Programs for Superconductivity in China

1.National High Technology Research and Development Program (863 Program)

Main goals:

- Manufacture technology of Superconducting materials for practical applications.
- Superconducting technology: cable, FCL, magnet, and filter.

Main Projects including:

-- Manufacture techniques of high-performance Coated Conductor superconducting tapes

-- Manufacture techniques of superconducting strands for high-performance MRI application

-- Nb_3Sn superconducting wires for high-field application

-- large capbility HTS Superconducting cables

-- High voltage level superconducting FCL

Principal Investigator: Prof. Pingxiang Zhang

Total fund: 200 Million RMB (FY2011-FY2015) to 32 groups with more than 300 researchers.

The R&D Programs for Superconductivity in China

2.National Basic Research Program of China (973 Program)

Main goals:

- Exploring the novel superconducting mechanisms and superconductors.
- Basic scientisic questions of superconducting materials in application.

Main Projects including:

-- Exploration and strcture characterization of novel superconductors

-- Study on un-conventional superconducting materials and mechanism quetions

-- Theory and calcaulation of HTS

-- Novel HTS films and their interface charaters

-- Basic research of micro/nano scale superconducting materials and devices

Principal Investigator: Prof. Haihu Wen

Total fund: 100 Million RMB (FY2011-FY2015) to 14 groups with more than 200 researchers.

The R&D Programs for Superconductivity in China

3.National Fusion Research Program of China (ITER China)

Main goals:

● Developing new high-performance superconducting materials for high-field magnet application in next-generation fusion reactor.

Main Projects including:

-- R&D of High-performance Nb_3Al superconducting long wires for 15 T magnet

-- R&D of High-performance Bi-2212 round stands for 20 T insert magnet

-- Development of high-strength and high-Jc Bronze Nb_3Sn strands

-- Novel insulation and anti-irradiation materials for high-field magnet application

-- Design of China Fusion Engineering Test Reactor

Total fund: 150 Million RMB (FY2011-FY2015) to 10 groups with more than 100 researchers.

The R&D Programs for Superconductivity in China

4.National Natural Science Foundation of China (NSFC)

Main goals:

- Free exploration for basic research on superconducting materials and application.
- Training the scientific talents.

Main Projects including:

-- Novel theory and superconductor exploration

-- New synthesis methods and mehanisms on superconducting materals

-- New theory and methods on superconducting electrical power application

-- New application possibility on medical equipment, scientific instrument and transportation

-- Interdiscipline researches of superconducting technologies with microscopy, mechanics, life sciences and materials sciences;

-- Funding for the foreign young researchers to work in China

Total fund: 150 Million RMB (FY2011-FY2015) to 200 groups with more than 1000 researchers.

Progress of SC and its application in China (2011-2015)

Materials

- YBCO CC: 50m, Ic=140A@77K
  Laboratory scale
- YBCO CC: 1000m, Ic=280A@77K
  Industry scale
- 2011 — LTS：
  Starting mass production
- 2015 — 180t NbTi and 30t Nb_3Sn strands for ITER, 100t strands for MRI and HEP application

2011 — 2012 — 2013 — 2014 — 2015

Application

- 2012 — Power DEMO： HTS Power Substation
- 2013 — Cable：
  380m, 10000A DC
- 2014 — FCL：
  220kV, 3 Phase
- 2015 — FCL：
  550kV, 3 Phase

The R&D of superconducting materials and applications in China cover all the fields today.

2. Progress of LTS (NbTi/Nb_3Sn/Nb_3Al)

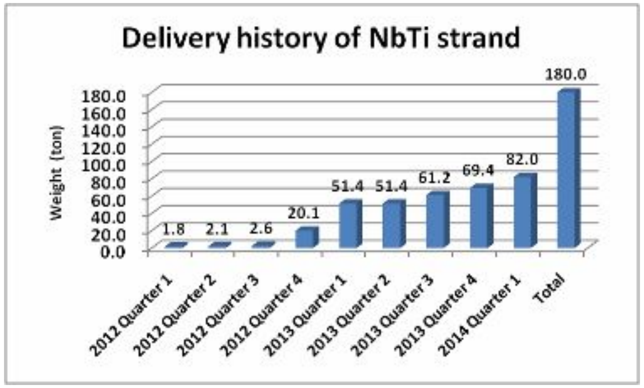
A. NbTi alloy and strands
Iter and MRI

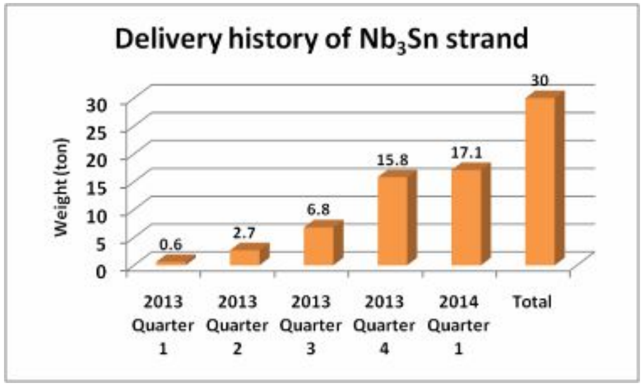
B. Nb_3Sn strands
Internal Sn and Bronze methods

C. Nb_3Al wires
PIT and Jelly-roll methods

- Western Superconducting Technologies Co., Ltd. (WST)
- Northwest Institute for Nonferrous Metal Research (NIN)

Overview of NbTi and Nb_3Sn Strands for ITER



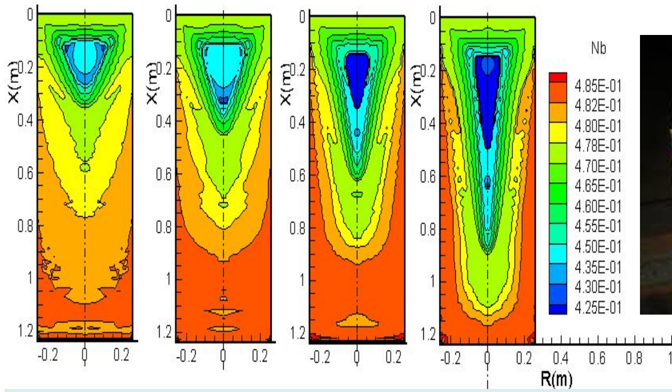


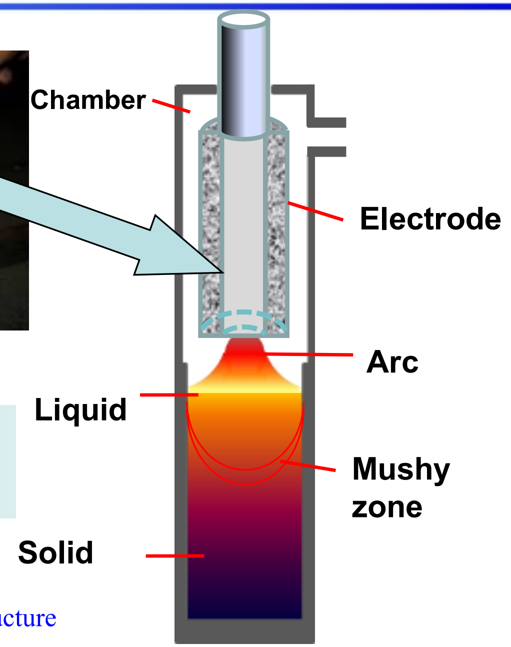
WST launched mass production of NbTi and Nb_3Sn strands for ITER in 2009 and delivered 180t NbTi and 30t Nb_3Sn strands until 2015.

WST Stock No. 831628, NEEQ China

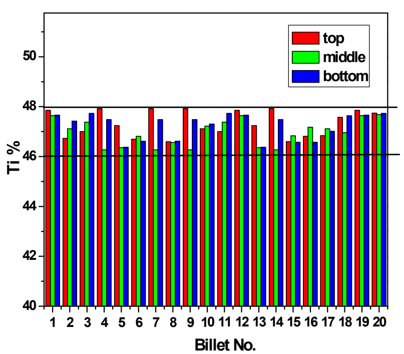
ITER project pushed the R&D and production of LTS in China

High homogeneity NbTi alloy

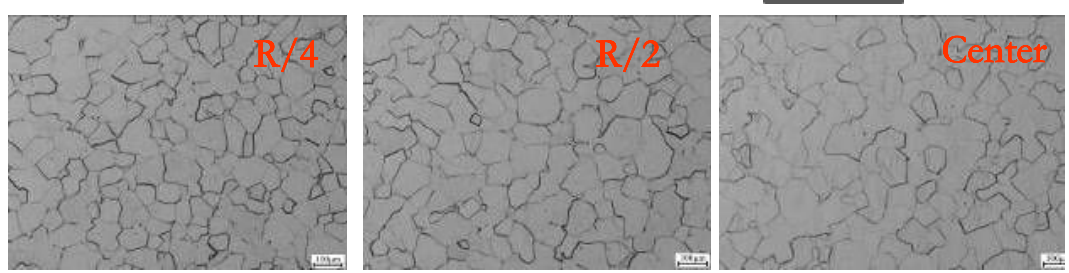




The distribution of energy in the Nb element in electrode is the key issue for homogeneity.

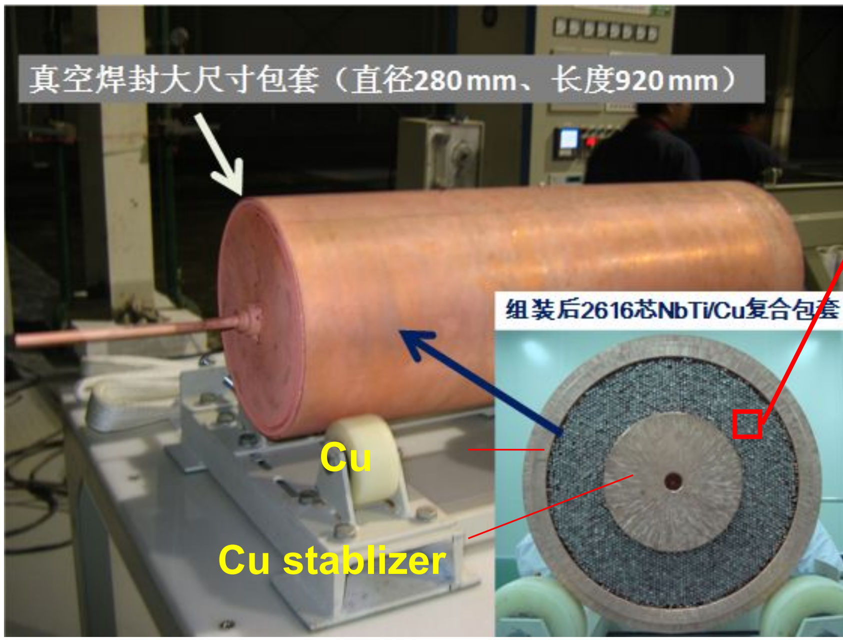


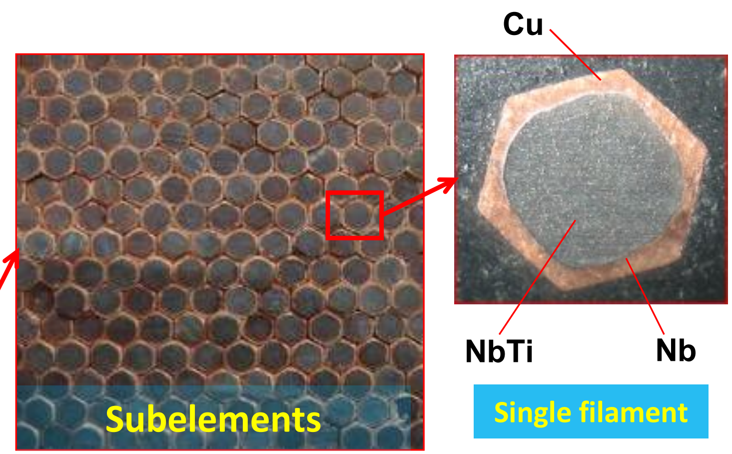
High homogeneity of componet and microstructure



High-homogeneity NbTi alloy has been developed and produced in large scale for ITER and MRI application

Fabrication of large size NbTi/Cu composite billet

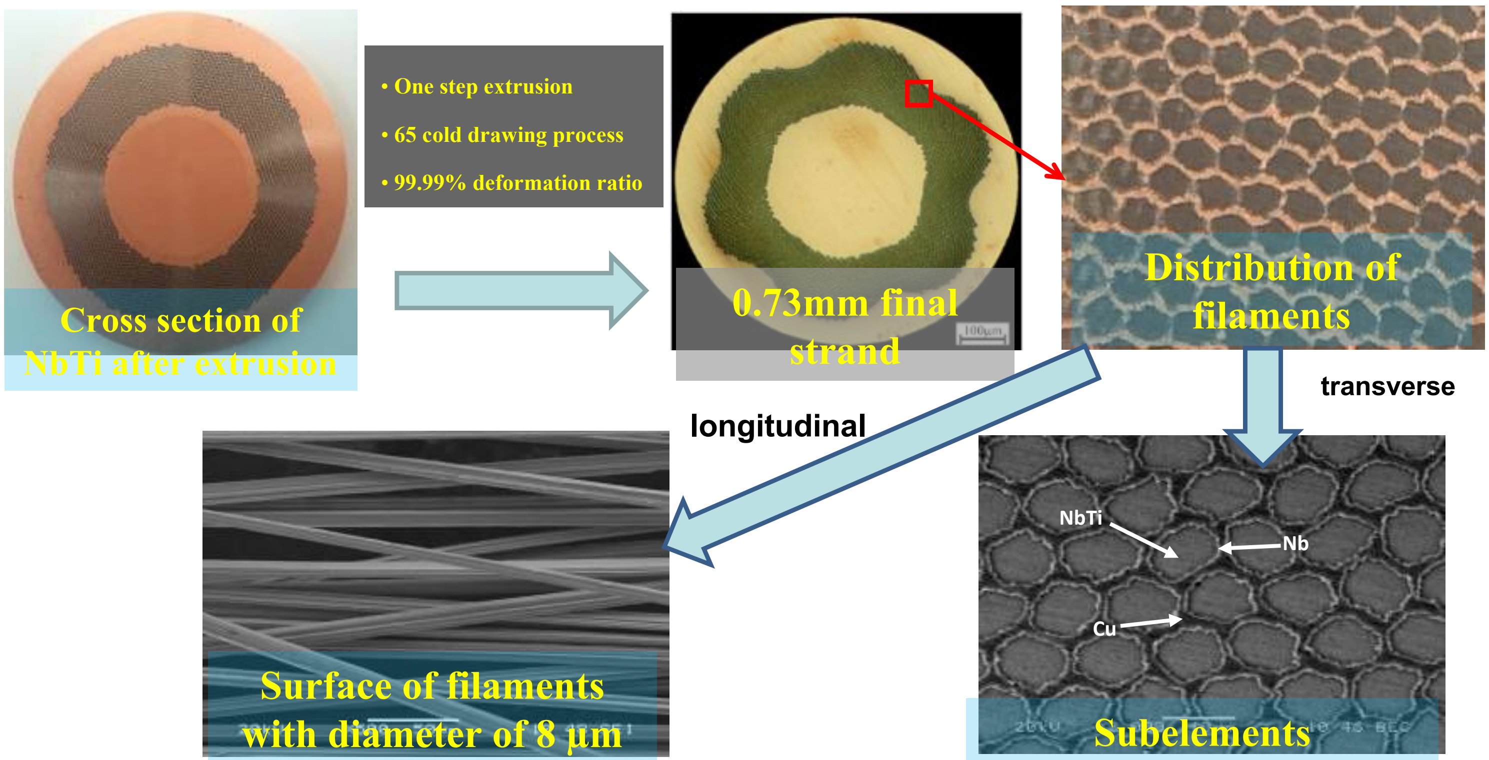




450kg billlet with 2616 filaments in one step assembly process. Fill ration reaches 98%.

WST developed the fabrication technology to make large size NbTi/Cu billet with high quality long wires

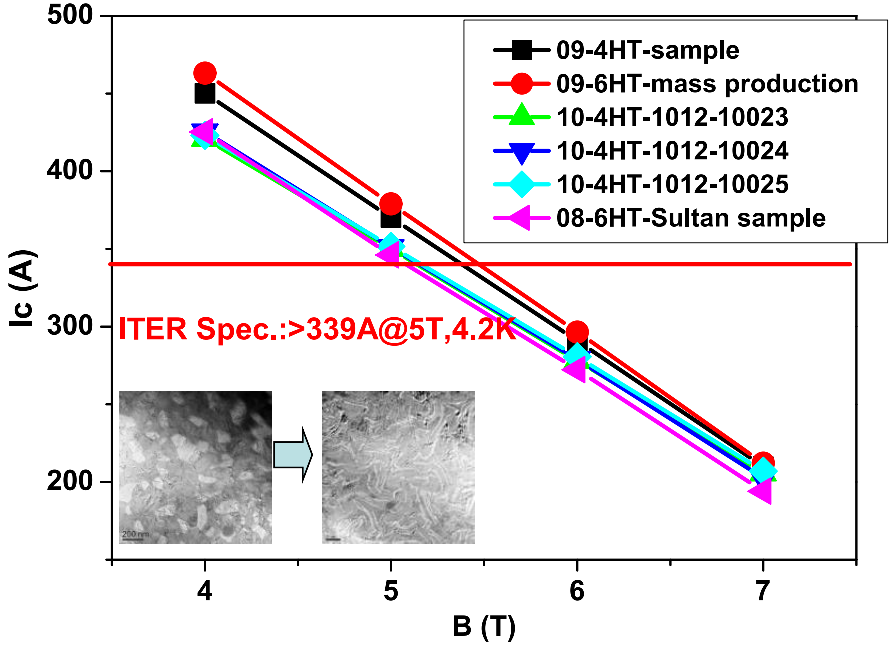
Bundledrawing: Ultrafine filamentary NbTi strands

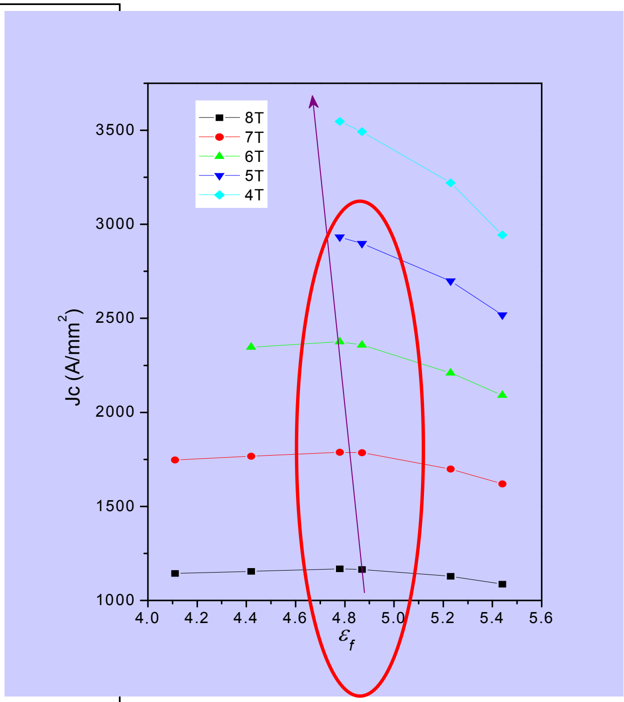


The maximum unit length of final NbTi strand for ITER with ultrafine filament is 90km

Enhencement of performance of NbTi by optimization of HT and additional deformation

The 4 times HT method was developed instead of traditional 6 times HT method.





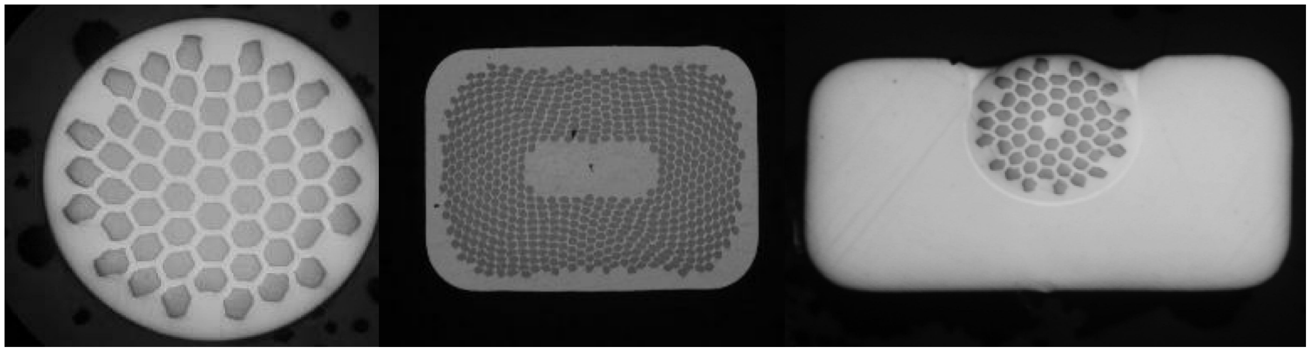
The Heat treatment times and additional deformation have significant effect microstructure of NbTi to enhance the critical current density of strands.

NbTi Strand for MRI Application

- **Monolith and WIC wire for MRI and scientific application have been developed and manufactured in large scale.**

See also: 2A-WT-P-02

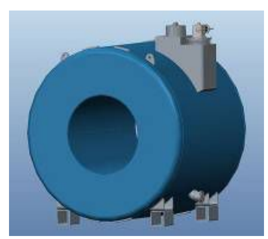
Typical Cross Section



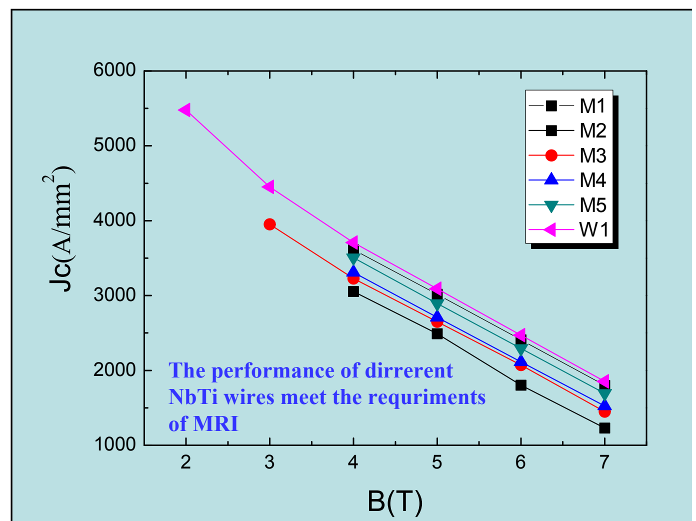
The domestic MRI system manufacturers in China

www.united-imaging.com

http://alltechmed.com



http://www.xmc.cn



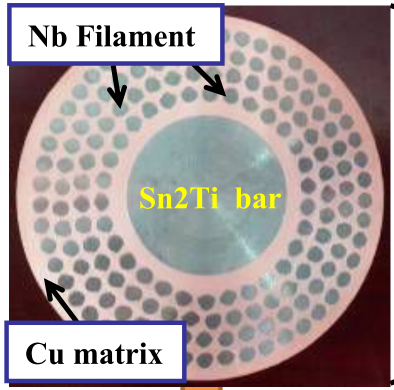
Internal-tin Nb_3Sn Strand: Conductor design

High Jc → High content of Nb_3Sn pahse → High ratio of Nb and Sn

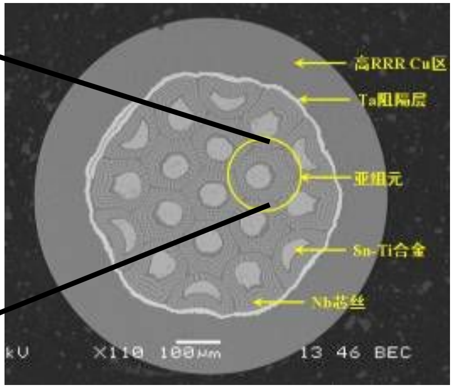
Low AC loss → Distance of filaments → High ratio of Cu

} **Key issues**

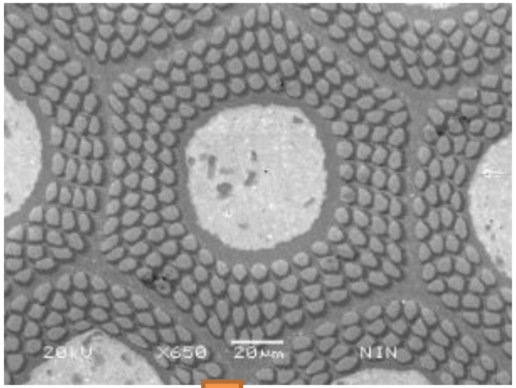
Ratio of Cu:Nb:Sn=2.97:1.57:1



Filaments Number of Nb_3Sn strand is 3040.



The subelement in strand



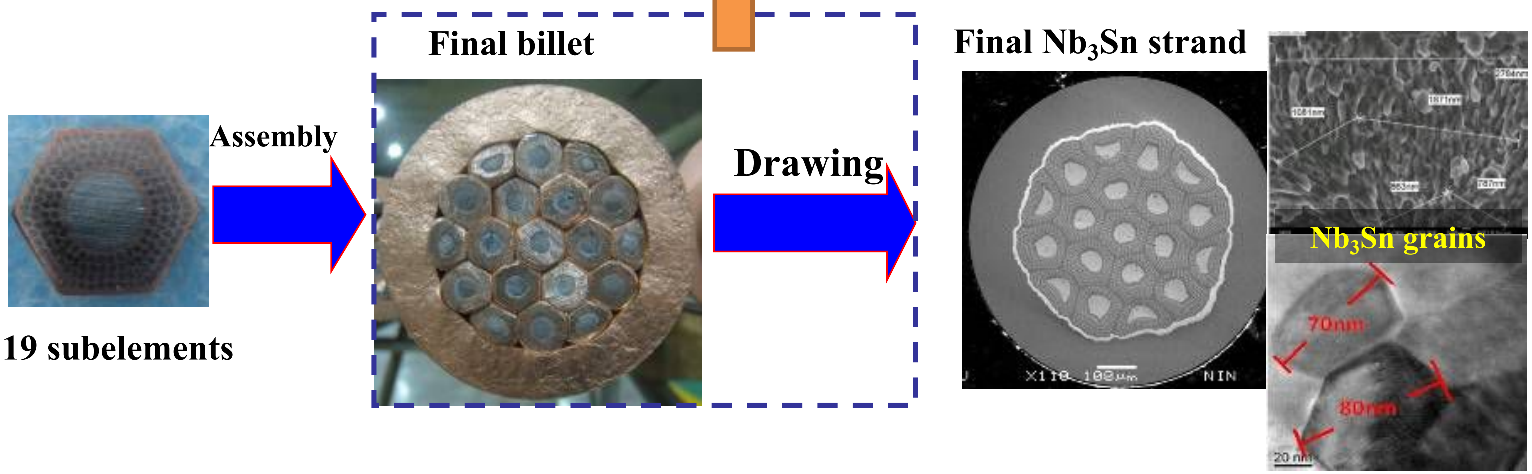
Low AC loss: (To avoid coupling)
The copper surround Nb filament
The copper surround subelement

The distance of filaments is about 2 μm and of subelements is about 5 μm

The ratio of Cu/Nb/Sn elements and distance ensure high Jc and low AC loss of internal-tin Nb_3Sn strands for ITER

Internal-tin Nb_3Sn Strand: Fabrication

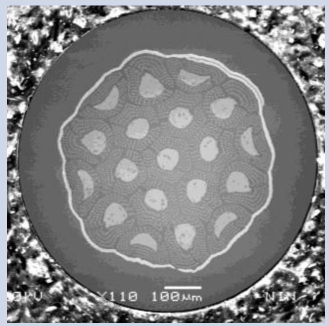
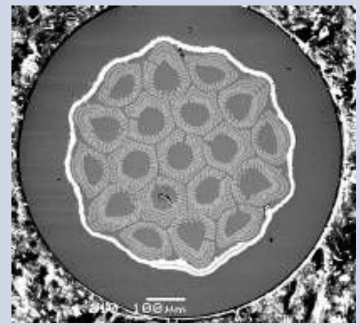
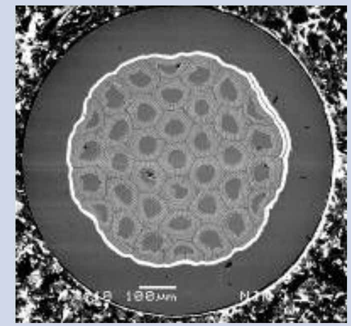
Step	characteristic	Size（mm）	Drawing rate（%）	Purpose
1	Low Drawing rate	65-47	7-14	Hardening of all elements synchronously
2	High Drawing rate	47-5.85	23-29	Deformation of all elements synchronously
3	Middle Drawing rate	5.85-0.82	12-18	Low resistance to deformation



The special defromation controlling technology ensure the homogenity of all elements in composite to get fine Nb_3Sn grains

Internal-tin Nb_3Sn Strand: New Structure

- **New structure strand were fabricated and investigated to improve total performance for the future fusion application.**

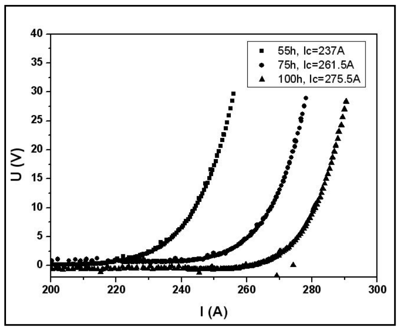
Strand type	Type 1	Type 2	Type 3
Cross section			
Structure feature	Cu split	Cu split	Cu split
	--	Tin spacer	--
	--	--	37 subelements
I_C (A) @4.2K,12T	>250	>280	>270
n value @4.2K,12T	>20	>20	>20
RRR(273K/20K)	>100	>100	>100
Q_h (mJ/cm^3) @4.2K,±3T	<300	<340	<320

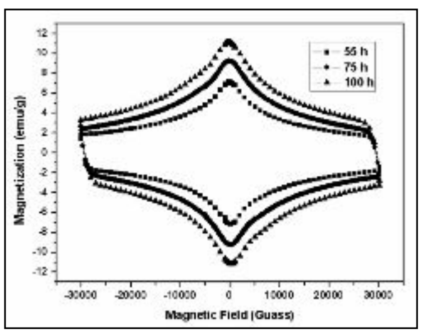
Q_h level is efficiently decreased by Cu split in subelements
Ic is increased by tin spacers in final billets

Internal-tin Nb_3Sn Strand: Performance

- **Heat treatment was investgated to understand the intrinsic property of the strand**

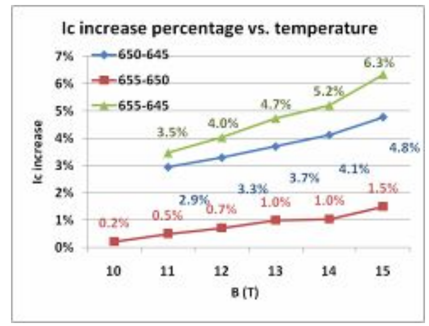
Duration at reaction temperature

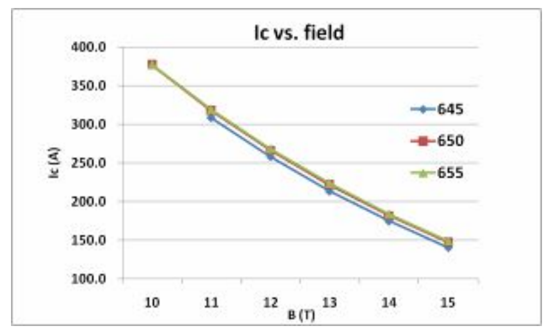




The increase rate of Q_h is much more significant than I_c when duration is varied from 55 h to 100 h.

Temperature sensitivity





I_c is very sensitive to temperature fluctuation specially from 645 °C to 650 °C at field above 12 T.

Heat treatment duration has greater impact on Q_h
I_c is very sensitive to temperature variation of ± 5 °C at high field

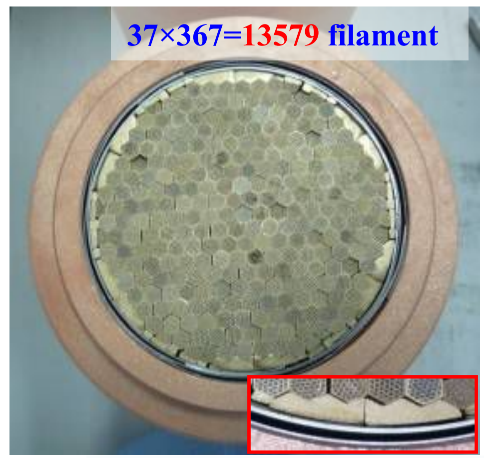
IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), October 2015.
Plenary presentation PL4 given at EUCAS 2015; Lyon, France, September 6 – 10, 2015.
Not submitted to IEEE Trans. Appl. Supercond.

Bronze Nb_3Sn wires: Conductor design

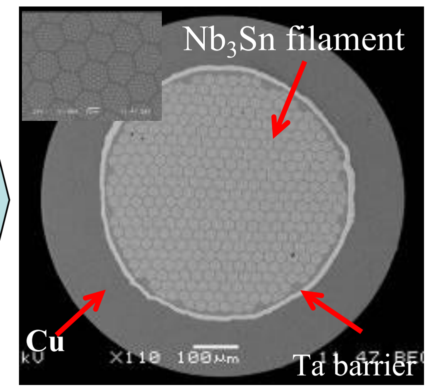
Key issues to fabricate the Nb_3Sn wires with High Jc and low AC loss:

- a. High-Sn content in bronze
- b. Enough fine filament

First stacking



Re-stacking



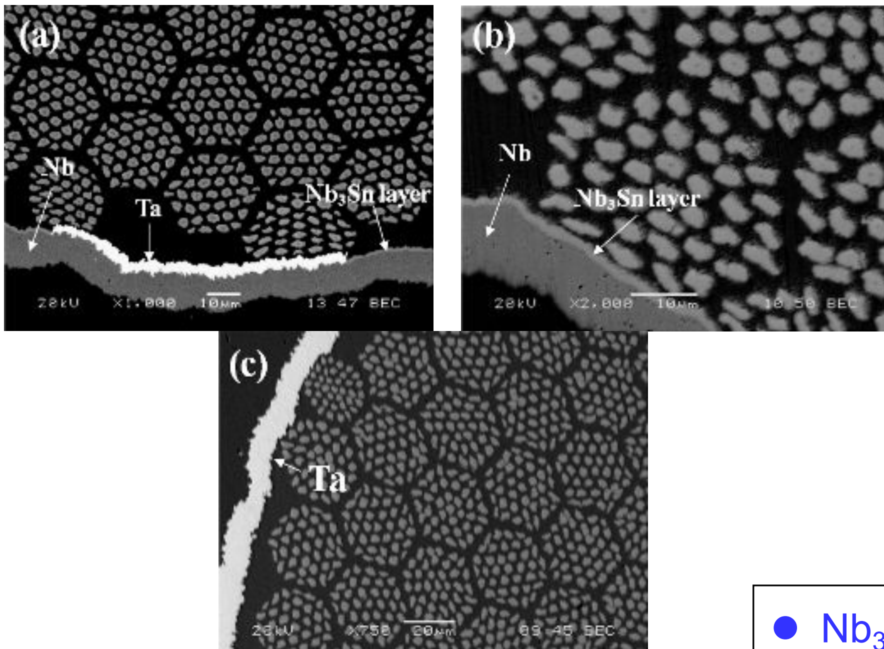
Final strands

Our design idea:

a) Using the high-Sn Bronze with 15.5 wt.% Sn content as the raw material;
b) Increasing the filament number to 13579, make the filament size up to 2 um;
c) Using the hetermophous bronze rod to make the filling ratio up to 97.8%.

Bronze Nb_3Sn wires: Conductor design

Effect of diffusion barrier on hysteresis loss



The SEM images of bronze processed Nb_3Sn strand after heat treatment

(a) Nb_3Sn strand with combined Nb-Ta diffusion barrier (Sample-1).
(b) Nb_3Sn strand with single Nb diffusion barrier (Sample-2).
(c) Nb_3Sn strand with single Ta diffusion barrier (Sample-3).

Performance of Nb_3Sn wires with different barrier design

	Sample -1	Sample -2	Sample -3
Number of filaments	13579	13579	11581
Filament material	Nb	Nb	NbTa
Barrier material	Nb+Ta	Nb	Ta
Ic (A) @4.2K, 12T	236	244	201
Hysteresis loss (mJ/cm^3) @4.2K, ±3T	159	309	53

- Nb_3Sn ring formed by Nb barrier leads a high loss.
- Ta strips interrupt the circular Nb_3Sn layer reacted by Nb barrier which results a middle loss.

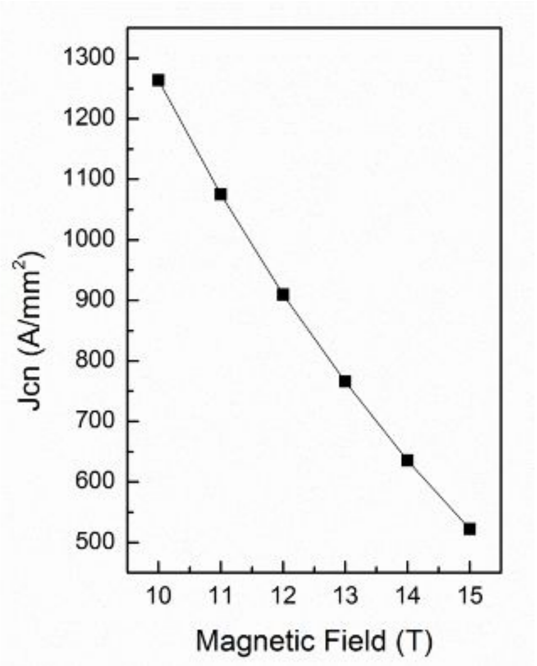
Bronze Nb_3Sn wires: Performance

Effect of bronze/Nb ratio on J_{cn}

See also:1A-WT-P-05

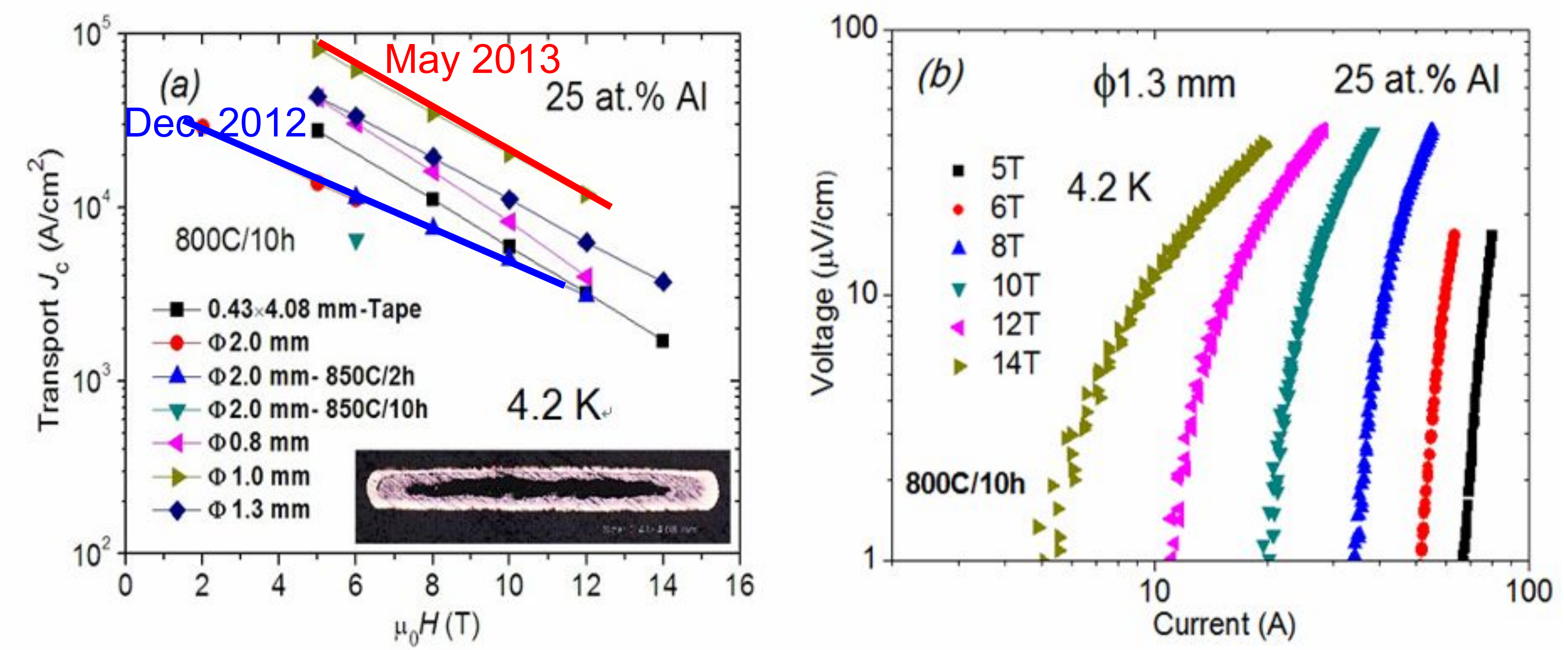
Performance of Nb_3Sn wires with bronze/Nb ratio

	Design 1	Design 2	Design 3
Matrix material		Cu15.5Sn0.25Ti	
Filament material		Nb	
Number of filaments		13579	
Bronze/Nb area ratio	2.5	2.2	2.0
Filament spacing(μm)	1.4	1.3	1.2
I_c (A) @4.2K, 12T	236	239	244
J_{cn} (A/mm²)@4.2K,12T	907	923	930
n value	37	36	40



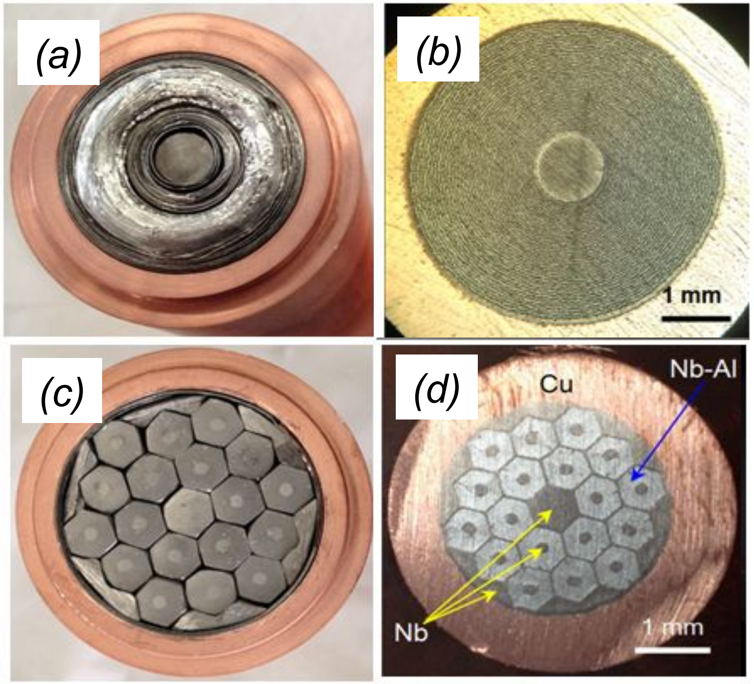
- **J_{cn} increase slowly with the bronze/Nb area ratio reducing for the increase of Nb_3Sn volume fraction.**
- **By optimizing the design, now the J_{cn} of bronze Nb_3Sn superconducting wires exceeds 900A/mm² at 4.2K and 12T .**

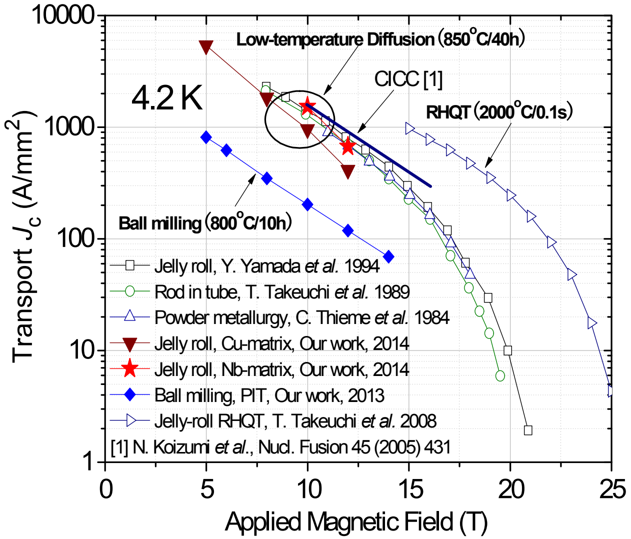
Fabrication of Nb_3Al superconducting wire by combing ball-milling and PIT methods



By optimizing the fabrication technique, now the transport Jc of Nb_3Al superconducting wires, made by PIT method, exceeds 100 A/mm² at 4.2K and 12T .

Development of Jelly-roll Nb_3Al superconducting wires





Superconducting properties of Nb_3Al wires by two heat-treatment routes:

(1) Low-temperature diffusion：Transport J_c@4.2K、12T=670 A/mm^2;

(2) RHQ method：T_c: 17.9-18.0 K、$H_{c2}(0)$: 29.7 T。

3. Progress of high Tc superconductors (HTS）

A. Bi2223 tapes and Bi2212 wires

B. MgB_2 wires

C. Fe-based wires

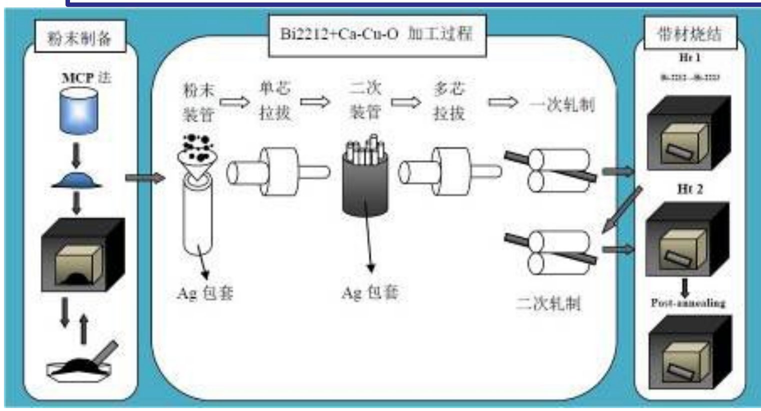
D. YBCO coated conductors

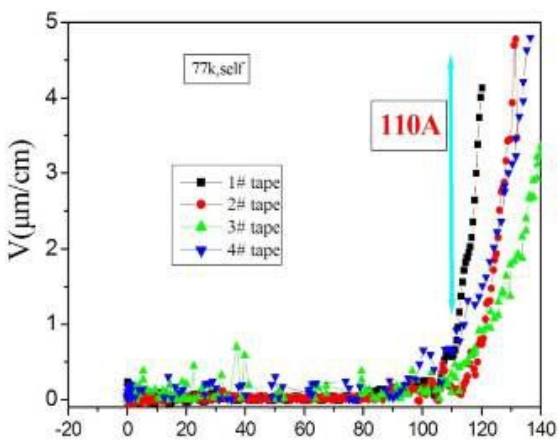
Bi2223 tapes and Bi2212 wires

- Western Superconducting Technologies Co., Ltd. (WST)
- Northwest Institute for Nonferrous Metal Research(NIN)

Bi-2223 HTS tapes

Bi-2223 tapes have been successfully used for extensive demonstration applications.

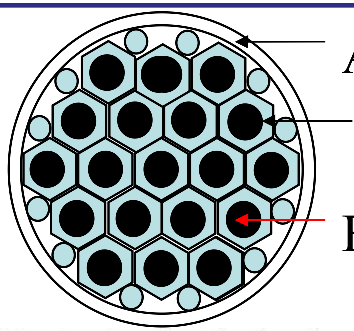


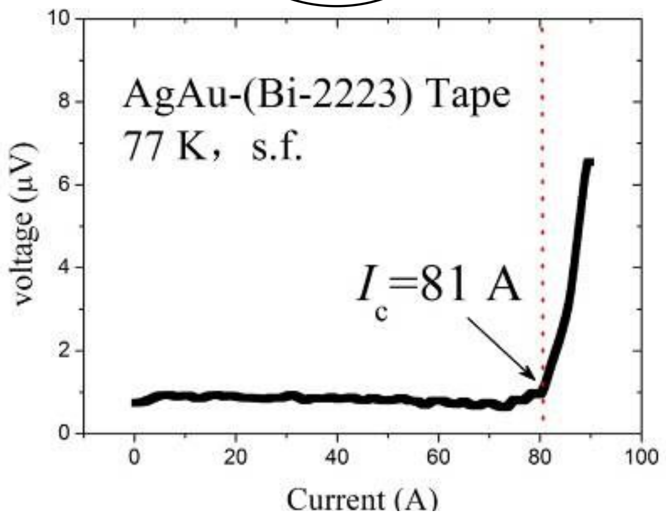


200-500 meters long Bi-2223 tapes can be fabricated in NIN in batches with the I_c of ~100A, $J_c=4\times10^4$A/cm^2 (77K, s.f.).

Bi-2223 HTS tapes

NIN is now developing AgAu-sheath Bi-2223 tapes for the fabrication of current lead with low thermal conductivity for the design and build of CFETR in China.





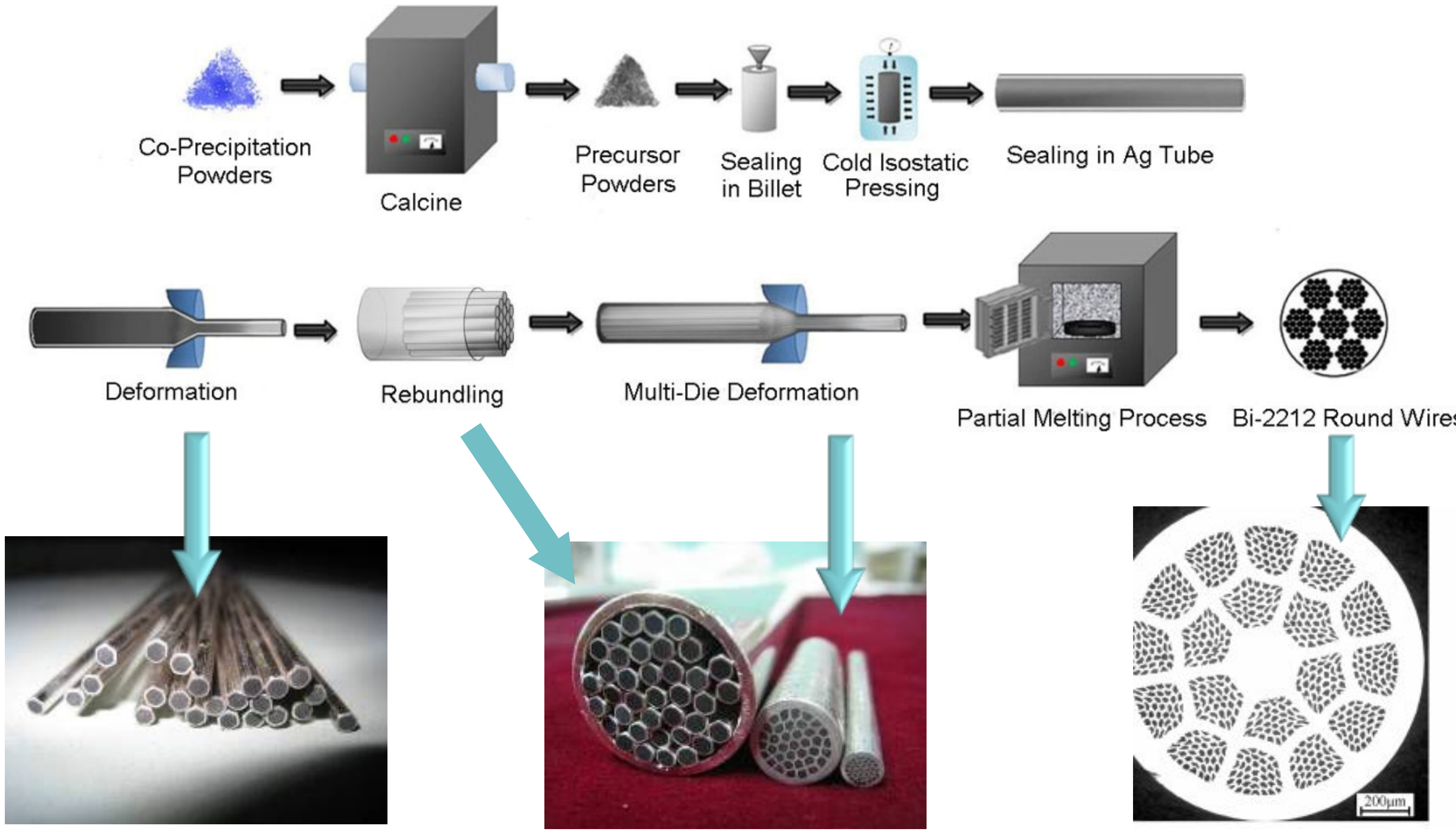
Matrix: Ag-Au alloy (5.4 wt. % Au)
Thickness : 0.25 mm
Width : 4.3 mm
Critical Tesile Stress: 50 MPa
Critical Current : ~80 A

Our goal is to achieve AgAu-(Bi-2223) tapes with *I*c of ~120 A

IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), October 2015.
Plenary presentation PL4 given at EUCAS 2015; Lyon, France, September 6 – 10, 2015.
Not submitted to IEEE Trans. Appl. Supercond.

Bi-2212 HTS wires

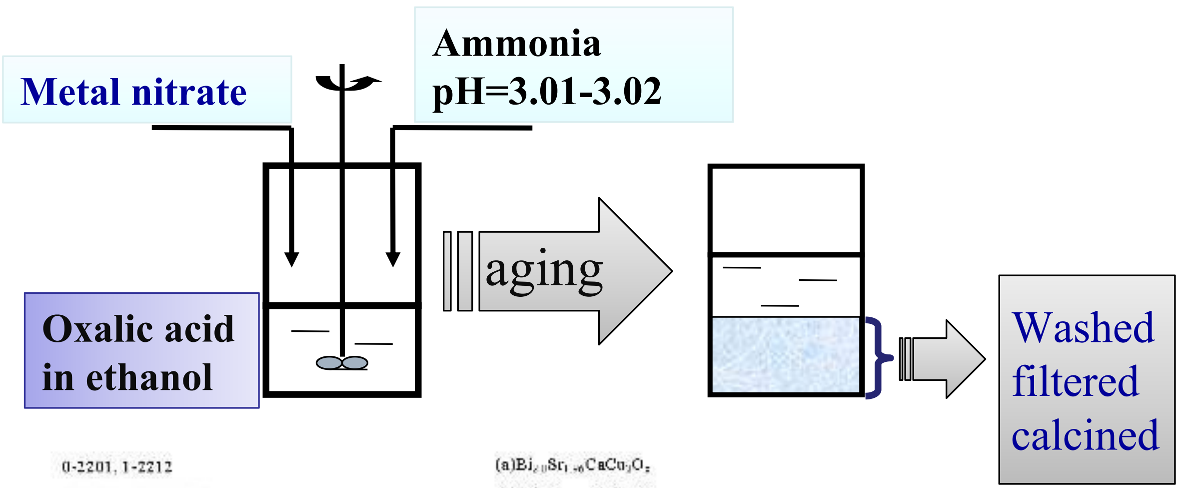
Powder in tube process is adopted in NIN for the fabrication of 200-m long Bi-2212 wires

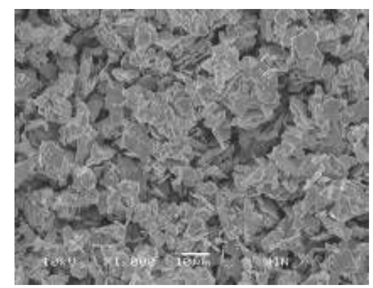


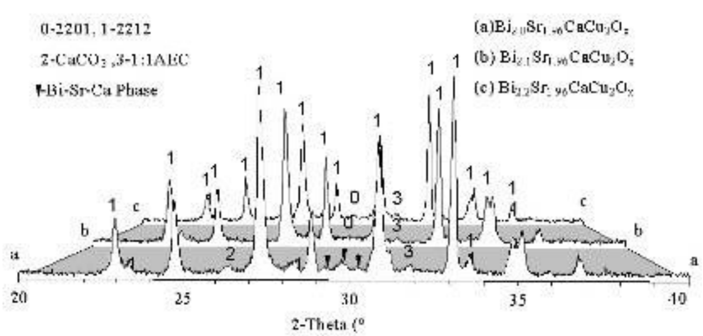
IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), October 2015.
Plenary presentation PL4 given at EUCAS 2015; Lyon, France, September 6 – 10, 2015.
Not submitted to IEEE Trans. Appl. Supercond.

Bi-2212 precursor powders fabrication

Modified Co-precipitation Process is adopted for the fabrication of Bi-2212 precursor powders with high uniformity and high reactivity.





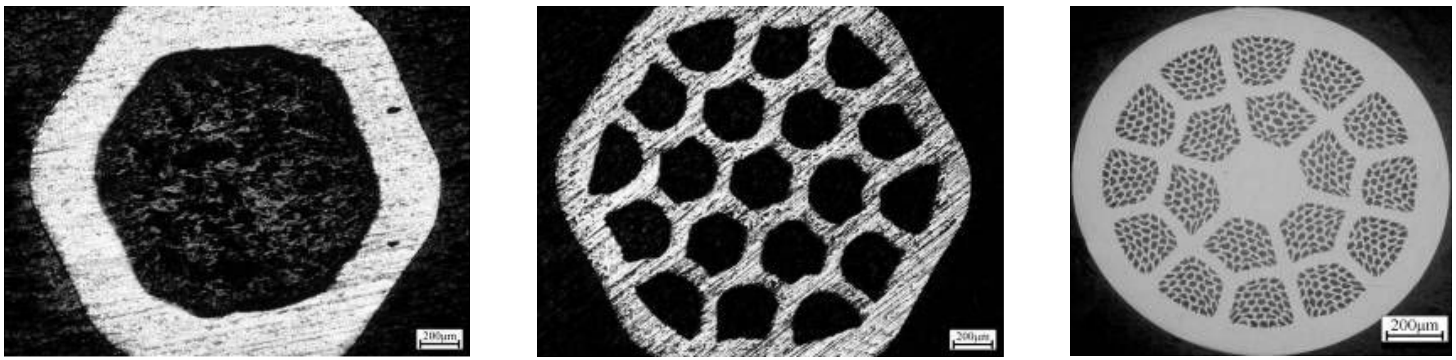


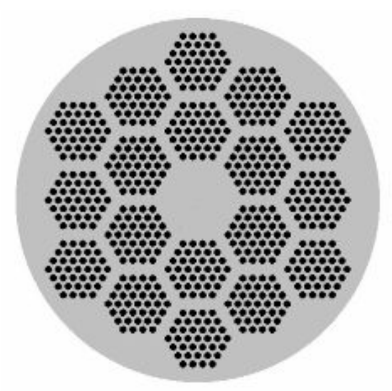
2212 content	97-98%
Residual carbon content	150 ppm
Average Particle size	3~6 µm

IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), October 2015.
Plenary presentation PL4 given at EUCAS 2015; Lyon, France, September 6 – 10, 2015.
Not submitted to IEEE Trans. Appl. Supercond.

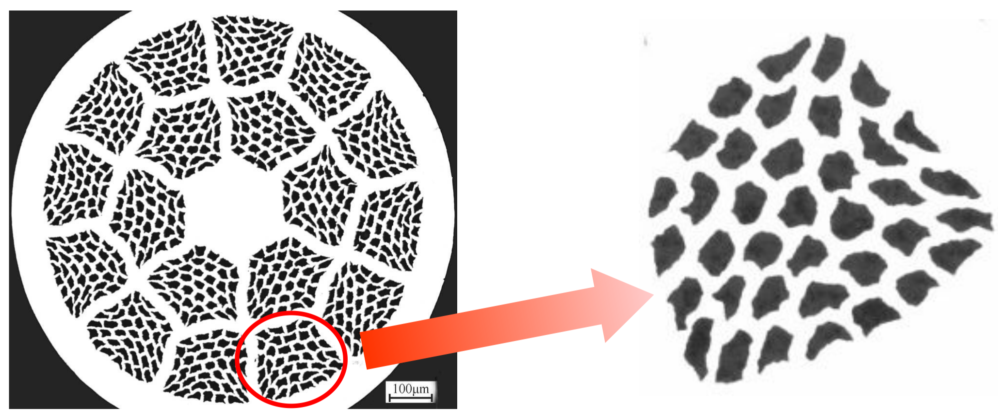
Cold working process for Bi-2212 wires

By improving the configuration design and optimize the cold working parameters, Bi-2212 wires with uniformly deformed filaments are achieved.





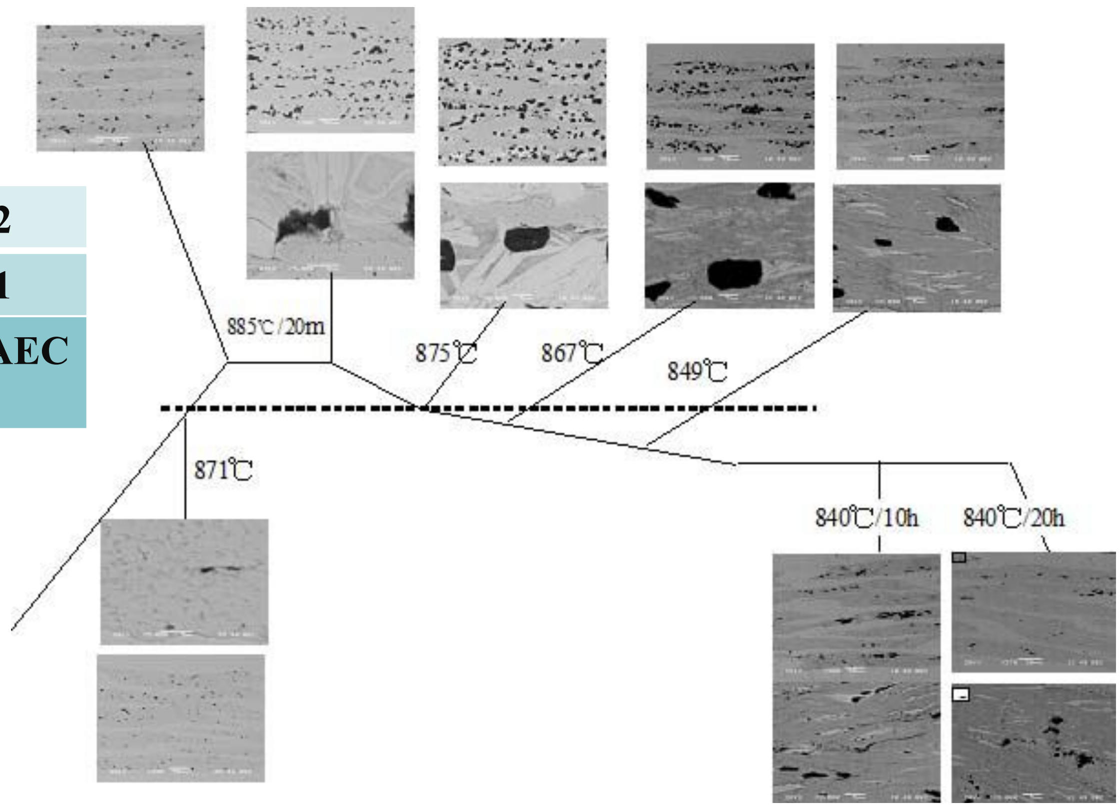
37×(18+1)



Partial melting process for Bi-2212 wires

Based on the study of phase evolution mechanism during partial melting process, we can control the growth of secondary phases and improve both the Bi-2212 phase content and the intergrain connections.

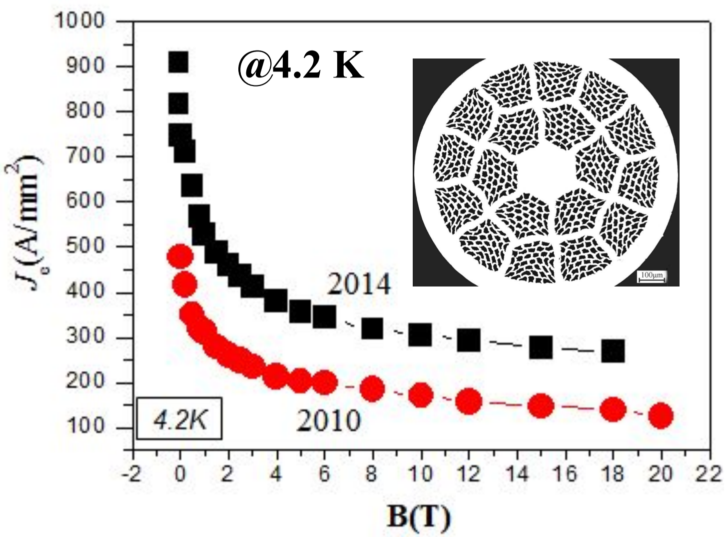
Grey	Bi-2212
White particles	Bi-2201
Black spherical particles	14:24 AEC



Development of Bi-2212 superconducting wires in NIN

Short samples:
I_c=890 A
J_{ce}=1100 A/mm²
J_c=5200 A/mm²
(4.2 K， s.f.)

Batch production ability for 200-m long Φ1.0mm wires
4.2 K, 0 T: J_{ce} ~ 920A/mm²， J_c ~ 4400 A/mm²。
4.2 K, 20 T: J_{ce} ~ 270A/mm²， J_c ~ 1200 A/mm²。



（Oral: 3M-M-02.06)

Bi-2212 wires

Bi-2212 wires can achieve J_c of > 1000 A/mm² @4.2 K, 20 T, which shows great potential for the application in high-field magnets or large current cables.

Trial-production of Bi-2212 CICC conductors

First stage cable	**Number of wire**	**2**
	Tension	**20 N**
	Pitch	**18-20 mm**
Second stage cable	**Number of wire**	**2×3**
	Tension	**20 N**
	Pitch	**49 mm**
Third stage cable	**Number of wire**	**2×3× 7**
	Tension	**30 N**
	Pitch	**90 mm**

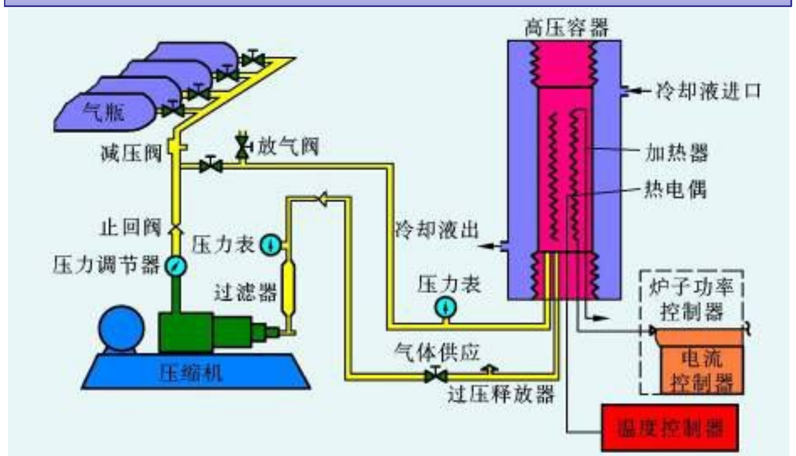
Bi-2212 cables

- NIN is now working with IPP-CAS on the fabrication of Bi-2212 CICC;
- 42 Bi-2212 wires were adopted for 5m long conductor;
- *Ic* measurement is on the way…

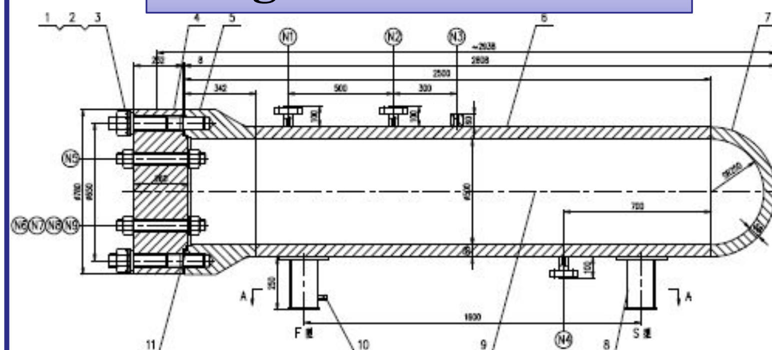
Overpressure treatment of Bi-based wires

Overpressure treatment is an effective method for the improvement of current capacity of Bi-based wires and tapes.

High-pressure treatment system



High-Pressure tank



Pressure: 30 MPa
Inner diameter: 500 mm
Length: 2500 mm

NIN is now developing the high-pressure treatment system, aiming at the further improvement of filament density and current capacity of Bi-2212 wires and Bi-2223 tapes.

MgB_2 wires

- Northwest Institute for Nonferrous Metal Research (NIN)

Conductor design and optimization

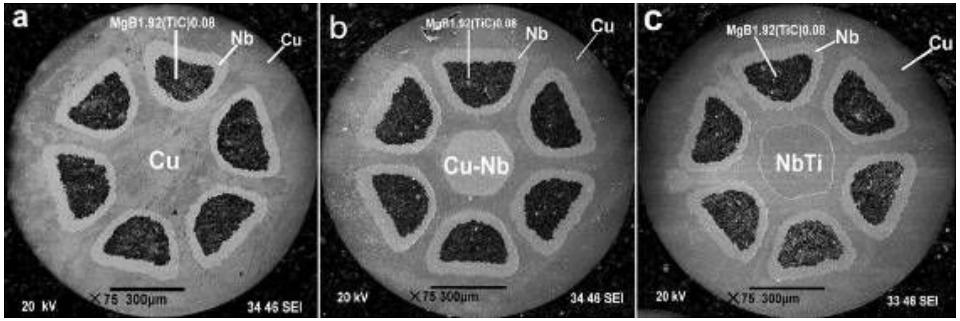
Central reinforcement Materials

7-MgB_2 filaments

Central filament broken

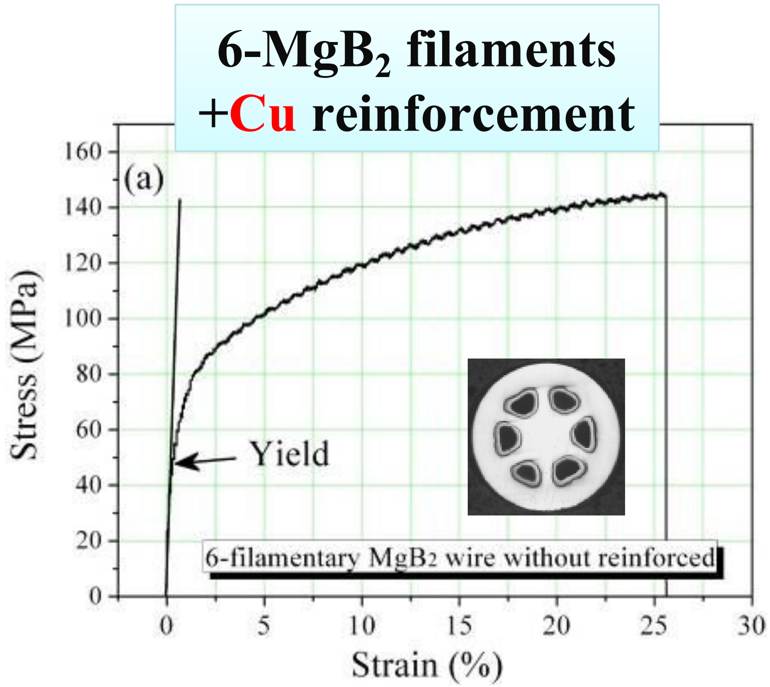
6-MgB_2 filaments +Cu reinforcement

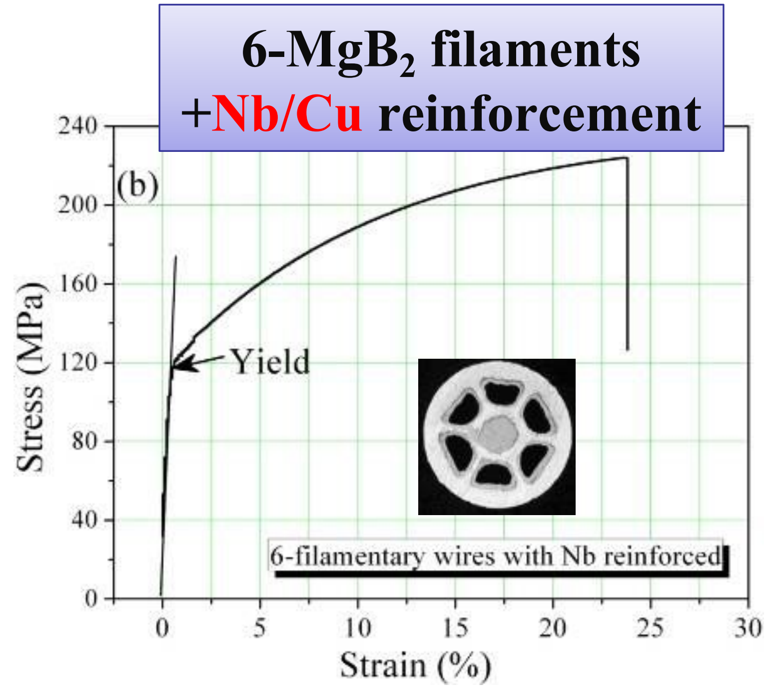
6-MgB_2 filaments +Nb/Cu or NbTi reinforcement



Configuration design and optimization

Mechanical Properties

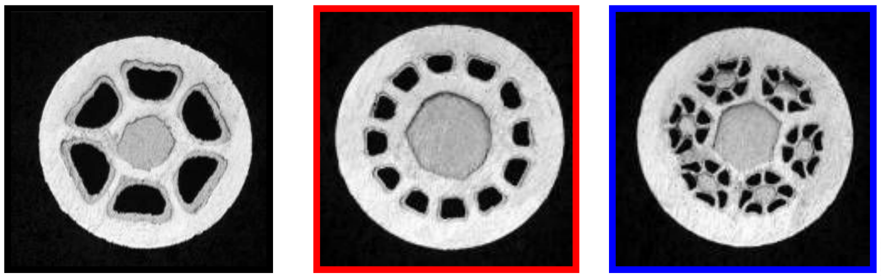




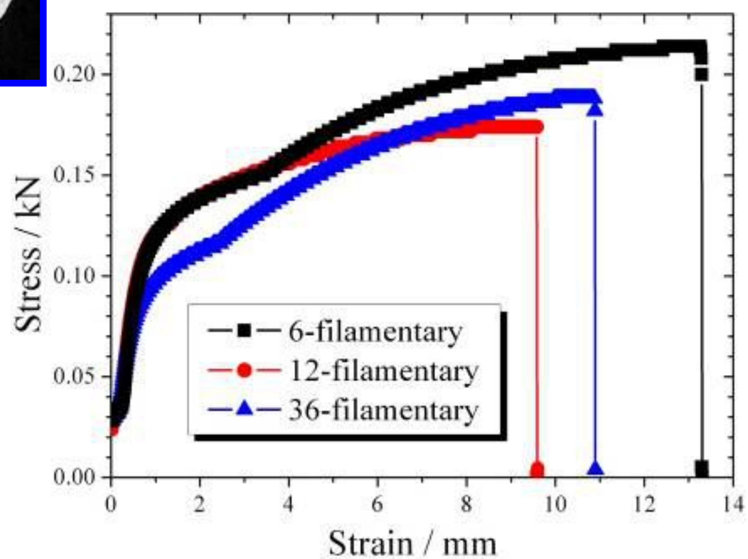
- Nb reinforced wire exhibits higher mechanical properties. The yield strength of the reinforced wire is about 118 MPa and only 50 MPa for the wires without reinforced.
- The Nb reinforcement could remarkably enhance the mechanical property of the 6 filaments MgB_2 wires.

Configuration design and optimization

Filament Number



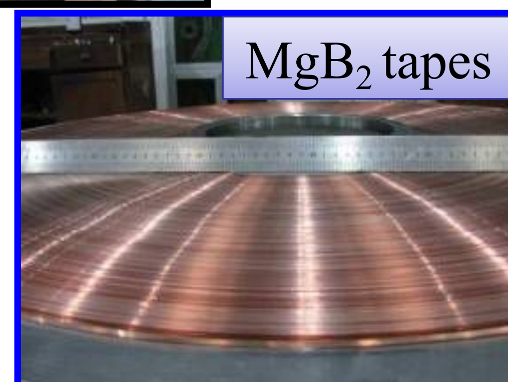
Filament	6	12	36
MgB_2	21.89	14.14	13.95
Nb	23.61	21.88	20.97
Cu	54.50	63.98	65.08



The intensity of 6 filaments wire is higher than that of other wires due to the higher Nb-content

Fabrication of *km*-grade MgB_2 wires

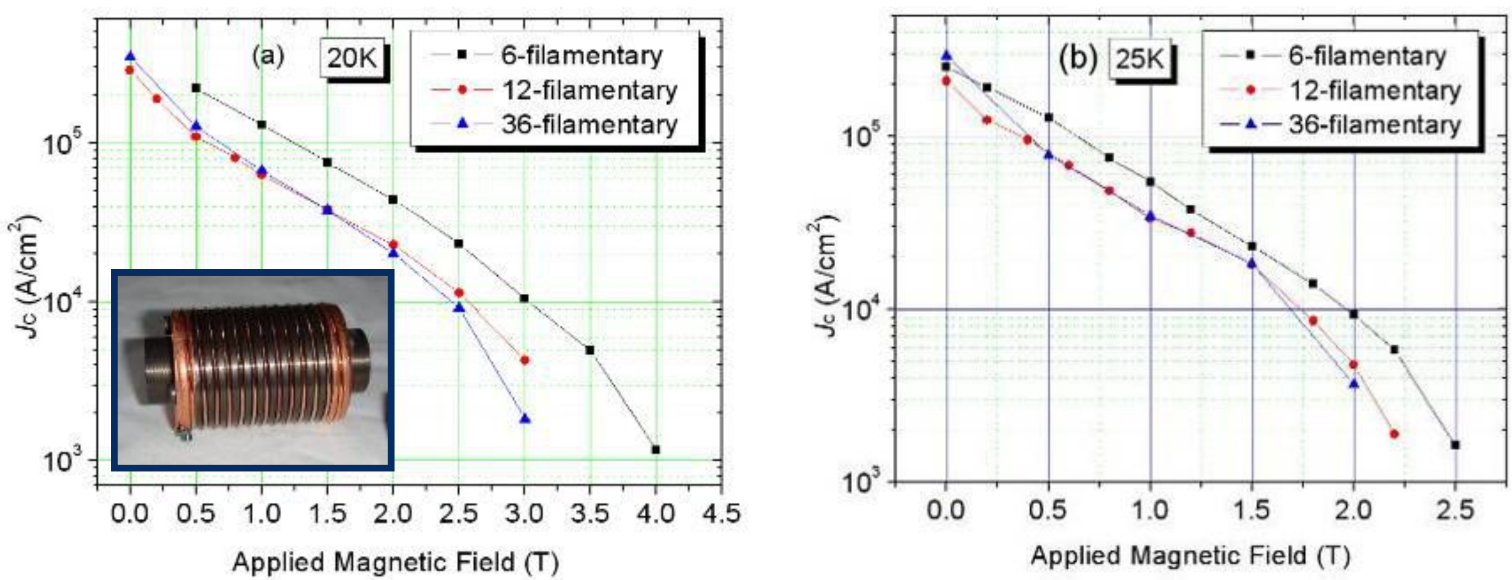
Production of **1500 m** MgB_2 wires/tapes



The preparation technology of kilometer MgB_2 wire is stable, we have prepared **20 kilometers** MgB_2 superconducting wires

Fabrication of *km*-level MgB_2 wires

Superconducting Properties of km-level wires



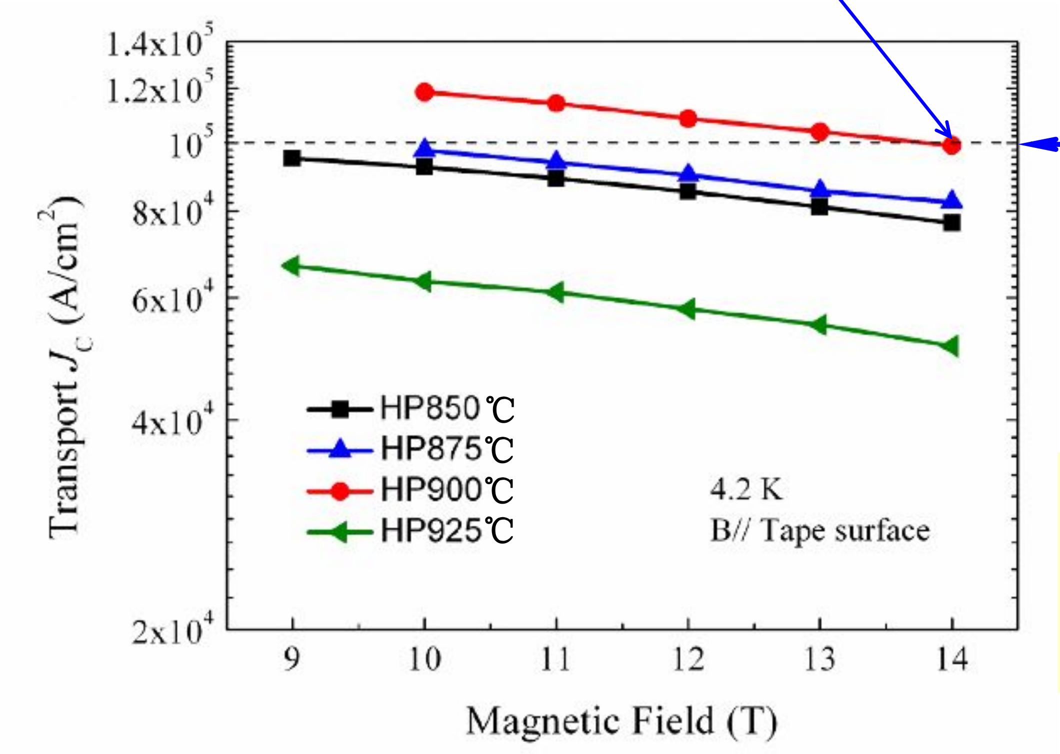
Now we can produce 1500 meter MgB_2 superconducting wires.
At 20 K、2 T, J_c= 4.3×10^4 A/cm^2

Fe-based wires

- Institute of Electrical Engineering Chinese Academy of Sciences (IEE-CAS)

By Hot Pressing

The high transport J_c values were achieved in $SrFe_2As_2$/Ag tapes: J_c ~ 1.0×10⁵ A/cm² (4.2 K, 14 T)



Practical level J_c!

At 4.2 K and 10 T:

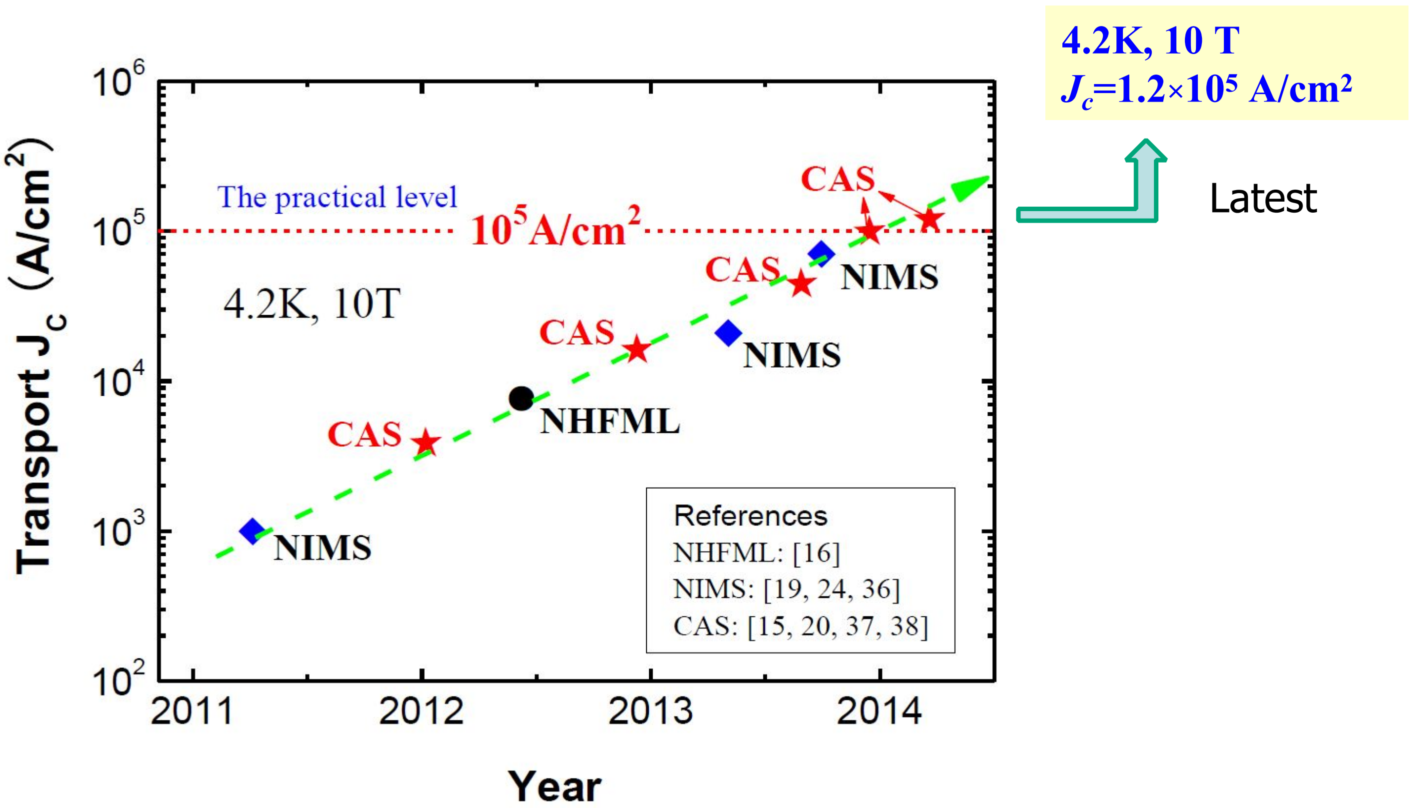
$J_c = 1.2\times10^5$ A/cm²

The superior J_c can be attributed to higher grain texture and improved densification.

Is there still a room for the J_c improvement by hot pressing?

Lin et al., *Sci. Rep.* 4 (2014) 6944

In the past several years, the J_c has been rapidly enhanced particularly for $SrFe_2As_2$(122) wires and tapes



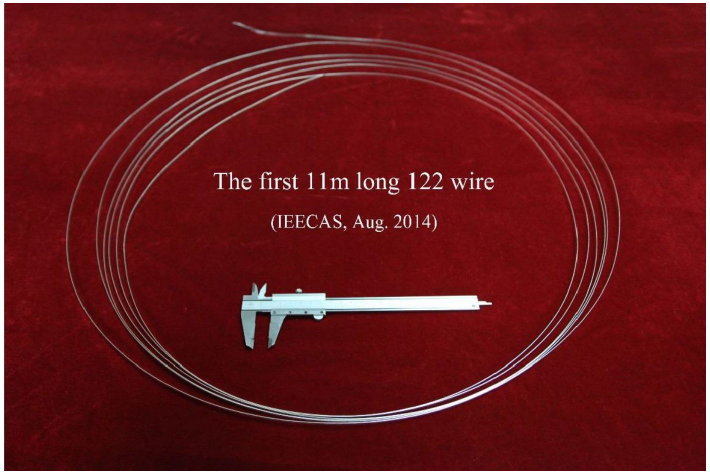
For a Review: Yanwei Ma, Development of high-performance iron-based superconducting wires and tapes, *Physica C* 516 (2015) 17-26.

Ma , *Physica C* 516 (2015) 17

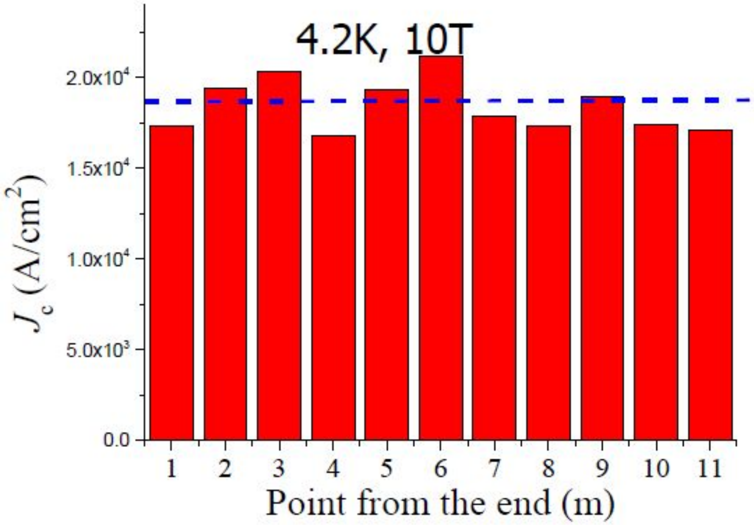
J_c (10 T) of the first 11m long $SrFe_2As_2$ tape

-- by the scalable rolling process

The first long wire-- 11 m



Uniform wires can be fabricated

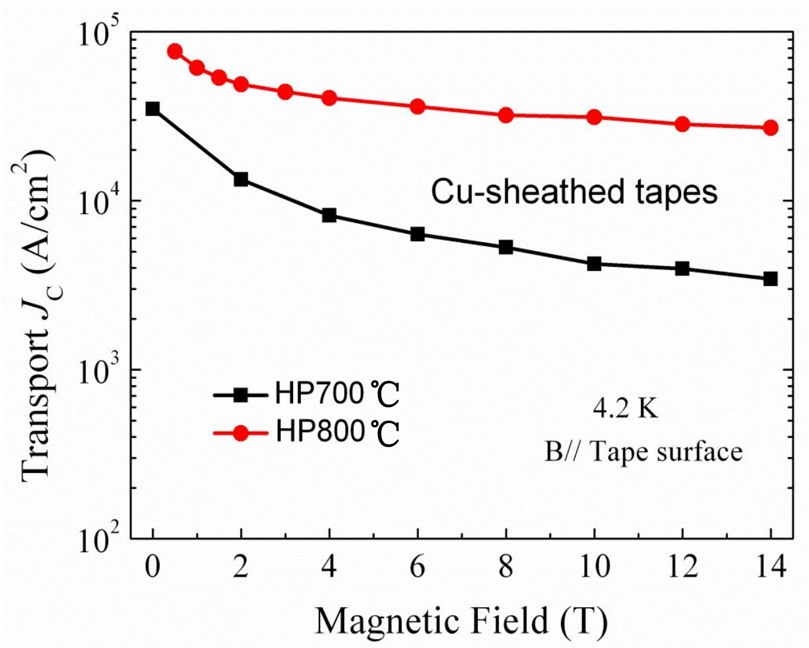


The minimum J_c ~1.7×10^4A/cm²

The average J_c of this long Sr122/Ag wire is ~ 18400A/cm²
The fluctuations of the J_c is ~5%

Low material cost

High J_c in Cu-sheathed $SrFe_2As_2$ tapes



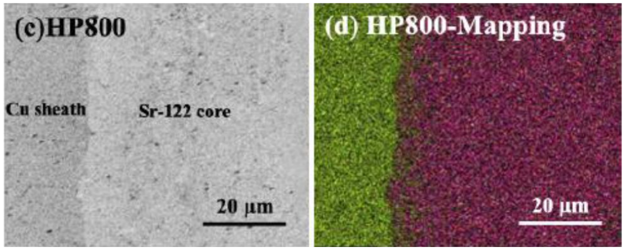
At 4.2 K, 10 T

Transport J_c:

3.1×10^4 A/cm^2

Engineering J_e:

$>10^4$ A/cm^2



We obtained nearly phase-pure Sr-122 tapes with hot pressing at 800^{o}C for 30 minutes. This rapid fabrication method can effectively thwart the diffusion of Cu into polycrystalline Sr-122 core.

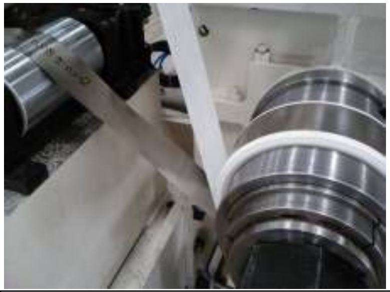
Lin, et al., *Sci. Rep.* 5 (2015) 11506

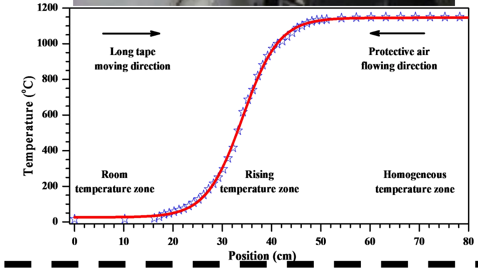
YBCO coated conductor

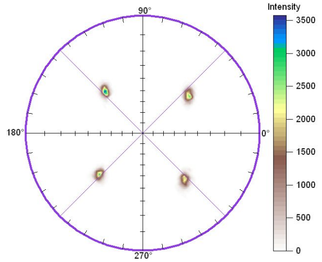
- NIN and Beijing University of Technology： **Substrate**
- Suzhou Advanced Materials Institute(SAMRI)： **MOCVD**
- Shanghai Jiao Tong University ： **PLD**

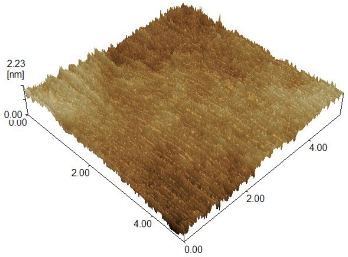
Development of Long-length & Textured Ni5W，Ni7W and Ni9W tapes for Coated Conductors

NiW-alloy ingot

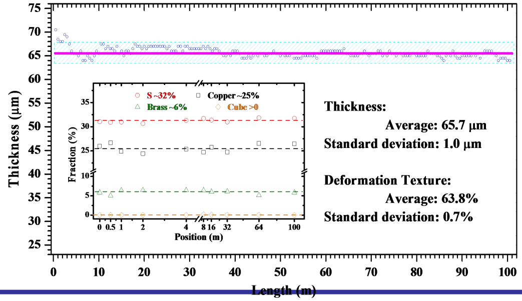








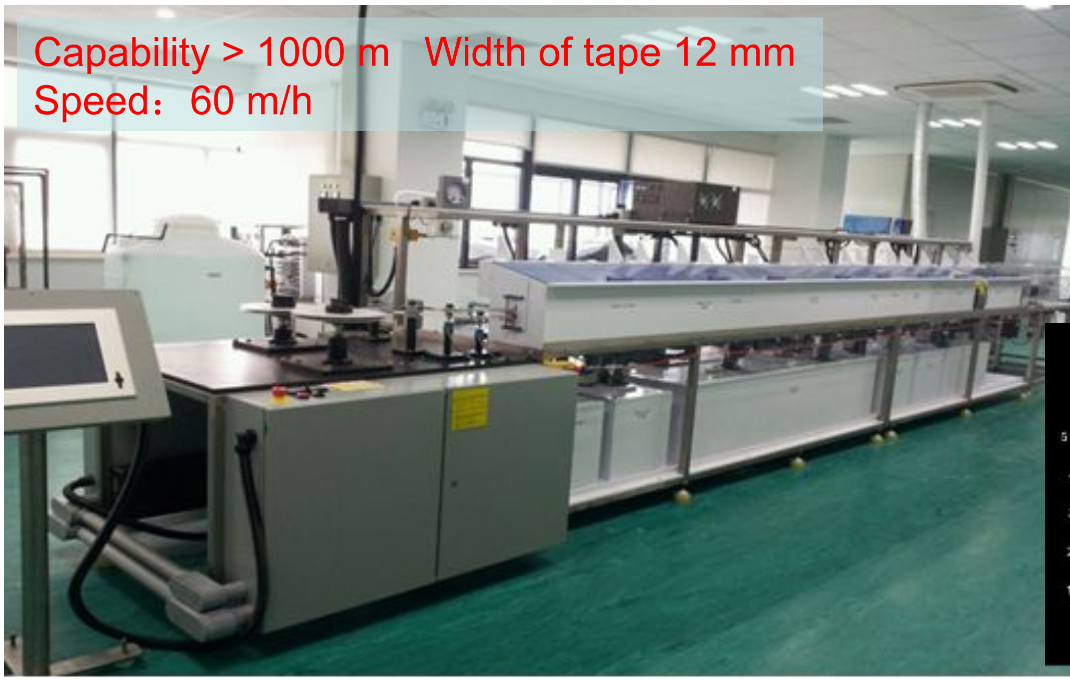
- ✓ **Thickness~66 μm**
- ✓ **Width=10 mm**
- ✓ **Length>500 m**

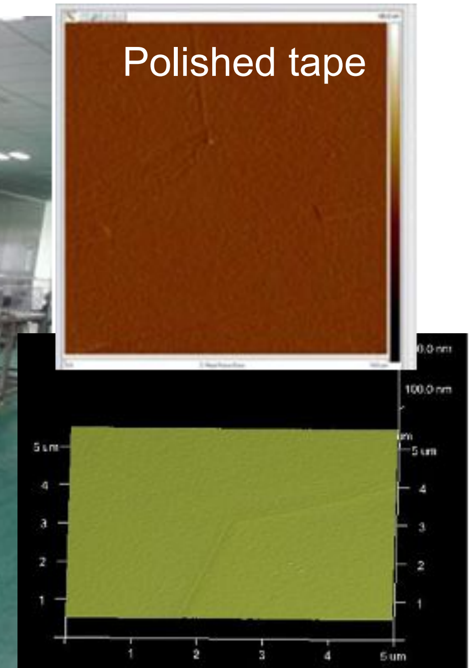


- **Sharp cube textured (~100%) Ni5W tapes with the level of hundred meters were obtained by conventional metallurgy method.**
- **Content of cube texture in Ni7W and Ni9W tapes reaches 99.5% and 94% respectively.**

Development of km-level YBCO CC by MOCVD/PLD

1. Electropolishing technology of substrate

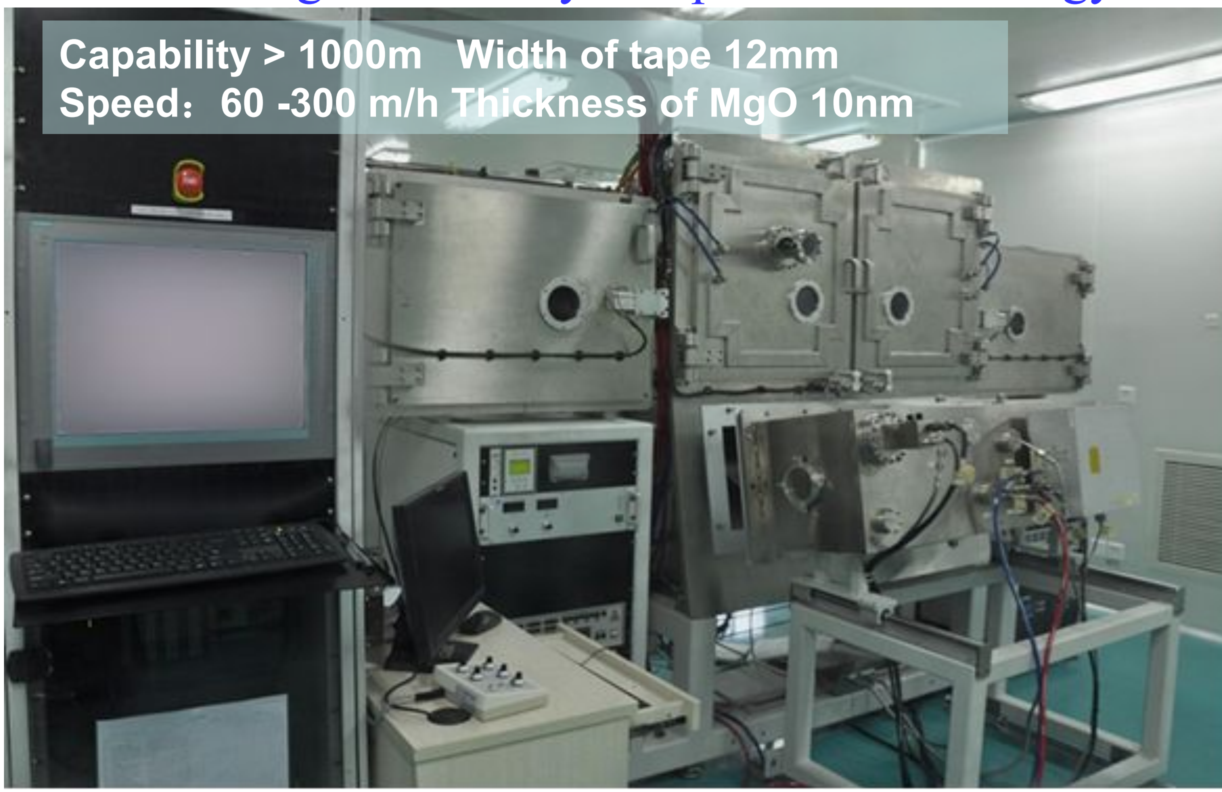


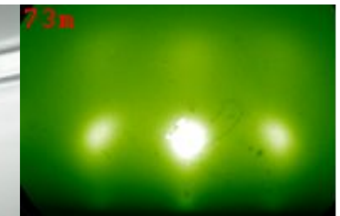


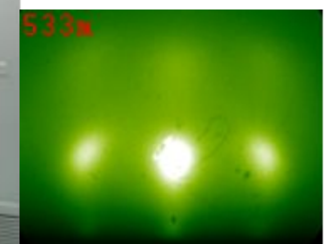
The km-level metal substrate polishing system can produce tape with surface roughness 1 nm in SAMRI.

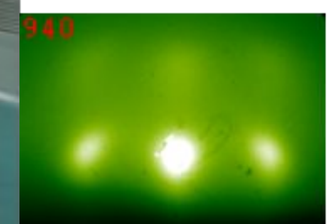
Development of km-level YBCO CC by MOCVD/PLD

2. IBAD-MgO buffer layer deposition technology





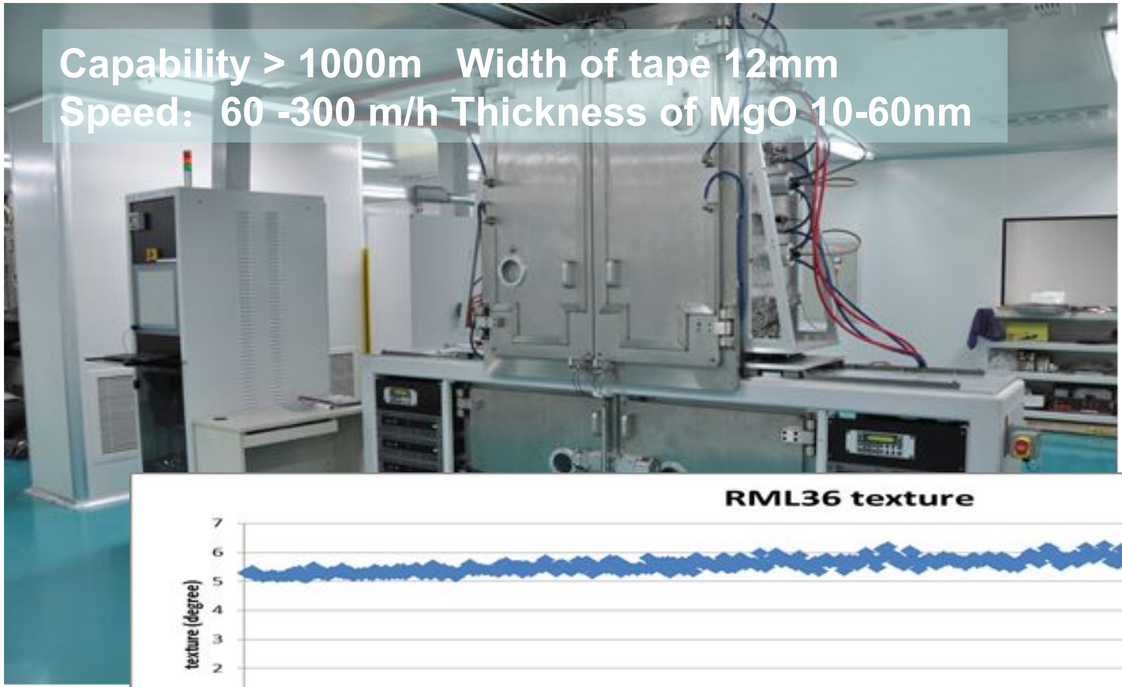


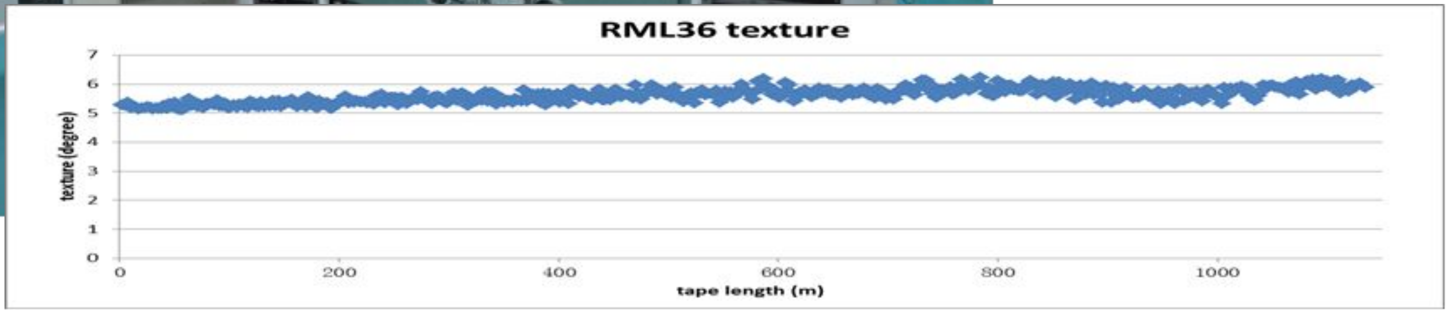


The IBAD system can deposit 10 nm MgO layer with sharp texture on km-level metal substrate.

Development of km-level YBCO CC by MOCVD/PLD

3. Sputtering-MgO buffer layer deposition technology

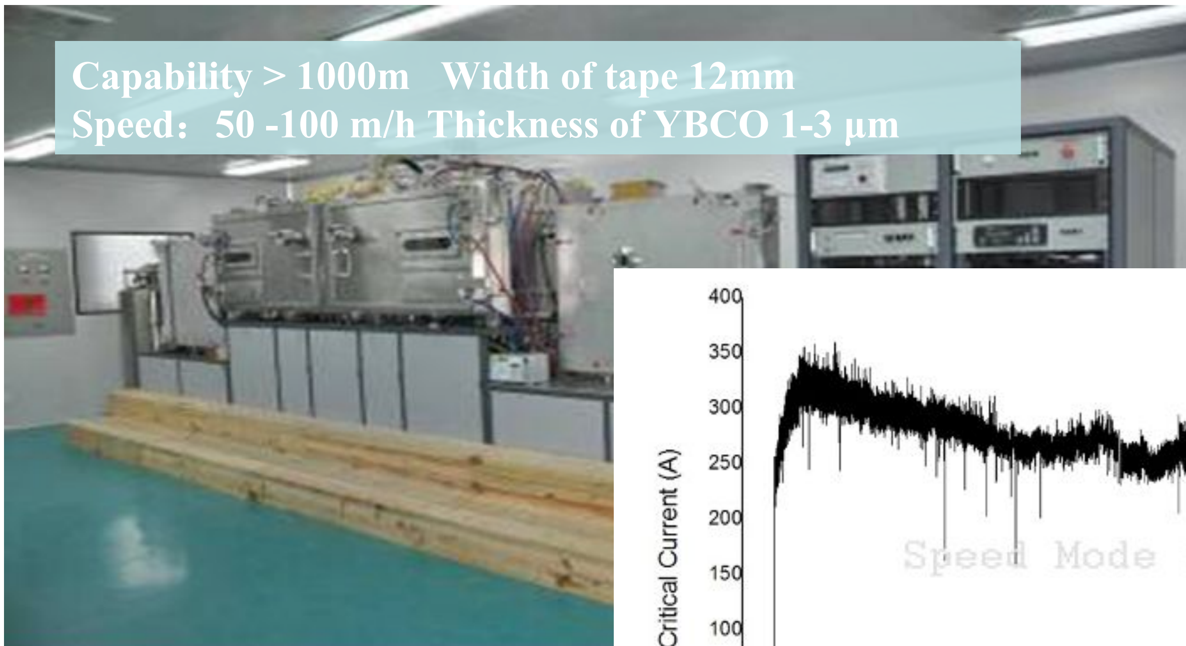


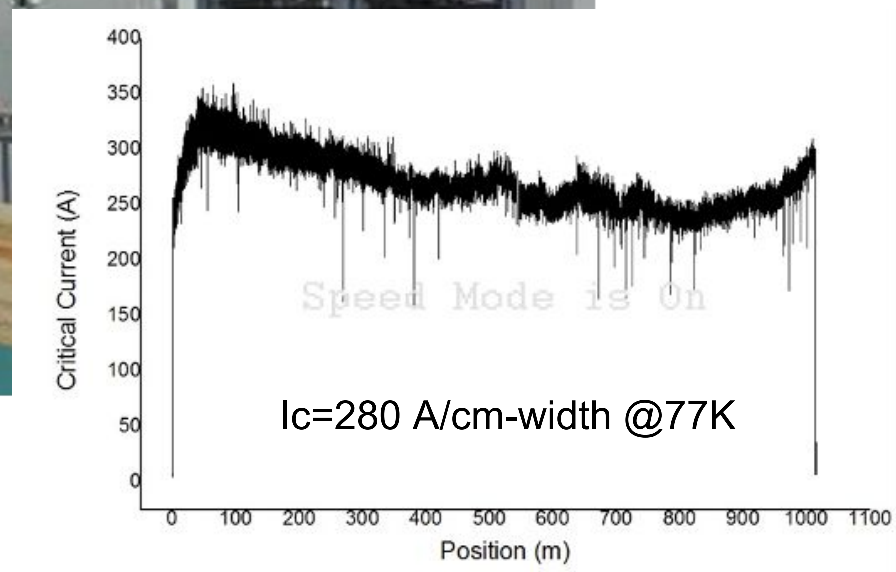


The sputtering system can deposit 30 nm MgO layer with sharp texture on km-level IBAD-MgO layer.

Development of km-level YBCO CC by MOCVD/PLD

4. MOCVD-YBCO layer deposition technology

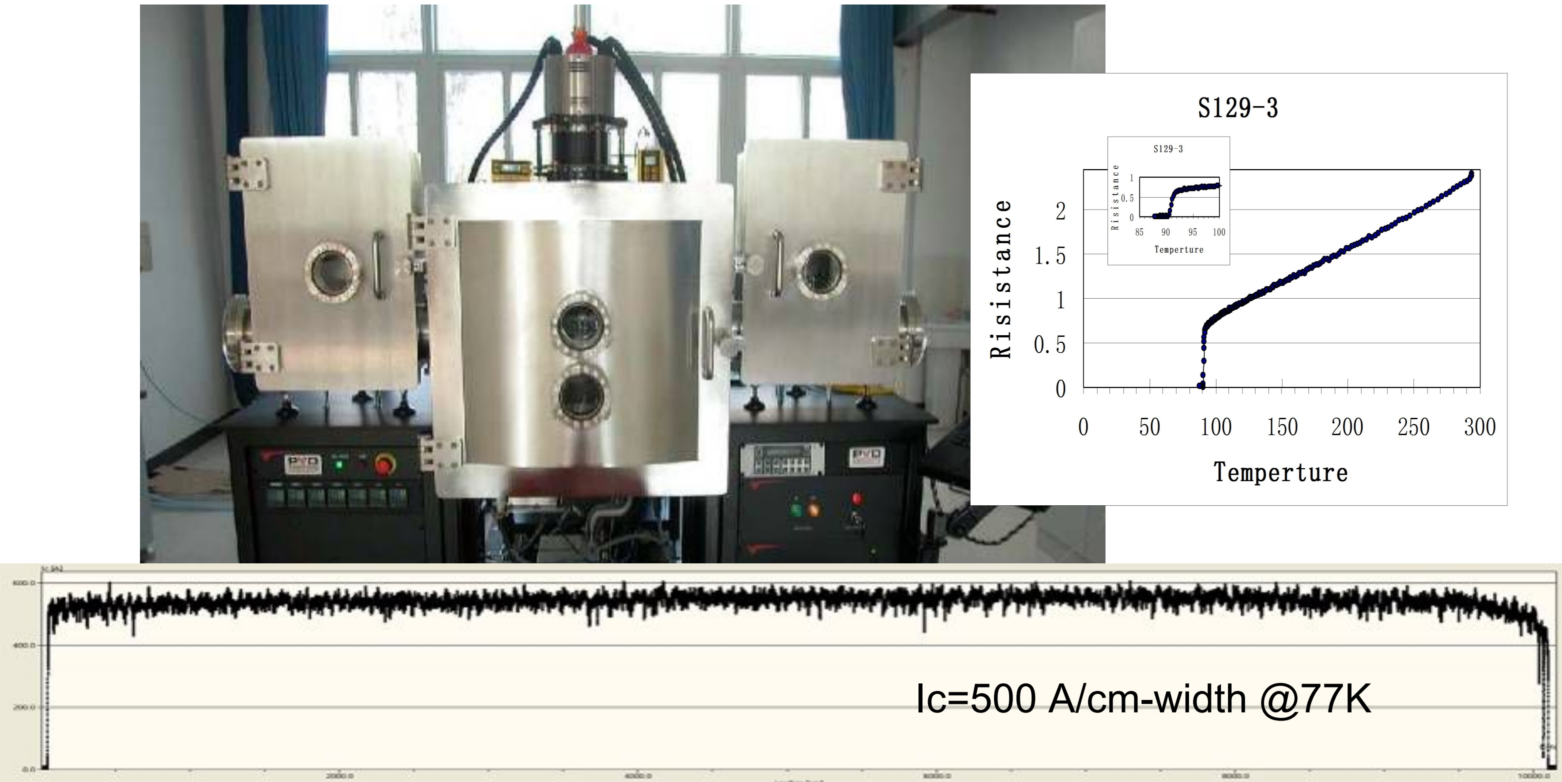




The MOCVD system can deposit 1-3 μ m YBCO layer with sharp texture on km-level IBAD-MgO layer.

Development of km-level YBCO CC by MOCVD/PLD

5. PLD-YBCO layer deposition technology



The PLD system can deposit 1-3 μ m YBCO layer with sharp texture on 500m-level IBAD-MgO layer.

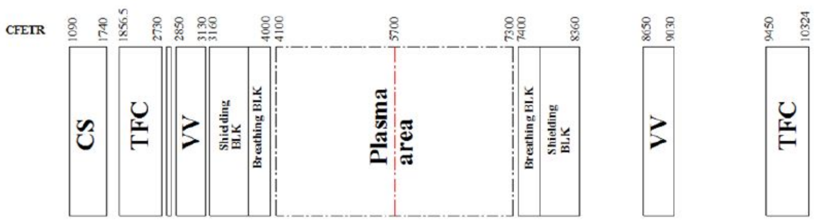
4. Progress of superconducting applications

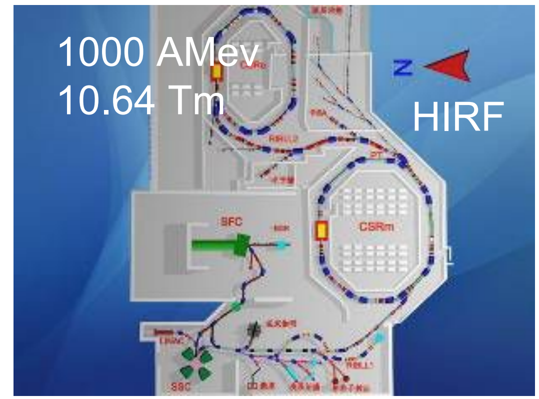
Magnet application

Electrical power application

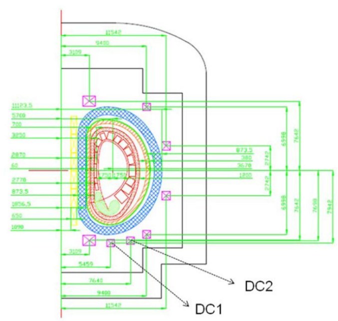
The national major scientific and technological infrastructure construction project

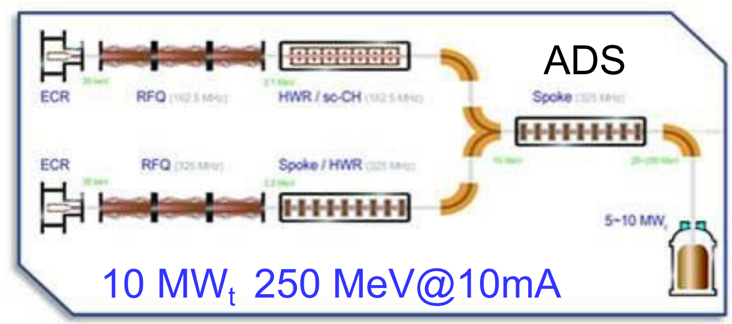
- China Fusion Engineering Test Reactor (CFETR)
- Heavy Ion Research Facility (HIRF)
- Accelerator Driven Sub-critical System (ADS)





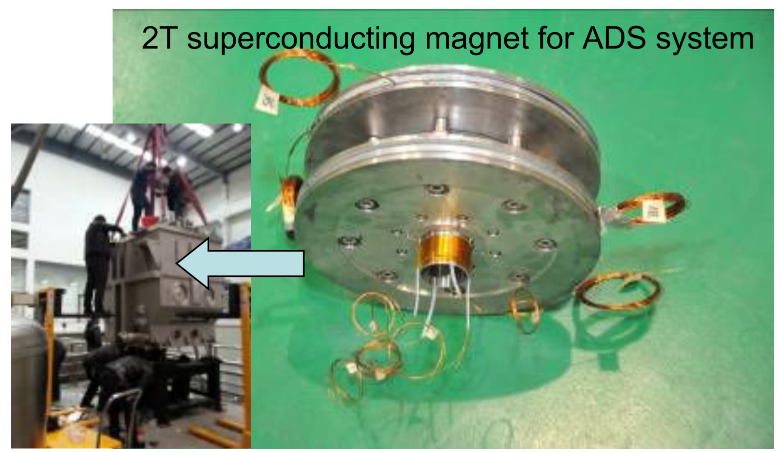
I_p= 8-10 MA
B_{to} = 4.5-5.0T
R_0 = 5.7-5.9 m ;
a = 1.6 m;
k= a/b=1.9 ~ 2.0
$q_{95} \geq 3$;
β_N ~ 2
P_n ~ 0.5MW/m²





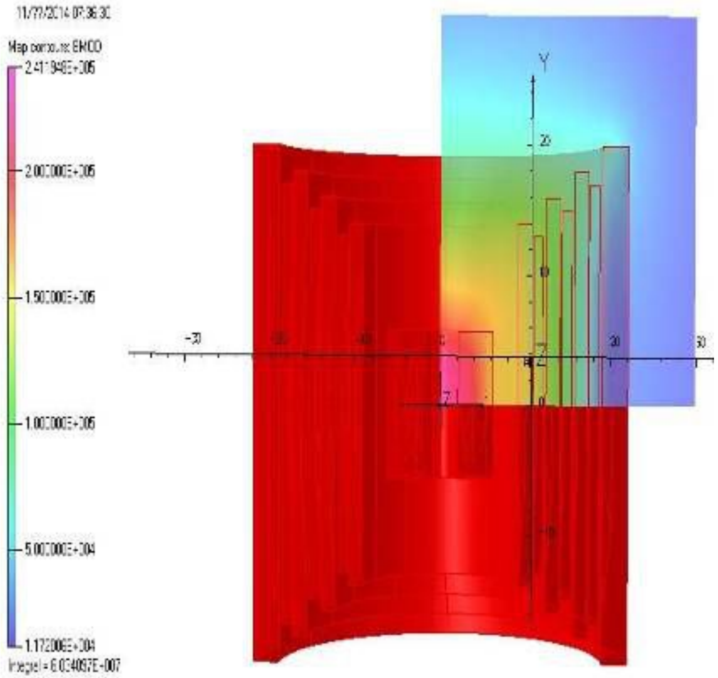
The big science instruments and facilities in HEP field require and push the R&D of superconducting technology in China.

The application of superconducting magnet in HEP



The R&D groups in China can design and fabricate different NbTi and Nb_3Sn superconducting magnets for HEP application.

The 25T superconducting magnet

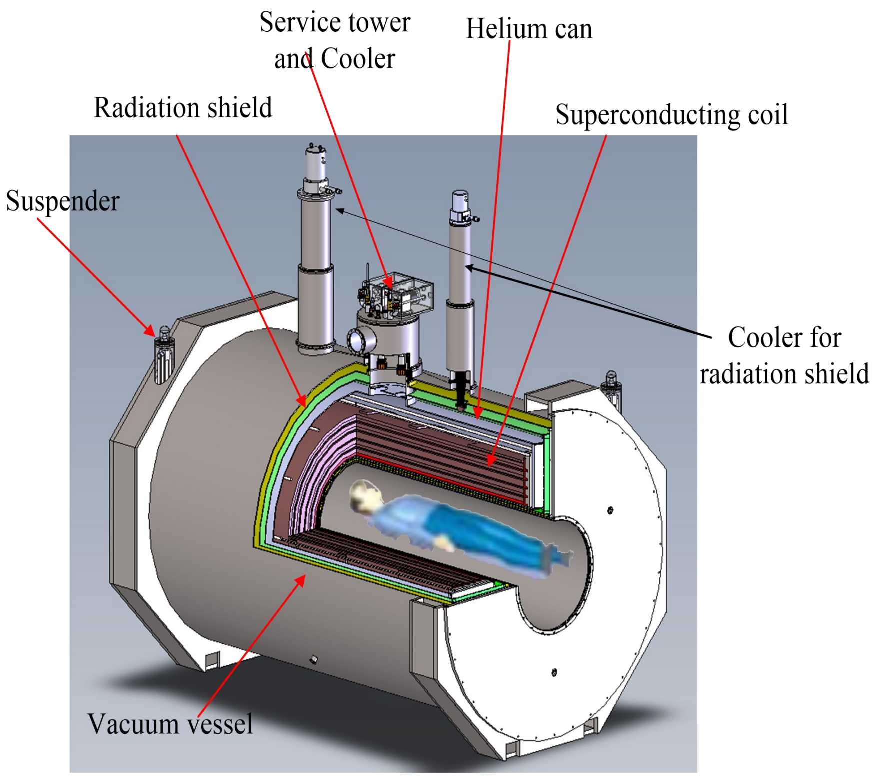


No.	Materia	A1	A2	H	turn	layer
1	YBCO	20.5	62	115	4514	24
2	Nb_3Sn	92	108	280	2340	12
3	Nb_3Sn	110	120.6	260	1448	8
4	Nb_3Sn	124.2	141.1	320	3360	14
5	Nb_3Sn	142.85	154.87	400	2250	10
6	NbTi	158.2	174.23	360	3374	14
7	NbTi	175.23	187.24	340	2280	10
8	NbTi	190.91	221.29	400	10608	34

Assembly of the YBCO double pancake and installed in the LTS configuration

A 25 T superconducting magnet with a 10 T YBCO insert and a 15 T Nb_3Sn and NbTi outsert is being fabricated in IEE CAS.

9.4 T Superconducting Magnet System for Whole-body Metabolism Imaging



A 9.4 T superconducting magnet is being designed and fabricated with a warm bore of 800 mm for neuroscience research In IEE CAS

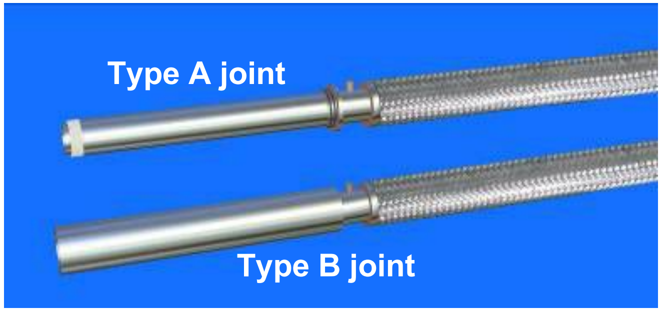
Magnet type	NbTi superconducting magnet
Magnetic field	9.4 Tesla
Shield type	Passive shield
Stability of magnetic field	≤ 0.03 ppm/h
Shimming magnetic field	Superconducting coil shims, room shims and passive iron piece shims
Homogeneity (RMS)	
22 cm DSV	≤ 0.05 ppm
30 cm DSV	≤ 0.1 ppm
5 G line (B_z and B_r)	≤ 22 m 18 m (no passive shield)
Magnet length	3.5 m
Warm bore diameter	≥ 800 mm
Weight of magnet (including 100 % LHe)	≤ 50 ton
Cooling method	Zero boiling off liquid helium

10kA HTS Cable: the design parameters

No.	Items	Parameters
1	**Total length of the DC HTS power cable**	362.4m
2	**Total length of the cryogenic envelope / LN_2 flow pipe**	350.1m / 367.4m
3	**Length / out diameter of the termination**	6.15m / 325mm
4	**Out diameter of the DC HTS power cable**	151mm
5	**Layers of the cable core**	5
6	**Winding angle of the cable core**	15^0 (with difference for each layer)
7	**Total length of the HTS tapes used**	46km
8	**Heat loss of the cryogenic envelope / LN_2 flow pipe**	2W/m / 1.0W/m
9	**Segmentations of the cryogenic envelope / LN_2 flow pipe**	Totally 8 segments
10	**Dielectric type**	Warm dielectric
11	**Total hest loss of the DC HTS power cable system**	2487W
12	**Refrigeration type / capacity**	LN_2 circulation / 4kW@77K
13	**Designed critical current**	12,500A
14	**Rated current**	10,000A
15	**Rated voltage**	1300V
16	**Minimum bending radius**	3.0m

The 360m/10kA cable was installed in ZhongFu electrolytic aluminium factory in 2013

Cryogenic envelope

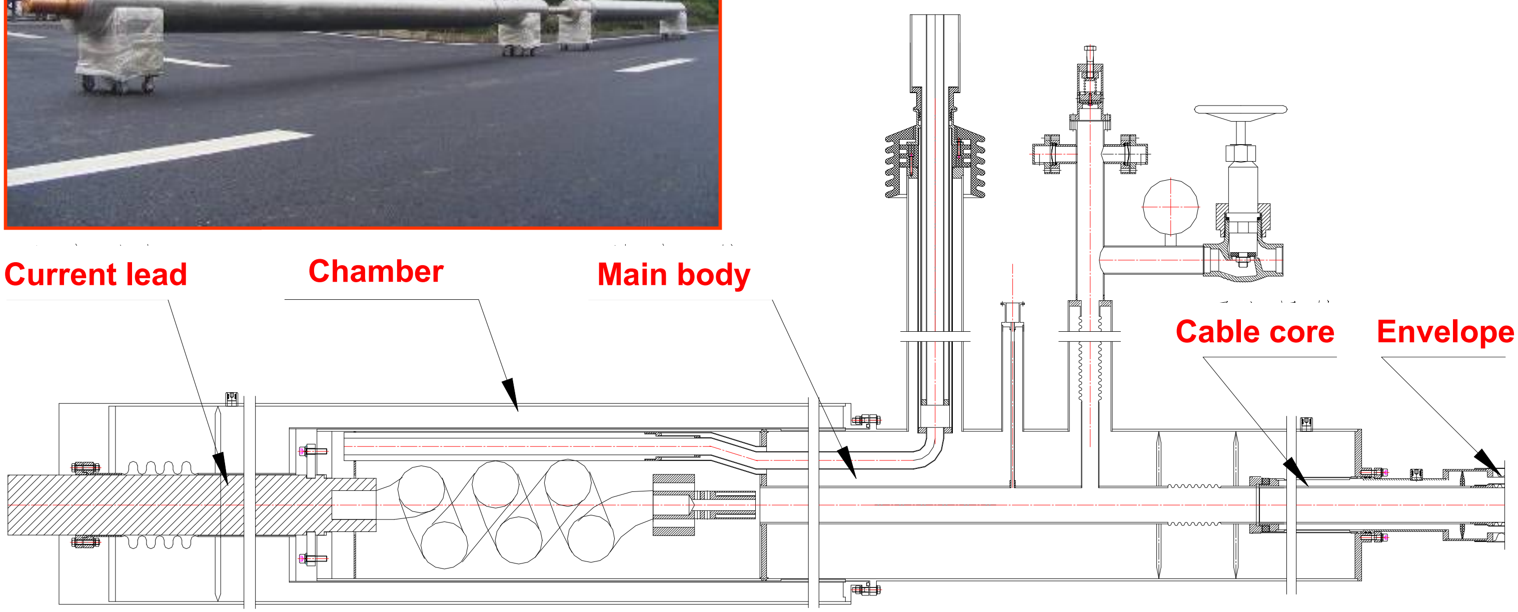


- The cryogenic envelope has been divided into 8 segments;
- Each segment has a standardized joint at both ends;
- Just inserts type A joint into type B joint when integration;
- The static heat loss for the envelope is less than 0.8W/m;
- This integration design and assembly is a good way for long-distance HTS cables.

IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), October 2015.
Plenary presentation PL4 given at EUCAS 2015; Lyon, France, September 6 – 10, 2015.
Not submitted to IEEE Trans. Appl. Supercond.

Cable terminator

- **Modularization: each functional part is independent;**
- **Three functional parts: the main body, current lead, chamber.**

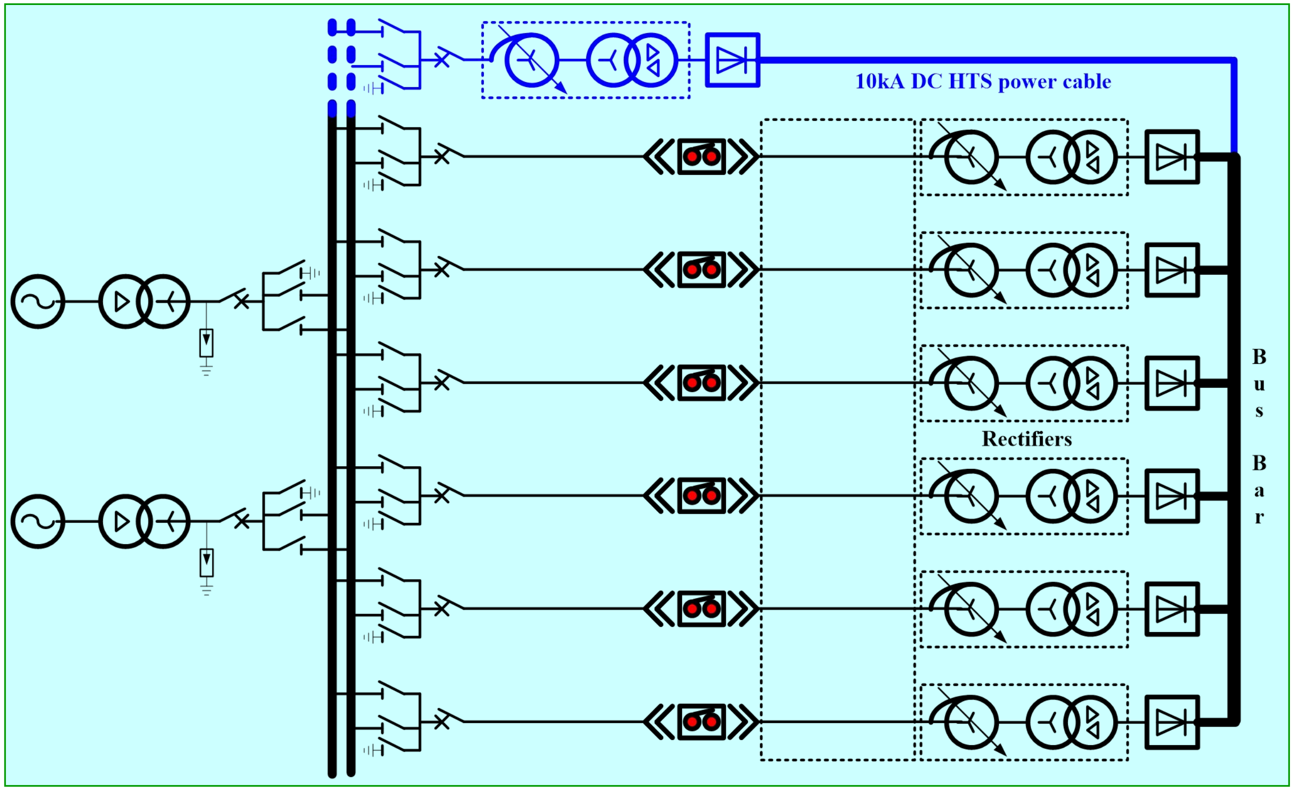


Refrigeration system: Stiring cryo-cooler

- Total heat loss of cable: **2487W;**
- Cryo-cooler: **Stirling refrigerator;**
- Total cooling capacity: **4kW@77K.**

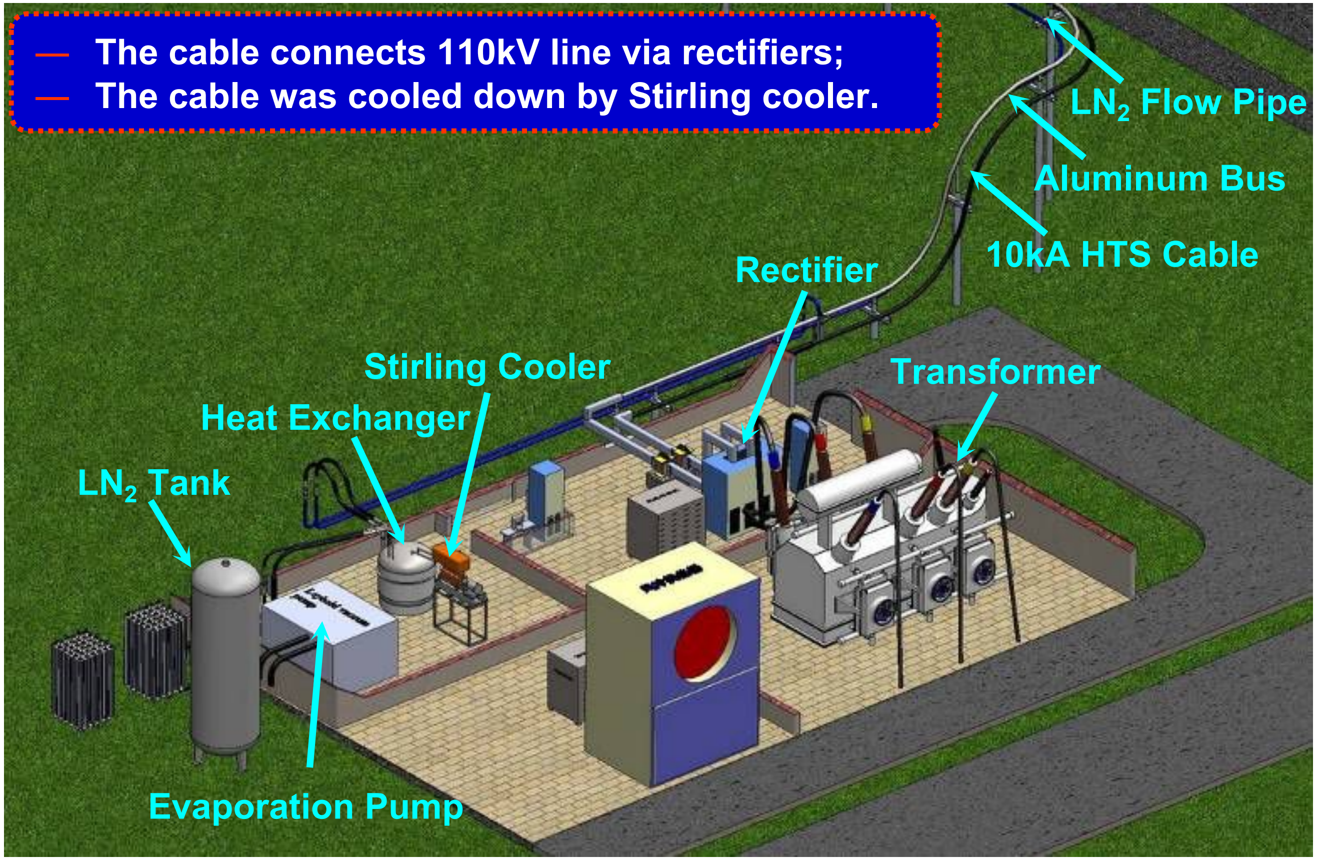
Stirling refrigerator and a backup refrigerator are employed for DC cable.

The HTS DC cable has been connected to the busbar for a alumina electrolyzer



Location of the DC cable: connects the rectifier with the bus bar

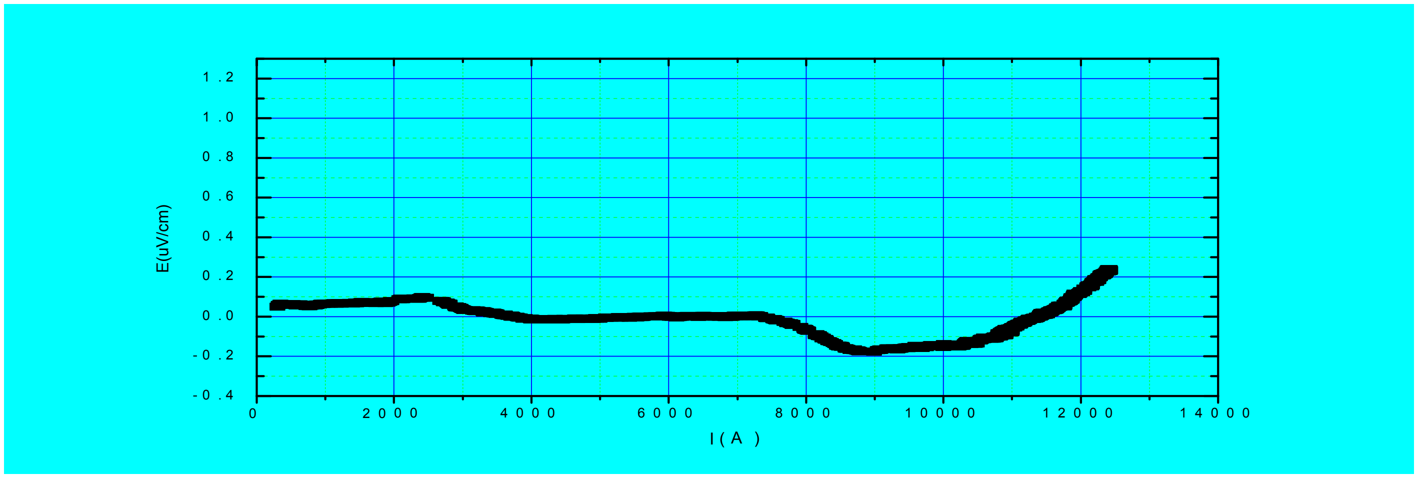
IEE: 10kA/360m HTS DC Power Cable

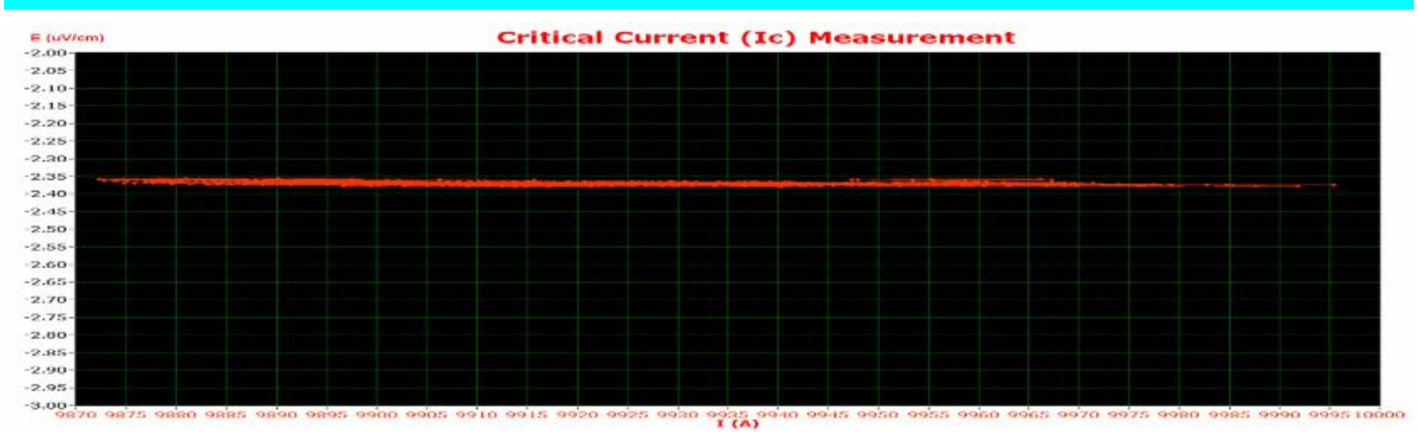


10kA/360m HTS Power Cable after Installation

The design of DC cable ensure the installation in complex environment

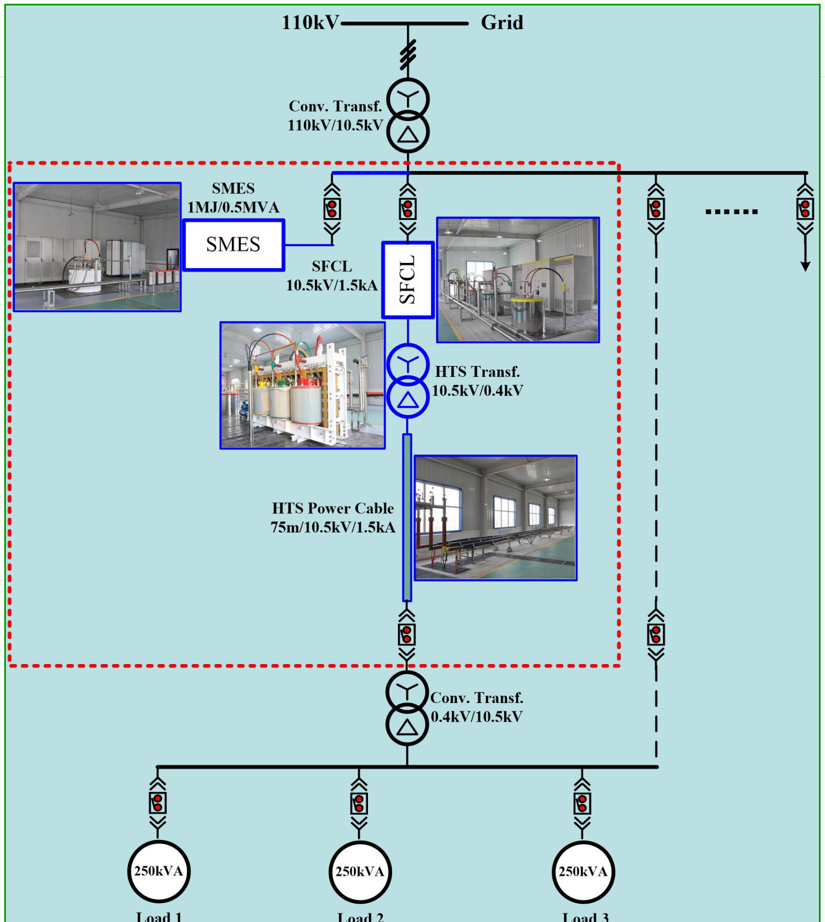
Tests of the Power Cable





Tests show that the Ic of Cable is larger than 12.5kA by 1uV/cm, and 2 hours of operation shows that the voltage drop in the cable is not changed.

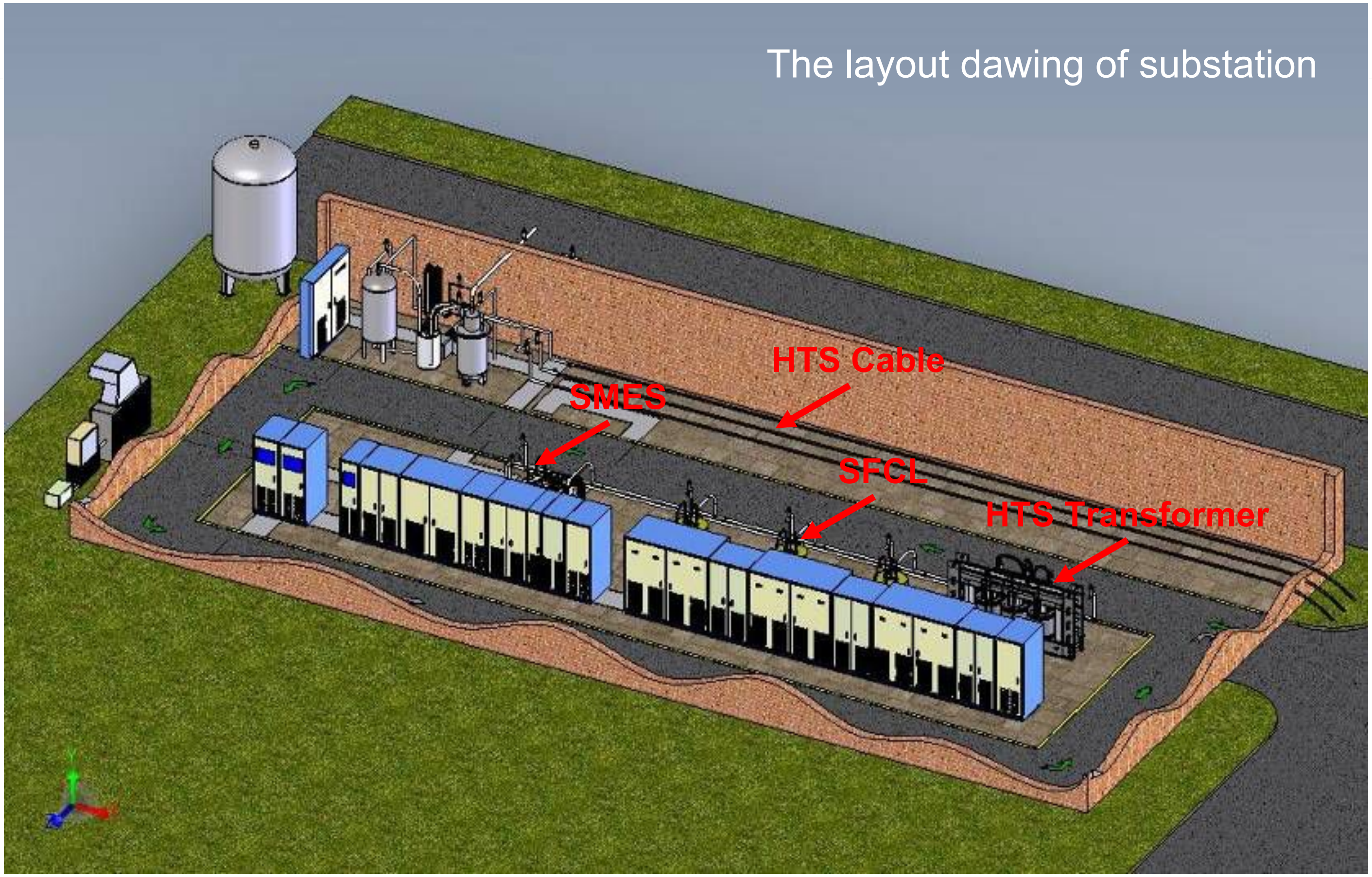
IEE: HTS Power Substation



- SMES:
  - Quick power compensation;
  - Improve power quality;
  - Uninterrupted power.
- Superconducting FCL:
  - Suppress Fault current;
  - Enhance dynamic stability and reliability of the gird;
  - Increase transmission capacity;
  - Prolong life of the equipment.
- HTS Power Transformer:
  - Lower Operational loss;
  - Increase unit capacity.
- HTS Power Cable:
  - Lower transmission loss;
  - Increase transmission capacity.

- **Enhance stability and reliability;**
- **Improve power quality;**
- **Lower transmission losses.**

IEE: HTS Power Substation

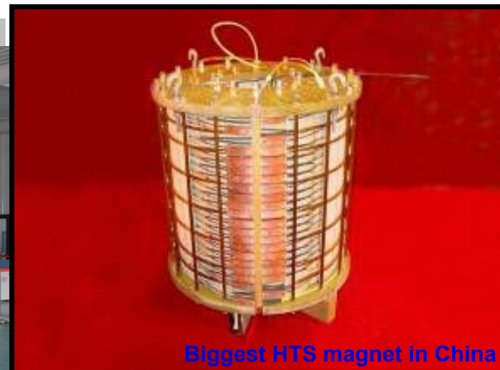


IEE: HTS Power Substation

IEE: HTS Power Substation

Device ① – The 10.5kV/1MJ/0.5MVA High Tc SMES

10.5kV/1MJ/0.5MVA SMES ⇒ **Power compensation, quality enhancement, …**



- Overview:
  - Integrates functions of **active power filtration, reactive & active power compensation**;
  - **First** in-grid-operation High Tc SMES in China for **more than one year**.
- Main parameters:
  - Rated voltage: 10.5kV;
  - Stored energy: 1.08MJ;
  - Output: 0.5MVA;
  - Response time: ≤1ms;
  - Conversion effic.: ≥90%;
  - Voltage fluctuation: ≤1%;
  - Power factor: 0.99.

IEE: HTS Power Substation

Device ② – The 10.5kV bridge-type SFCL

10.5kV/1.5kA SFCL → **Short-circuit current suppression, safety enhancement, …**

- Overview:
  - **Energized in 2005**;
  - The fourth in the world;
  - **3-∅ earthing tests** conducted in power grid;
  - Operation more than **20,000 hours** by far.
- Main parameters:
  - Rated voltage: 10.5kV;
  - Rated current: 1.5kA;
  - Short-circuit current shrinking rate: 82% (from 3500A to 635A);
  - Response time: 2ms;
  - Recovery time: 12ms;
  - Normal volt. Drop: 0.5%.

IEE: HTS Power Substation

Device ③ – The 630kVA HTS transformer

630kVA 3-∅ HTS Transformer → **Losses decrease, capacity enhancement, …**

- Overview:
  - **Energized in 2005**;
  - **Passed the industrial standard tests** by the national authority;
  - Largest amorphous alloy HTS transformer core;
  - Operation more than **one year** in real grid.
- Main parameters:
  - Rated power: 630kVA;
  - Voltage: 10.5kV/0.4kV;
  - Current: 34A/909A;
  - Short-circ. resist. 2.45%;
  - Connection: Yyn0+d7;
  - Efficiency: 98.3%.

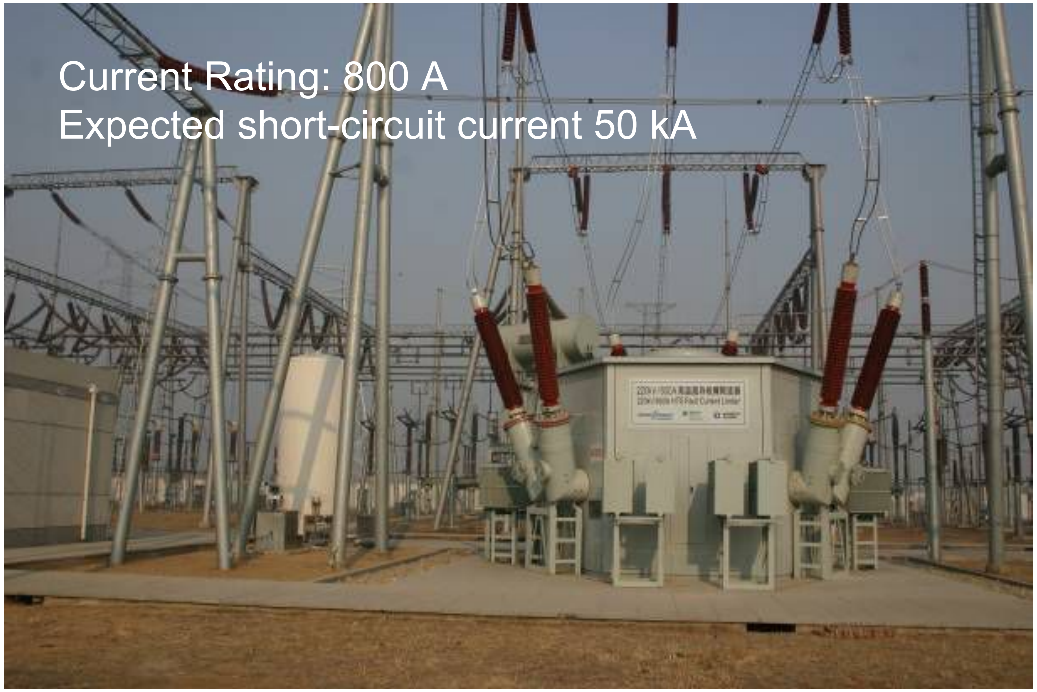
IEE: HTS Power Substation

Device ④ – The 75m HTS power cable

75m/10.5kV/1.5kA HTS power cable → **Capacity enhancement, loss decrease, …**

- Overview:
  - **Energized in 2004**;
  - For multiple factories;
  - Operation more than **15,000 hours** in the real power grid;
  - Stably and reliably.
- Main parameters:
  - Length: 75m;
  - Rated voltage: 10.5kV;
  - Rated current: 1.5kA;
  - DC critical current: 5kA;
  - Joint resistance: $10^{-7}\Omega$;
  - Heat loss of cryogenic envelope: 1.5W/m;
  - Min. bend. Diam.: 2.4m.

The progress of FCL in power grid



Innopower Superconductor Cable Co. (Innopower)

The saturated core Type
3 phase, 220 kV.

Time to open of 220kV
FCL system <8ms

Energize recovery time of
220kV FCL system <600ms

The continuous operating time is more than 10 months.

The 220 kV FCL was put into operation at Tianjin electrical power company in 2013 .

The progress of FCL in power grid

The 550 kV FCL DEMO is under construction at China Southern Power Grid.

Summary

1. The Chinese government input funds more than 600 Million RMB and industry input funds more than 700 Million RMB for R&D of superconducting materials and applications in the period of 12^{th} Five-Year plan.
2. The LTS industry has been formed in China.
3. The YBCO and BSCCO tapes can meet the requirements of electrical power DEMO .
4. The Chinese government will support continuously the R&D of superconductivity in the period of 13^{th} Five-Year plan (from 2016).

Contributors

Northwest Institute for Nonferrous Metal Research

G. Yan, C.S.Li, Q.Y. Wang, S.N.Zhang, Q.B.Hao.

Western Superconducting Technologies Co., Ltd. (WST)

Y.Feng, X.H.Liu, J.F.Li, J.W.Liu.

Institute of Electrical Engineering Chinese Academy of Sciences

L.Y.Xiao, H.W.Gu, Y.W.Ma, G.M.Zhang, S.T.Dai, Q.L.Wang.

Suzhou Advanced Materials Institute

H.W.Gu, F.Z.Ding, Y.Cai.

Shanghai Jiao Tong University

Y.J.Li.

INNOPOWER/ China Southern Power Grid

Y.Xin, A. R. Lin, Z.J.Shi, M.Z.Yu.

Thanks for your attention