Recent Research Activities of Applied Superconductivity in China

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Presented at ASC 2016, September 4-9, 2016, Denver, USA

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Content

- Overview of Research Teams and Financial Support;
- Recent Progresses at Materials, Electronics and Large-scale Applications;
- Near Future Progresses, Plans or Proposals;
- Summary

Research Teams for Materials (11 Teams)

Research Institute or Company	Research Activities
NIN/Western Superconductor	NbTi, Nb3Sn/Al, BSCCO-2212, 2223, MgB2, YBCO Substrates
IEE-CAS	YBCO, MgB2, Fe-based Wires or Tapes
SHJT Univ/Shanghai Supercond.	YBCO by IBAD+PLD
Shanghai Univ/Shangchuan Supercond.	YBCO by IBAD+MOD
Suzhou-NANO	YBCO by IBAD+MOCVD
BUT	YBCO Substrates
Innova Superconductor	BSCCO-2223 tapes
Tianjing Hytech	YBCO Film
GRINM	YBCO Bulk
Peking Univ	MgB2 Film
STUE	YBCO Film

Research Teams for Electronics (10 teams)

Research Institute or Company	Research Activities
IOP-CAS	SQUID and Application, Microwave Filter, qubit
Peking Univ	SQUID and application (MCG and other Geophysics)
SIMIT-CAS	SQUID and application (MCG, Geophysics and ULF-NMR/MRI), Single-photon Detection
Nanjing Univ	Single-photon Detection, THz, qubit
Tsinghua Univ/Zongyi Superconductor	Microwave Filter, qubit
USTC	Qubit, Single-photon Detection
Zhejiang Univ	qubit
PMO-CAS	THz
16th Institute	Filter
NIM	Voltage standard

Research Teams for Large-Scale Applications (15 Teams)

Research Institute or Company	Research Activities
IEE-CAS	FCL, Cable, SMES, Transformer, Electric Machine, NMR, MRI, High Field Magnet, accelerator magnet, Fusion Magnet and other applications
HUST	FCL, SMES, Electric Machine
WHI-712	Electric Machine
Tsinghua Univ	MRI, Cable, FCL, SMES
Tianjing Univ/Innopower	Cable, FCL
CEPRI	Cable, SMES, FCL
NCUEP	Cable
SWJTU	Maglev
SICT	Cable
Western Superconductor	MRI, High Field Magnet
Hefei-CAS	Fusion Magnet, High Field Magnet
IHEP-CAS	Accelerator Magnet, MRI, ADS magnet, Magnetic separation
IMP-CAS	Accelerator Magnet, ADS magnet
IAEC	cyclotron accelerator magnet
TIPC-CAS	Fusion Magnet, high field Magnet
SIAP-CAS	Magnet for FEL, Cavity

MRI Industries in China

1.Ningbo Jansen magnetic resonance Technology LTD : MRI magnet and System (0.35-1.5 T)

2.Shanghai United Imaging Healthcare LTD: MRI magnet and system（1.5T， 3T)

3. Alltech Medical System LTD: MRI magnet and system(1.5T)

4.Shengyang Neusoft Medical system LTD: MRI magnet and system (1.5T)

5. Xinli Superconductor: MRI magnet and system (1.5T)

6. Times medical system LTD , MRI system

7. Beijing Wangdong medical equipment LTD, MRI system (0.35T,1.5T)

8. BASDA medical system LTD, MRI system

9. Liaoning KAMPO Medical system LTD, MRI system (0.35,1.5T)

10. Suzhou Lonri Medical system LTD, MRI System (0.35T, 1.5T)

11.Xingaoyi Medical system LTD, MRI system (0.35T,1.5)

12.Anke medical system LTD, MRI system(1.5T,0.35T)

Financial Supports for Applied Superconductivity in China (last 5 yrs)

Central Government	863 Plan for Superconductivity (tech), 100M RMB 973 Plan for Superconductivity (basic), 100M RMB National Natural Science Foundation China Contribution to ITER & related, 250M RMB EAST Project for Fusion in China, 200M RMB
Local Governments	Beijing City Government, 10M RMB Shanghai City Government, 50M RMB
Industry Company	China State Power Grid, 10M RMB South Power Grid, 30M RMB Datang Telecommunication, 20 M RMB Zhongtian Group, 30M RMB ……
CAS & Institutes	CAS, IEE, IOP, IHEP, IMP, SIMIT, SIAP, TIPC
MRI's Companies	~12 companies for R&D of MRI magnet and system
	Total: ~ 1150M RMB (=175M USD) /last 5 yrs

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The R&D of Superconducting materials in China

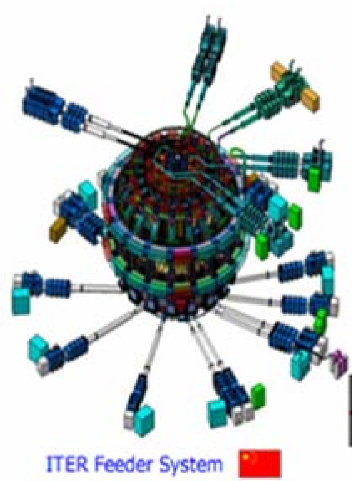
- LTS for ITER and MRI: Western Superconductor;
- BSCCO-2223, 2212: NINMR;
- Substrates: NINMR and Beijing Polytechnic;
- IBAD+MOCVD: Suzhou Nano, IEE-CAS
- IBAD+MOD: Shanghai University/Shangchuan Superconductor;
- PLD: Shanghai Jiao Tong University/Shanghai Superconductor;
- MgB2 wires and tapes: NINMR, IEE-CAS
- Fe-based wires and tapes: IEE-CAS.

LTS Materials at Western Superconductor

Western Superconducting Technologies Co., Ltd. (WST) was founded in 2003 in Xi'an City, China and focus on the production of the superconducting strands for ITER project, and NINMR is its largest share holder and the founder institution.

Production capability of Ti alloy and superconductor: 6000 ton ingots of Ti alloy, 3000 ton rods of Ti alloy and 400 ton superconductor per year

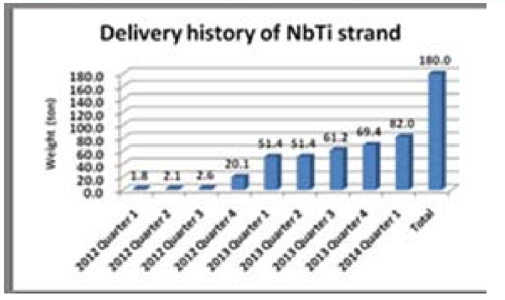
China's contribution of superconductors for ITER project

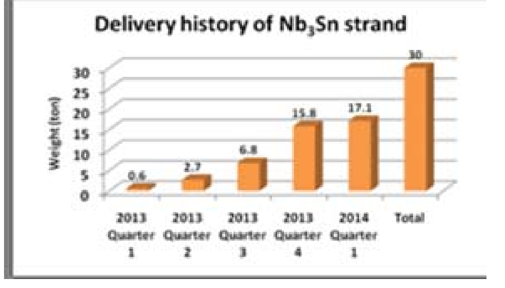


China (WST):

180 tons of NbTi strand

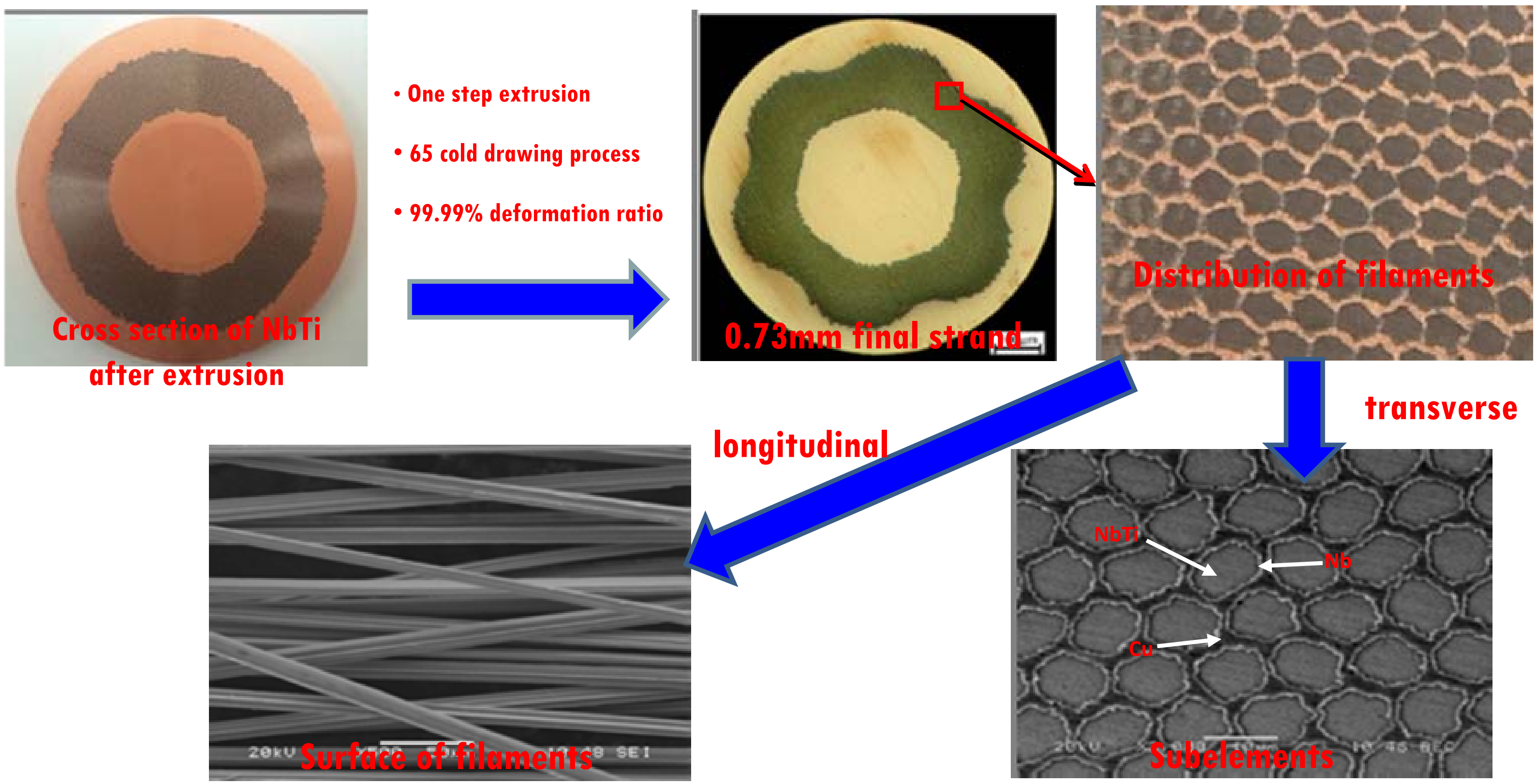
30 tons of Nb_3Sn strand





Coils	Superconducting wire	Weight (t)	Percentage (%)					
			CN	EU	JA	KO	RF	US
TF	Nb_3Sn	420	7.5	20.2	25	20	19.3	8
CS	Nb_3Sn	122			100			
PF	NbTi	224	65				35	
CC/Feeder	NbTi	21	100					

WST: Ultrafine filamentary NbTi strands for ITER

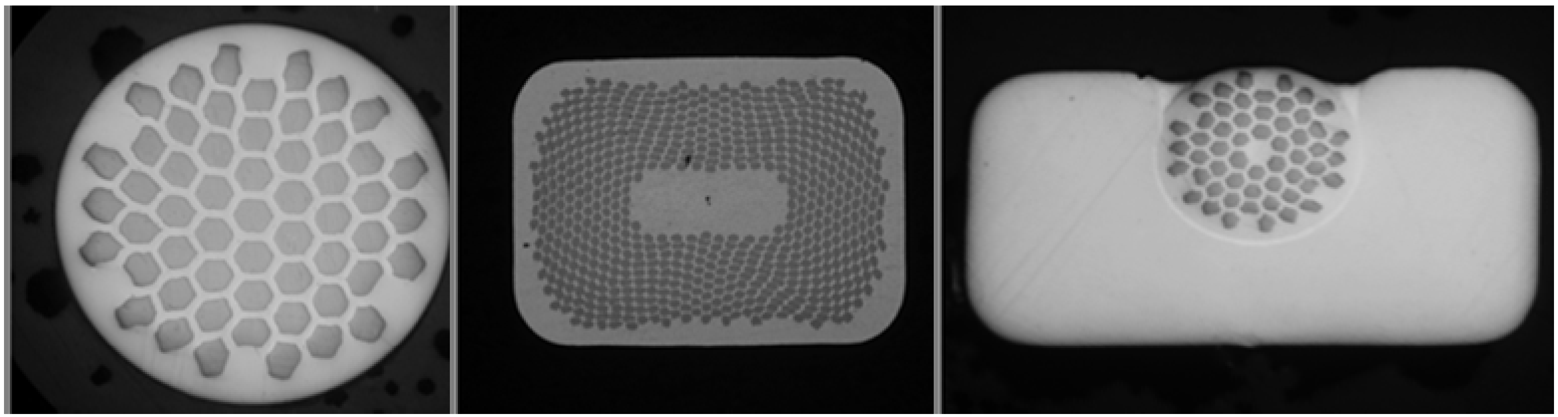


The length of the strand can be reached up to 90km

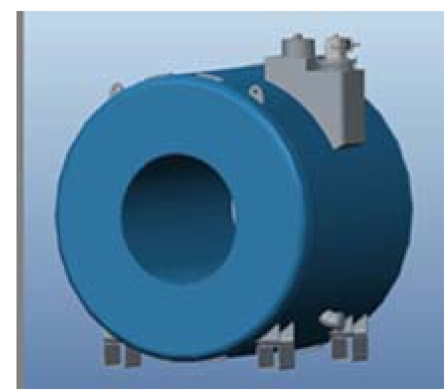
WST: NbTi Strand for MRI Application

- Monolith and wires for MRI and scientific application have been developed and manufactured, and used for the Companies in China.

Typical Cross Section



Principal Civil Customers

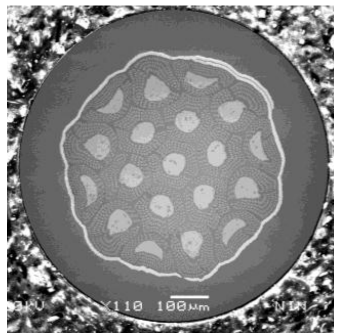
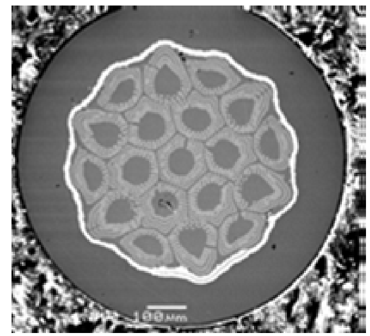
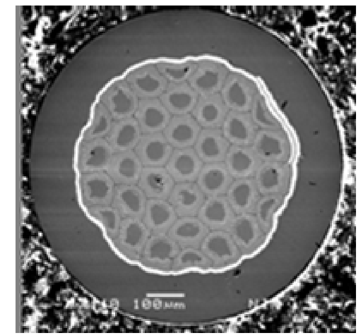


www.united-imaging.com

http://alltechmed.com

http://www.xmc.cn

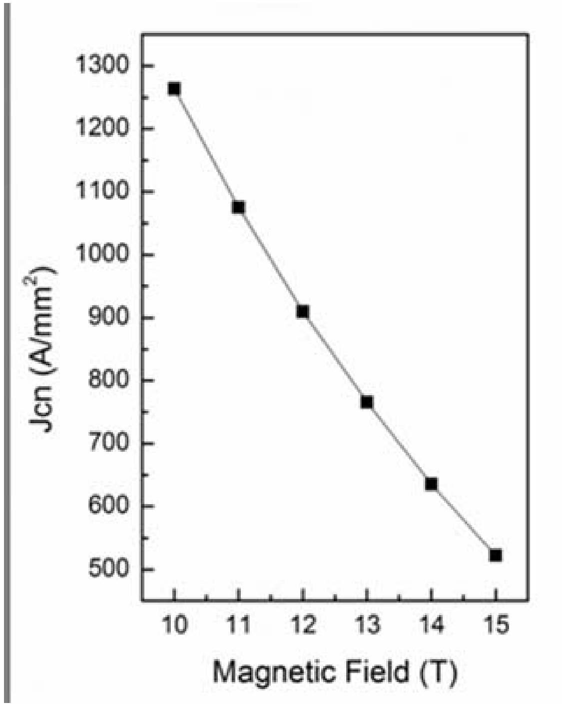
WST: Internal-tin Nb_3Sn Strand for ITER

Strand type	Type 1	Type 2	Type 3
Cross section			
Structure feature	Cu split	Cu split	Cu split
	--	Tin spacer	--
	--	--	37 sub-elements
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

WST: Bronze Nb_3Sn wires

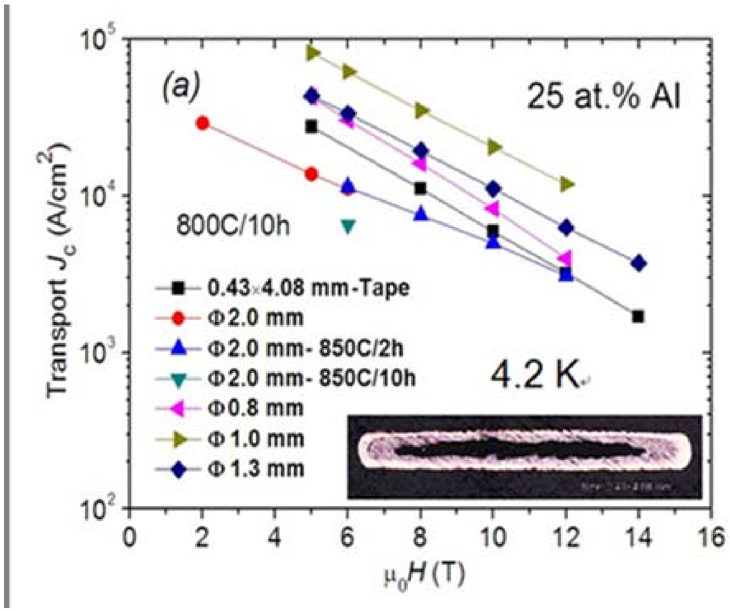
Performance of Nb_3Sn wires with bronze/Nb ratio

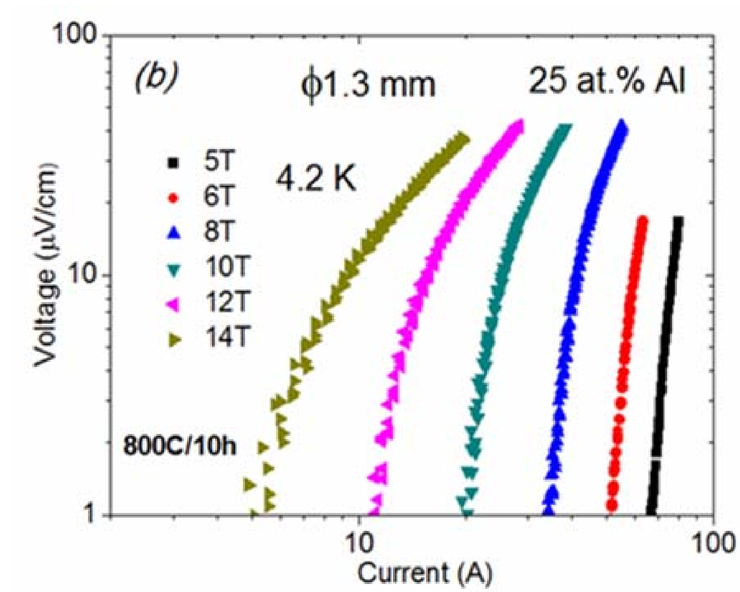
	Design 1	Design 2	Design 3
Matrix material		Cu15.5 Sn0.25 Ti	
Filament material		Nb	
Number of filaments		13579	
Bronze/Nb area ratio	2.5	2.2	2.0
Filament spacing (μm)	1.4	1.3	1.2
I_c (A) @4.2K, 12T	236	239	244
J_{cn} (A/mm^2)@4.2K,12T	907	923	930
n value	37	36	40



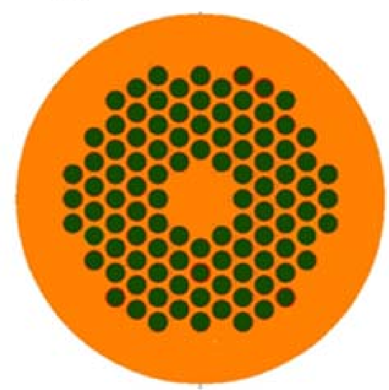
- By optimizing the design, the J_{cn} of bronze Nb_3Sn superconducting wires exceeds 900A/mm^2 at 4.2K and 12T .

WST: Fabrication of Nb_3Al wire by combing ball-milling and PIT

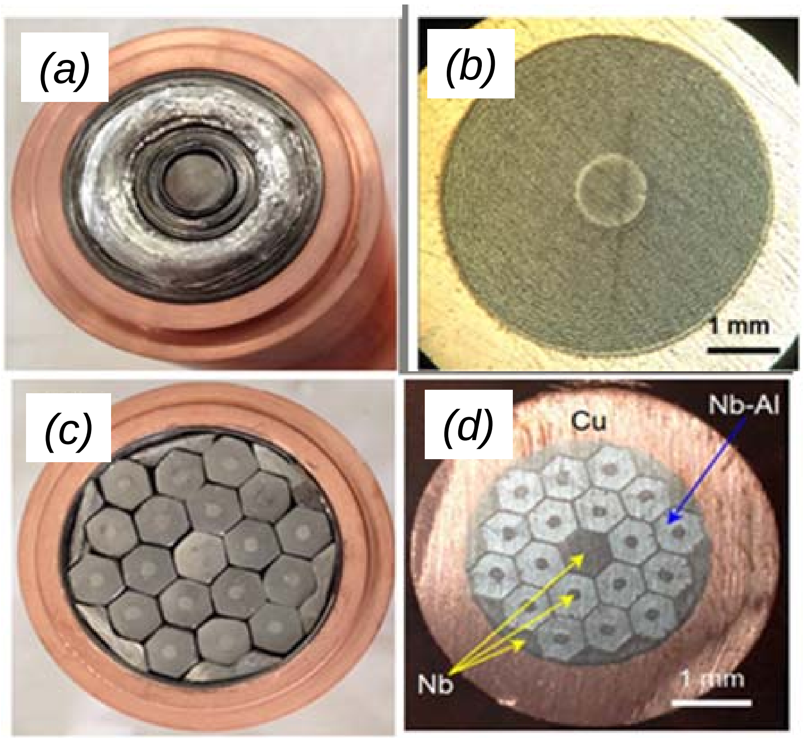


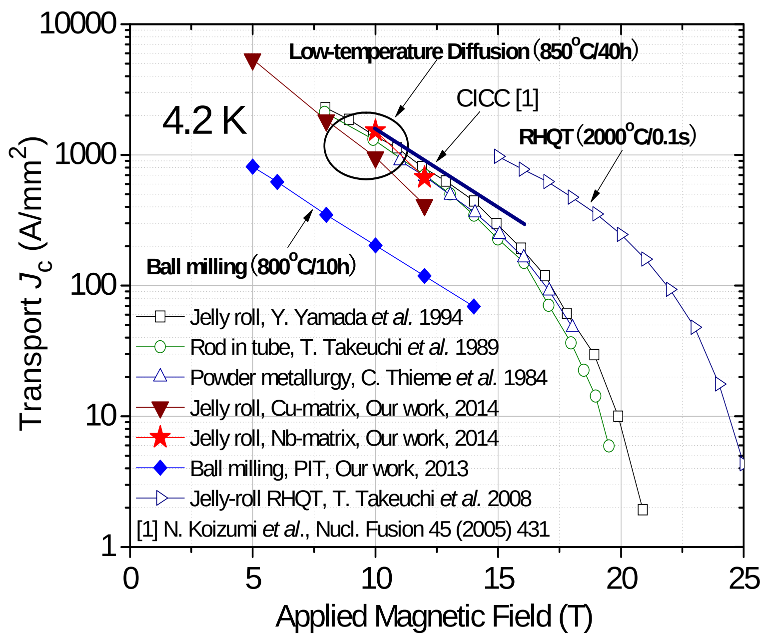


By optimizing the fabrication technique, the transport Jc of Nb_3Al superconducting wires made by PIT method, is up to 10000 A/cm2 at 4.2K and 12T .



WST: Development of Jelly-roll Nb_3Al



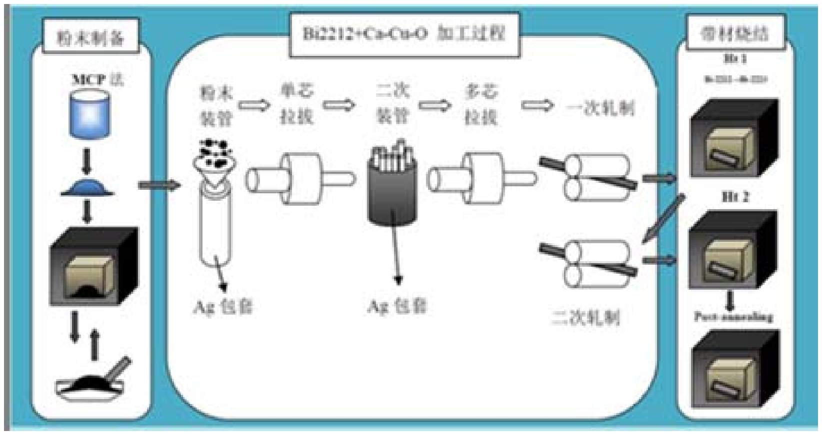


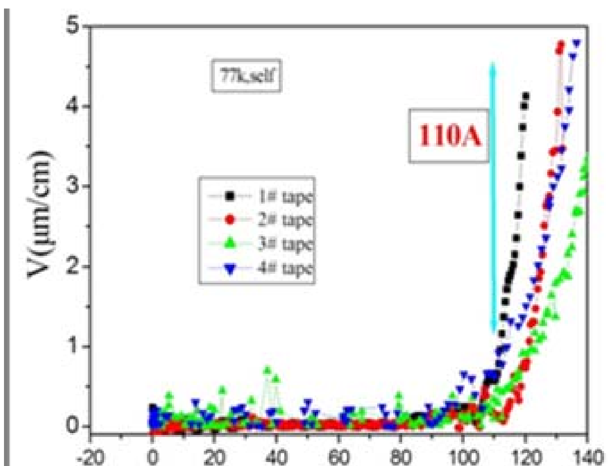
Properties of Nb_3Al wires by two heat-treatment methods:

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

(2) Rapid Heating Quench： J_c (4.2K、 15T)=1000 A/mm^2 , T_c: 17.9-18.0 K、 $H_{c2}(0)$: 29.7 T

NINMR: Bi-2223 HTS tapes

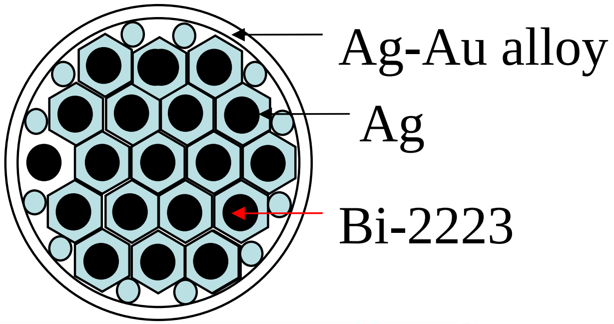


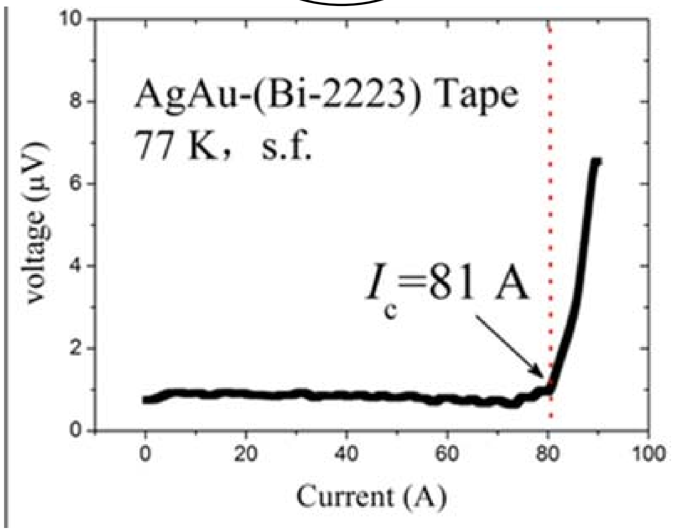


200-500 meters long Bi-2223 tapes fabricated by NINMR: with the Ic of ~100A， J_c=4×10^4A/cm^2（77K, s.f.）

NINMR: Bi-2223/AgAu tapes for current leads

Used for the design and built of CFETR in China.





Matrix: Ag-Au alloy (5.4 wt. % Au)
Thickness : 0.25 mm
Width : 4.3 mm
Critical Tensile Stress: 50 MPa
Critical Current : ~80 A -100A

NINMR: Bi-2212 superconducting wires

Short samples：

I_c=890 A

J_{ce}=1100 A/mm^2

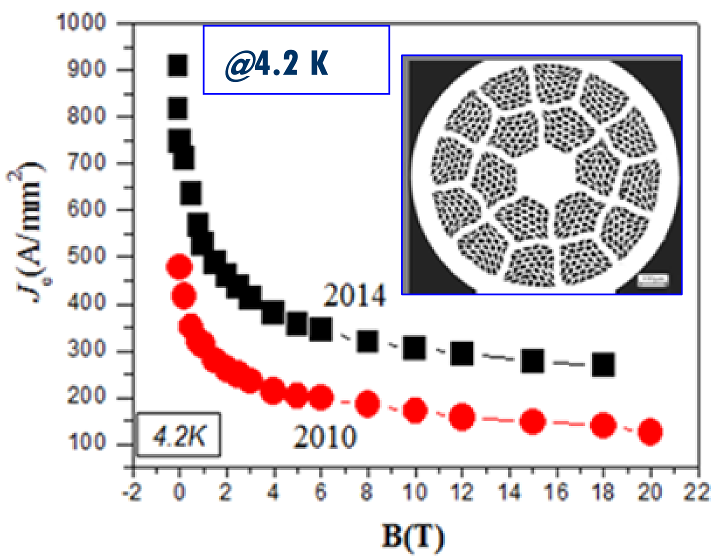
J_c=5200 A/mm^2

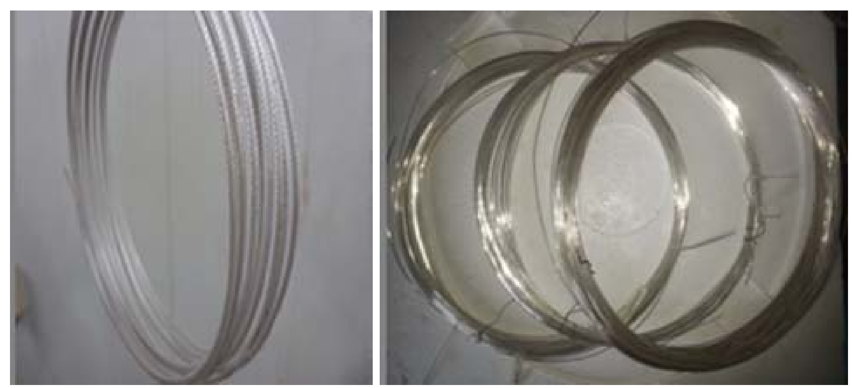
(4.2 K， s.f.)

Fabrication of 200-m long Φ1.0mm wires

4.2 K, 0 T: J_{ce} ~ 920A/mm^2， J_c ~ 4400 A/mm^2

4.2 K, 20 T: J_{ce} ~ 270A/mm^2， J_c ~ 1200 A/mm^2





Bi-2212 wires

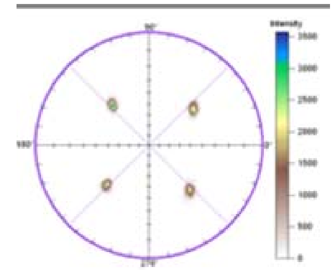
NINMR: Fabrication of Bi-2212 CICC conductors

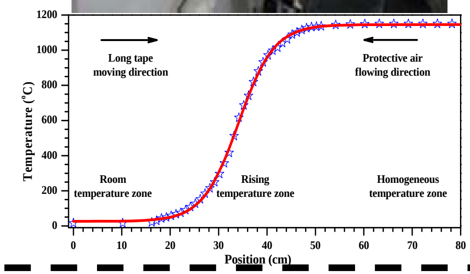
First stage	Number of Bi-2212 wires	2
	Tension	20 N
	Pitch	18-20 mm
Second stage	Number of Bi-2212 wires	2×3
	Tension	20 N
	Pitch	49 mm
Third stage	Number of Bi-2212 wires	2×3× 7
	Tension	30 N
	Pitch	90 mm

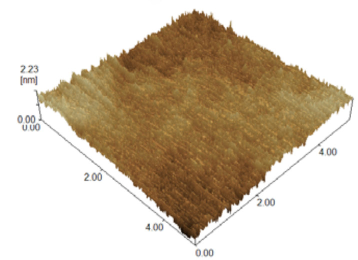
Bi-2212 cables

NINMR: Long-length & Textured Ni5W, Ni7W and Ni9W tapes

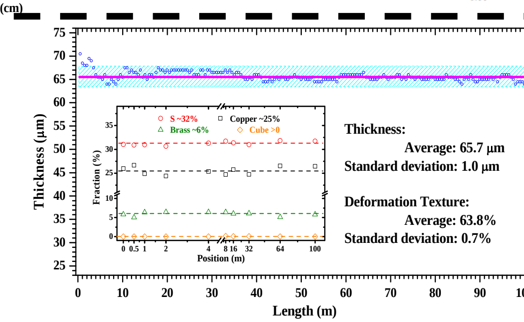
NiW-alloy ingot





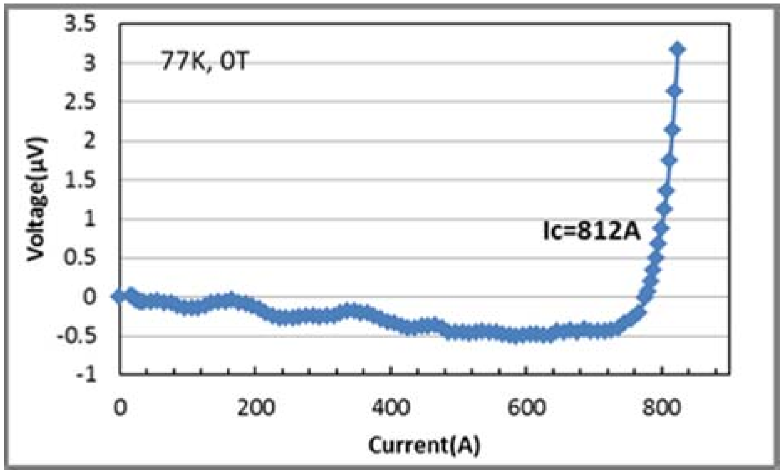


- ✓ Thickness~66 μ m
- ✓ Width=10 mm
- ✓ Length>500 m

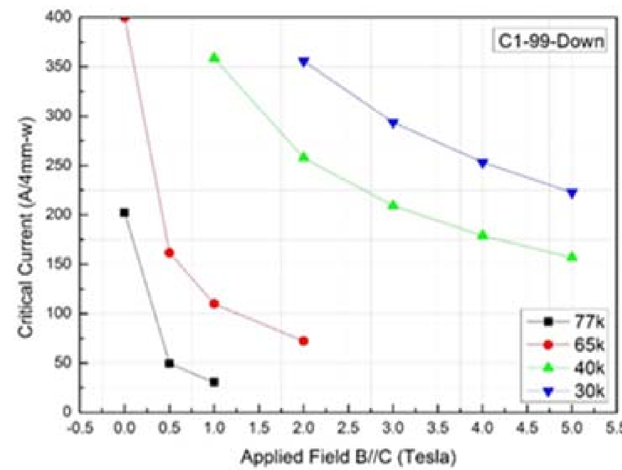


- ➢ Sharp cube textured (~100%) Ni5W tapes with the level of hundred meters were obtained by conventional metallurgy method.
- ➢ Content of cube texture in Ni7W and Ni9W tapes reaches 99.5% and 94% respectively.

SUZHOU NANO/IEE-CAS: YBCO Coated Conductor by MOCVD



Short sample (12mm-w） at 77 K, self field

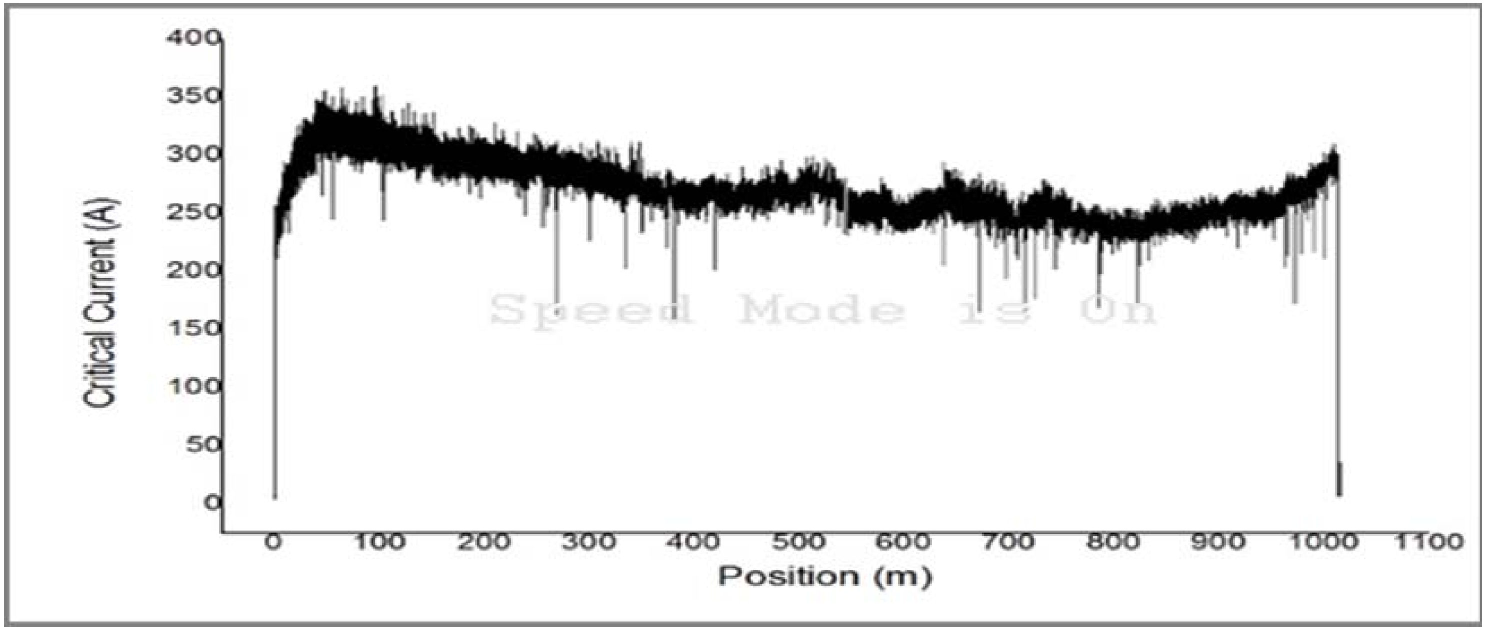


Short sample under magnetic field (12mm-w)

Production capability: 1000m, with width of 12mm and thickness of YBCO 1-3 μm;

Speed： 50 -100 m/h;

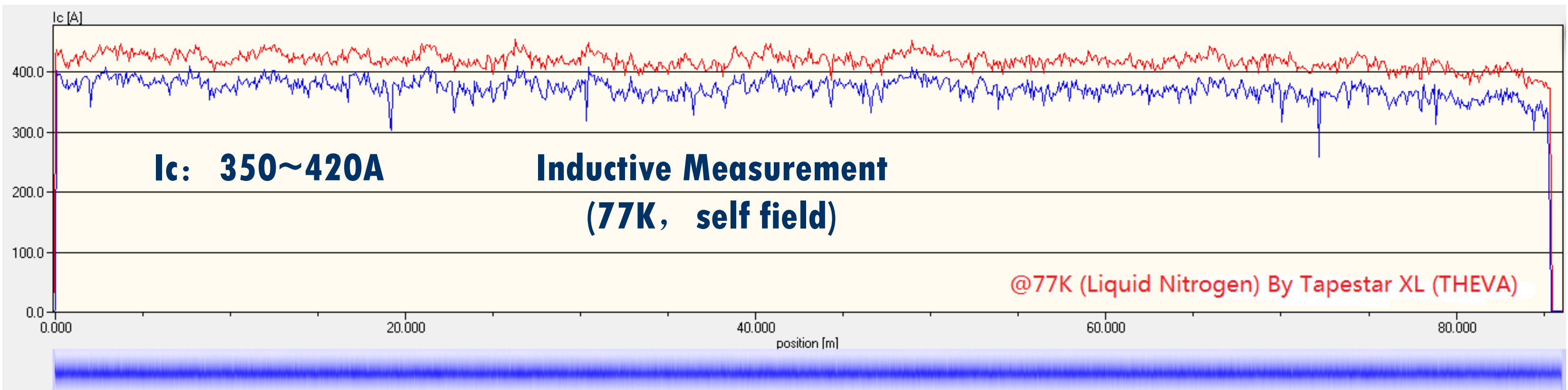
SUZHOU NANO/IEE-CAS: YBCO Coated Conductor by MOCVD



$Ic_{\_average}$=280 A @77K

1000 m long YBCO tape fabricated by MOCVD

Shanghai University/Shangchuan Superconductor: YBCO by MOD




Solution Preparation

Coating + Low temperature Pyrolysis

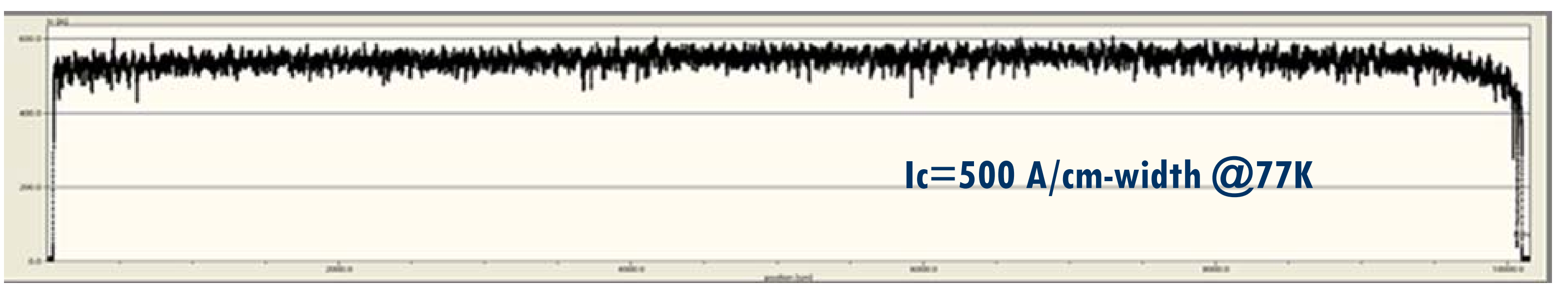
High-temperature Crystallization

Oxygenation

Shanghai University/Shangchuan Superconductor: YBCO by MOD

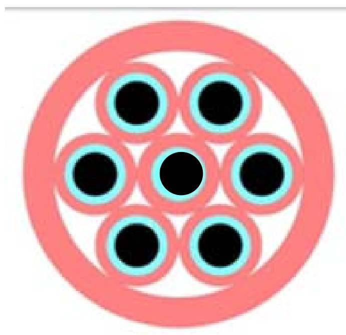
Laminated with Brass and Polyimide Insulating Tapes

SHJT Univ./Shanghai Superconductor: YBCO by PLD



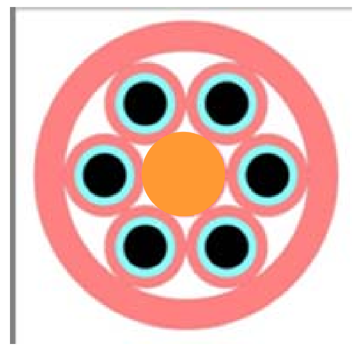
Test of the Jc homogeneity of the 100m long tape

NINMR: MgB2 Wires and Tapes

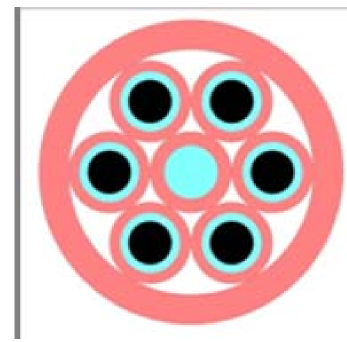


7-MgB_2 filaments

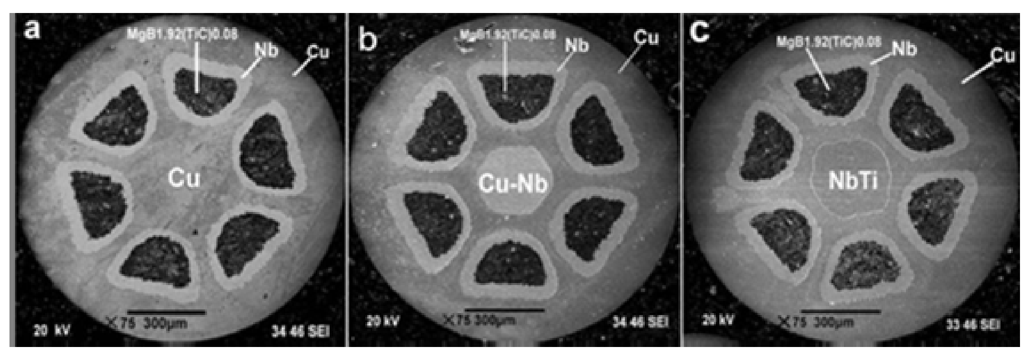
Central filament broken



6-MgB_2 filaments +Cu reinforcement

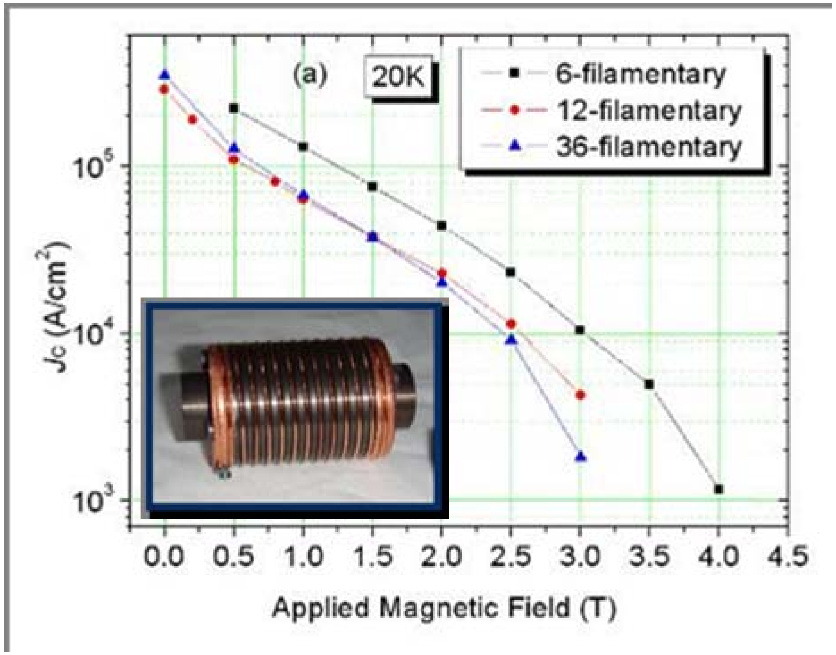


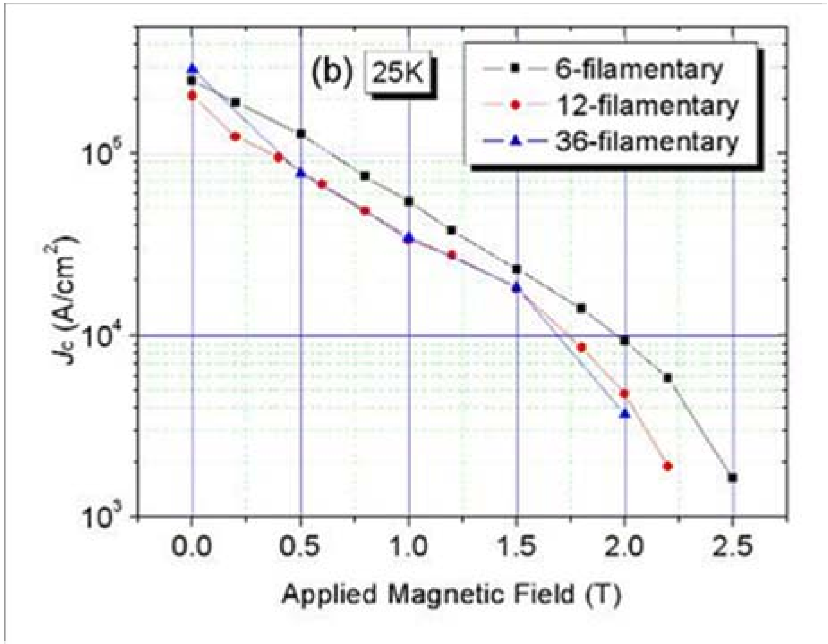
6-MgB_2 filaments +Nb/Cu or NbTi reinforcement



NINMR: MgB2 Wires and Tapes

Superconducting Properties of km-level wires

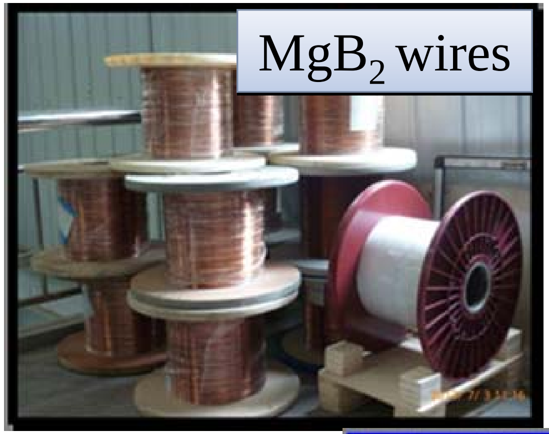


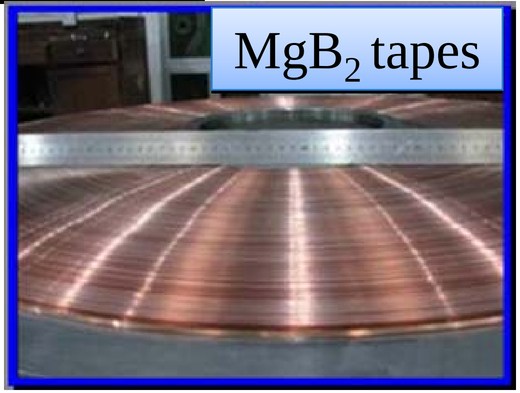


Capability: 1500 meters long MgB_2 superconducting wires
At 20 K、 2 T, J_c= 4.3×10^4 A/cm^2

NINMR: MgB2 Wires and Tapes

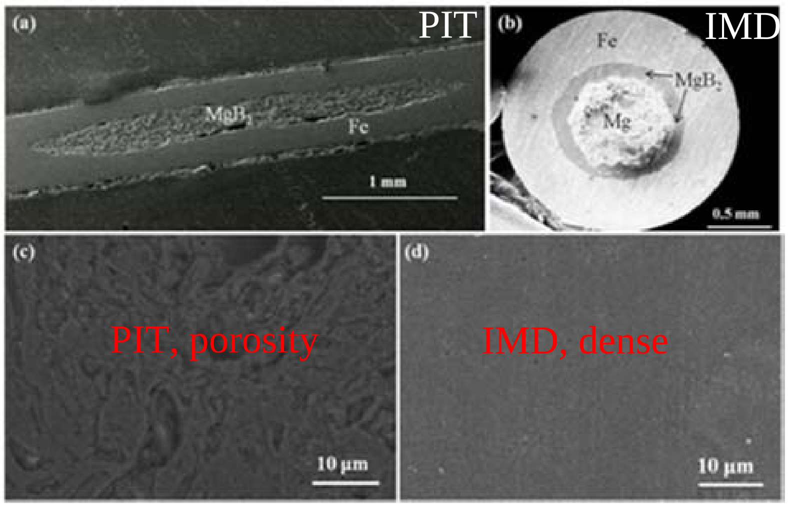
Production of 1500 m MgB2 wires/tapes

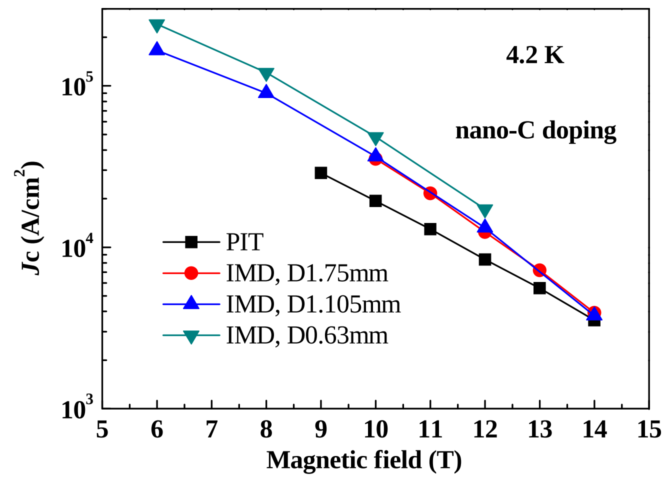




The fabrication technology of kilometer MgB_2 wire is stable, and 20 kilometers MgB2 superconducting wires have been fabricated.

IEE-CAS: IMD-processed MgB_2 wire fabricated with crystalline boron powders

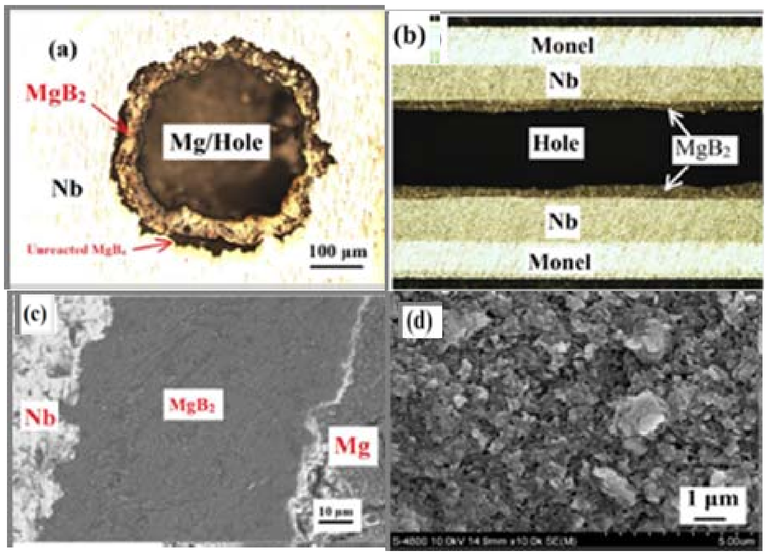


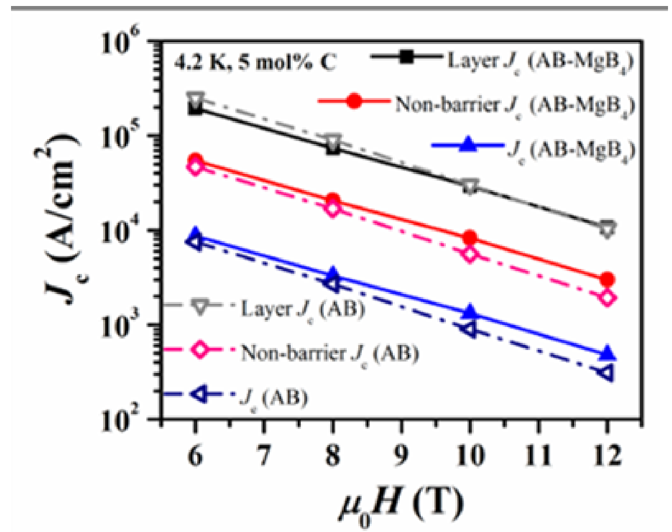


- ➢Compared with PIT-processed MgB_2 tape, the MgB_2 reacted layer of IMD-processed wire presented a better homogeneity.
- ➢The IMD process is also found to be less sensitive to the purity of the boron powders, compared to the PIT method.
- ➢The J_c of 4.8×10^4 A/cm^2 at 10 T was achieved for IMD-processed MgB_2 wires fabricated with crystalline boron powders, which is almost comparable to that made by amorphous boron powders.

Wang et al., *Supercond Sci Technol, 28 (2015) 105013*

IEE-CAS:IMD-MgB_2 wires using MgB_4 precursors



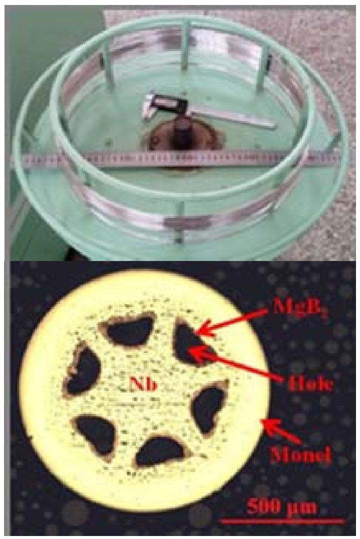


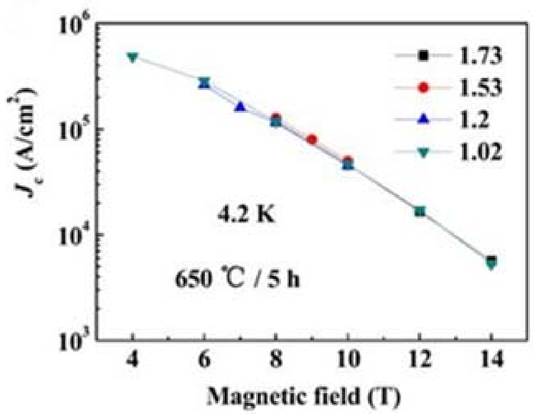
➢Monofilament MgB_2/Nb/Monel wires were fabricated using MgB_4 precursors by internal Mg diffusion (IMD) process.

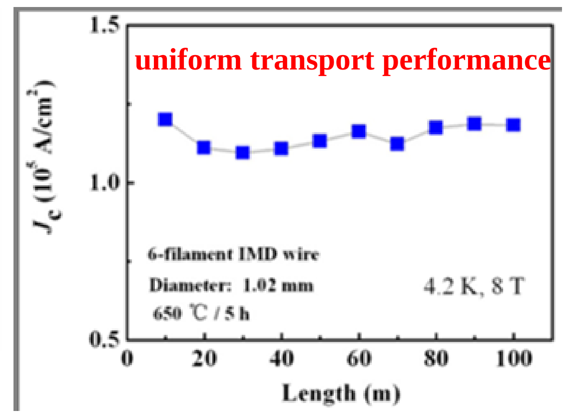
➢Compared to the IMD-processed wires fabricated using boron precursors, the engineering J_e of MgB_2 wire made using MgB_4 precursor were enhanced due to the improved grain connectivity and the enlarged fill factor.

Xu et al., *Supercond Sci Technol, accepted*

IEE-CAS: 100 m-class IMD-processed 6-filament MgB_2 wire





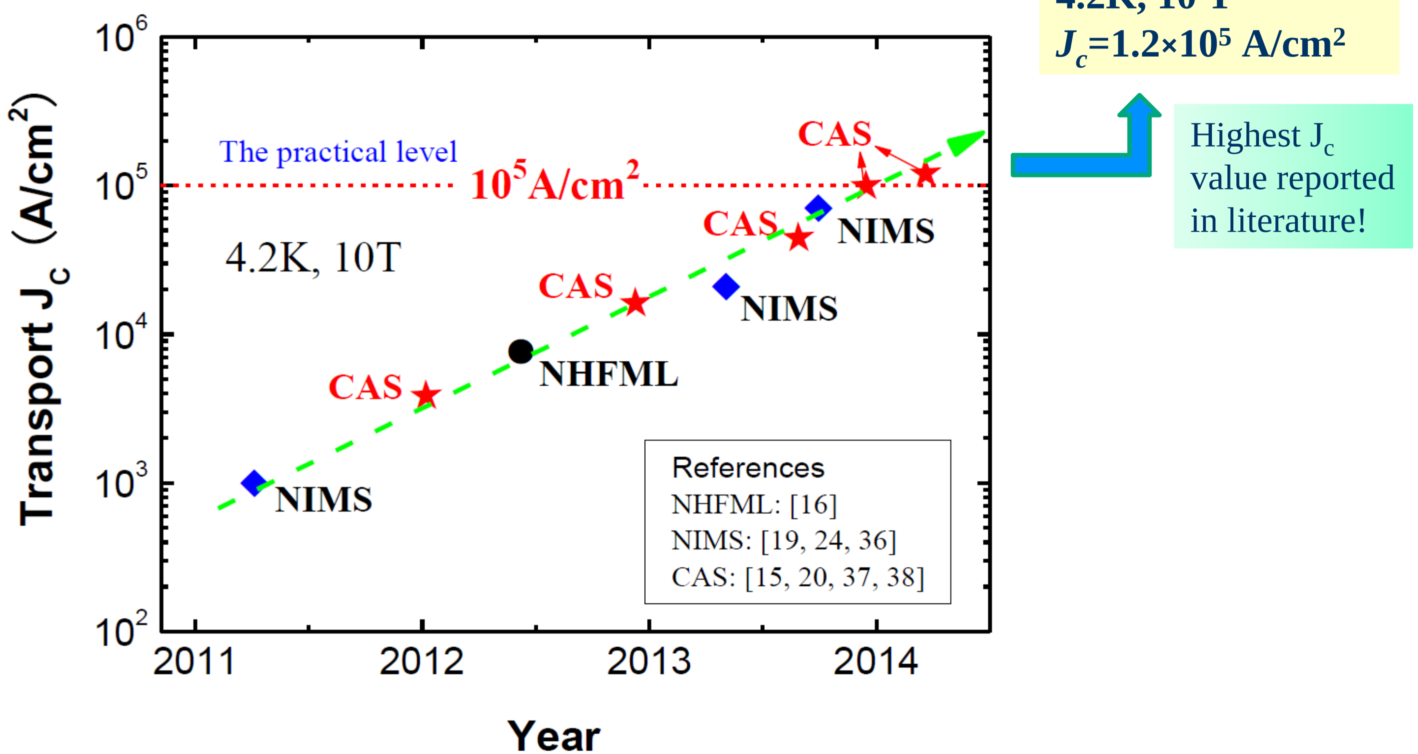


- A 100-m long 6-filament MgB_2 wire was successfully fabricated using internal magnesium diffusion (IMD) process.
- The MgB_2 layer and the sub-filament region are regular, and the J_c values have a fairly homogenous distribution throughout the wire.
- A layer J_c as high as 1.2×10^5 A/cm^2 at 4.2 K and 8 T was obtained, which was the highest value of the long multifilament IMD wire reported so far, to our knowledge.

Wang et al., *Supercond Sci Technol, 29 (2016) 065003*

IEE-CAS: Fe-based SrKFeAs-122 (Sr-122) tapes or wires

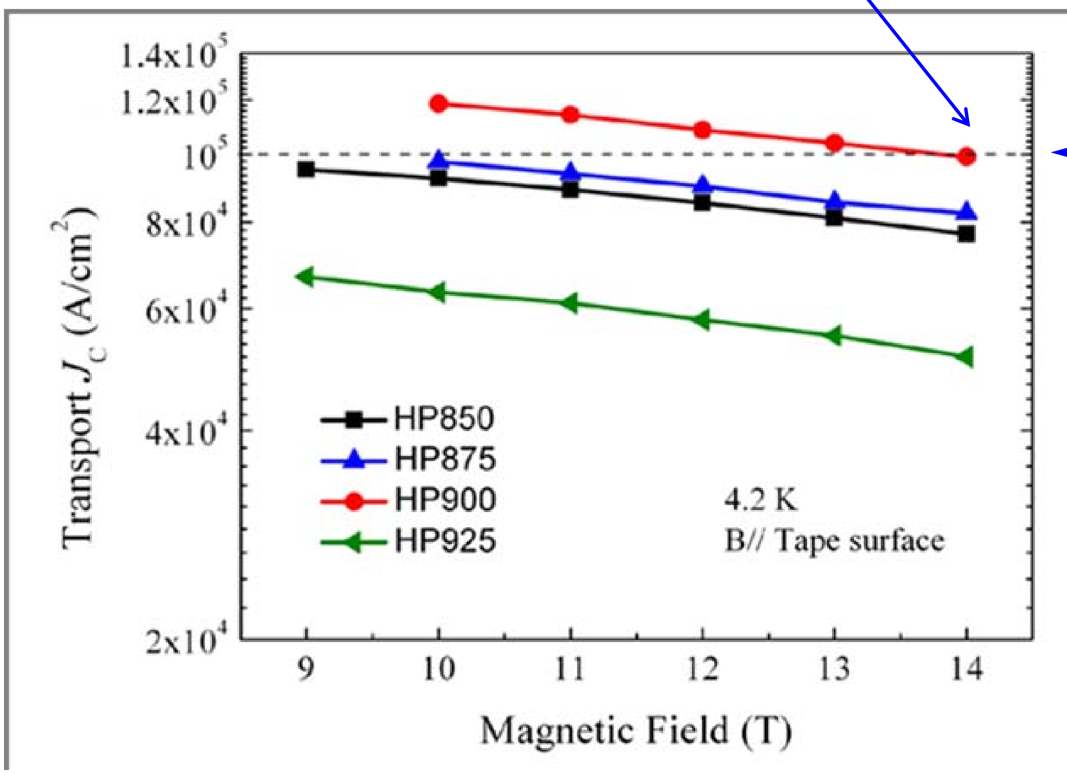
In last few years, the J_c has been rapidly enhanced for Sr-122 wires and tapes



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

IEE-CAS: Fe-based SrKFeAs-122 (Sr-122) tapes or wires

By hot-pressing method, J_c values were achieved in Sr-122/Ag tapes: $J_c \sim 1.0\times10^5$ A/cm^2 (4.2 K, 14 T)



Highest J_c value reported in literature!

At 4.2 K and 10 T:

$J_c = 1.2\times10^5$ A/cm^2

Main challenge:

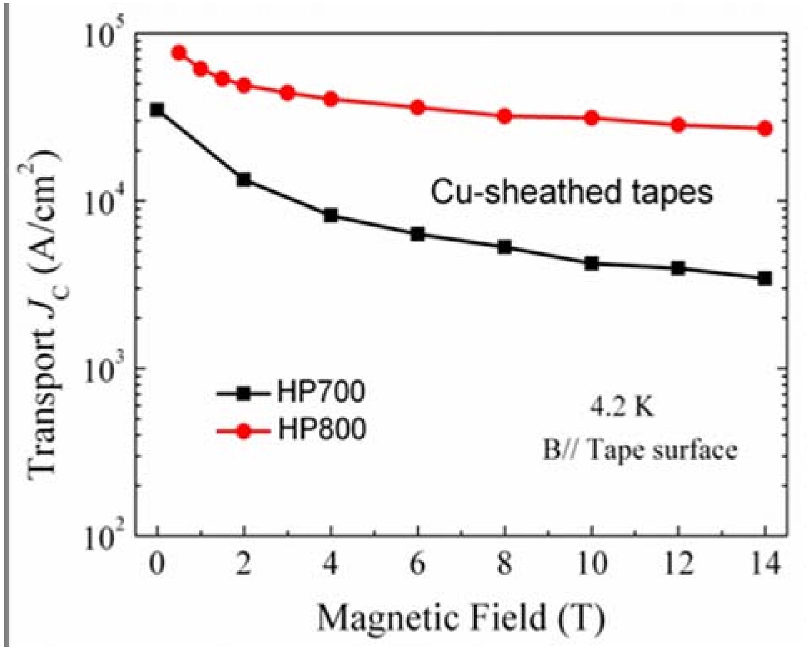
How to transfer the already achieved high J_c to the long tapes or wires required for application.

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

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

IEE-CAS: Fe-based Sr-122 tapes or wires

Fabrication of Cu-sheathed Sr-122 tapes



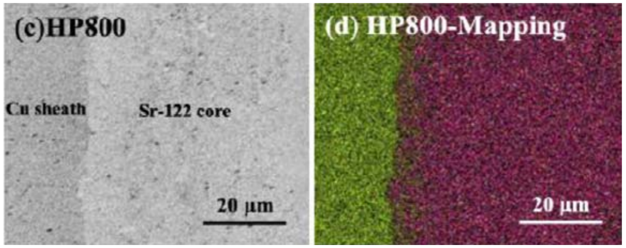
At 4.2 K, 10 T

Transport J_c:

3.1×10^4 A/cm^2

Engineering J_e:

$>10^4$ A/cm^2

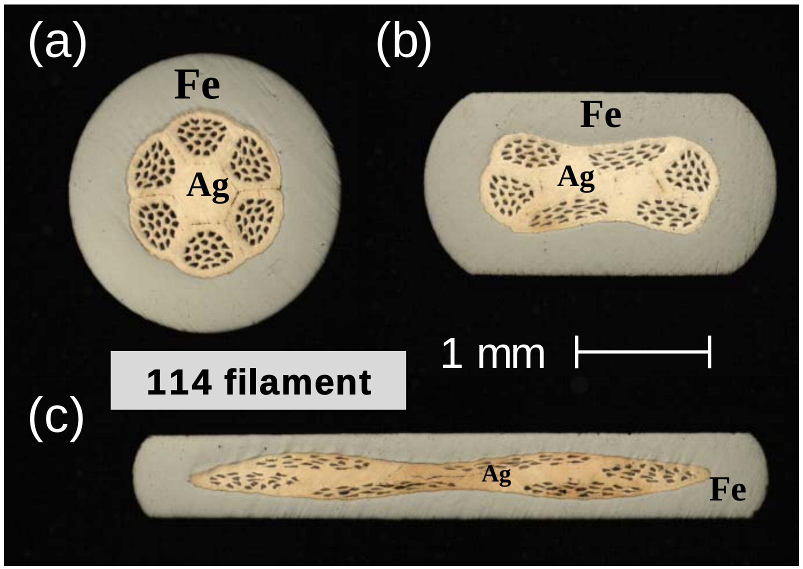


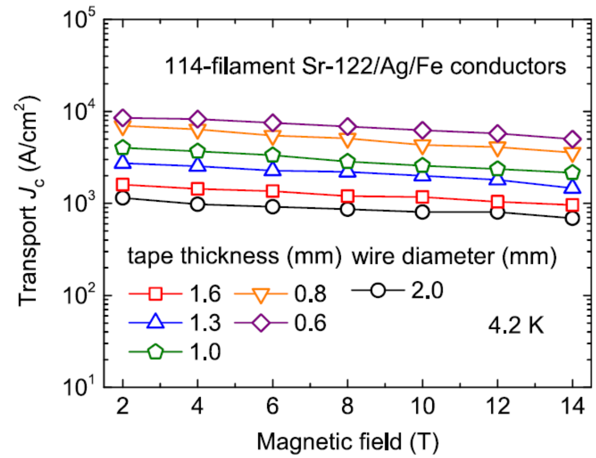
We obtained nearly phase-pure Sr-122 tapes with hot pressing at 800°C for 30 minutes. This rapid fabrication method can effectively thwart the diffusion of Cu into Sr-122 core.

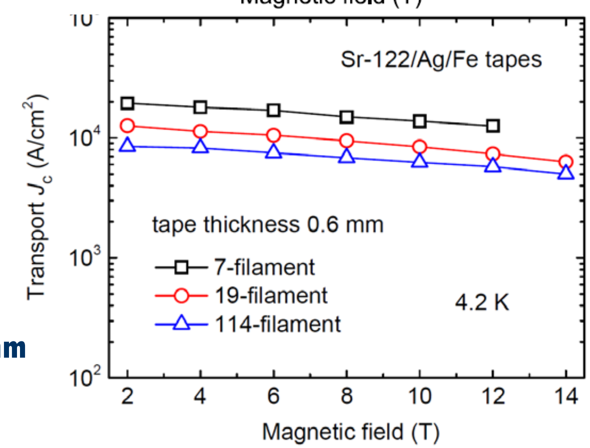
Lin, et al., *Sci. Rep.* 5 (2015) 11506

IEE-CAS: Fe-based Sr-122 tapes or wires

Fabrication of 114-filament Sr-122/Ag/Fe wires by the drawing and rolling







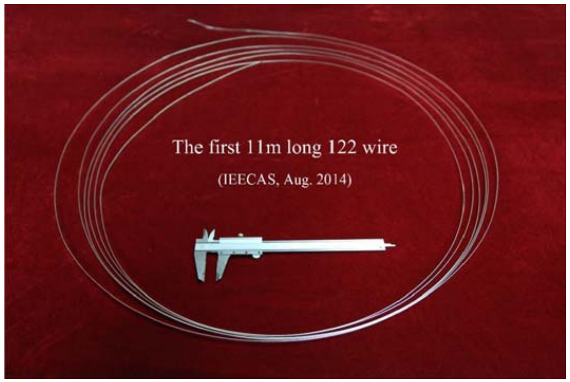
Yao et al., *JAP* 118 (2015) 203909

At 4.2 K, 10 T:

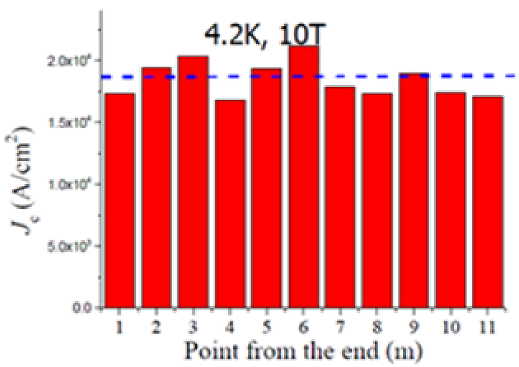
- 114-core round wires: J_c=800 A/cm^2.
- When they are flat rolled into tapes, the J_c grows with the reduction of tape thickness. the J_c =6.3×10^3 A cm^{-2} in 0.6 mm thick tapes.
- 7-core tapes: J_c= 1.5×10^4 A/cm^2.
- This J_c degradation can be ascribed to the sausage effect.

IEE-CAS: Fe-based Sr-122 tapes or wires

The first 11m long Sr-122/Ag tape

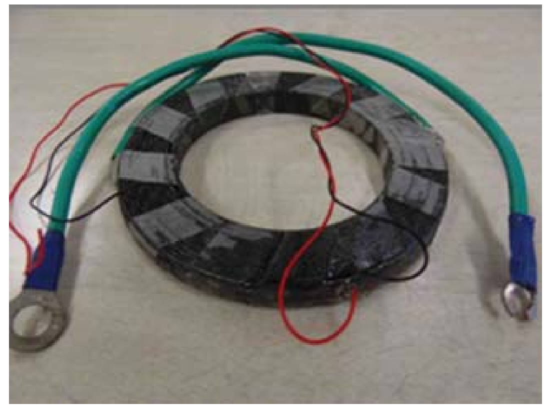


Uniform wires can be achieved.



The minimum J_c ~1.7×10^4A/cm^2

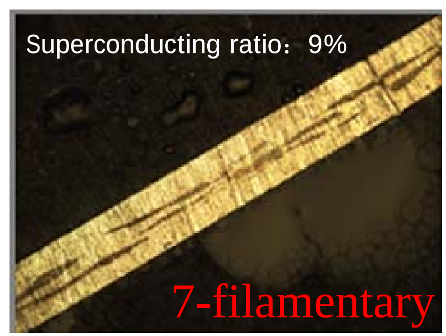
Test coil using 10 m long Sr-122/Ag tape



OD: 110 mm

ID: 71.5 mm

Turns:15×2



Length：10 m
Thickness：0.44 mm
Width：3.7 mm
Short tape I_c: ~100 A (4.2 K, 0 T)

The average J_c of this long Sr-122/Ag wire is ~ 18400A/cm^2

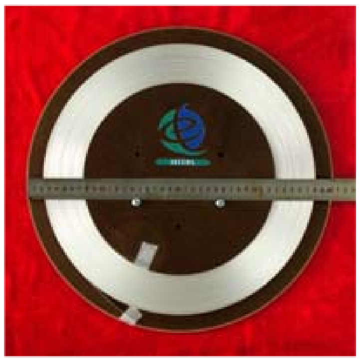
Ma , *Physica C* 516 (2015) 17

In Aug., 2016

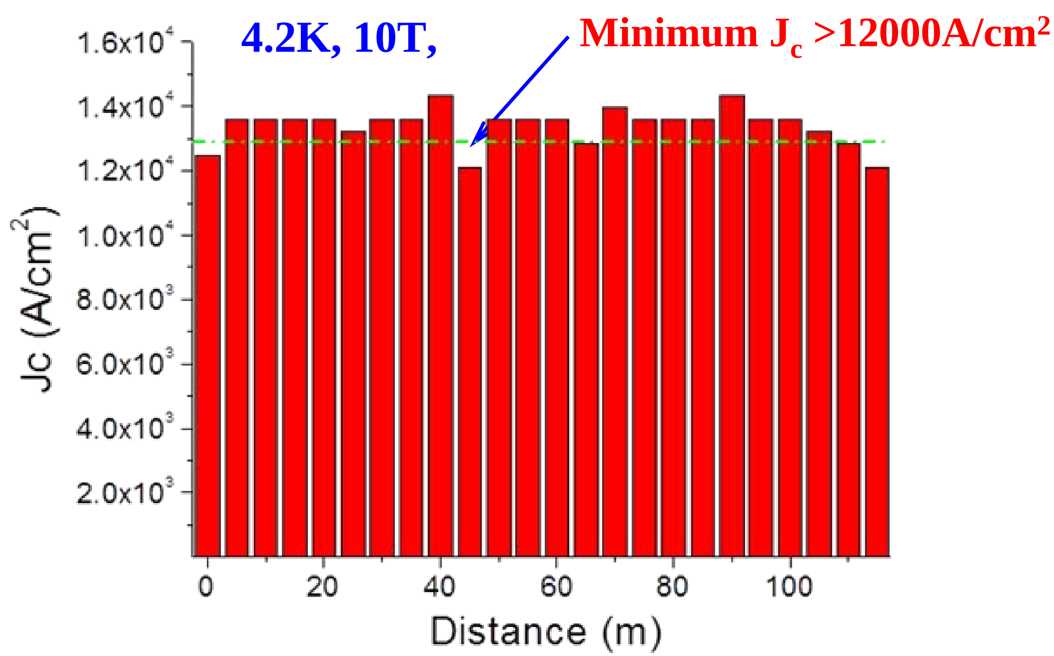
Significant Progress

IEE-CAS: Latest achievement-the first 100 m long Sr-122 tapes

100m long 7-filament wire



Iron-Based Superconductor



Transport Jc distribution along the length of the first 100 m long 7-filament Sr-122 tape

Superconducting Electronics in China

- Single Photon detectors (SNSPD, TES…)
- SQUIDs (MCG, Geophysics, ULF-NMR/MRI…)
- MW filters and subsystems
- Superconducting qubits
- THz
- Metrology

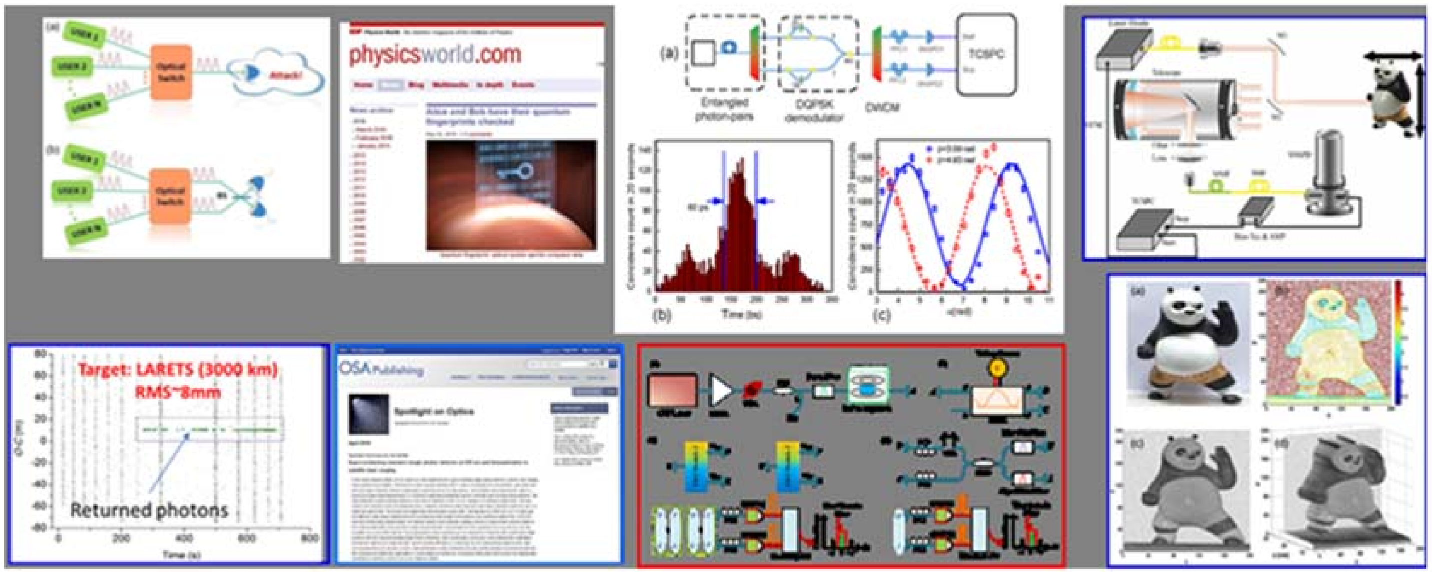
Nanjing University: Superconducting Nanometer-SPD

SNSPDs	Wavelength (nm)	System efficiency (%)	Time jitter (ps)	Repetition rate(Hz)	Detection area (μm^2)	Fiber
SNSPD/Si	1550	60 %	< 50	100 M	10×10	Single mode /multimode
SNSPD/Si	1550	60 %	< 50	50 M	15×15	Single mode /Multimode
SNSPD/Si	1650/ 1550	80% 72%	~ 70	10 M	30×30	Single mode /Multimode
SNSPD/MgF_2	532-1550 - 2700	> 30% > 1.6 %		40M	10×10	Single mode /Multimode
1×6 SNSPD	1550	> 40%				Single mode

Dark cunt rate: 100 cps
Temperature: 2.3K

Updated by 31th Dec, 2015.

SNSPD applications



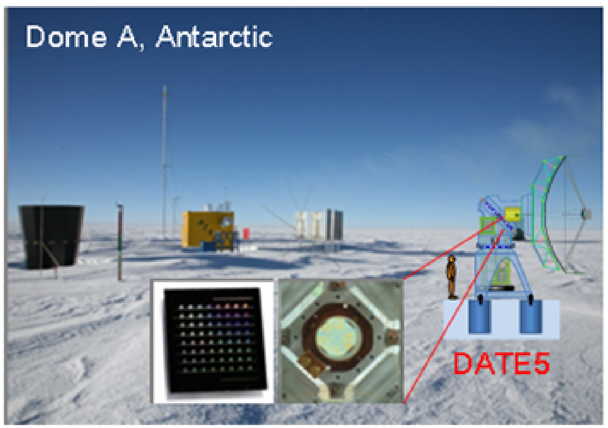
Multiple systems used in

-MDI-QKD (measurement device independent quantum key distribution)
-Quantum fingerprinting protocol for quantum communication
-Quantum source characterization
-Light detection and ranging (LiDAR)
-Photon imaging

Jian-Yu Guan et al, PRL 116, 240502 (2016); Hao li, et al, OE, 24, 3535(2015)

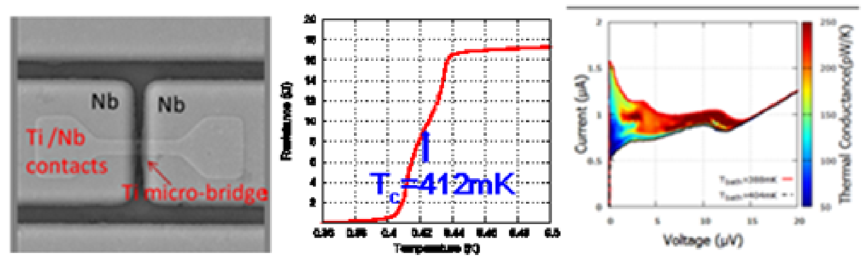
THz Superconducting Imaging Array (TeSIA) Developed for DATE5 Telescope

By Purple Mountain Observatory, CAS



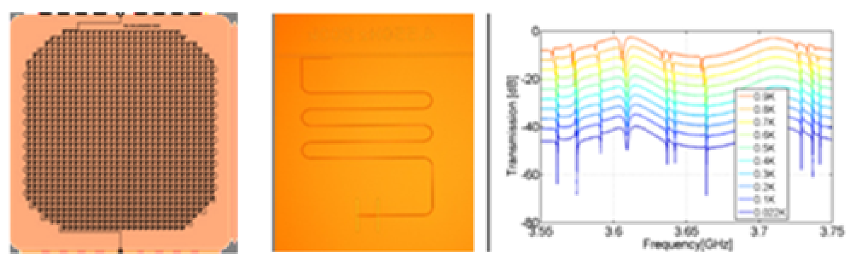
THz Superconducting Imaging Array (TeSIA)
Band: 0.9THz/350mm
Detector: MKIDs or TES
Sensitivity: ~1x10^{-16}W/Hz$^{0.5}$

Ti TES: NEP$_{dark}$≈6.5x10^{-17}W/Hz$^{0.5}$



Ti TES detector (l), measured R-T (m) & I-V/G-V (r)

TiN MKIDs: NET$_{dark}$≈1.6x10^{-6} K/Hz$^{0.5}$ @ 5kHz

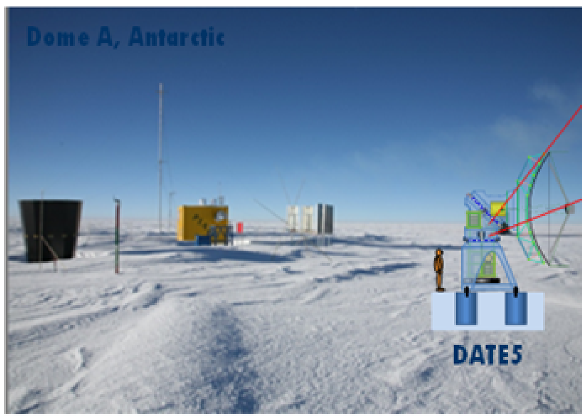


32x32 TiN MKIDs chip (l), a single resonator (m) & measured S21 characteristic at different bath temperatures (r, showing a few resonators)

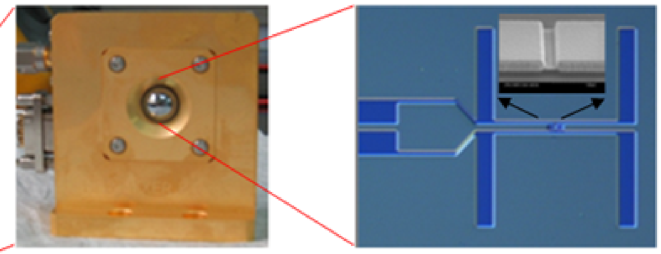
S.C. SHI et al., J Low Temp Phys (2015)
W. Zhang et al., J Low Temp Phys (2015)
J. Li et al., J Low Temp Phys (2015)

THz Superconducting Hot-Electron Bolometer (HEB) Mixer Developed for DATE5 Telescope

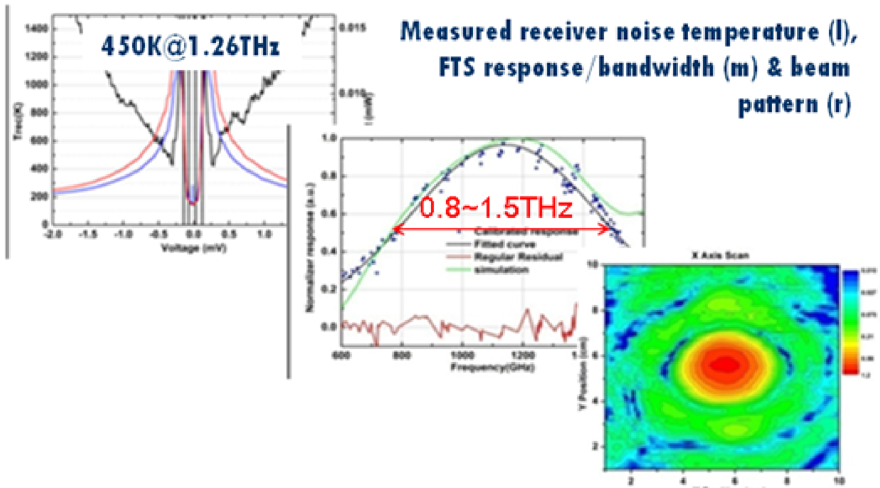
By Purple Mountain Observatory, CAS



China's planned observatory at Dome A, Antarctic, including a 5m THz Telescope (DATE5) operating at 0.9 & 1.4 THz



1.4THz superconducting HEB mixer (left) & NbN HEB device (right)

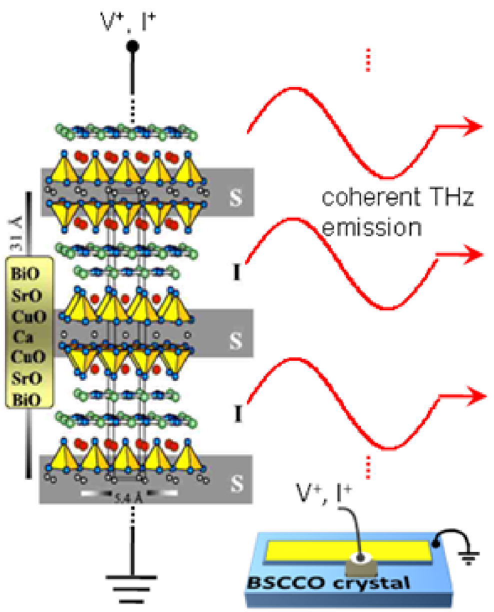


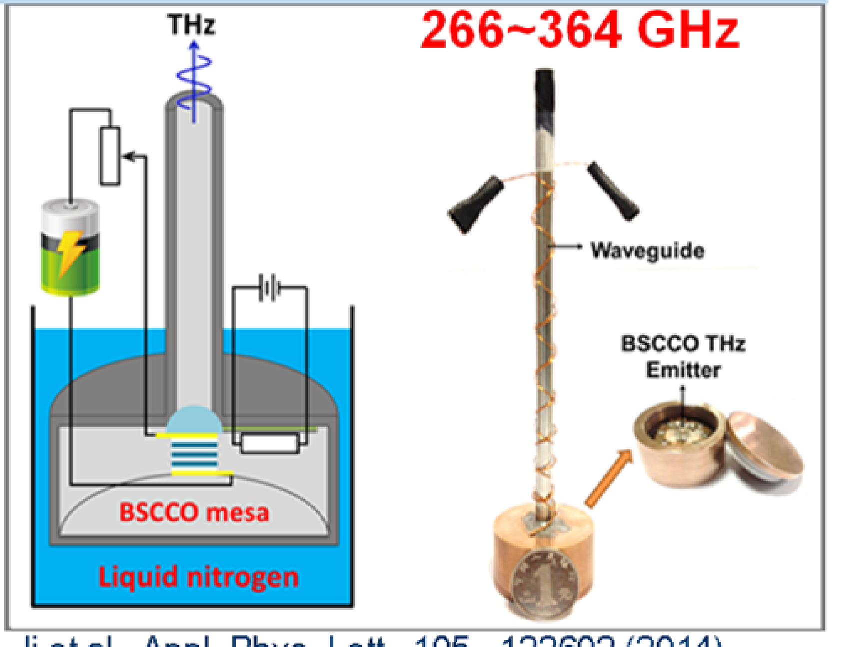
Measured receiver noise temperature (l), FTS response/bandwidth (m) & beam pattern (r)

K.M. Zhou et al., IEEE Appl. Supercond. 25/3 (2015)
W. Miao et al., APL 104, 052605 (2014)
Zheng Lou et al. Rev. Sci. Instrum. 85, 064702 (2014)

Nanjing Univ: THz torch operated in liquid nitrogen

"While intrinsic 'natural' junctions in BSCCO were discovered well over 20 years ago, the potential for the first truly attractive application as a portable THz source cooled by liquid N_2 has been demonstrated only recently (Hao *et al.*, 2015)" ------Alex I. Braginski, Handbook of SC Materials, Chapter E4.4.3, (2015)

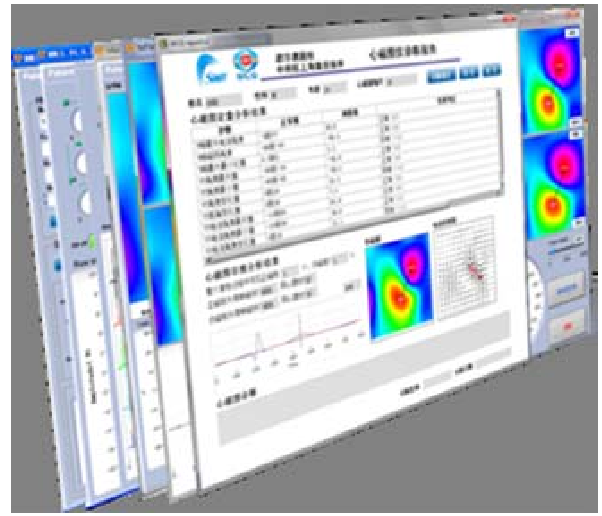




Ji et al., Appl. Phys. Lett., 105 , 122602 (2014)
Hao et al., Phys. Rev. Applied, 3, 024006 (2015)

Nanjing Uni., NIMS, and Tuebingen Uni.

SIMIT-CAS: MCG system development and applications



4-9 chn SQUID gradiometer based MCG systems under clinical trials

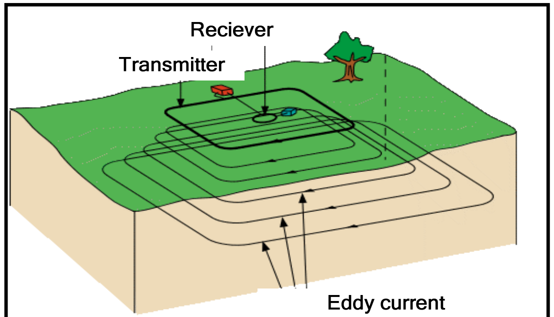
- 4 chn system installation: Shanghai sixth hospital, Beijing 309 hospital

- 9 chn system installation: Shanghai Xuhui and Jiangding central hospitals

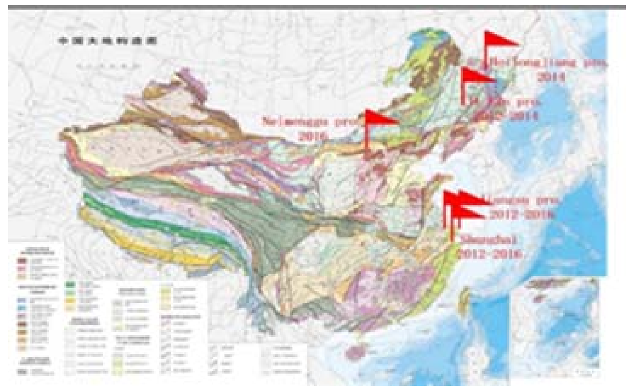
36 chn SQUID magnetometer based MCG system under optimization

4 chn feto-MCG prototype developed

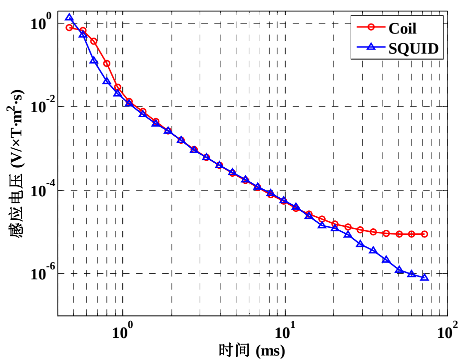
IMIT-CAS/PKU: SQUID geophysical applications – TEM



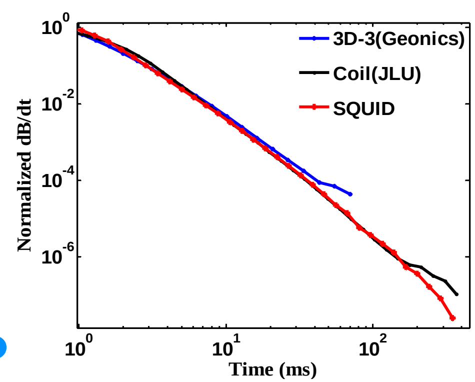
SQUID: excellent deep resource prospecting

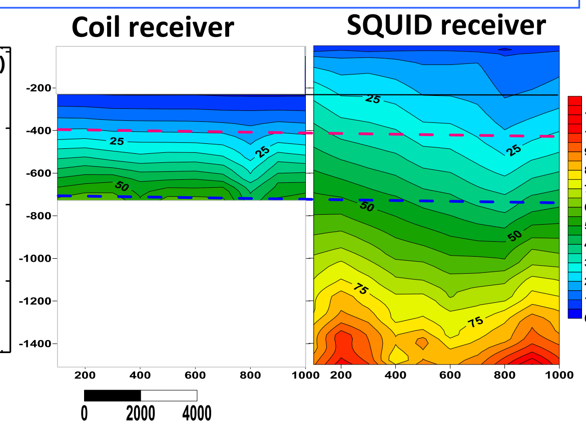


Medium resistivity (>100Ω·m)



Low resistivity overburden (<100Ω·m)

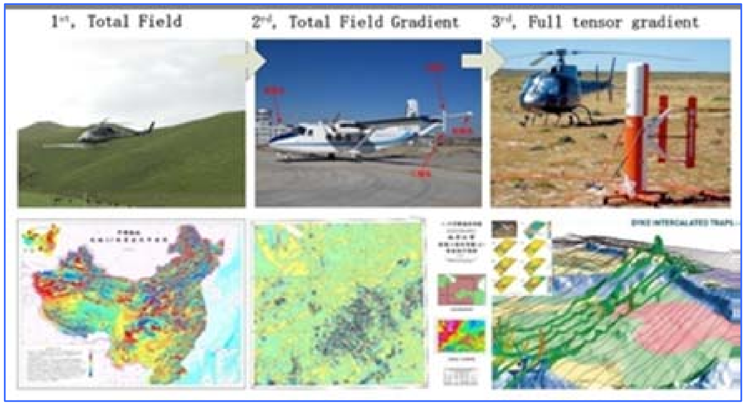




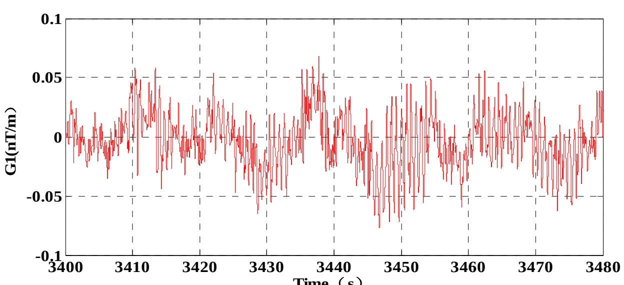
SQUID receiver demonstrates superior capability for high resolution conductivity measurements for both deep and shallow regions compared to coil receiver

SIMIT-CAS: Full tensor system for aeromagnetic

Development for aeromagnetics

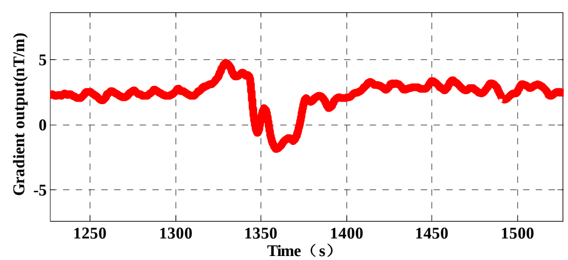


Full tensor system developed by SIMIT

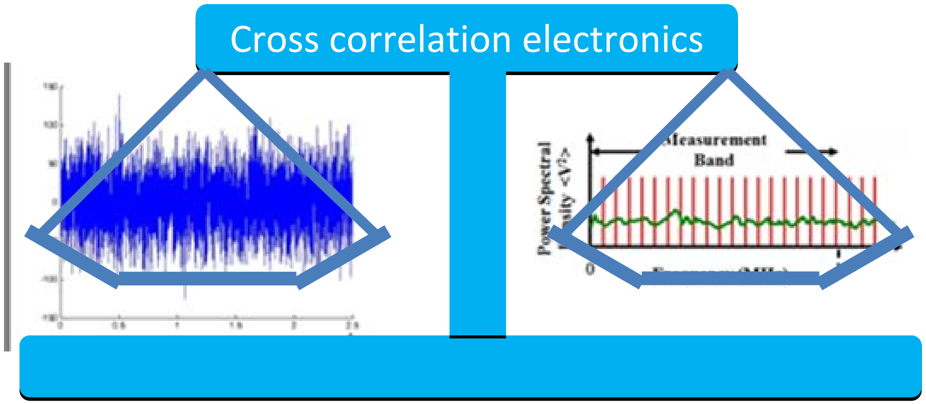


System resolution
< ± 0.05 nT/m

A 4nT/m geological anomaly detected by FTG system@ 200m



NIM: Quantum voltage calibrated noise thermometer



Johnson noise $\langle V_R^2 \rangle$ Quantum voltage noise $\langle V_Q^2 \rangle$

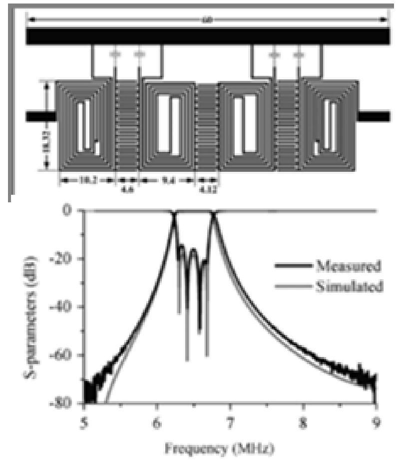
$$k = \frac{\langle V_R^2 \rangle}{\langle V_Q^2 \rangle}\Bigg|_{f=0} \frac{\langle V_Q^2 \rangle_{cal}}{4TR}$$

- **NIM-NIST collaboration**
- **Determine k_B through comparing the Johnson noise to the quantum accurate voltage waveform synthesized with AC-Josephson Voltage Standard.**
- **Relative uncertainty of 3.9×10^{-6}, contribute to CODATA2014**

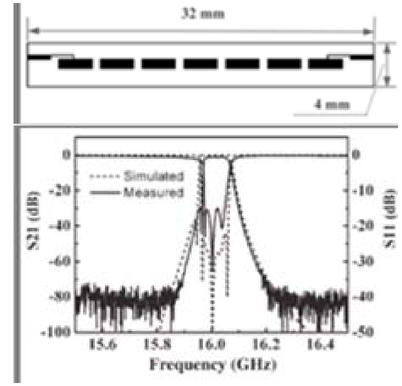
Qu et al., *Metrologia* 52 S242 (2015)

R&D for HTS filter in China

- **HTS filters**

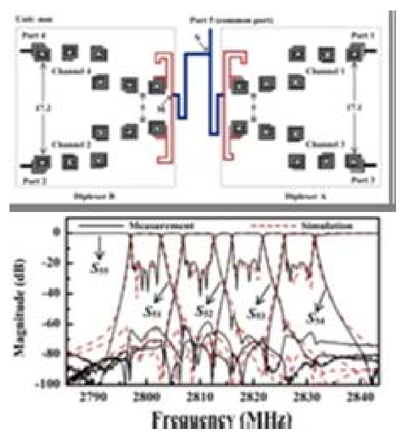


HF (6.5 MHz) HTS Filter

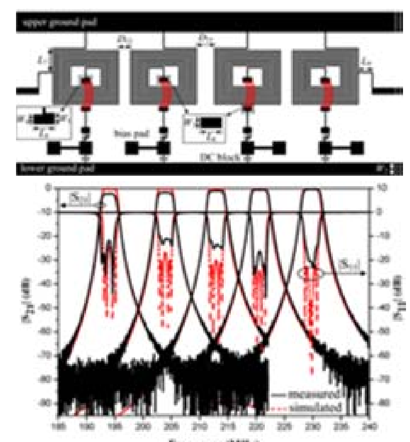


Ku (16 GHz) HTS Filter

- **HTS filter systems**



S-band HTS Quadruplexer

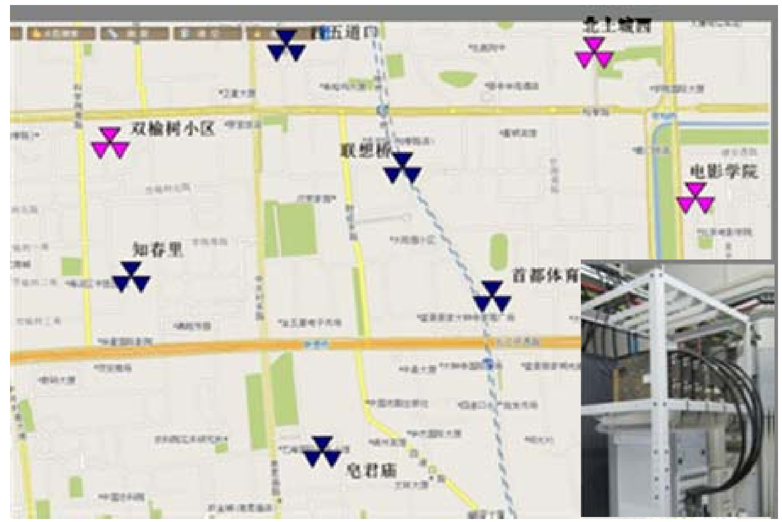


HTS Tunable Filter

Application of the HTS filter in Beijing & Guangzhou

- **Field test of HTS filter subsystems in eight CDMA base stations (BTS) in urban area of Beijing**

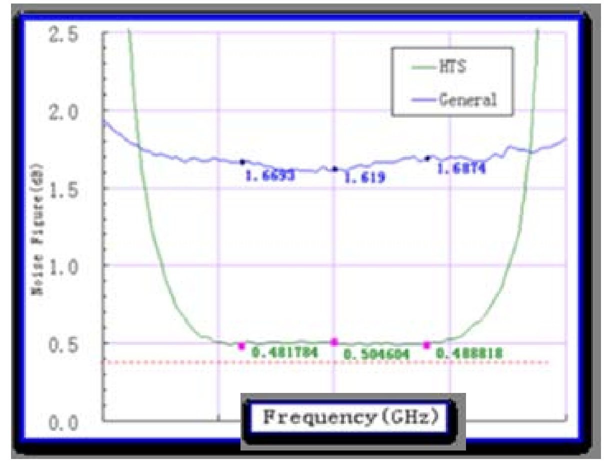
The Mobile mean Tx power decreases 4.2 dB



- **Recent years, Development of HTS filter systems for 4G LTE mobile base stations in Guangzhou, cooperating with China Unicom.**

IOP-CAS: HTS Microwave Applications in Civilian Satellites

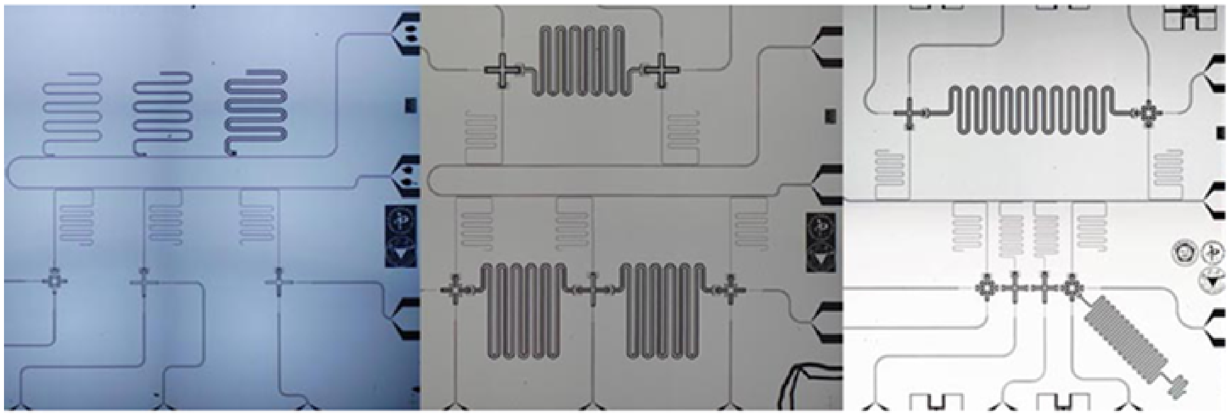
Comparison test between HTS and conventional satellite receiver front-end was carried out in 2005. Results showed a reduction of noise temperature of 73% (from 129 K to 35 K).



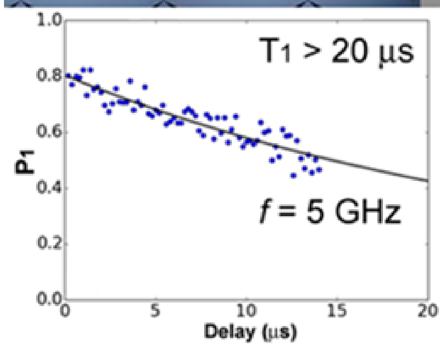
On October 14,2012, our HTS filter subsystem was launched into Space with a Chinese Experimental Satellite (SJ-9). This is the first space experiment for HTS device in China.

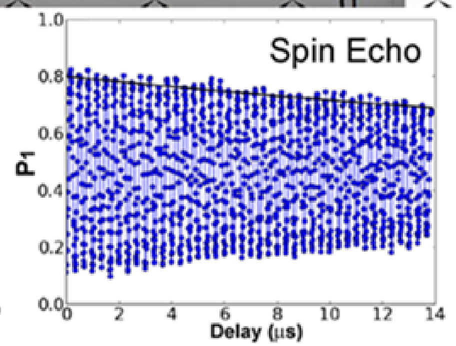
The HTS subsystem as a payload of the Chinese space laboratory has been developed and will be launched in 2016.

OP-CAS/ZJU/USTC: Xmon Qubit



3 qubits,
5 qubits,
6 qubits,
10qubits
……





--Based on the quantum chip, we succeeded in demonstrating an quantum HHL algorithm .

--More designs are in fabrication.

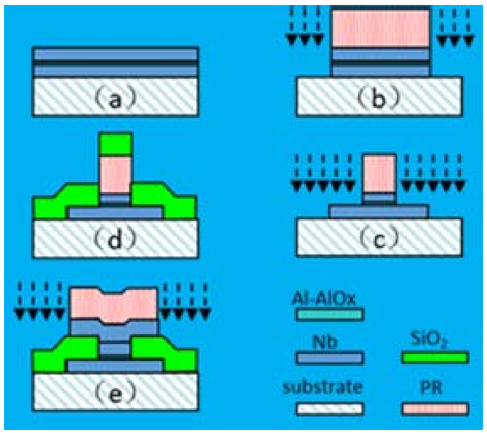
- ✓ Xmon qubits: Best T_1 above 20 μs (10 – 20 μs on average),
  T_2^* above 10 μs (5 - 10 μs on average).
- ✓ Single-qubit gate fidelity above 99.5% (RB).

Nat. Commun. 7, 11018 (2016)

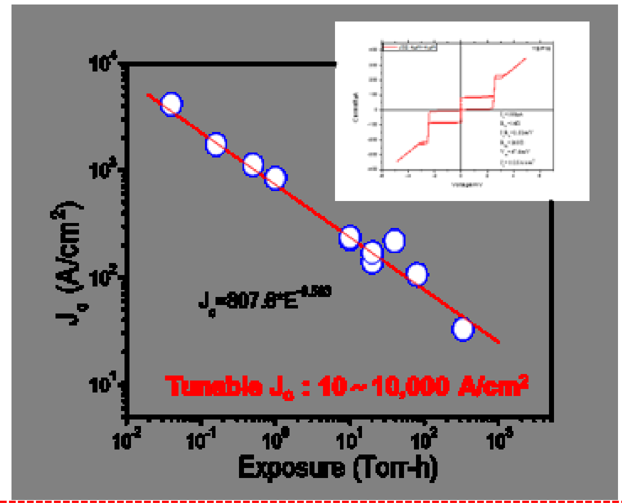
T_1 = 10 μs, T_2^* = 5 μs

SIMIT: Nb/AlOx/Nb and NbN/AlN/NbN junctions

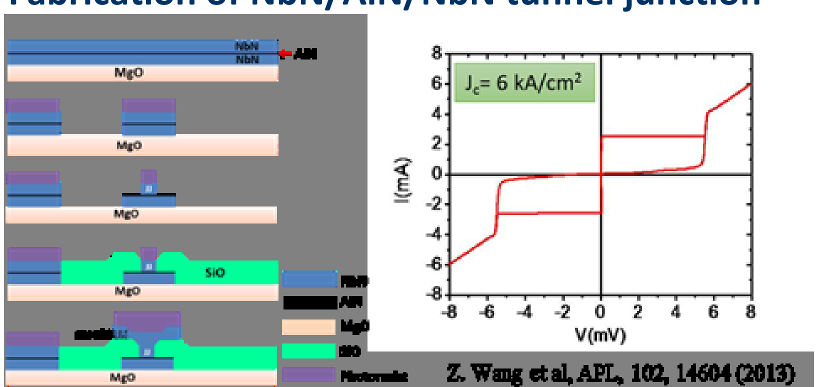
Nb/AlOx/Nb tunnel junction with tunable critical current density



X. J. Kang et al., **Physica C,** 503, 29-32 (2016).



Fabrication of NbN/AlN/NbN tunnel junction



Z. Wang et al, APL, 102, 14604 (2013)

V_g=5.53mV, I_cR_N=3.4mV

V_m=68.8mV, R_{sg}/R_N=20

Large-Scale Application in China

- Power Application;
- Fusion Magnet;
- Accelerator Magnet;
- MRI/NMR;
- High Field Magnet;
- Other Applications;

IEE-CAS: The First Superconducting Power Substation

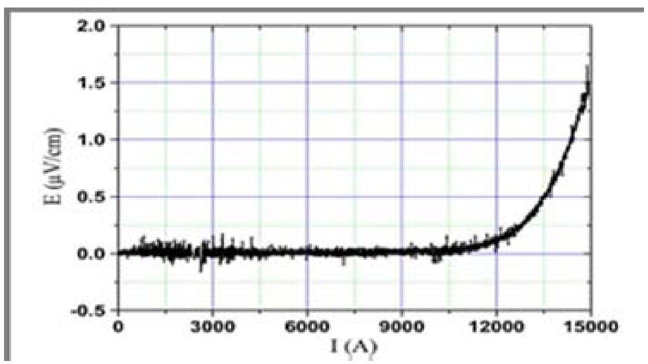
1MJ SMES

10kV HTS FCL

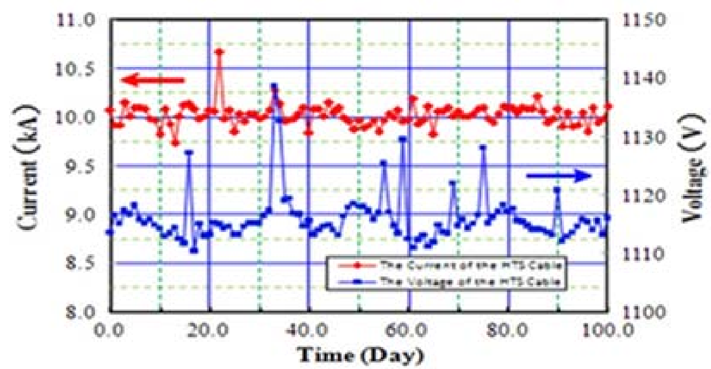
10kV HTS Transformer

75m/10KV Power Cable

IEE-CAS: 360m/10kA DC Superconducting Power Cable



Ic Test of the Cable



Operation of Cable

—The Cable was demonstrated at Zhongfu Aluminum Electrolyzer Workshop;
—Demonstration shows it can save 65% of transmission losses compared with the conventional cable;

Innopower: 220kV AC-SFCL (Saturated Type)

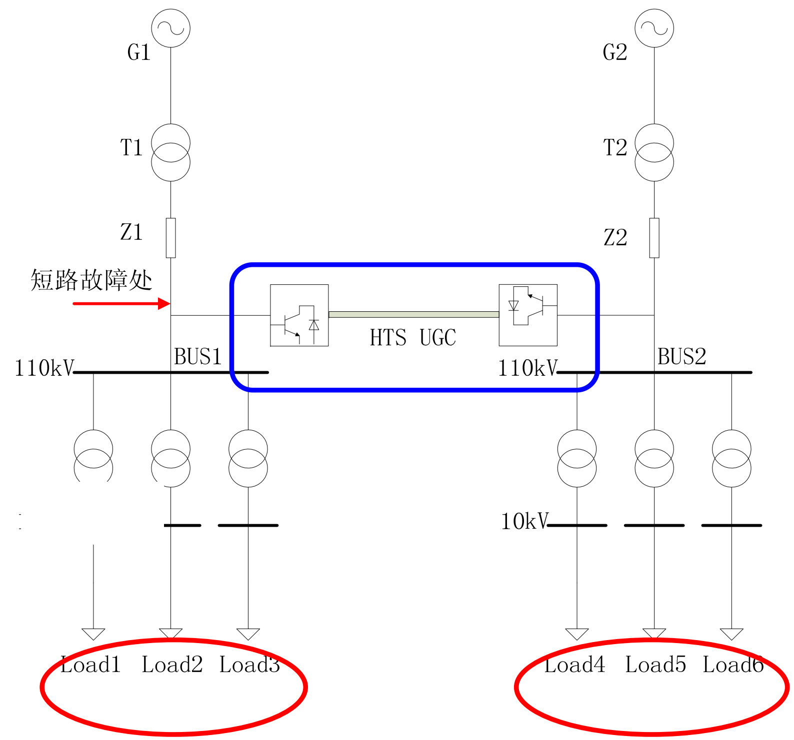
Parameters	Specifications
Rated voltage (kV)	220
Rated current (A)	800
Rated frequency (Hz)	50
Insulation grade	A
Impedance at power transmission (Ω)	1.85
Max. prospective fault current (kA)	50
Max. limited fault current (kA)	30
Limiting action time	Immediate
Recovery time (ms)	500
Total weight(t)	120
Installation volume L×W×H (m^3)	8×8×9

Innopower: 220kV AC-SFCL (Saturated Type)

In 2012, the 220kV/300MVA SFCL was manufactured and installed at Shigezhuang substation of Tianjin, in grid operation.

singhua University: Closed-loop Distribution by HTS DC Cables

HTS DC Cables + VSC-HVDC



Advantages:

1) reducing backup capacity of 110kV lines;

2) improving quality of bus voltage;

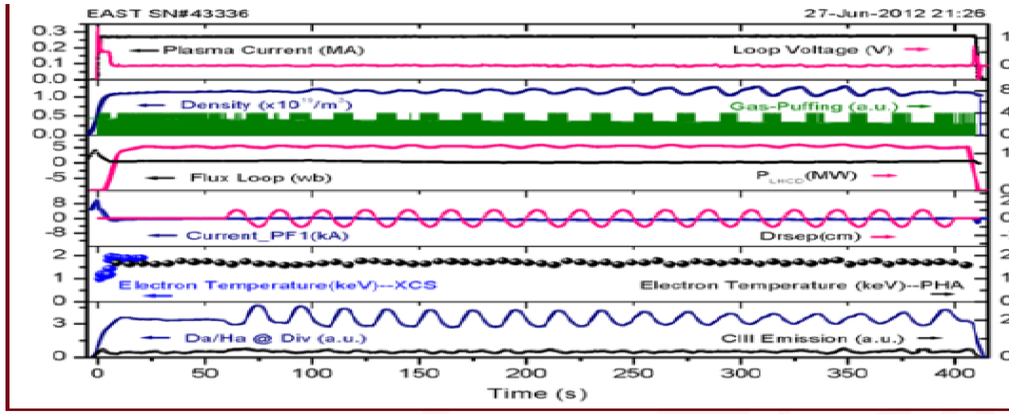
3) reducing oscillations after a fault;

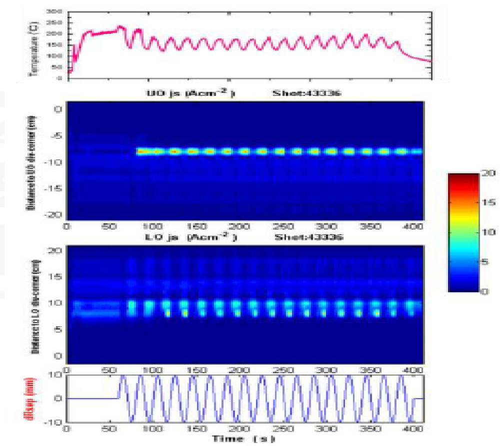
4) enhancing reliability and security.

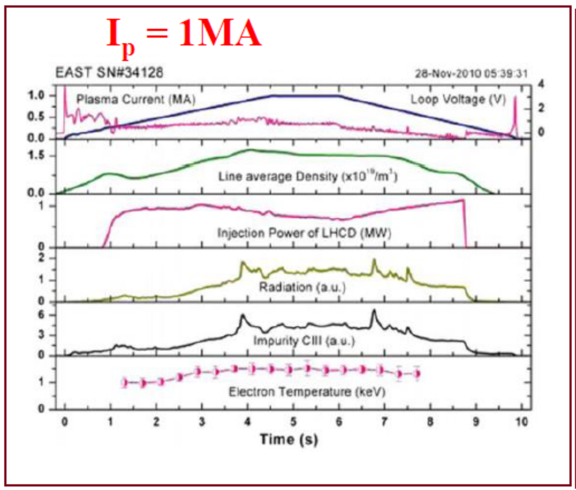
Project is ongoing

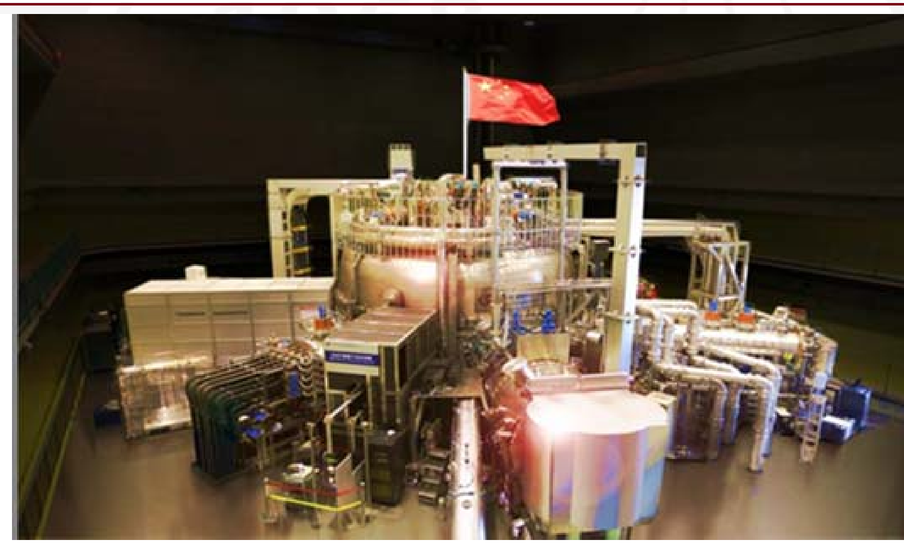
IPP-CAS: Experimental Advanced Superconducting Tokamak (EAST)

411 sec. Steady state operation



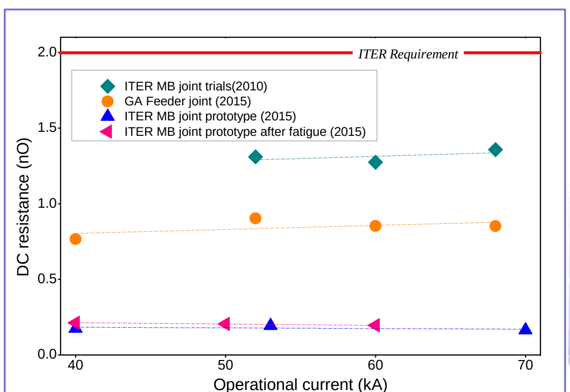






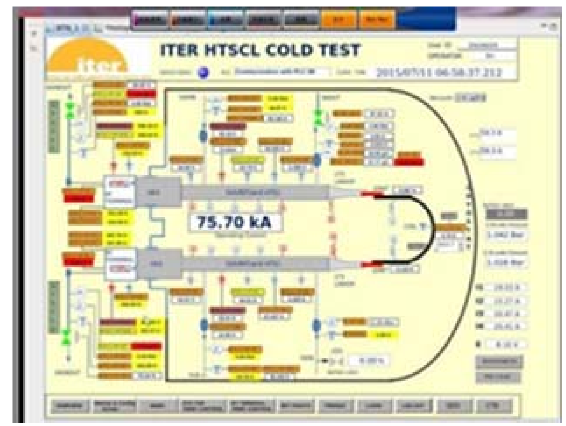
IPP-CAS: ITER Superconducting Feeder

- The qualified 68kA & 10kA HTSCL, superconducting joint and other key components have been completed, and the feeder has been in fabrication for ITER.

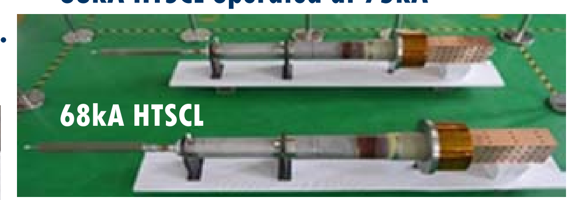


Test results of joint resistance

Overview of Feeder
>1600 tons, >60 thousands of parts.



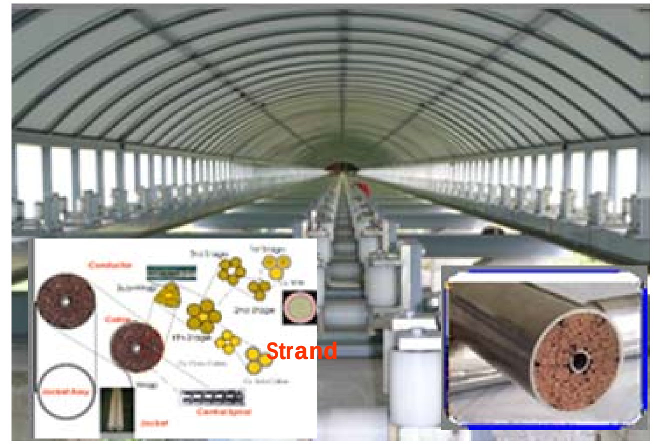
68kA HTSCL operated at 75kA



Twin boxes superconducting joint

IPP-CAS: ITER Superconducting Conductor

- **TF conductor PA: 11 conductors, 7.5% of ITER TF conductor**
- **PF conductor PA: 60 conductors of PF/2/3/4 and PF5, 69% of ITER PF conductor;**
- **Correction Coil (CC) and Feeder conductor PA: 18 CC conductors, 3 Main Busbar and 2 CC Busbar conductors**



1000 meters' winding production lines

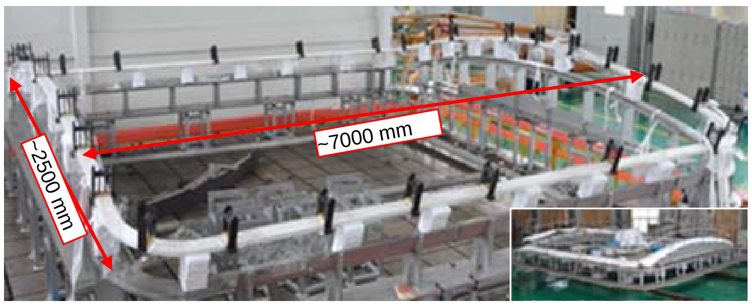
Winding of PF2/3/4 conductor

ITER Conductor

6 TF conductors, 15 PF conductors, 14 CC conductors, and 5 Feeder conductors' production and acceptance test have been completed. 26 conductors have been accepted by ITER and delivered.

IPP-CAS: ITER Correction Coil & PF6 Coil

- Composed of 18 coils, made from NbTi superconducting cable.
- The series production has been started from 2016.



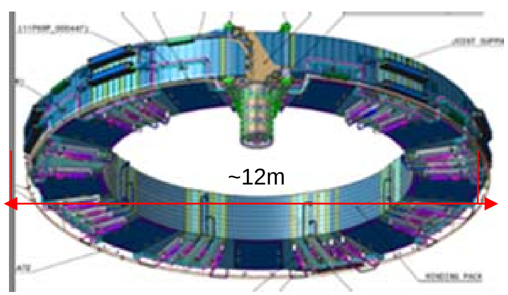
Coil after winding

Dummy coil after VPI

Automatic welding of coil case

Insulation qualification

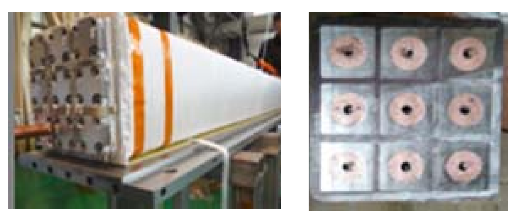
ITER PF6 Coil



PF6 Coil (~400tons)

Winding platform

Vacuum chamber for leak check



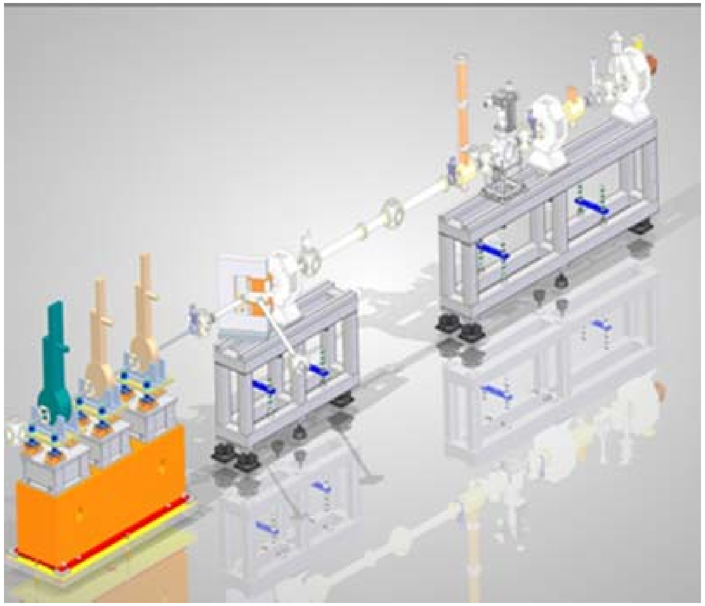
Short 3*3 trial VPI mock-up

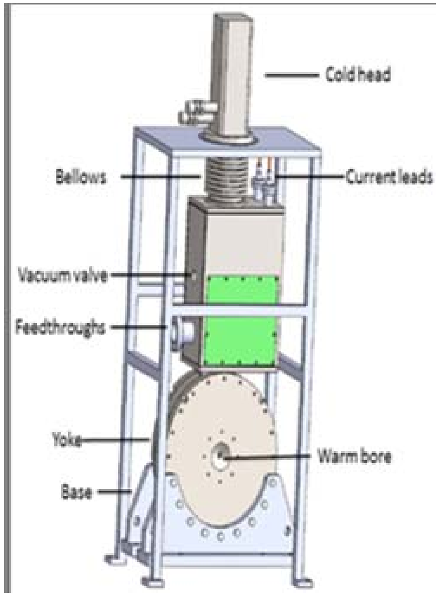
- Short 3*3 trial VPI mock-up which has passed 90kV(acceptance criteria is 5.7kV) high voltage test
- The qualification of dummy coil is on going.

IHEP-CAS:HTS Solenoid Lens

for Electron Microscope in Shanghai Jiaotong University

- The HTS solenoid magnet is designed to focus the high energy electron beam for the ultra-fast electron microscope.
- The double-pancake Bi-2223 HTS coil and iron yoke design, with 2T.





MRI in China: typical products, 1.5T MRI System

	BASDA Bstar-150	AllTech Centauri	Anke SuperNova 1.5T	XGY SuperScan-1.5T	Neusoft NSM-S15
1、 magnet					
Magnetic field	1.5T	1.5 T	1.5 T	1.5 T	1.5 T
homogeneity （ppm）	45 cm dsv < 8ppm	45 cm dsv < 10 ppm	45 cm dsv < 15 ppm	45 cm dsv < 15 ppm	45 cm dsv < 8 ppm
2、 gardient					
Switch rate	130T/m/s	105T/m/s	93T/m/s	110T/m/s	82T/m/s
3、 sequence					
Imaging matrix	1024X1024	1024 True with standard protocols.	1024X1024	1024X1024	1024X1024
FOV	450mm	400 mm	420mm	440mm	450mm
4、 RF system					
# of channel	8~16	8	8	4	8

MRI in China: typical products, 1.5T MRI System

Country	The installed units of MRI / one million people
Japan	38
US/EU	54
Korea	7
China	3

The potential market for MRI in China will be a big number.

Tsinghua University: a 7 T Animal MRI Magnet

Magnetic Field Intensity： 7.0±0.05T

Magnetic Field Uniformity: <5 ppm（80 mm DSV）

Air Bore: 160 mm

Stability of magnetic field: <0.1 ppm/hr

Intensity of gradient: 100 mT/m

Gradient linearity: <±5%（80mm DSV）

Gradient switching rate: 500 mT/m/ms

IEE-CAS: magnet for NMR with Cryocooler

1) Zero liquid helium boiling-off
2) Center field from 7-11.75 T

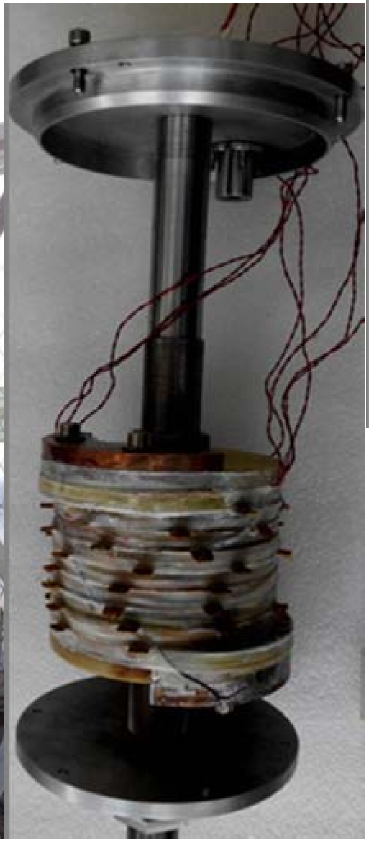
PARAMETERS FOR SUPERCONDUCTING MAGNET	
Magnetic field	11.75T
Available bore	54mm
Operating current	103.7A
Stability of magnetic field	10^{-6}/h
Homogeneity	0.2 ppm in diameter of 50 mm
5G line in axial	1.8m
5G line in radius	1.2 m
Operating temperature	4.2 K
PTR cooling capacity	1.0W/4.2 K
Liquid helium boiloff	Near zero
Superconducting wire	Nb3Sn/NbTi

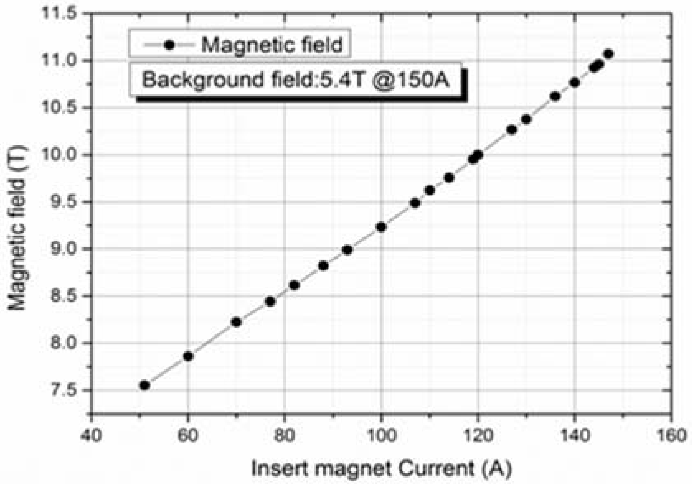
	Bruker	IEE-CAS
NMR Frequency	400 MHz	400MHz
Drift	8 Hz/hr	0.7~4 Hz/hr
SC shim coils	Z_1, Z_2, Z_3, X, Y, ZX, ZY, XY, X^2-Y^2	Z^1, Z^2, Z^3, X, Y, ZX, ZY, XY, X^2-Y^2
Radial 5G Stray Field from Magnet Center	55 cm	53 cm
Axial 5G Stray Field from Magnet Center	100 cm	100 cm
System weight	651 kg	491 kg
LHe volume	95 /	61
LHe hold time	270 days	3 years
LHe hold time	14 days	No
LN2 refill	58 /	0
Vibration	Set anti vibration leg	anti vibration leg + inner struct.

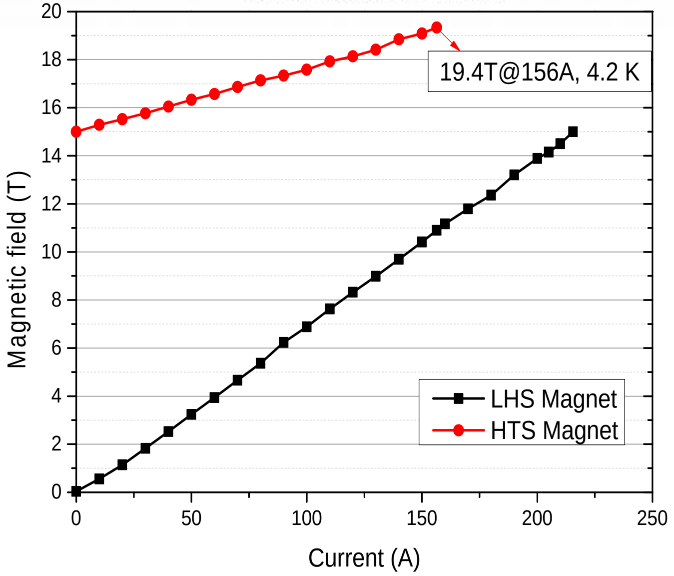
IEE-CAS: 19.8T superconducting magnet system with HTS insert

YBCO+ Bi2223/11T/40mm

Bi2223/4.8T/35 mm



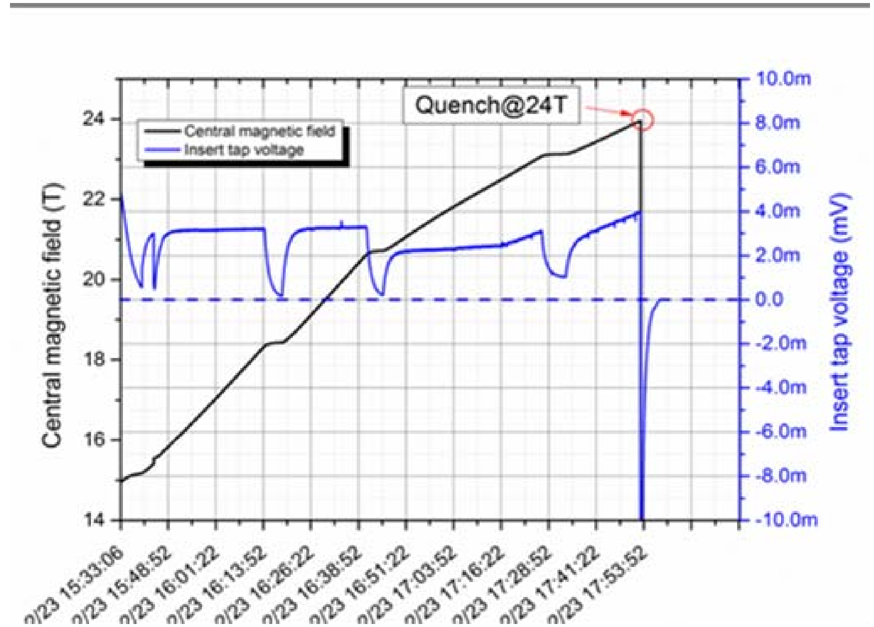




Background magnetic field 15 T

IEE-CAS: 24.3T superconducting magnet system with HTS Insert

YBCO Insert in 9 T/40 mm Background B =15 T/160mm



IHEP-CAS: HGMS for kaolin mine purification

Kaolin	Fe%	Ti%	Al%	others
Raw ore	0.73	0.04	37.77	yellow
Product	0.49	0.01	37.88	Concentration,15% Flow velocity, 3.0cm/s Filling rate,6% dispersant,2‰

Nepheline syenite	Fe%	Ti%	Al%	others
Raw ore	8.25	/	/	black
Product 0# (0.5T)	6.54	0.69	18.81	Concentration,15% Flow velocity, 1.5cm/s Filling rate,6% dispersant,3‰
Product 1# (2.5T)	1.23	0.01	21.18	
Product 1# (5.5T)	0.37	0.01	19.99	

Content

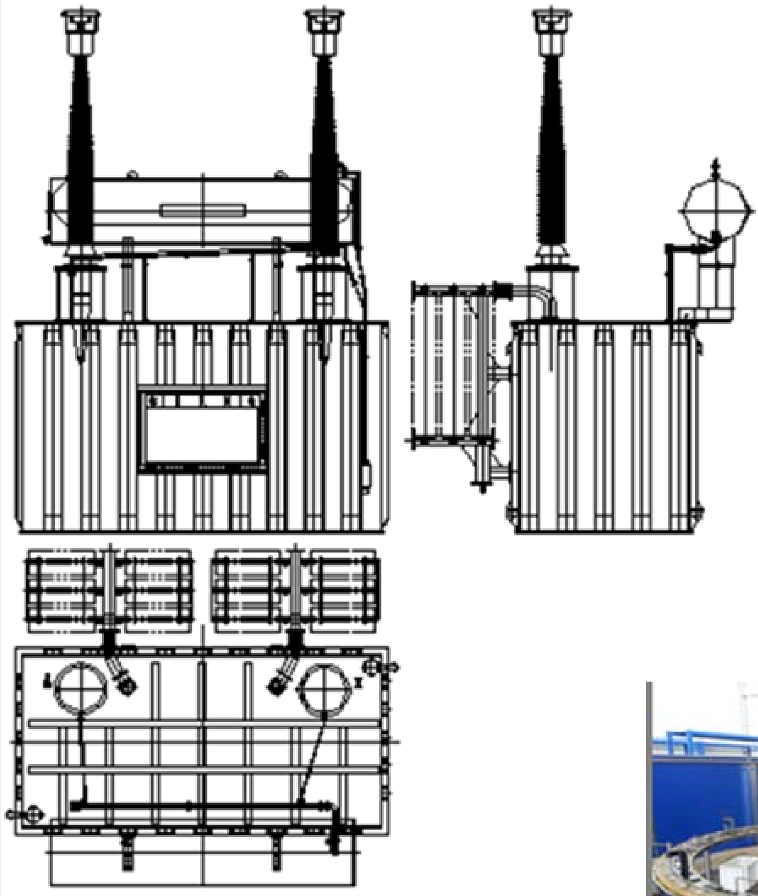
✓ Overview of Research Teams and Financial Support;

✓ Recent Progresses at Materials, Electronics and Large-scale Application;

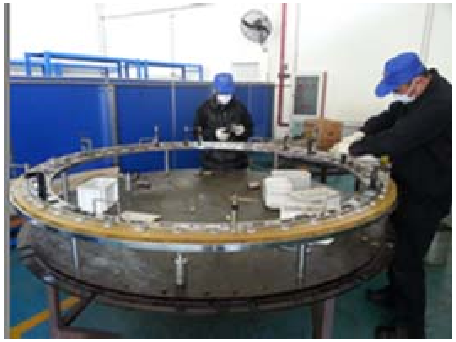
➡ Near Future Progresses, Plans or Proposals;

➡ Summary

South Power Grid: 500kV AC-SFCL (Saturated Type)



Weight of core and windings	155t
Weight of oil	96t
Transport weight	200t
Total weight	320t
Outline:L×W×H	9m × 7.5m × 11.5m
Transport dimension:L×W×H	8.8m×4.5m×4.8m



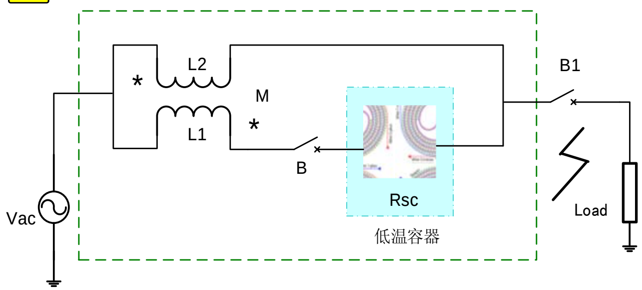
IEE-CAS/Xi'An Electric: 1MJ FCL-SMES for wind power

Major parameter:
(1)Power rating :1MVA
(2)Energy storage capability: 1MJ
(3)Operational voltage level: 10kV
(4)Fault current limiting rate:⩾ 50%
(5)Fault current endurance time:⩾100ms
(6)Response time: ⩽2ms
(7)Efficiency: ⩾90%
(8)Total harmonic distortion:⩽5%


Superconducting coil


Power conditioning system

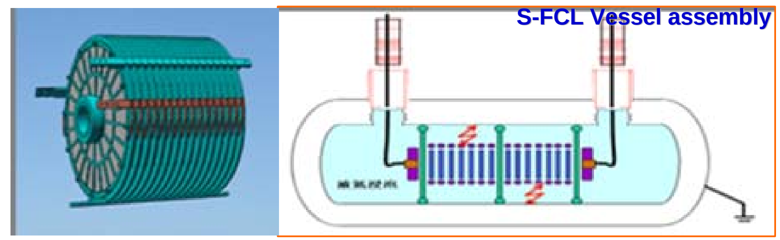
IEE-CAS/Zhongtian Group: 220 kV/1.5kA AC Resistive FCL

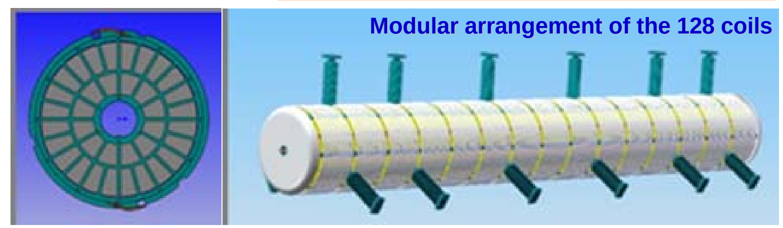


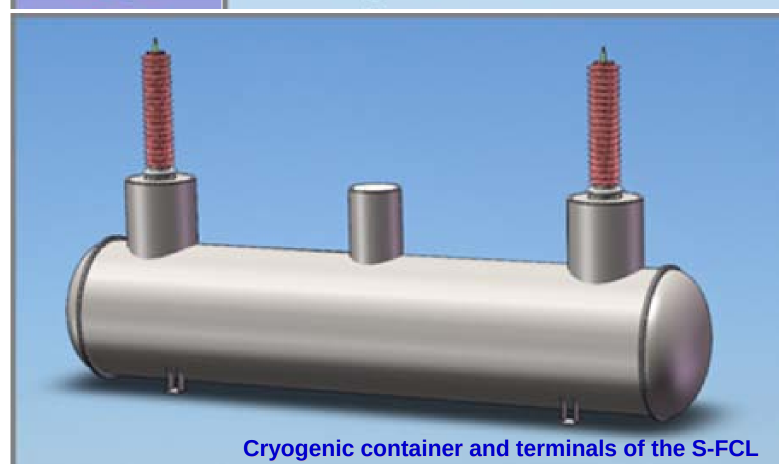
Schematic diagram of FCL

The main parameters of the FCL

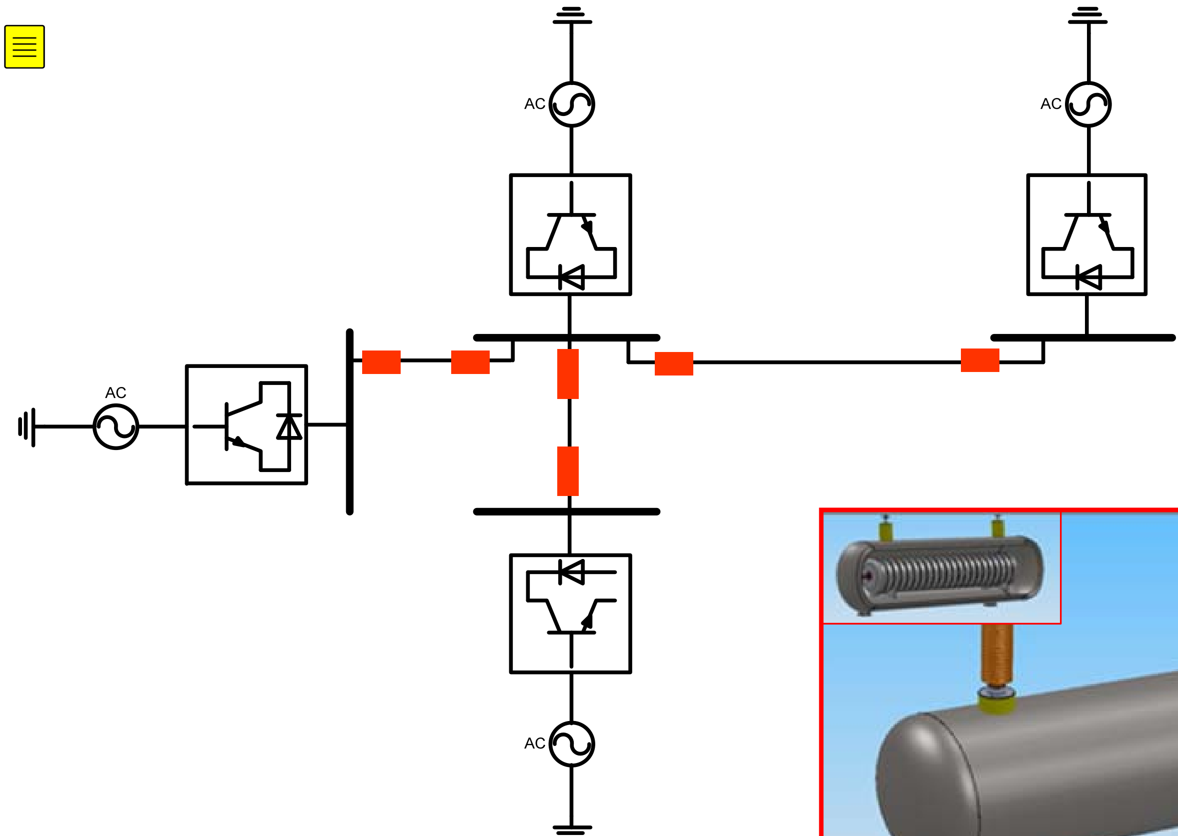
Items	Parameters
Rated Voltage	220 kV
Rated Current	1.5 kA
Prospective Current	63 kA
Current-Limiting Impedance	2.74-3 Ω
$R_{supercond}$	18Ω（40-60ms）
Lasted for Super. Element.	30-40 ms
12 mm wide steel-stabilized YBCO conductor	11 km
Bifilar Coils	128
Cryogenic vessel	Ø2.5 m/11 m

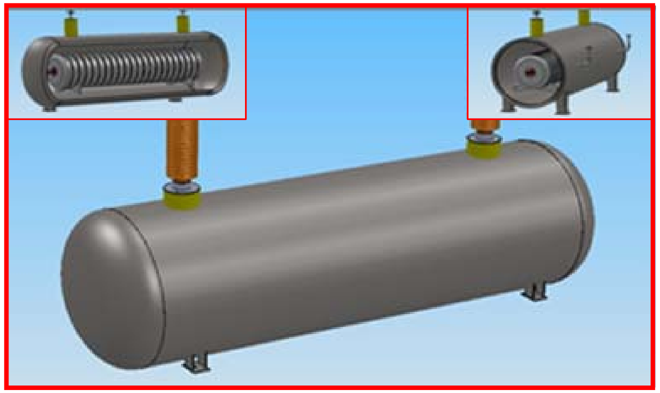






DC Superconducting fault current limiter for VSC-HVDC Grid 160~200kV/1kA



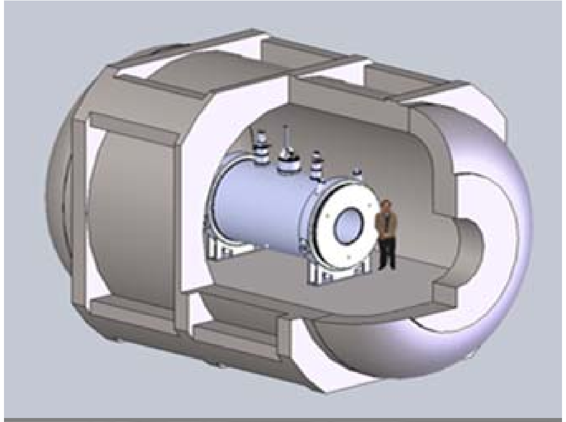


HTS DC Resistive FCL

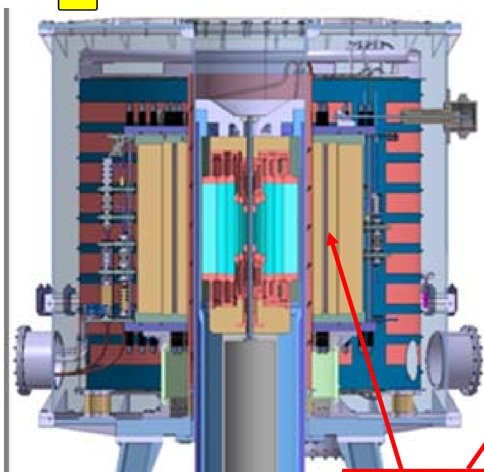
IEE-CAS/IBP-CAS: 9.4 T MRI System

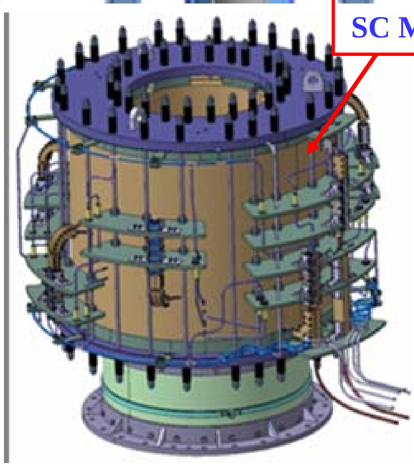
Design of the Magnet

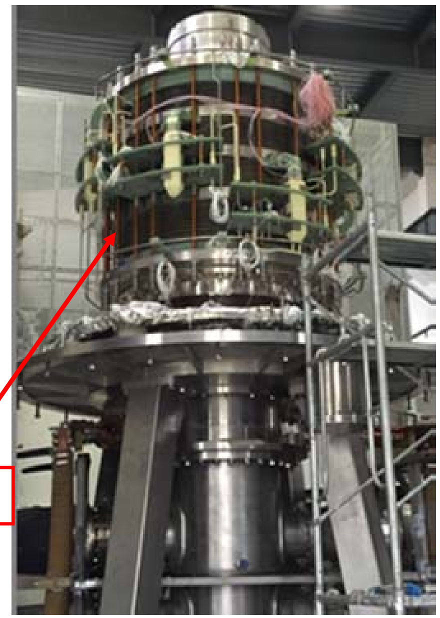
Length of magnet	3500 mm
Height of magnet	1842 mm
Center field	9.4 T
Warm bore	800 mm
Total turn	118764
Total inductance	5286 H
Stored energy	138 MJ
Volume of LHe	~ 1000 l
homogeneity	<±0.1ppm(DSV 300mm)
Stability of field	<0.02ppm/h
Weight of Magnet	25 ton

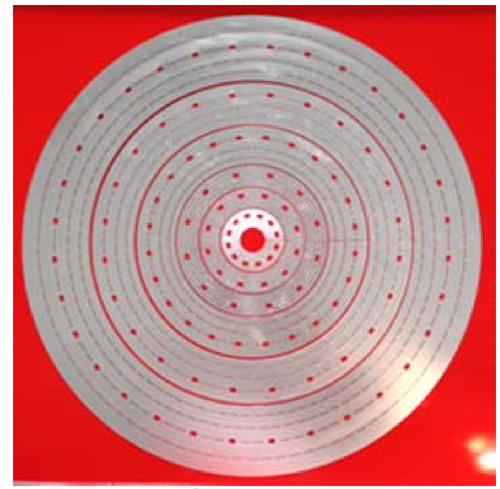


China High Magnetic Field Laboratory-CAS: 45 T Hybrid Magnet



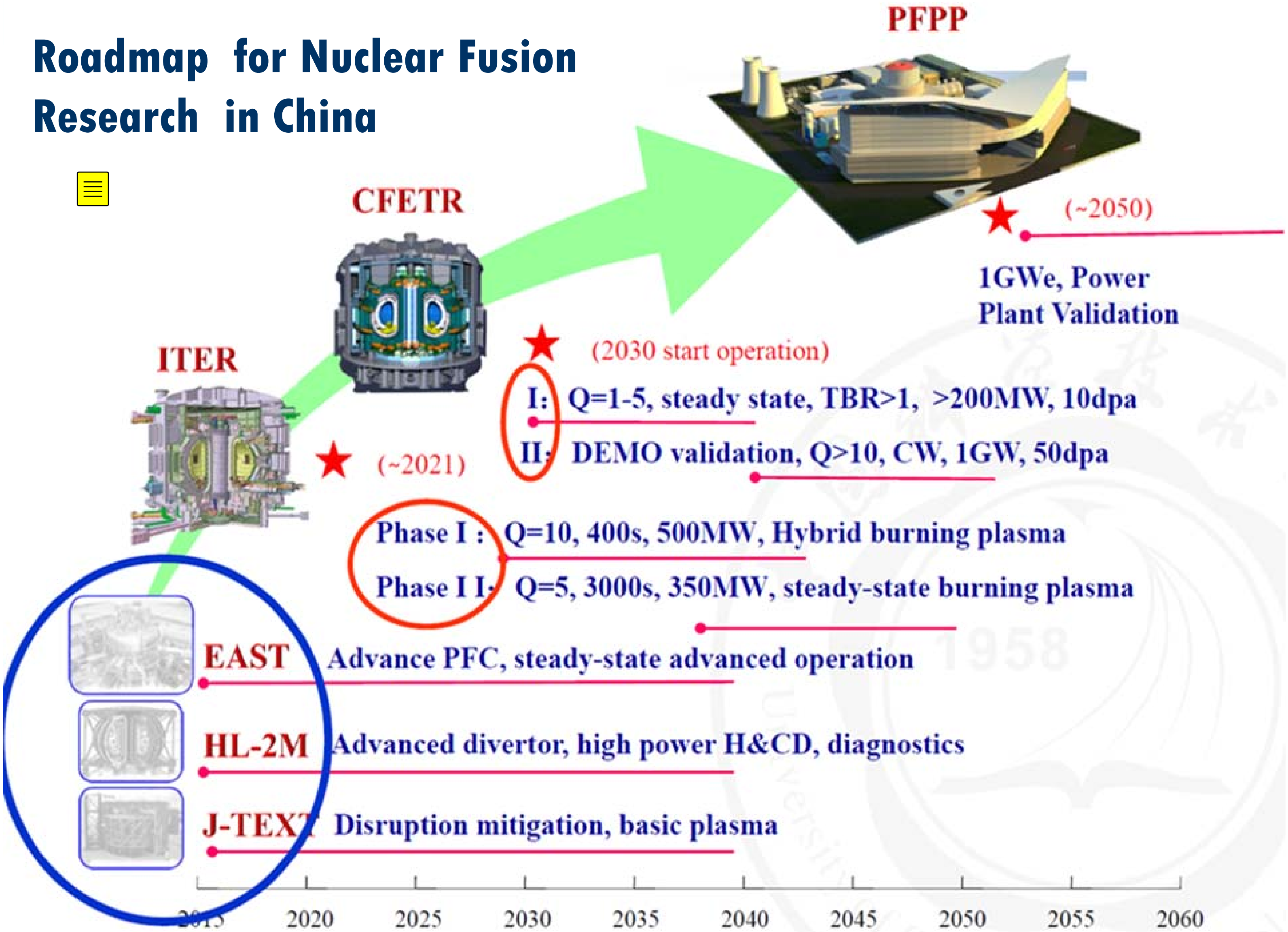






Bitter Disks Six Coils
Inner diameter 38 mm
Outer diameter 710 mm

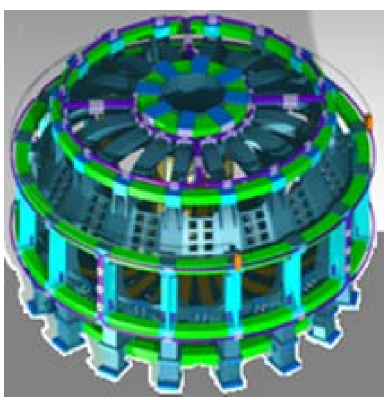
A 11T/800mm superconducting outsert of the CHMFL hybrid magnet is being assembled now. The outsert composed of three Nb_3Sn coils wound from four grades of Cable-in-Conduit Conductor (CICC) cooled with forced-flow supercritical helium at an inlet temperature of 4.5 K.

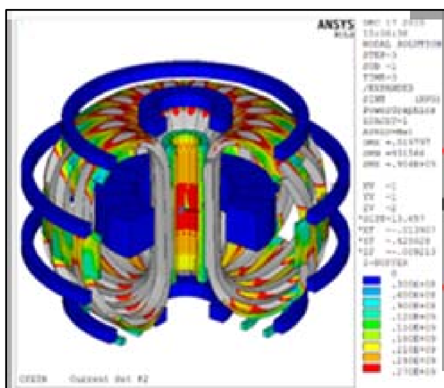

Roadmap for Nuclear Fusion Research in China
PFPP
(~2050)
1GWe, Power Plant Validation
CFETR
(2030 start operation)
I: Q=1-5, steady state, TBR>1, >200MW, 10dpa
II: DEMO validation, Q>10, CW, 1GW, 50dpa
ITER
(~2021)
Phase I : Q=10, 400s, 500MW, Hybrid burning plasma
Phase I I: Q=5, 3000s, 350MW, steady-state burning plasma
EAST
Advance PFC, steady-state advanced operation
HL-2M
Advanced divertor, high power H&CD, diagnostics
J-TEXT
Disruption mitigation, basic plasma
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060

IPP-CAS: China Fusion Engineering Test Reactor (CFETR)

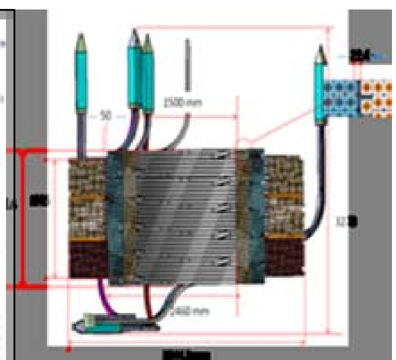
- The conceptual design of magnets has been completed
- The R&D of CFETR CS model coil is on going
- The test of CS Nb3Sn conductor has been completed

- Design and analysis of CFETR Magnets
- R&D of CS Model coil for CFETR

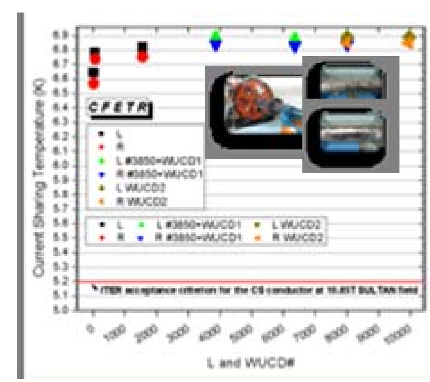




Design and analysis of CFETR Magnets



Design of CFETR CS model coil



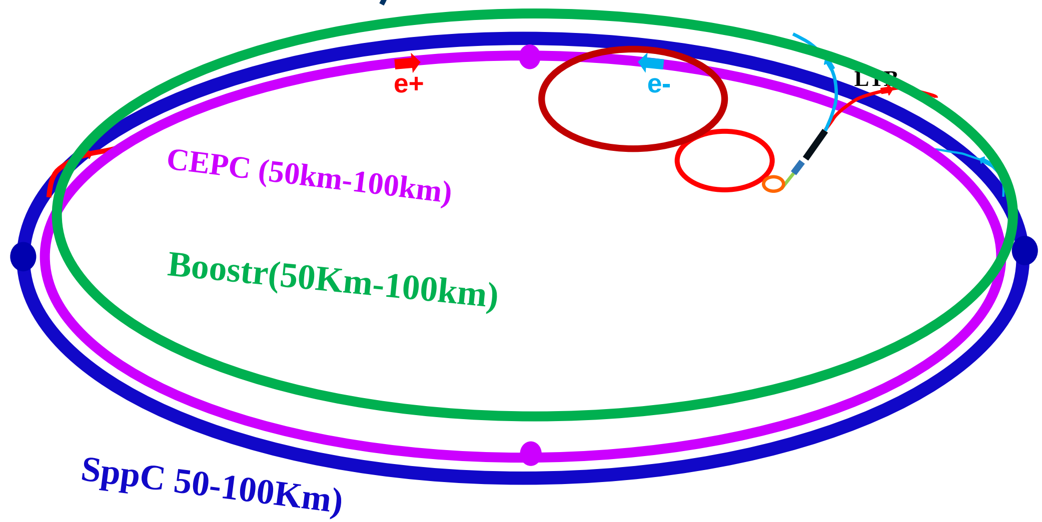
Test results of CFETR Nb3Sn conductor

China Fusion Engineering Test Reactor (CFETR)

Proposals for high Energy Accelerator in China

--CEPC(Circular Electron-Positron Collider)

--SppC(Super Proton-Proton Collider)



Phase 1: e^+e^- **Higgs (Z) factory** two detectors, 1M Z Boson & Higgs events in 10yrs

$E_{cm}\approx$240GeV, luminosity ~2×10^{34} $cm^{-2}s^{-1}$, can also run at the Z-pole

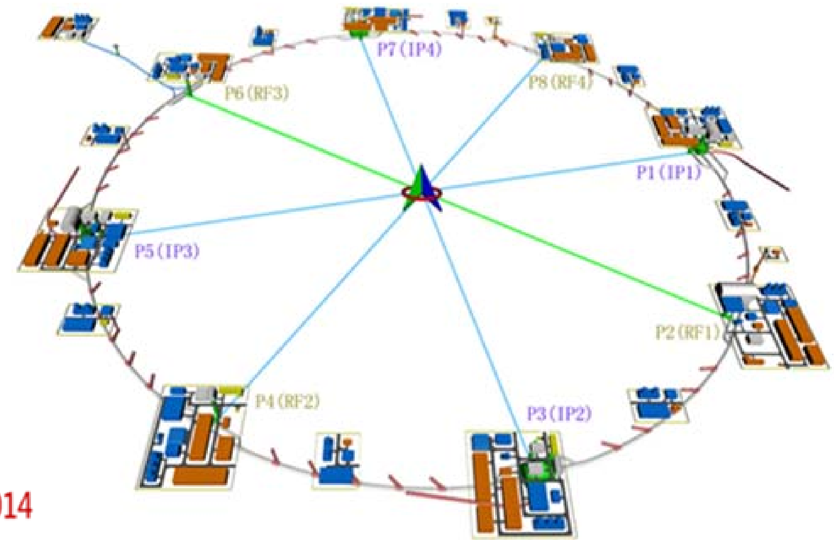
Precision measurement of the Higgs boson (and the Z boson)

Phase 2: **a discovery machine**; pp collision with $E_{cm}\approx$ 50-100 TeV; ep/HI options

Discovery machine for Beyond Standard Model

CEPC-SPPC site and schedule
Candidate: Qinghuandao)

- **CEPC**
  - Pre-CDR studyR&D and preparation work
    - Pre-study: 2013-15 → Pre-CDR by the end of 2014
    - R&D: 2016-2020
    - Engineering Design: 2015-2020
  - Construction: 2021 – 2027
  - Data taking: 2030 – 2036
- **SppC**
  - Pre-study, R&D and preparation work
    - Pre-study: 2013-2020
    - R&D: 2020-2030
    - Engineering Design: 2030-2035
  - Construction: 2036-2042
  - Data taking: 2042 -



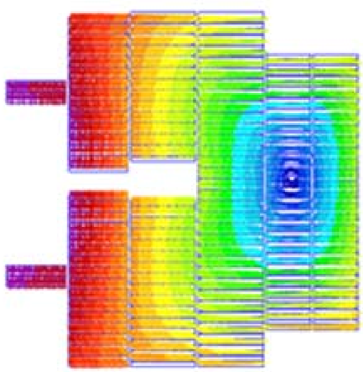
CEPC-SPPC in Qinhuangdao, 50km or 100 km

Conceptual Design for SPPC Dipole Magnets

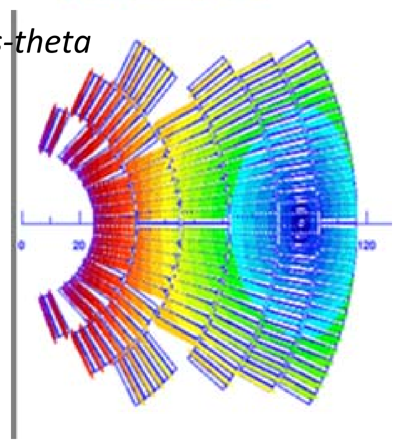
Comparison of different coil configurations

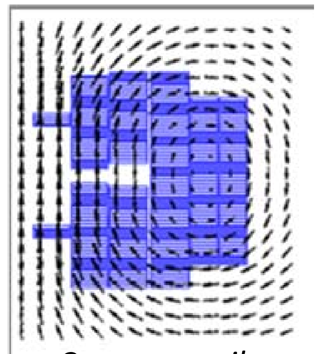
Common coil vs Cos-theta

Common coil



Cos-theta



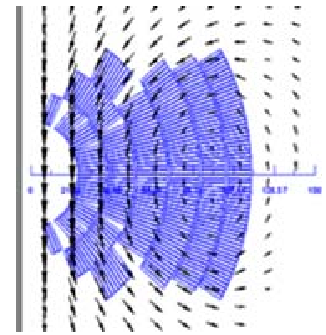


Common coil

Different coil configurations for 20-T dipole magnet

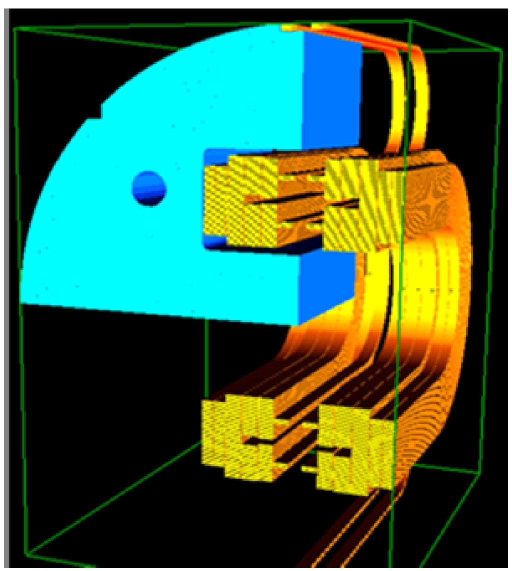
Left: Common coil

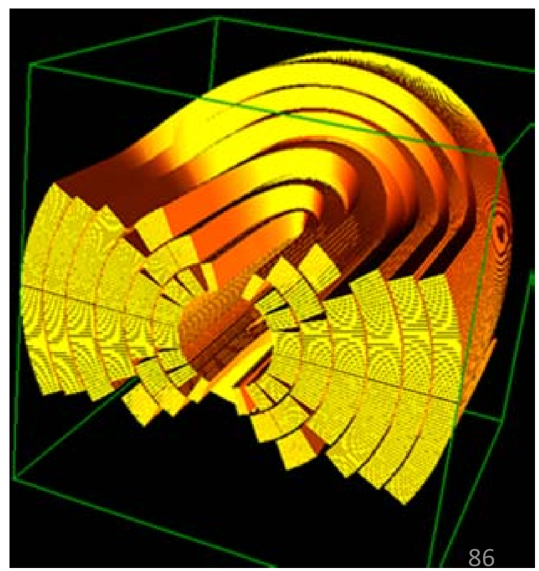
Right: Cos-theta



Cos-theta

Coil ends

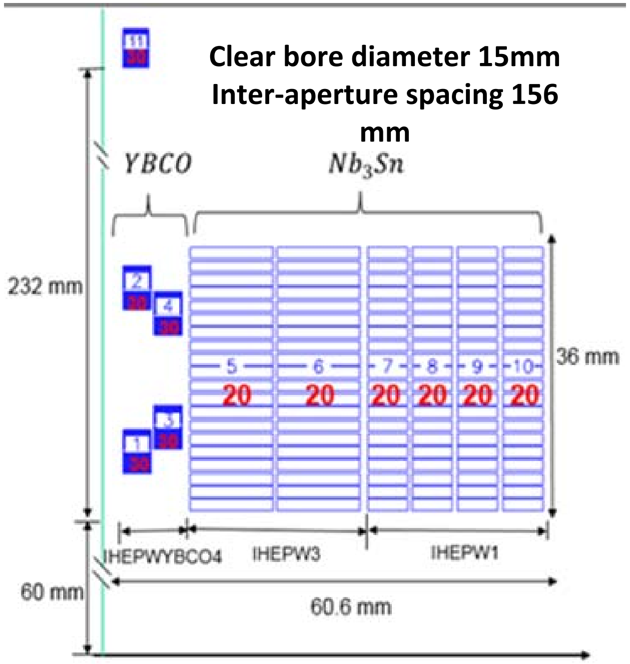




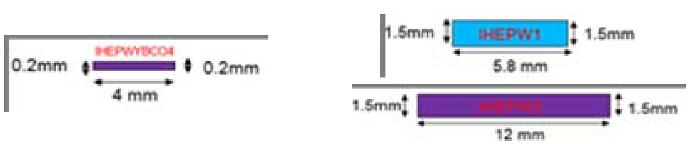
Model Magnet Development for SPPC

To fabricate a 14-T dipole magnet (with two apertures) with HTS and Nb_3Sn superconductors, to test the field optimization method of HTS & Nb_3Sn coils.

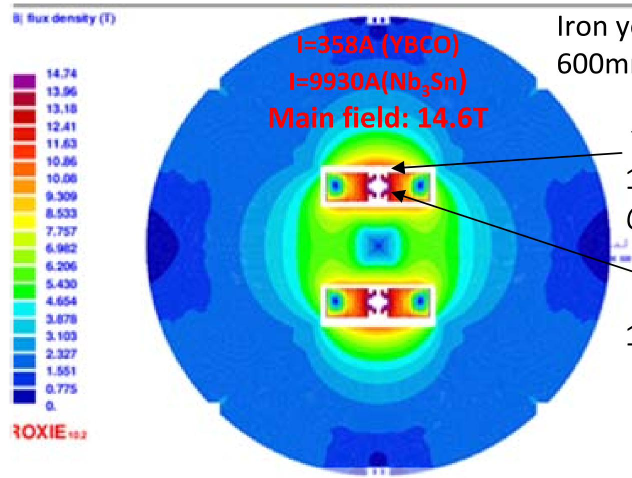
Clear bore diameter 15mm
Inter-aperture spacing 156 mm



Coil configuration in the 1st quadrant



For per meter of such magnet, the required length of the strand: YBCO: 0.6 Km; Nb_3Sn in total: 9.12 Km



Iron yoke OD: 600mm

YBCO B_{peak} 14.7T @4.2K

Nb_3Sn B_{peak} 14.5T @4.2K

Field distribution in the cross section of the magnet

Main parameters of the cables

Cable	Hight	Width-i	Width-o	Ns	Strand	Filament	Insulation
IHEPW1	5.8	1.5	1.5	14	IHEPWCJC	Nb3Sn	0.15
IHEPW3	12	1.5	1.5	29	IHEPWCJC	Nb3Sn	0.15
IHEPWYBCO4	4	0.2	0.2	1	IHEPWYBCO	YBCO	0

Main parameters of the strands

Strand	diam.	cu/sc	RRR	Tref	Bref	Jc@ BrTr	dJc/dB
IHEPWCJC	0.82	1	100	4.2	12	2400	400
IHEPWYBCO	-	-	-	4.2	12	1020	40

87

Content

- ✓ Overview of Research Teams and Financial Support;
- ✓ Recent Progresses at Materials, Electronics and Large-scale Application;
- ✓ Near Future Progresses, Plans or Proposals;
- ➡ Summary

Summary

- In China, we have established a completed research system in applied superconductivity, and the research teams cover all aspects of applied superconductivity in materials, electronics and large-scale applications;
- In last five years, China has achieved a lot of progresses in applied superconductivity, and made good contributions in international collaborations such as ITER etc;
- In the future, China will have a big market for superconducting products, and the energy development and scientific research would lead to more challenges and requirements for superconducting technology in China.

Content

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Many Thanks