MT25

25th International Conference on Magnet Technology

RAI - Amsterdam
August 27 - September 1, 2017

Advanced superconductors developed at WST

Jianwei Liu

September 29th 2017, Amsterdam, The Netherlands

Western Superconducting Technologies Co., Ltd.

Milestones of WST

February 1965

西北有色金属研究院
Northwest Institute For Non-ferrous Metal Research
陕西省材料科学工程院
Shaanxi Institute For Materials Engineering

- Superconductivity Discovery
- NbTi Superconductivity
- NIN Founded
- Jc Record of NbTi strand
- WST Founded
- NbTi Qualification for ITER
- Nb_3Sn Qualification for ITER
- Nb_3Sn Delivery for ITER
- WIC Qualified by GE
- NbTi Delivery for ITER

1911 · 1957 · 1965 · 1984 · 2003 · 2009 · 2010 · 2015 · 2017

Milestones of WST

JOURNAL DE PHYSIQUE
Colloque C1, supplément au n° 1, Tome 45, janvier 1984 page C1-437

PROPERTIES OF NbTi50 SUPERCONDUCTING COMPOSITE WIRE

Zhou Lian, Li Chengren, Wu Xiaozu, Zhou Nong, Zhang Tingjie and Wang Keguang

Baoji Institute for Non-Ferrous Metal Research, P.O. Box 71, Baoji, Shaanxi, China

Abstract - The results of critical current measurements of NbTi50 multifilamentary wire at 4.2 K in the fields up to Hc2 are reported in this paper. The measurements show that the best optimized samples have excellent critical current properties, especially in mid-field. Its Jc(4.2K), for instance, is 3460 A/mm^2 at 5 T, and 1020 A/mm^2 at 8 T. The crucial role played by multiple heat treatments in developing high Jc values in NbTi50 alloy are described. The flux pinning force and microstructural features are discussed.

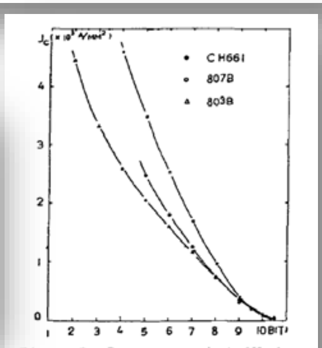


Fig.1 Jc-B curves at 4.2K for the samples studied

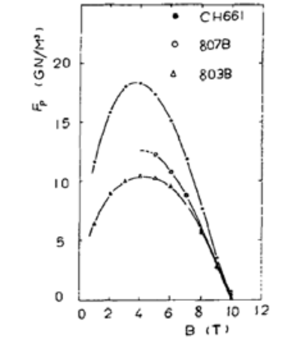


Fig.2 The pinning force vs. B curves at 4.2 K

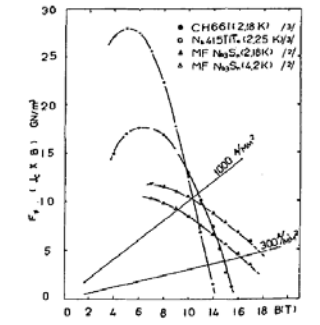
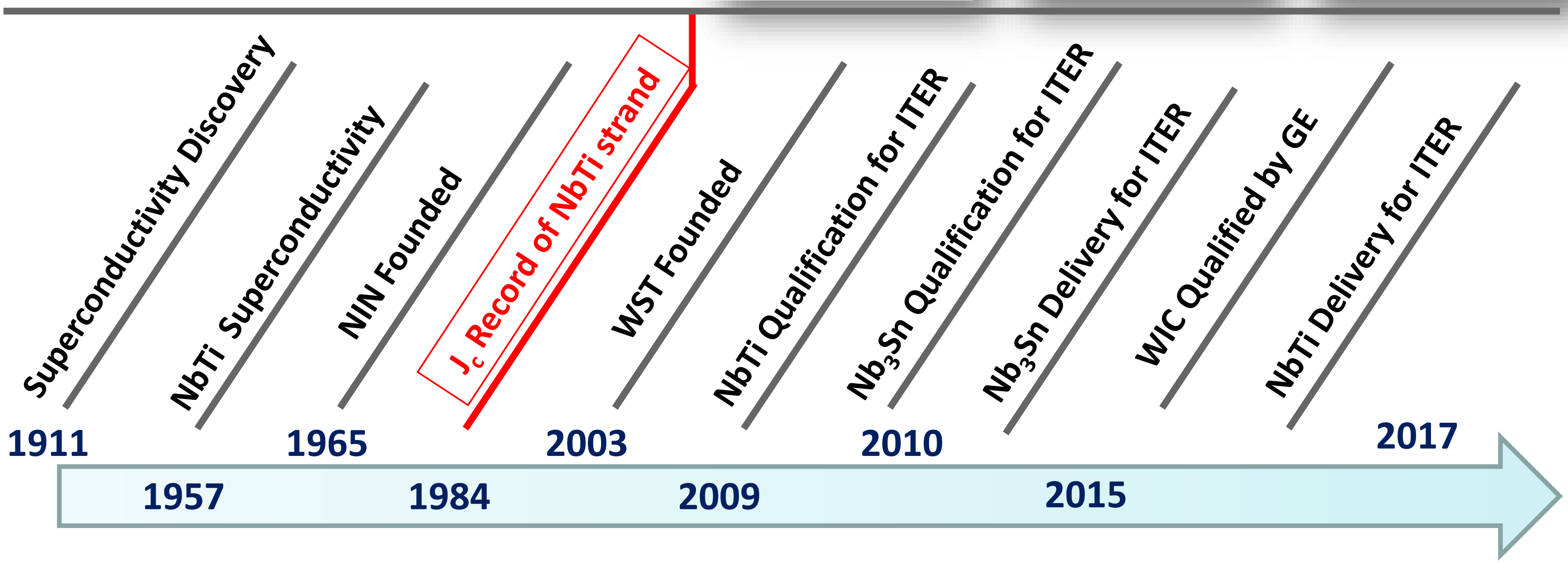


Fig.3 Fp vs.B curves for NbTi, MF Nb$_3$Sn and NbTiTa at 4.2, 2K



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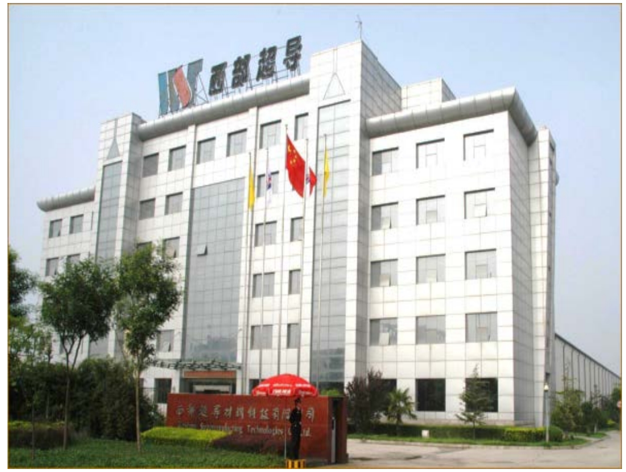

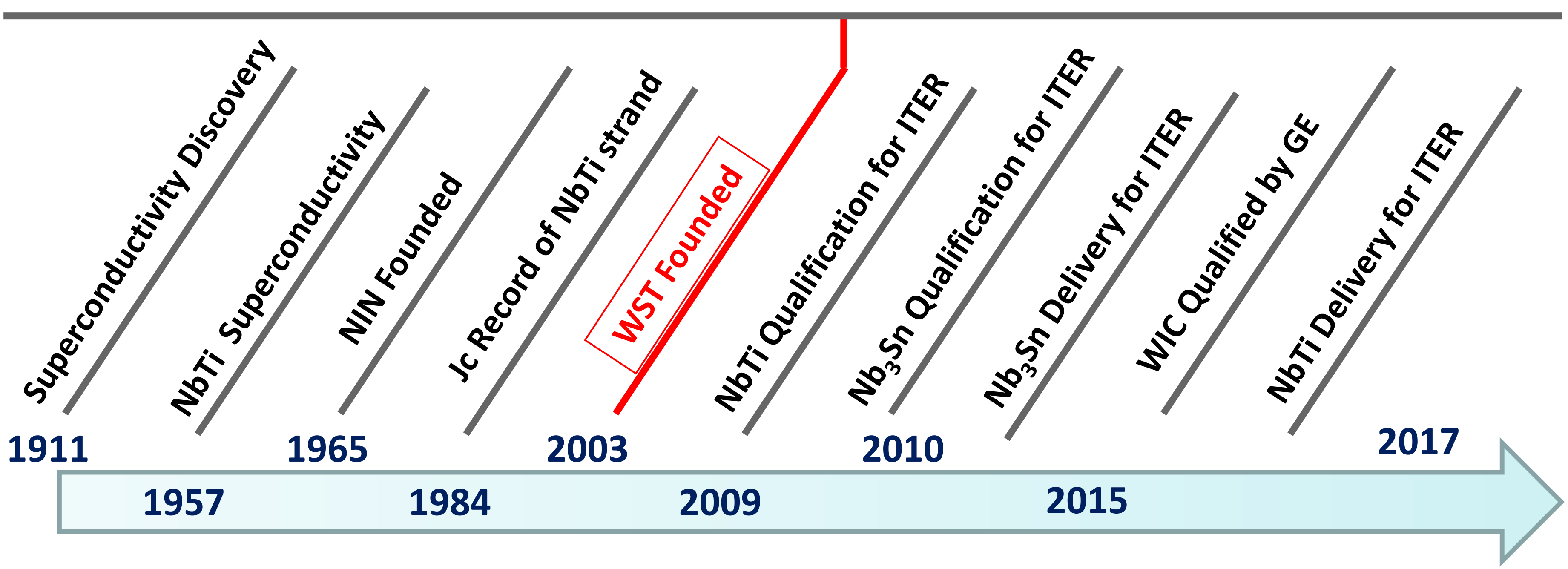

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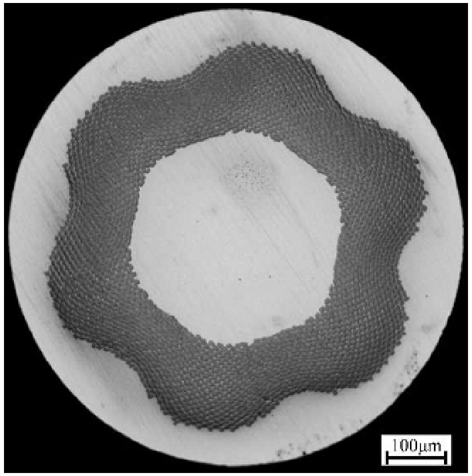
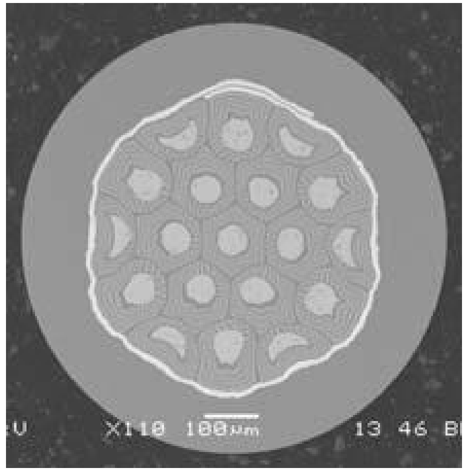
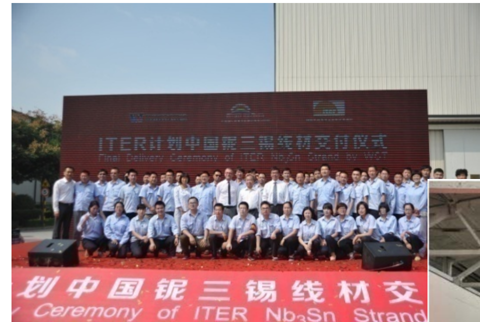


May 2010

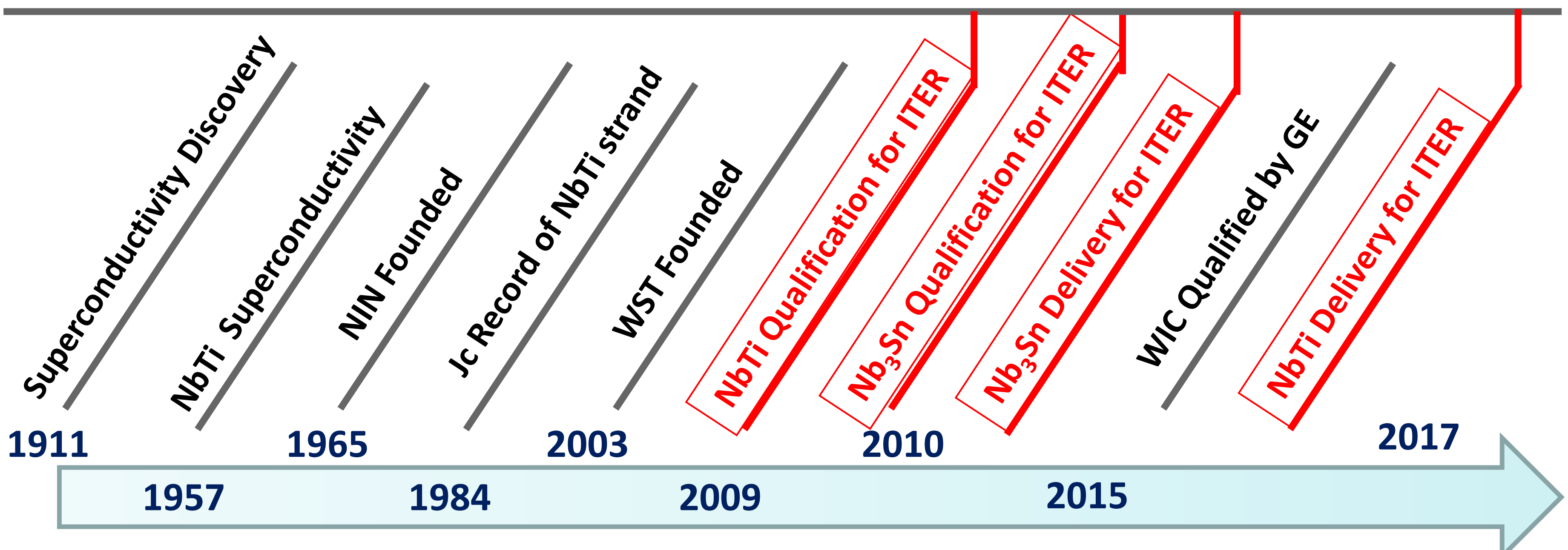


October 2010

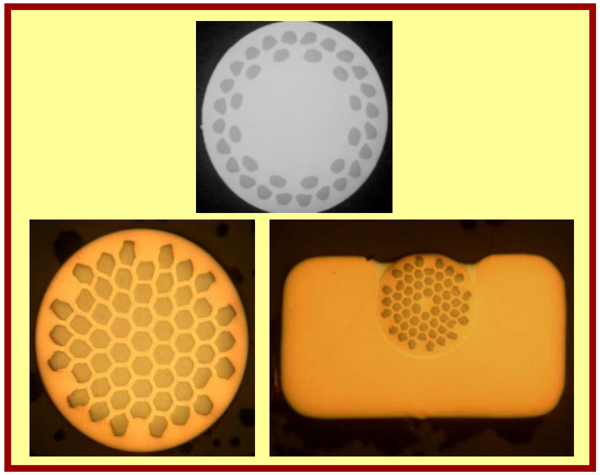


September 2015

March 2017



Milestones of WST



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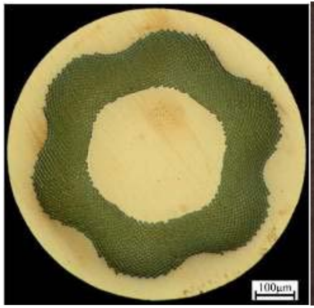
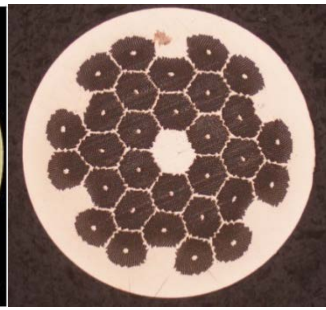
Superconductor Family of WST

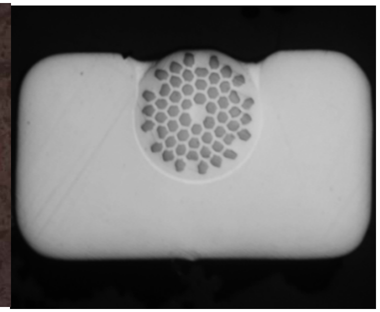
LTS



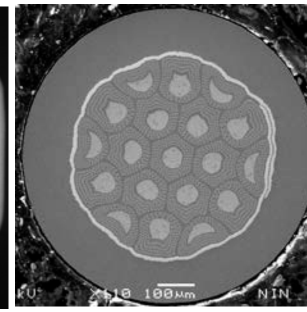
NbTi



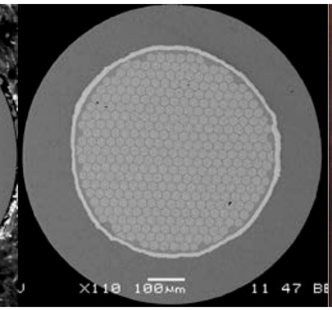
NbTi/CuNi



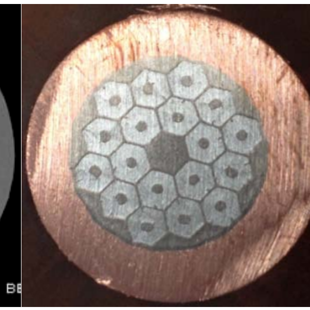
WIC



IT Nb_3Sn

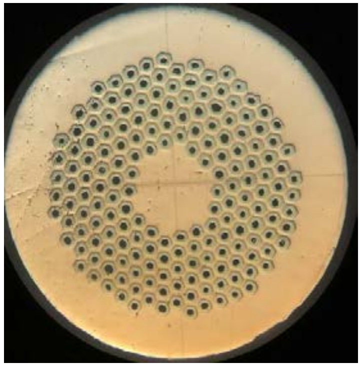


Bronze Nb_3Sn

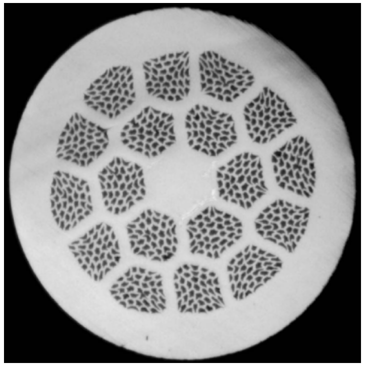


Nb_3Al

HTS



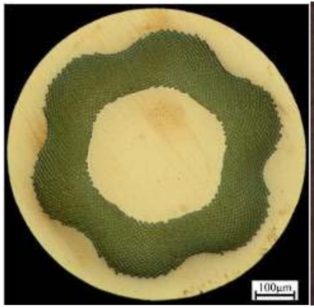
MgB_2



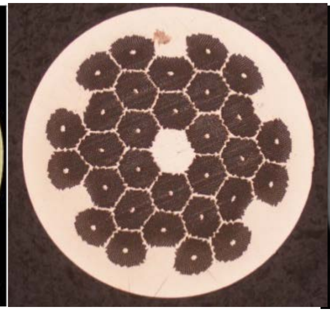
Bi-2212

Superconductor Family of WST

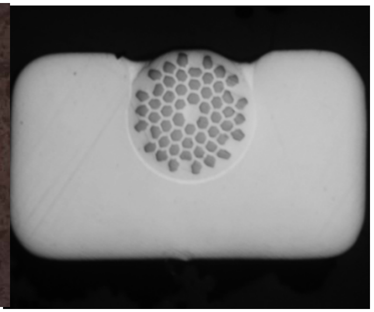
LTS



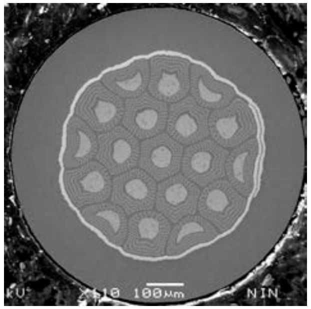
NbTi



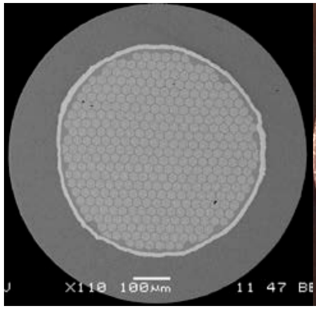
NbTi/CuNi



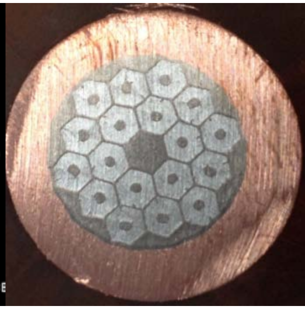
WIC



IT Nb_3Sn

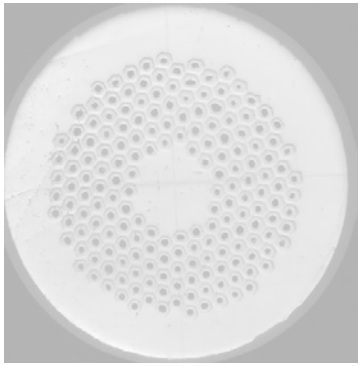


Bronze Nb_3Sn

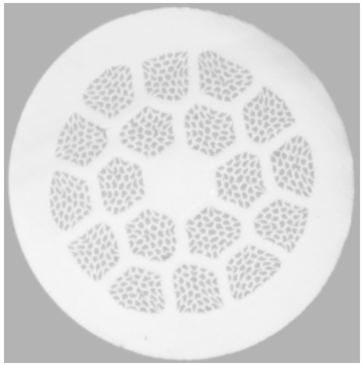


Nb_3Al

HTS



MgB_2

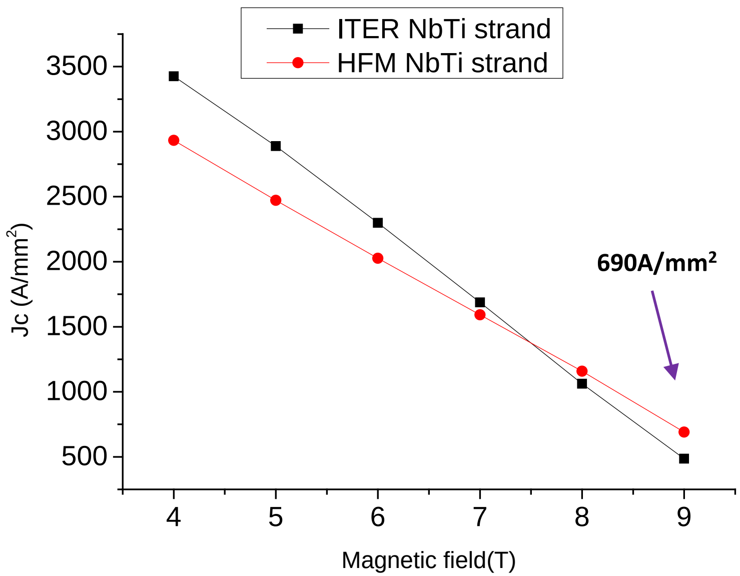


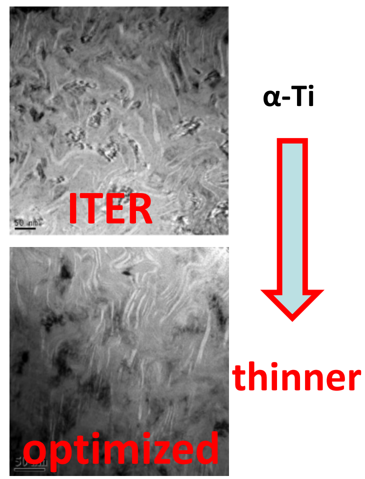
Bi-2212

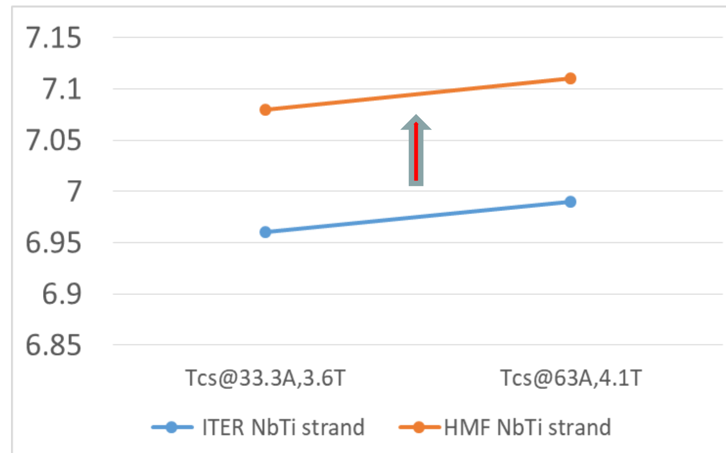
NbTi strand for high magnetic field

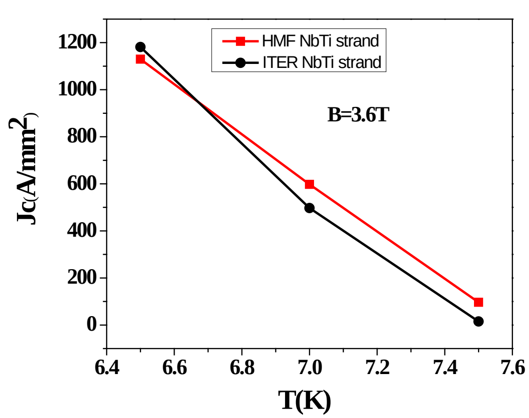
Improvement of J_c and T_{cs}

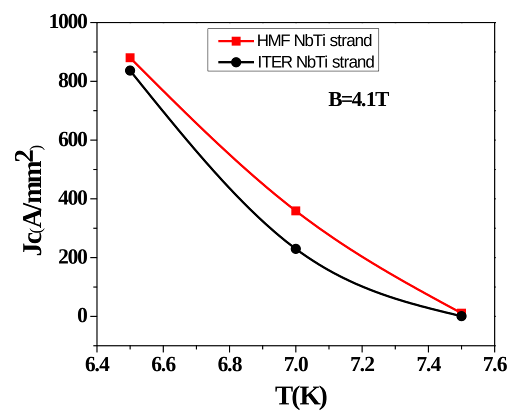
- NbTi strand for high magnetic field: J_c=690A/mm², T_{cs}=7.1 K
- At 7 K, J_c=600 A/mm²@3.6 T; J_c=380 A/mm² @4.1T







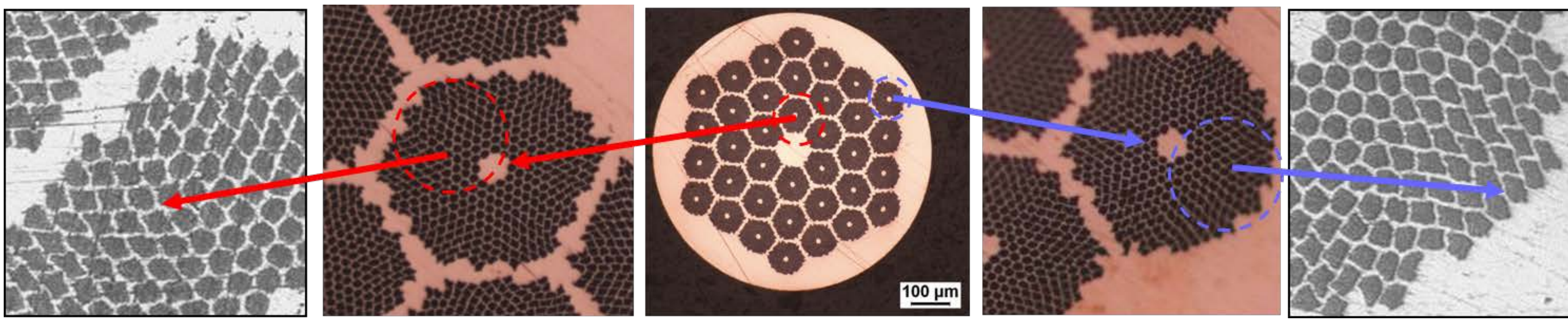




NbTi strand with CuNi or CuMn matrix for HF impulse magnet

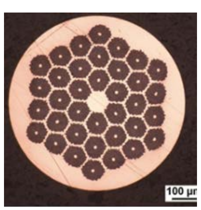
Structure and performance

Uniform deformation of 12960 filament design. Filament diameter: 4μm

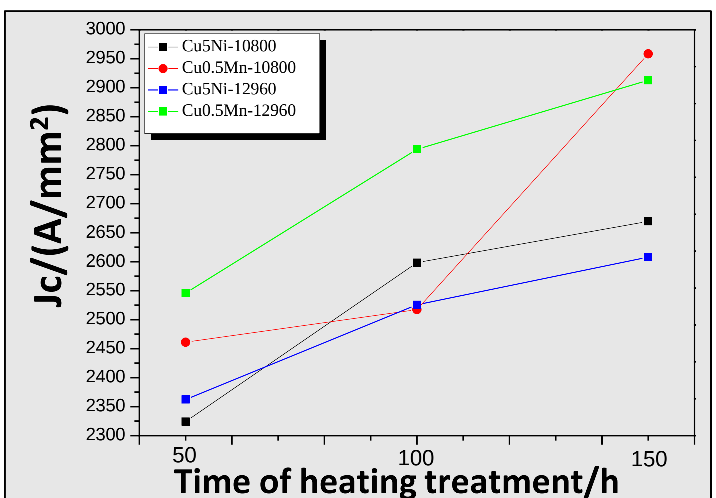


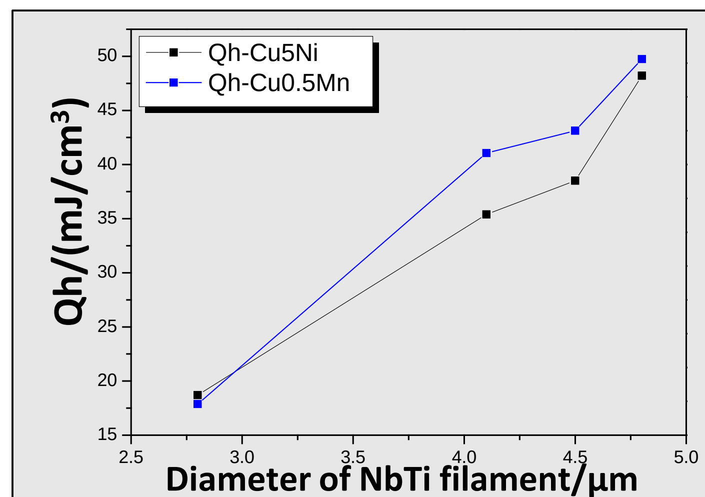
- J_c achieves 2669 A/mm² in Cu5Ni matrix and 2985A /mm² in Cu0.5Mn matrix, at 5T, 4.2 K.
- Q_h is decreasing with the diameter of NbTi filament. The lowest is 18 mJ/cm³ with 2.8 μm.

10800-cores



12960-cores



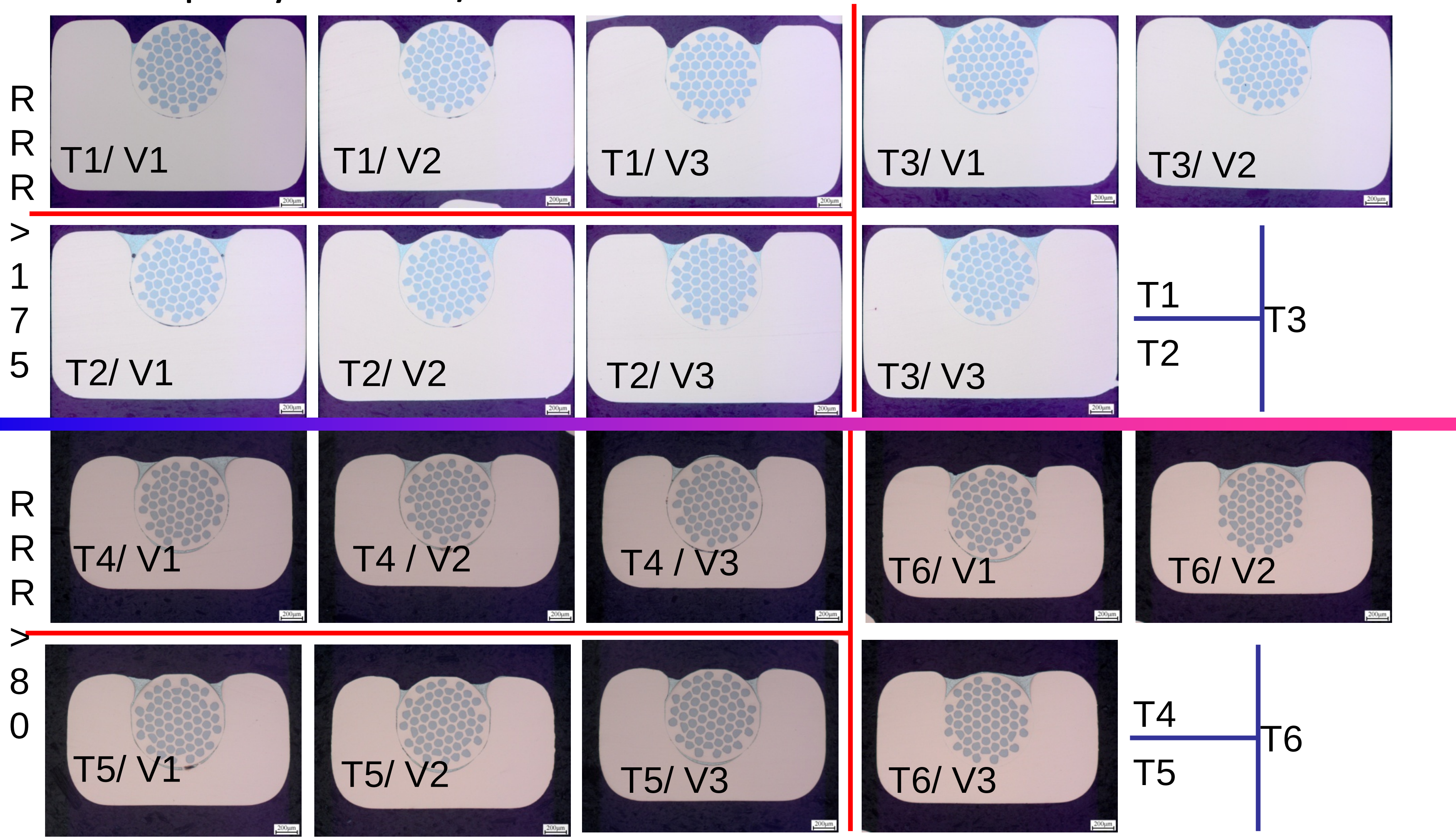


Wire-in-channel wire

WIC solder technique

◆ Develope the lead-free solder technique of WIC wire for MRI magnet for GE and SIEMENS.

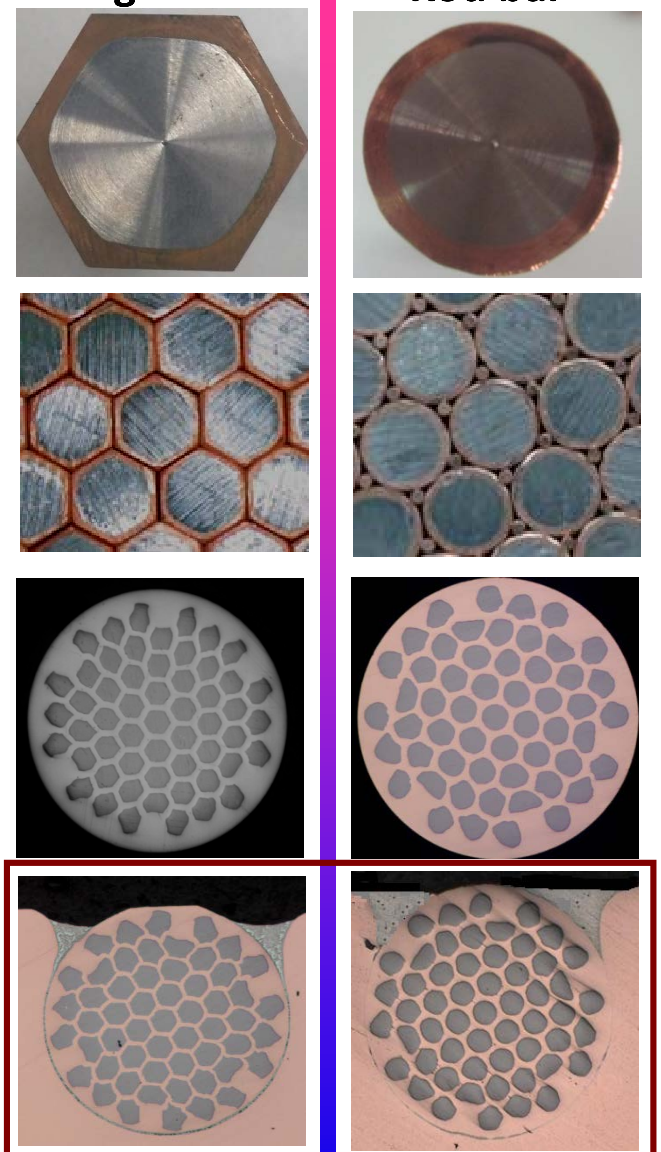
◆WIC wire capability: minimal Cu/Sc of 4.5 and minimal dimension of 1.6X1.05 mm



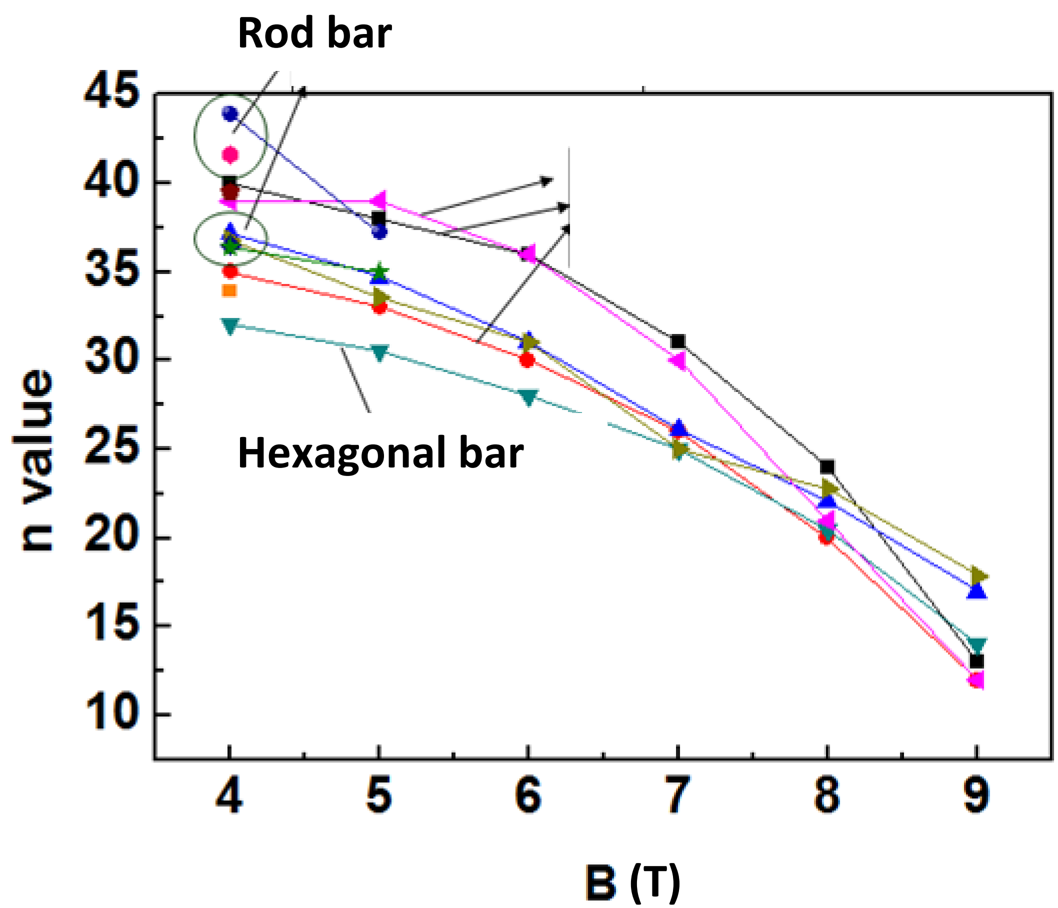
Wire-in-channel wire

Improving n value

Hexagonal bar | **Rod bar**



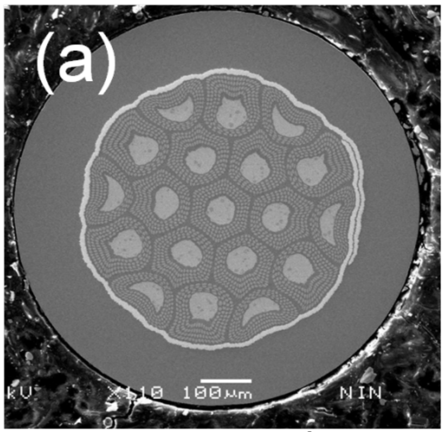
◆ Rod monofilament bar improved deformation homogeneity and n value



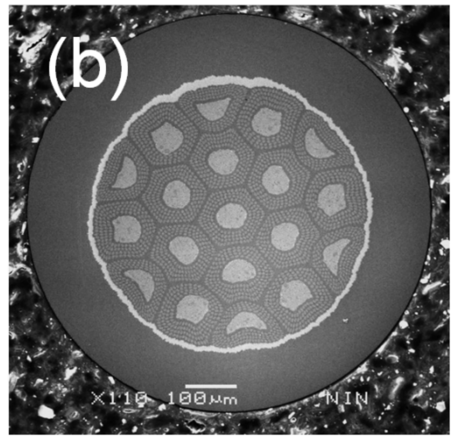
Internal-tin Nb_3Sn strand for fusion

Improvement for higher J_{cn} and lower Q_h

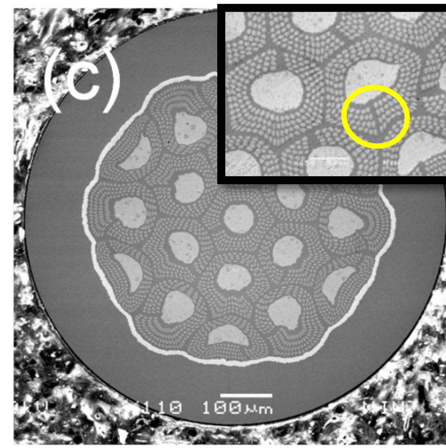
- Three routes: deformation optimization, Cu splits and reaction degree increase.
- Support CFETR, CRPP and ENEA for fusion after ITER.



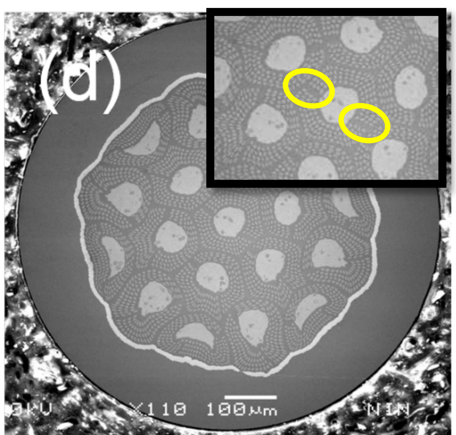
ITER strand



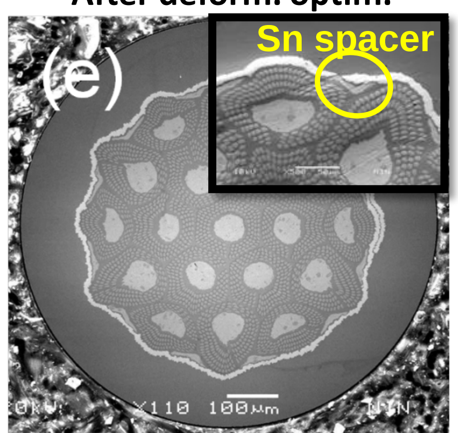
After deform. optim.



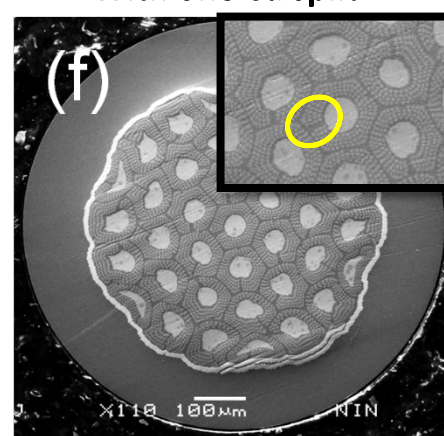
With one Cu split



With two Cu splits



Sn spacer + one Cu splits

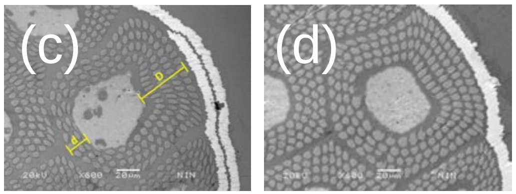


37 sub. + one Cu splits

Internal-tin Nb_3Sn strand for fusion

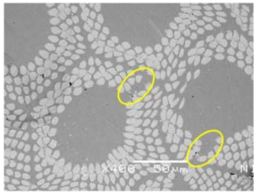
Improvement for higher J_{cn} and lower Q_h

Deformation optimization



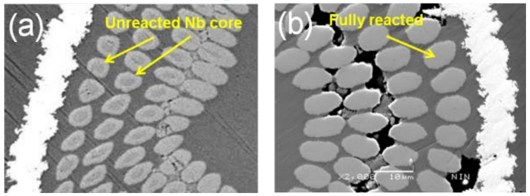
D/d: from 2.46 to 1.33
J_{cn} increase 10.2%
Q_h increase 16.7%

Cu split

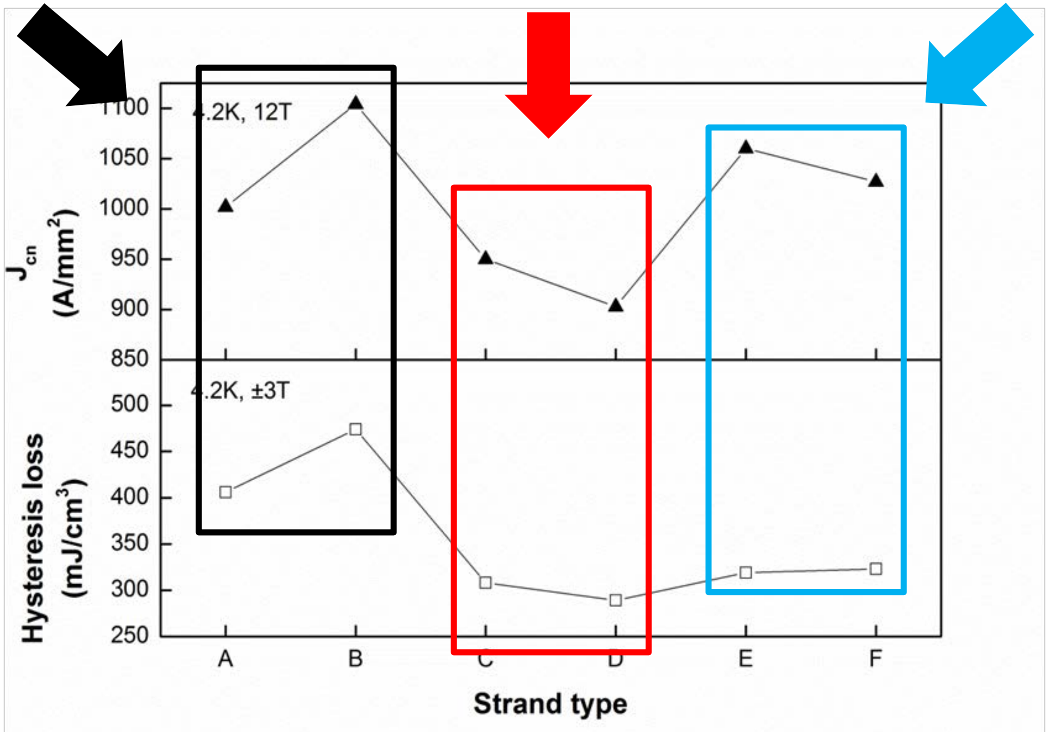


Cu split breaks Nb_3Sn ring
J_{cn} drops 5%-10%
Q_h below 300 mJ/cm3

Reaction degree increase



Both high J_{cn} and low Q_h
Sn spacer harms deform.
One Cu split + 37 sub. is best



Bronze Nb_3Sn strand

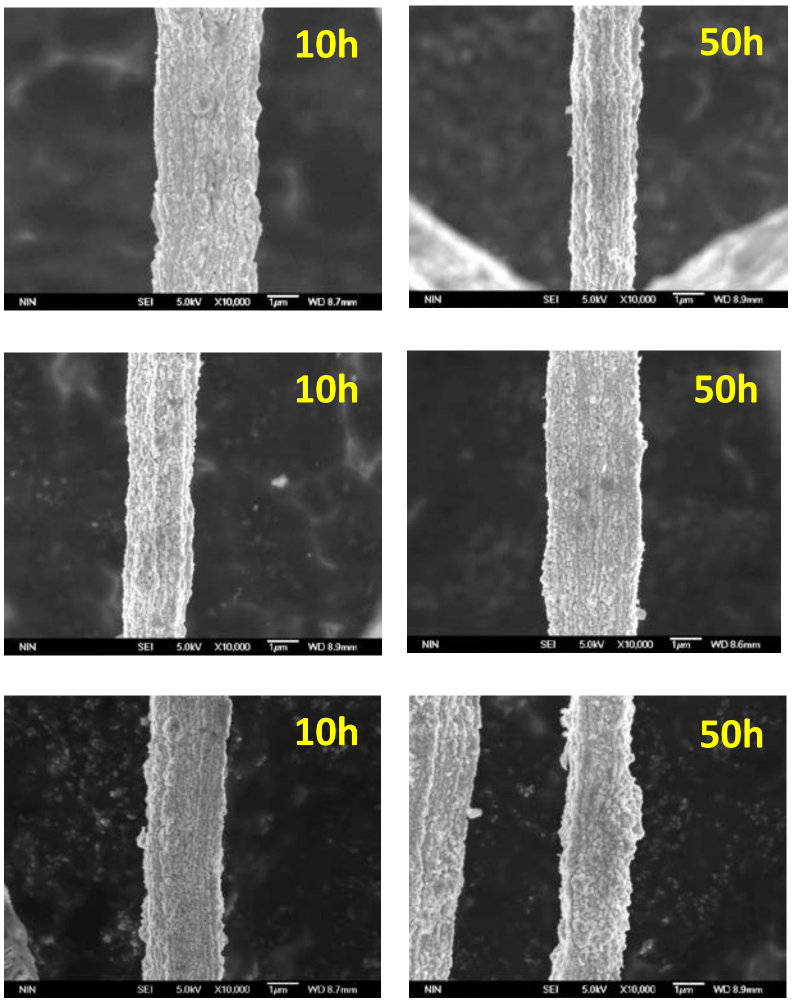
Nb_3Sn pre-reaction in process

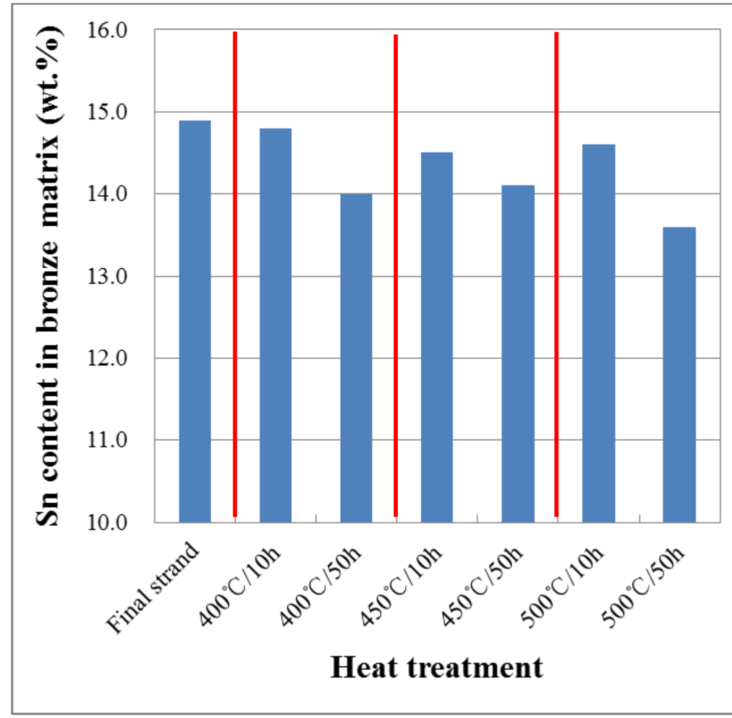
- Up to 450 °C, less Nb_3Sn particles on the Nb surface.
- At 500 °C, Nb_3Sn particles are easily grown.

400 °C

450 °C

500°C

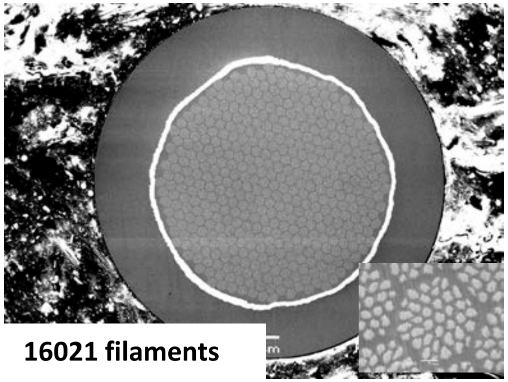




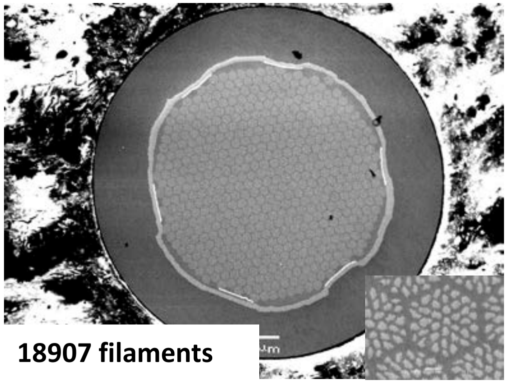
- Sn content in bronze is proportional to Nb_3Sn pre-reaction.
- After 10 h, Sn content changed little and small Nb_3Sn particles appeared.
- After 50 h, Sn content dropped and dense Nb_3Sn particles created. Most for 500 °C.

Bronze Nb_3Sn strand

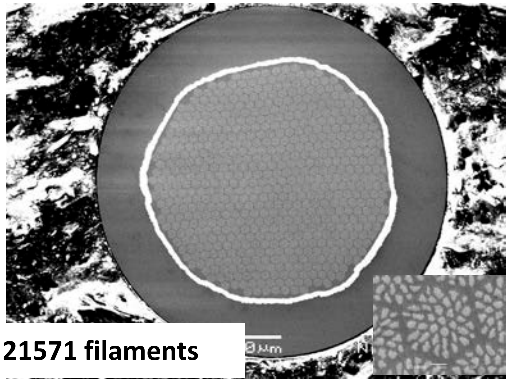
Performance improvement



16021 filaments



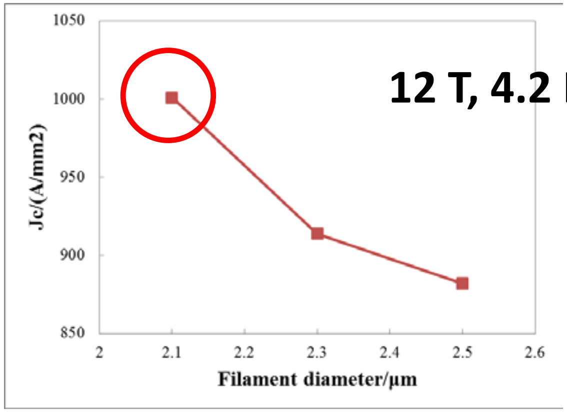
18907 filaments



21571 filaments

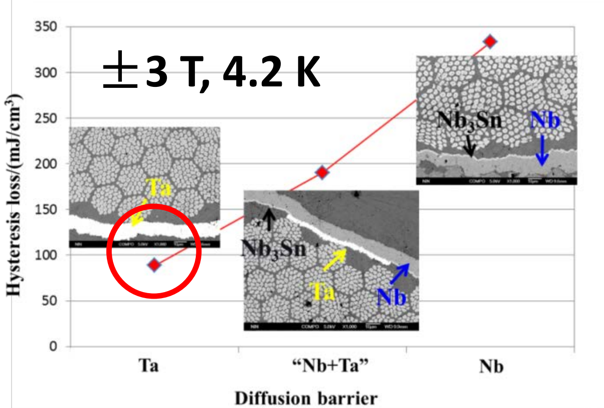
Three strands were manufactured to study the influence of filament diameter on J_c and influence of diffusion barrier on Q_h.

Influence of filament diameter



J_c increases with the reduction of filament diameter with the same bronze/Nb ratio, which can be explained by the full reaction of smaller filaments.

Influence of diffusion barrier

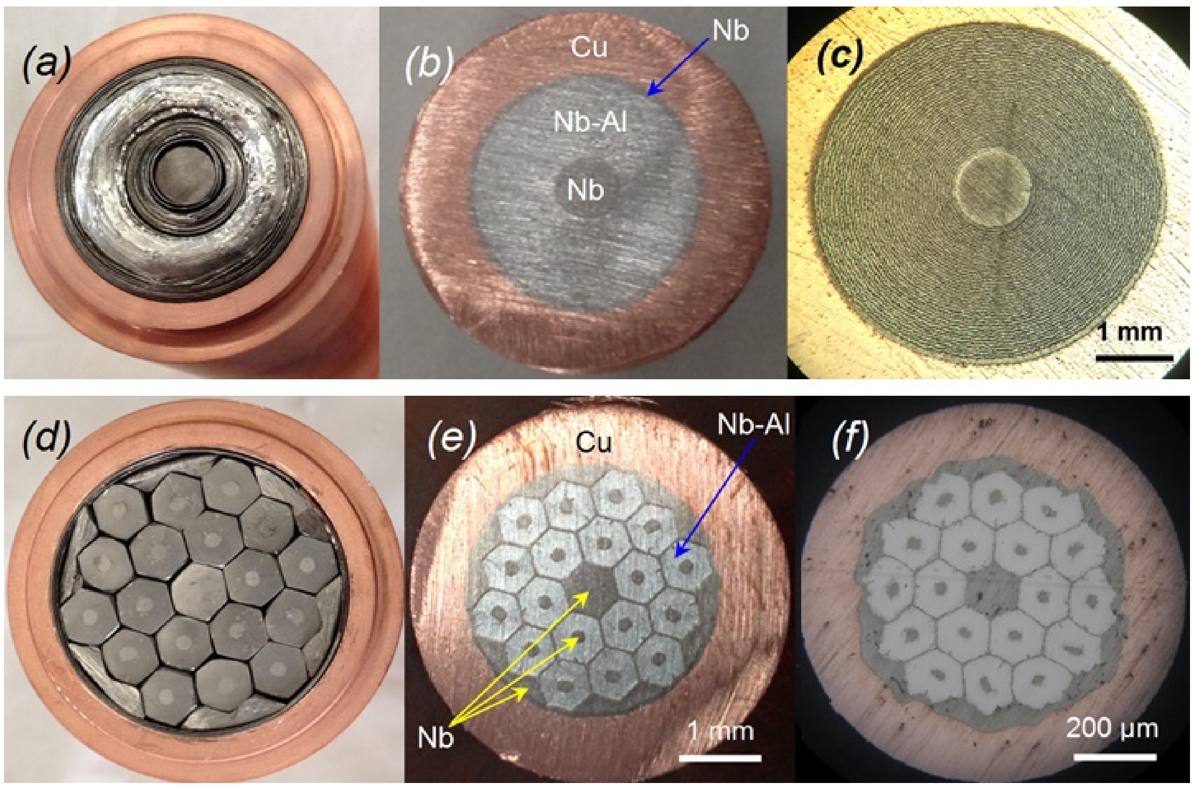


- ◆Ta diffusion barrier is best to reduce Q_h below 100 mJ/cm³.
- ◆Ta breaks the Nb_3Sn ring and reduces hysteresis loss.
- ◆A Nb_3Sn ring formed inside of the Nb diffusion barrier leads to a highest hysteresis loss.

Nb$_3$Al wire

Jelly-roll process

◆The cassette-roller die (CRD) is necessary to the mechanical deformation process of the Nb$_3$Al precursor for controlling their serious work hardening.

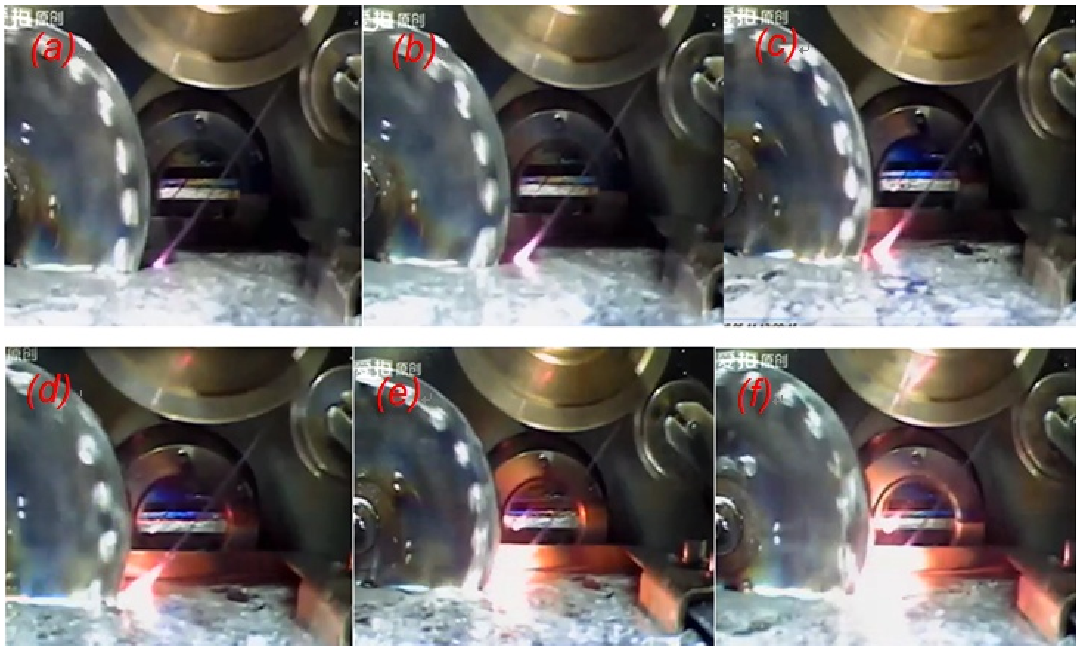


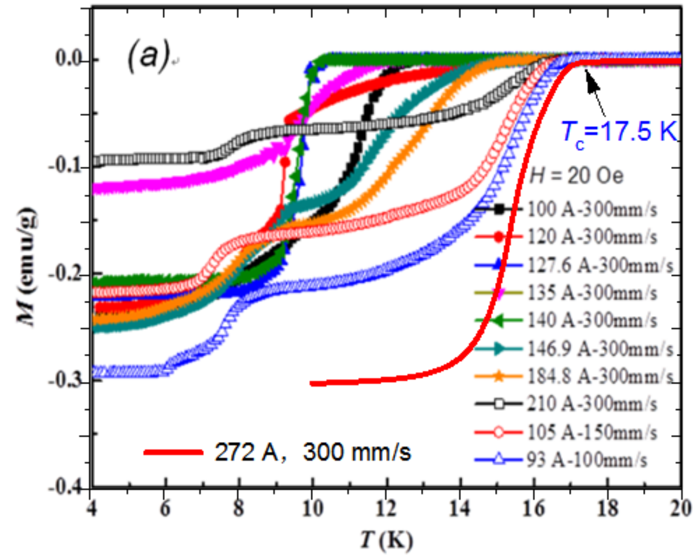
Preparation process of 18 filament Nb$_3$Al precursor wires

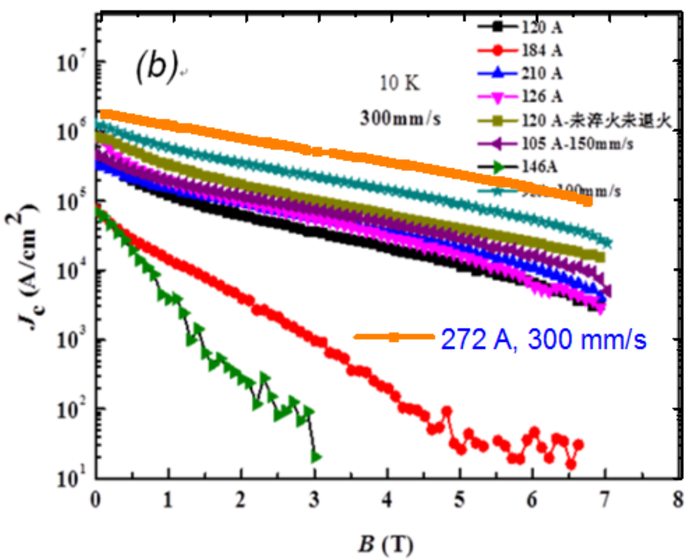
Nb_3Al wire

Rapid heating and quenching (RHQ) heat-treatment

◆RHQ heat-treatment process of reel-to-reel Nb_3Al wires with a continuous increasing sintering current.



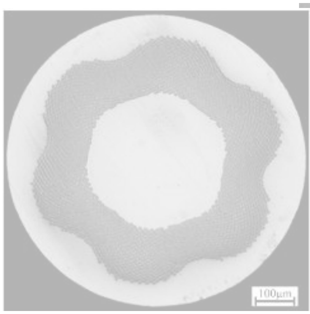




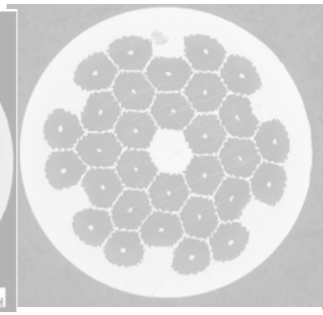
◆Our aim is to develop the practical high performance Nb_3Al superconducting wires, many efforts are still being ongoing.

Superconductor Family of WST

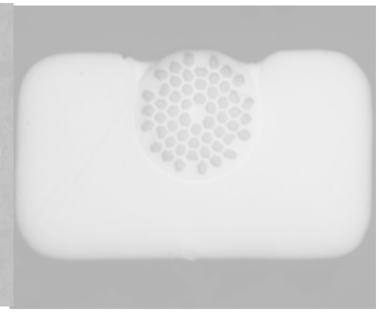
LTS



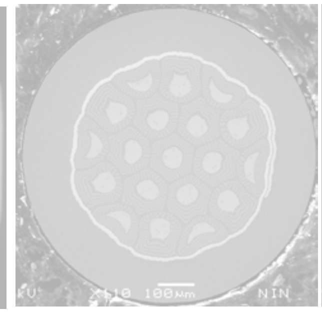
NbTi



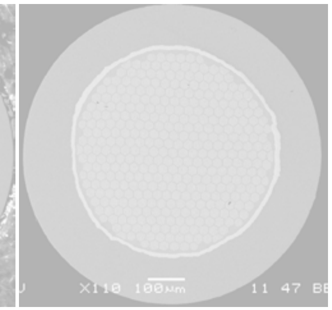
NbTi/CuNi



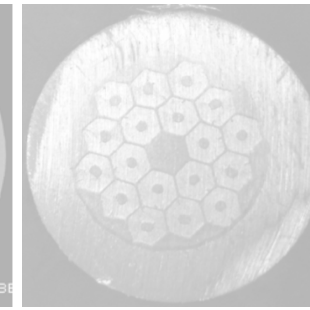
WIC



IT Nb_3Sn

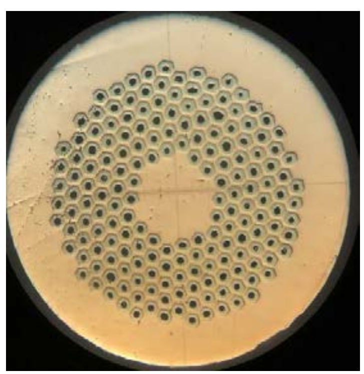


Bronze Nb_3Sn

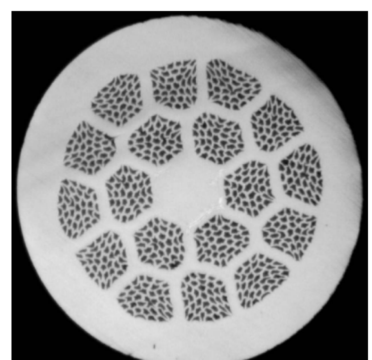


Nb_3Al

HTS



MgB_2

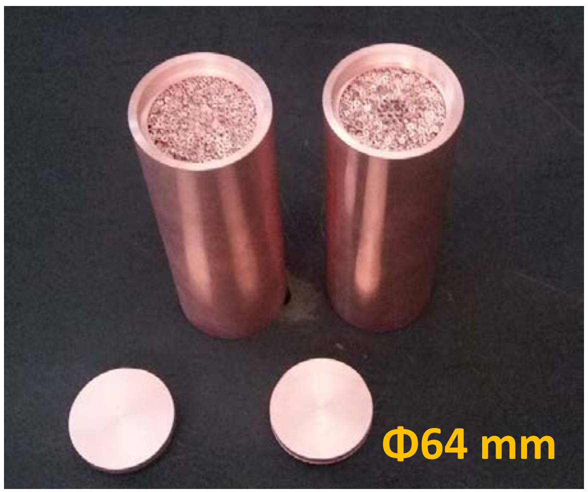


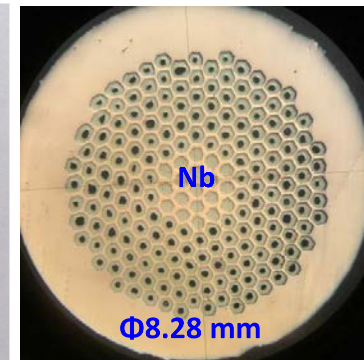
Bi-2212

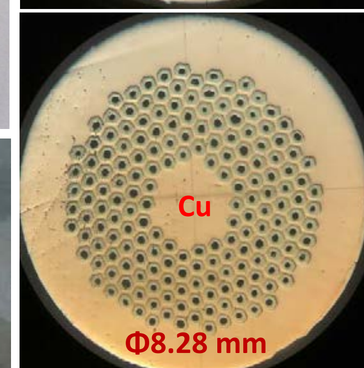
MgB_2 wire

Ex-situ and hot-extrusion method

- Ex-situ route is regarded as suitable for kilometer MgB_2 wires.
- with very fine filament, resulting in them with very low AC loss and be benefit of the application of cable, HEP accelerator and MRI.



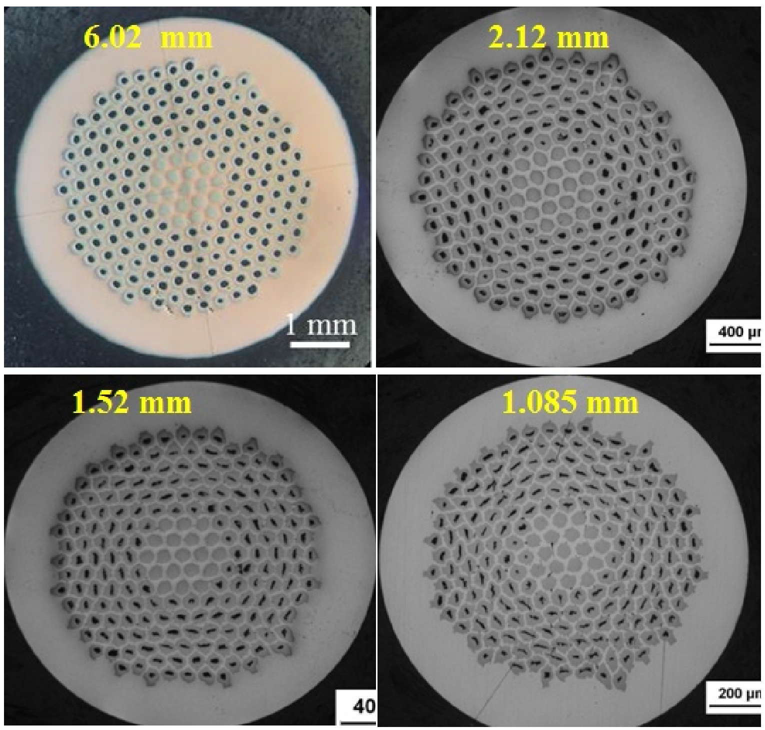




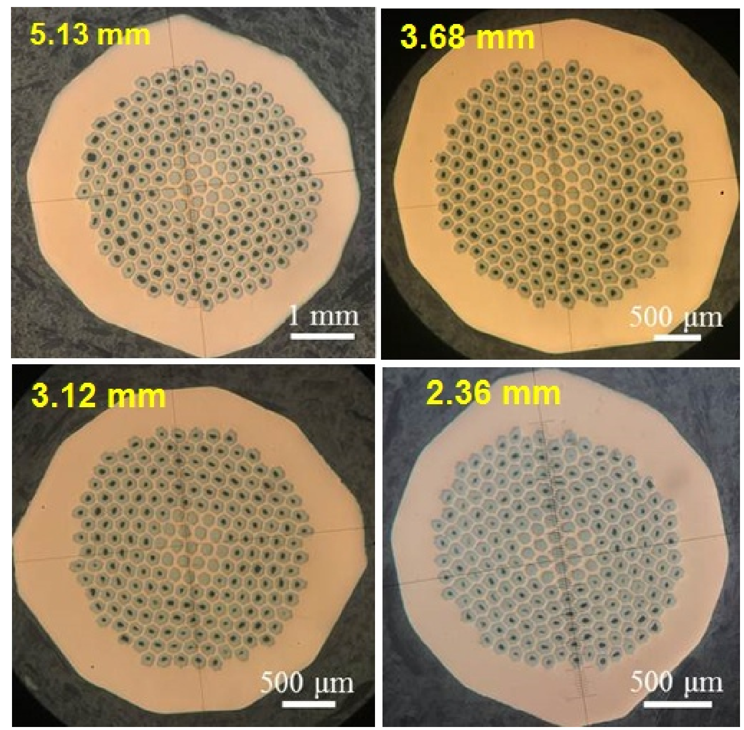
MgB_2 wire

Deformation optimization

- ◆Both rolling and drawing have been used to reduce the cross-section of MgB_2 wires after hot-extrusion.
- ◆Rolling process helps MgB_2 wire to deform more homogeneously.
- ◆The results suggest both the two methods are useful to make the practical kilometer ex-situ MgB_2 wires.



Cross-section evolution by drawing

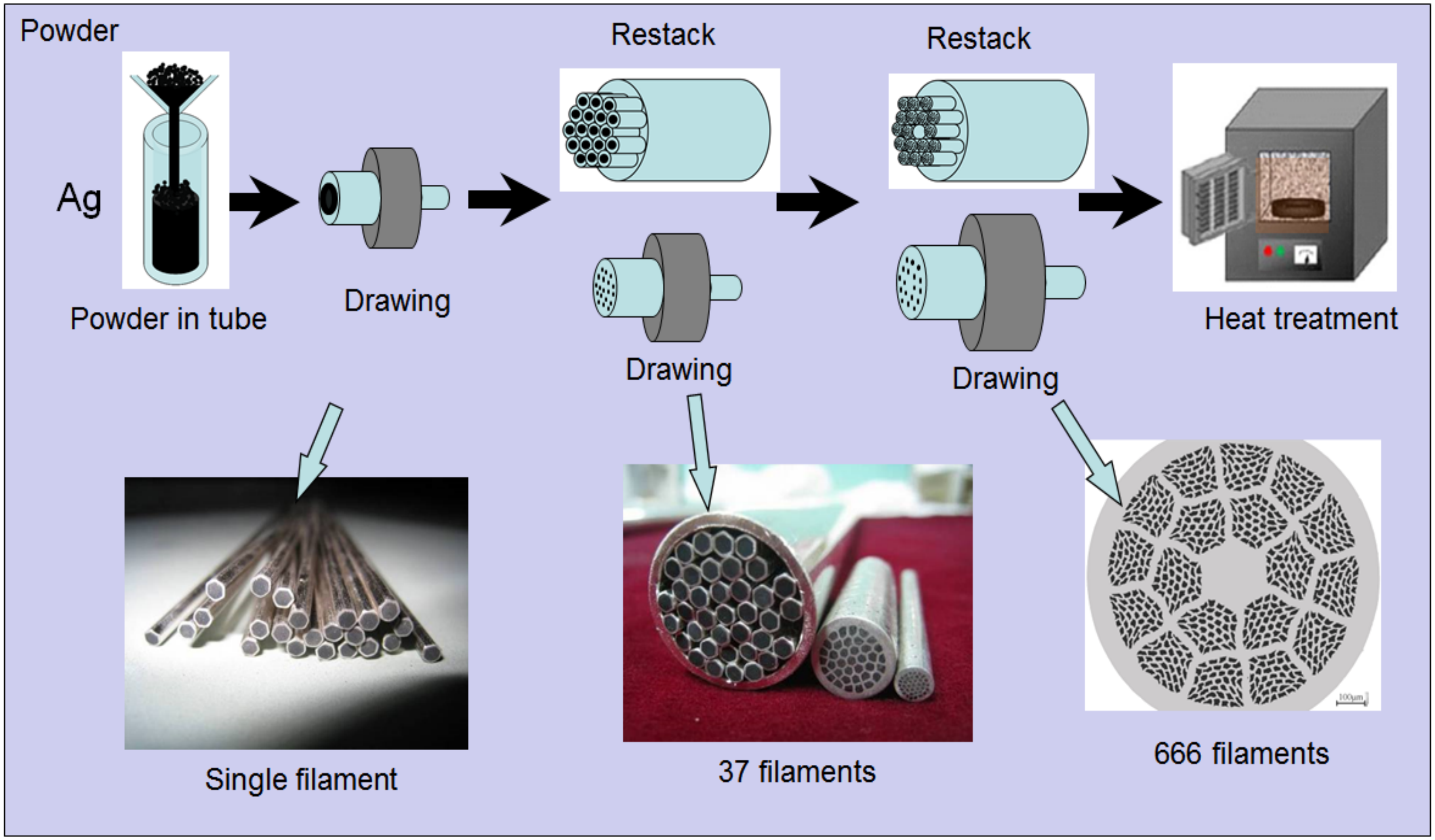


Cross-section evolution by rolling

Bi-2212 round wires

Fabrication process

- Bi2212 is currently the unique High-T_c superconductor, that can be prepared into round wires by using the simple powder-in-tube (PIT) method.
- Bi2212 superiority: T_c of 85 K, H_{c2} of more than 100 T, and J_e >500 A/mm^2 at 4.2 K and 30 T.
- Kilometer-grade Bi2212 round wire by PIT method.

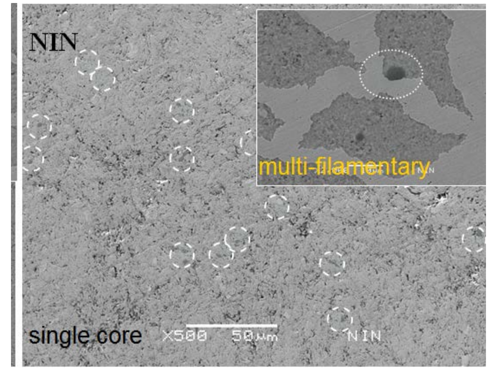


Bi-2212 round wires

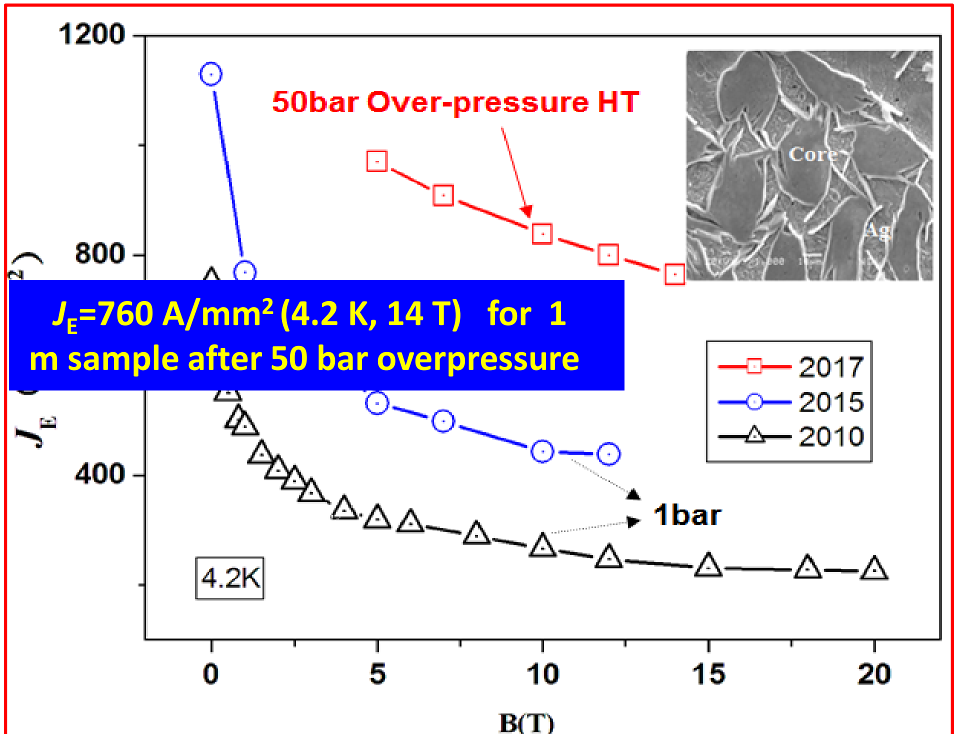
Recent progress in powder and performance

Significant improvement is anticipated by optimizing:

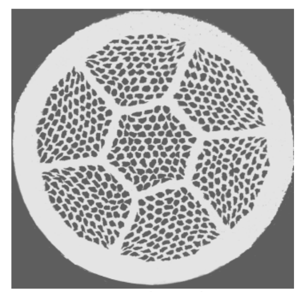
- Powder preparation technology
- Drawing parameter
- Overpressure, melting and solidification steps of heat-treatment



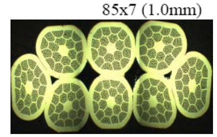
less and smaller hard particles in powder



J_E=760 A/mm^2 (4.2 K, 14 T) for 1 m sample after 50 bar overpressure



85x7 (1.0mm)



Summary

- WST has a long history of over 50 years in the R&D of superconducting materials.
- WST contributed 174 ton NbTi strand and 35 ton Nb_3Sn strand for ITER.
- LTS: Continue the production of MRI wire.
- Pursuing higher performance strand for fusion and accelerators.
- Low cost, flexibility and efficient service.
- HTS: process improvement for long length and performance stability.

Thanks for your attention!