Advanced superconductors developed at WST

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Western Superconducting Technologies Co., Ltd.
Milestones of WST

February 1965

- Superconductivity Discovery
- NbTi Superconductivity
- Jc Record of NbTi strand
- WST Founded
- NbTi Qualification for ITER
- Nb₃Sn Qualification for ITER
- Nb₃Sn Delivery for ITER
- WIC Qualified by GE
- NbTi Delivery for ITER

**Abstract** - The results of critical current measurements of NbTi50 multifilamentary wire at 4.2 K in the fields up to 9 T are reported in this paper. The measurements show that the best optimized samples have excellent critical current properties, especially in mid-field. Its $J_c(4.2K)$, for instance, is 3400 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 $J_c$ values in NbTi50 alloy are described. The flux pinning force and microstructural features are discussed.
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- NbTi Delivery for ITER

- 1911
- 1957
- 1965
- 1984
- 2003
- 2009
- 2010
- 2015
- 2017
Milestones of WST

- May 2010: Superconductivity Discovery
- October 2010: NbTi Superconductivity
- September 2015: Nb3Sn Qualification for ITER
- March 2017: NbTi Delivery for ITER

Key Dates:
- 1911: Superconductivity Discovery
- 1965: NbTi Superconductivity
- 2003: Jc Record of NbTi strand
- 2009: WST Founded
- 2010: Nb3Sn Qualification for ITER
- 2015: Nb3Sn Delivery for ITER
Milestones of WST

- Superconductivity Discovery (1911)
- NbTi Superconductivity (1965)
- NIN Founded (1984)
- Jc Record of NbTi strand (2003)
- WST Founded (2009)
- NbTi Qualification for ITER (2010)
- Nb₃Sn Qualification for ITER (2015)
- Nb₃Sn Delivery for ITER (2017)
- WIC Qualified by GE (2017)
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WST Today

- Rolling line
- MRI wire
- Swaging
- Superconductor
- Melting
- Free forging
- Storage
- R&D building
# Superconductor Family of WST

## LTS

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**NbTi strand for high magnetic field**

**Improvement of \( J_c \) and \( T_{cs} \)**

- NbTi strand for high magnetic field: \( J_c=690\,\text{A/mm}^2, \ T_{cs}=7.1 \text{ K} \)
- At 7 K, \( J_c=600\,\text{A/mm}^2 @ 3.6 \text{ T}; \ J_c=380\,\text{A/mm}^2 @ 4.1 \text{ T} \)
Structure and performance

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

- $J_c$ achieves 2669 A/mm² in Cu5Ni matrix and 2985 A/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.
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

![Graph showing the relationship between $B$ (T) and $n$ value for Rod bar and Hexagonal bar.](image)
Internal-tin Nb$_3$Sn 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](image_a)

![After deform. optim.](image_b)

![With one Cu split](image_c)

![With two Cu splits](image_d)

![Sn spacer + one Cu splits](image_e)

![37 sub. + one Cu splits](image_f)
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$_3$Sn ring
$J_{cn}$ drops 5%-10%
$Q_h$ below 300 mJ/cm$^3$

Reaction degree increase

Both high $J_{cn}$ and low $Q_h$
Sn spacer harms deform.
One Cu split + 37 sub. is best
Bronze Nb₃Sn strand

**Nb₃Sn pre-reaction in process**

- Up to 450 °C, less Nb₃Sn particles on the Nb surface.
- At 500 °C, Nb₃Sn particles are easily grown.

Sn content in bronze is proportional to Nb₃Sn pre-reaction.
- After 10 h, Sn content changed little and small Nb₃Sn particles appeared.
- After 50 h, Sn content dropped and dense Nb₃Sn particles created. Most for 500 °C.
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

$\pm 3$ T, 4.2 K

- Ta diffusion barrier is best to reduce $Q_h$ below 100 mJ/cm$^3$.
- Ta breaks the Nb$_3$Sn ring and reduces hysteresis loss.
- A Nb$_3$Sn ring formed inside of the Nb diffusion barrier leads to a highest hysteresis loss.

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

Performance improvement

Bronze Nb$_3$Sn strand
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
Rapid heating and quenching (RHQ) heat-treatment

- RHQ heat-treatment process of reel-to-reel Nb$_3$Al wires with a continuous increasing sintering current.

- Our aim is to develop the practical high performance Nb$_3$Al superconducting wires, many efforts are still being ongoing.
Superconductor Family of WST

**LTS**

- NbTi
- NbTi/CuNi
- WIC
- IT Nb$_3$Sn
- Bronze Nb$_3$Sn
- Nb$_3$Al

**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.

The extrusion temperature is 450 °C for 2 h.

MgB$_2$ rod after hot-extrusion
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
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.

Fabrication process
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

$J_E = 760 \text{ A/mm}^2 (4.2 \text{ K}, 14 \text{ T})$ for 1 m sample after 50 bar overpressure
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 Nb₃Sn 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!