EXPLORING HIGH PERFORMANCE SUPERCONDUCTING MATERIALS: COLLABORATION ACTIVITY BETWEEN CERN AND CNR-SPIN

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CNR-SPIN
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CERN
Phase diagram of technical superconductors

C. Tarantini et al., PRB 84, 184522 (2011)
Status of High Field Magnet R&D for CEPC-SPPC

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On behalf of the SPPC magnet working group

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SppC Design Scope (201701 version)

- **Baseline design**
  - Tunnel circumference: 100 km
  - Dipole magnet field: 12 T, iron-based HTS technology (IBS)
  - Center of Mass energy: >70 TeV
  - Injector chain: 2.1 TeV

- **Upgrading phase**
  - Dipole magnet field: 20-24T, IBS technology
  - Center of Mass energy: >125 TeV
  - Injector chain: 4.2 TeV (adding a high-energy booster ring in the main tunnel in the place of the electron ring and booster)

- **Development of high-field superconducting magnet technology**
  - Starting to develop required HTS magnet technology before applicable iron-based wire is available
  - ReBCO & Bi-2212 and LTS wires be used for model magnet studies and as an option for SPPC: stress management, quench protection, field quality control and fabrication methods

*Top priority: reducing cost! Instead of increasing field*
Collaboration on HTS

“Applied High Temperature Superconductor Collaboration (AHTSC)” was formed in Oct. 2016. with >13 related institutes & companies and 50 scientists & engineers to advance HTS R&D and Industrialization.

- **Goal:**
  1) To increase the $J_c$ of IBS by 10 times, reduce the cost to 20 Rmb/kAm @ 12T & 4.2K in 10 years, and realize the industrialization of the conductor;
  2) To reduce the cost of ReBCO and Bi-2212 conductors to 20 Rmb/kAm @ 12T & 4.2K in 10 years;
  3) Realization and Industrialization of iron-based SRF technology.

- **Working groups:** 1) Fundamental science investigation; 2) IBS conductor R&D; 3) ReBCO conductor R&D; 4) Bi2212 conductor R&D; 5) performance evaluation; 6) Magnet and SRF technology.
ACTIVITIES OF THE COLLABORATION:

**Bi-2212**
To reproduce the performance today obtained by high pressure heat treatment with a mechanical deformation process.

* A Malagoli, A Leveratto, L Leoncino, C Ferdeghini

**IBS**
To develop prototype IBS conductors that meets the Jc requirements through reliable, simpler and scalable techniques that could enable industrialization.

* V Braccini, G Sylva, A Malagoli, E Bellingeri, C Ferdeghini, M Putti, A Provino, P Manfrinetti

**MgB<sub>2</sub>**
To increase the operating field by adopting an original doping method.

* M Vignolo, G Bovone, M Capra, C Bernini, F Loria, A S Siri

GOALS:
To advance their performance using industrially scalable productive methods, to make them suitable for high-field magnet applications.
A flexible conductor technology (Round and other shapes)
The fabrication route similar to that for Nb-based and MgB2 superconductors

Bubbles and internal pressure formation in long length (≥1m) wires due to **Carbon impurity** and **porosity**
W & R like Nb$_3$Sn but, but more complex:

**Properties have significantly improved**

**GOAL OF THE COLLABORATION:**
Bi-2212 to achieve the performance today obtained by the optimization of mechanical deformation and thermal processes
Groove-rolling / drawing alternation


Not a fully dense wire but
- low residual porosity
- no bubbles
Investigation of novel configuration to increase f.f. and homogeneity of the cross-sections
In-situ X-ray diffraction of Bi(2212)-wire

Aim: Bi(2212) phase evolution during heat treatment

A. Martinelli et al submitted
Heat treatment optimization

- Information about Bi(2212) phase evolution
  - Texturing
  - Role of the Oxygen
  - Secondary phase

- Result: Bi(2201) recrystallizes at $T=850^\circ C$

NEXT STEP:
Perform an innovative heat treatment to prevent Bi(2201) phase growth (plateau 855°C/48h)
Iron based superconductors (IBS)

- Large $H_{c2}$
- $H_{irr}$ close to $H_{c2}$

C. Tarantini et al., PRB 84, 184522 (2011)

$J_c [A/cm^2]$ vs. $\mu_0 H [T]$

- $T = 4.2K$

Filled symbols: $H//c$
Empty symbols: $H//ab$

- Large
- Isotropic
- Field independent
Milde dependence of $J_c$ on the misorientation angle

$\theta$ [deg]

$J_c$ of technical conductors above the practical level

IBS advantageous GB over HTS

NEED OF DEVELOPING SCALABLE PROCESSES FOR MAKING LONG CONDUCTORS
to develop prototype IBS conductors through reliable, simpler and scalable techniques

- Develop method for preparing a large amount of 122 powders
- Optimization of mechanichal-thermal treatments for increasing density
Critical angle (about 10°) much higher than in ReBCO

The deposition temperature is much lower (300°-500°C) than for YBCO (800°C):

Oxygen deposition is no longer required. (substrate oxidation it is not an issue)

- Create a biaxially textured metallic substrate with a simpler structure than commercial ones.
- Reduce or even remove buffer layers
  ⇒ Reduce complexity and costs of production
  ⇒ Obtain a larger Jc

Ni alloys + buffer (CeO2, LaZrO2, CZO)

Iron alloys (Fe/Ni)
INVAR:
- Commercial alloy 64% Fe, 36% Ni
- Low cost
- FCC structure, compatible with Fe(Se,Te)

drawn / flat rolled $\Rightarrow$ 50 / 70 $\mu$m + HT @ 1000 °C

**First attempts of growth of Fe(Se,Te) on textured INVAR**

θ–2θ: epitaxial Fe(SeTe) film

Rocking Rolling Direction:
- Out-of-plane orientation

Φ scan:
- in-plane orientation

- Growth of epitaxial thin films on INVAR
- Superconducting properties not yet observed
Growth of epitaxial thin films on NiW5%+CeO2

\( T_c \approx 18 \text{ K}, H_{c2} \text{ large and isotropic} \)

\( J_c \text{ isotropic but not yet optimized} \)
- $T_c = 39$ K
- Metallic system
- Low density
- Low cost elements
- No evidence of “weak link”
- $H_{c2}(0) > 70$ T in thin films

- $H_{c2}(0) \sim 18$ T in undoped MgB$_2$
- Difficulty to introduce dopant elements, but for C which increases $H_{c2}$ and decreases $T_c$
- Difficulty to increase the pinning by nanoparticle additions, the principal pinning defects are grain boundaries
- To date MgB$_2$ is not a high field superconductor

![Graph showing $T_c = 39$ K and $H_{c2}(0) > 70$ T in thin films]

![Graph showing $H_{c2}(0) \sim 18$ T in undoped MgB$_2$ and other elements and their effects]

References:
- K Togano, et al., SUST 22 (2009) 015003
- G Z Li et al., SUST 26 (2013) 095007
- Shu Jun Ye, et al., SUST 27 (2014) 085012

(Courtesy of P.Kovac)
To increase the operating field by adopting an original doping method

**Synthesis of nano-boron**

Freeze drying technique to prepare doped nanosized B powder

Bovone G., Kawale S., Bernini C., Siri A., Vignolo M. Drying Technology 34, 2016, 923-929
Scaling up the process has taken one year-work

100 gr (Rough material) $\Rightarrow$ 500 gr
5 gr (Boron) $\Rightarrow$ 25 gr

50 gr of pure, amorphous nano-B are ready to be delivered to

to develop a novel route for realizing multi-filamentary tapes
Project is going on ....

see you at the next FCC week with more results