



Future Circular Collider conference
AMSTERDAM, The Netherlands
09 - 13 APRIL

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



M. Putti, V. Braccini, A. Malagoli, M. Vignolo

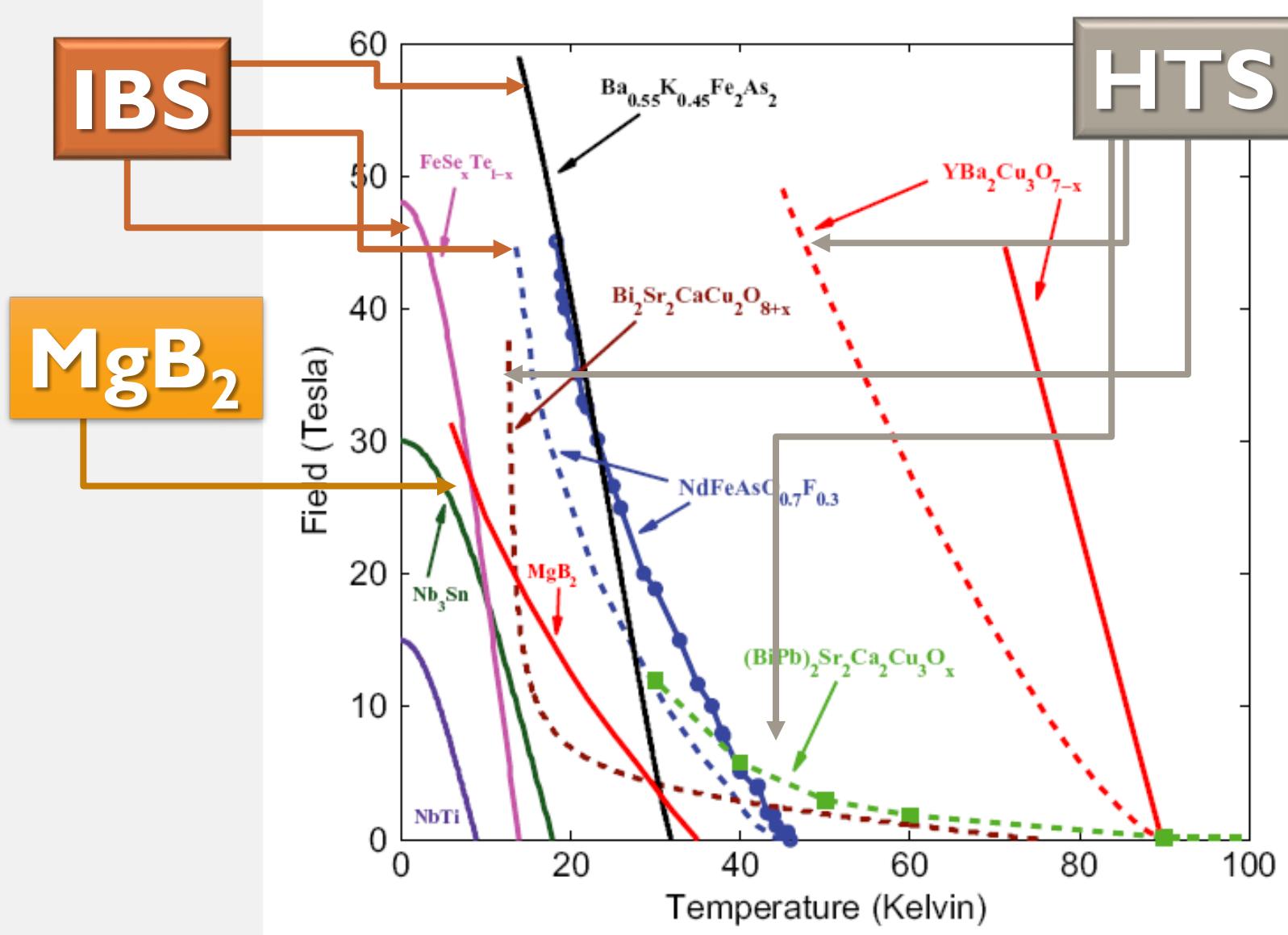
CNR-SPIN

Ballarino, S.C. Hopkins

CERN



Phase diagram of technical superconductors





MAY 29 - JUNE 2
BERLIN, GERMANY

Status of High Field Magnet R&D for CEPC-SPPC

Qingjin XU

On behalf of the SPPC magnet working group

Institute of High Energy Physics (IHEP), Chinese Academy of Sciences (CAS)

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

Top priority: reducing cost!
Instead of increasing field

- **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

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 J_c 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

MgB₂

- 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.



BI-2212 WIRES STATUS



- ✓ 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 ($\geq 1\text{m}$) wires due to **Carbon impurity** and
porosity
- ✗ W & R like Nb₃Sn but, but more complex:

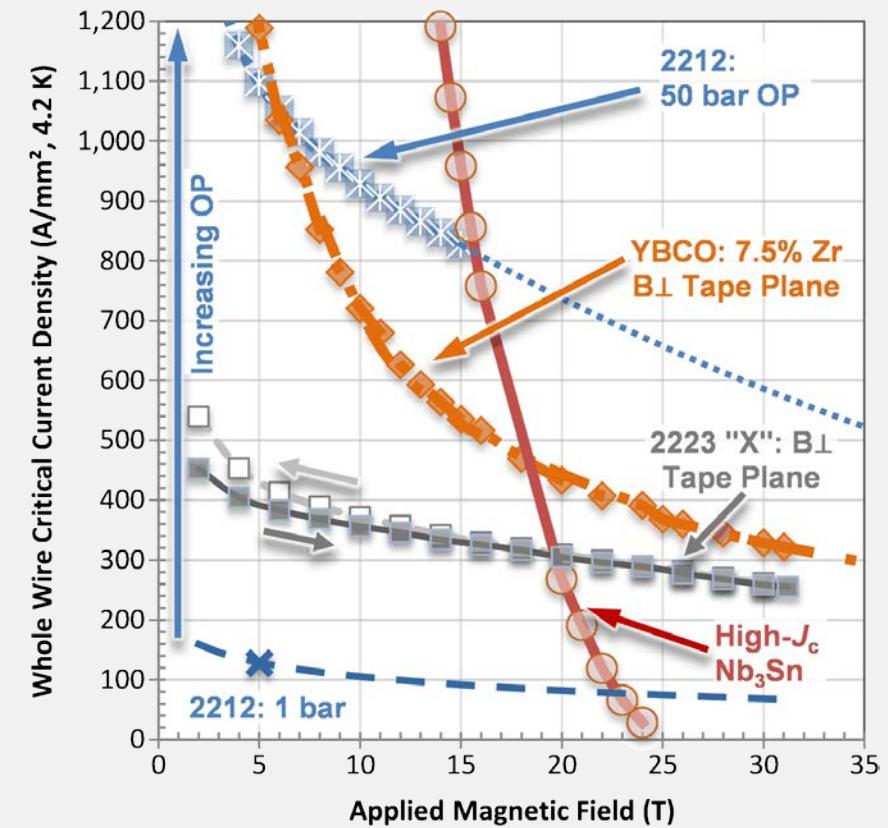
OP HEAT TREATMENT @ ASC

Properties have significantly improved

GOAL OF THE COLLABORATION:

Bi-2212

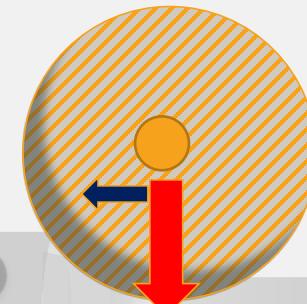
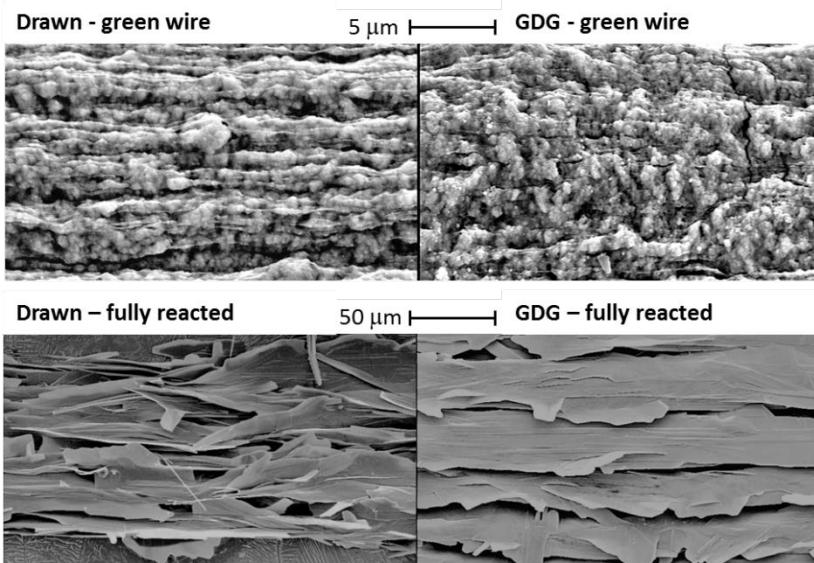
to achieve the performance today
obtained by the optimization of mechanical
deformation and thermal processes



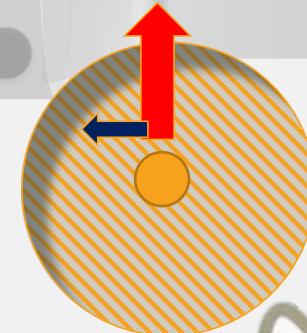
MECHANICAL DEFORMATION: GDG - PROCESS

Groove-rolling / drawing alternation

- A. Malagoli et al *Supercond. Sci. Technol.*, 26 (2013) 045004
A. Malagoli et al *Supercond. Sci. Technol.*, 27 (2014) 055022
A. Leveratto et al *Supercond. Sci. Technol.*, 29 (2016) 045005



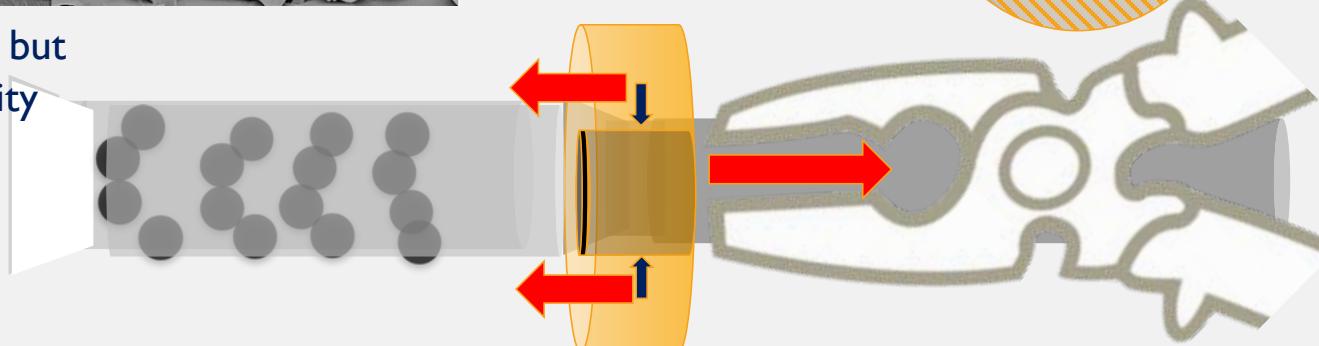
GROOVE-ROLLING



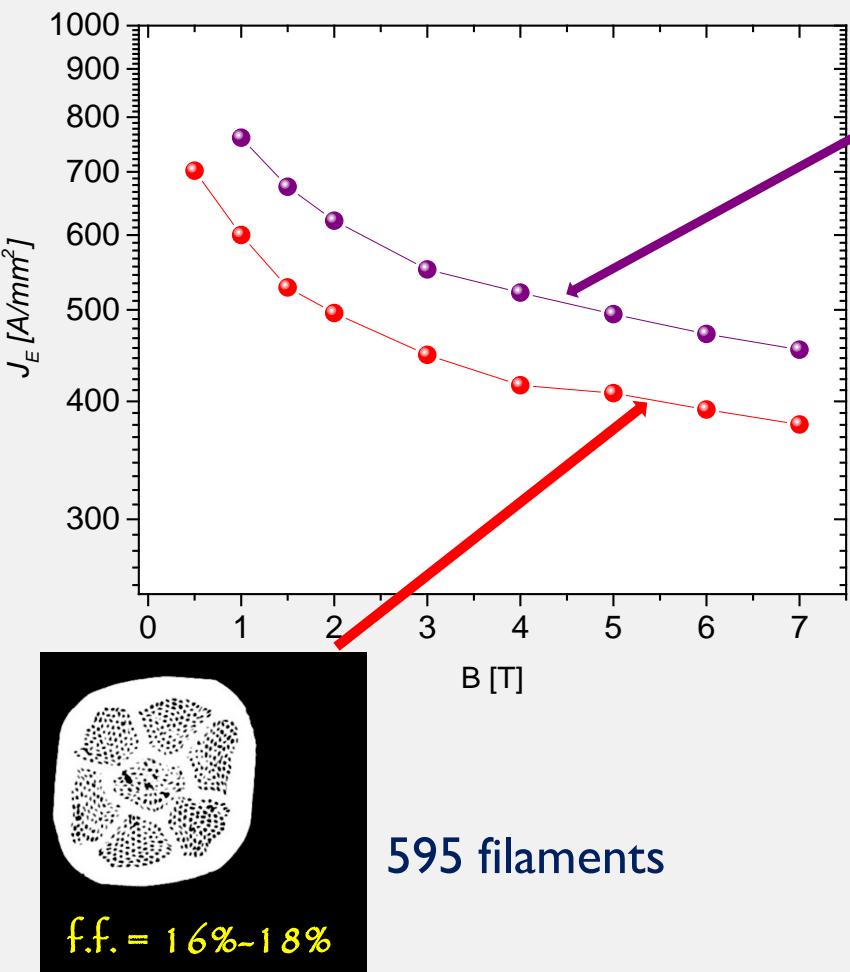
DRAWING

Not a fully dense wire but

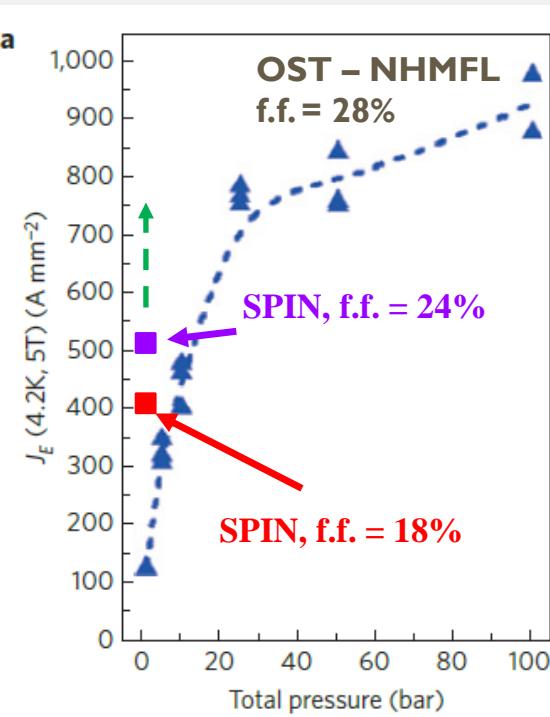
- ✓ low residual porosity
- ✓ no bubbles



WIRE-ARCHITECTURE OPTIMIZATION:



333 filaments

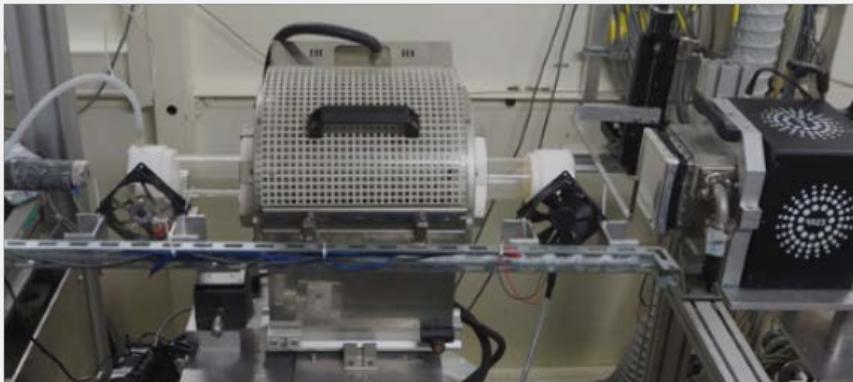
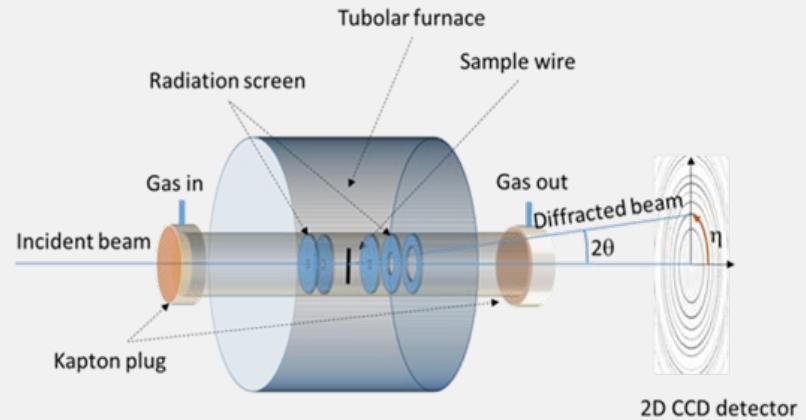
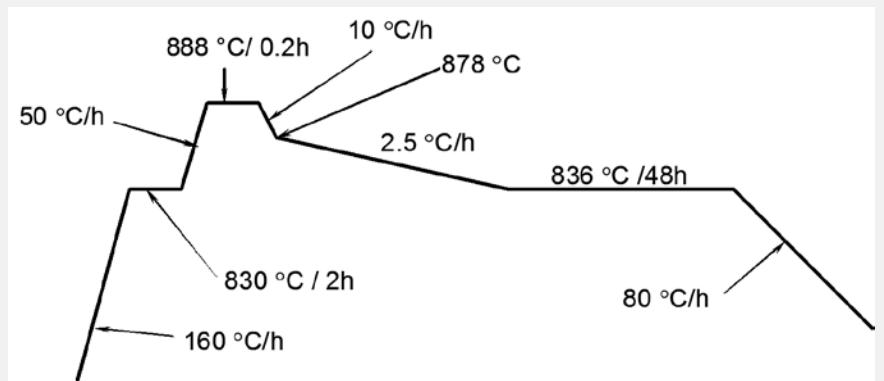


Investigation of novel configuration to increase f.f. and homogeneity of the cross-sections

HEAT TREATMENT OPTIMIZATION

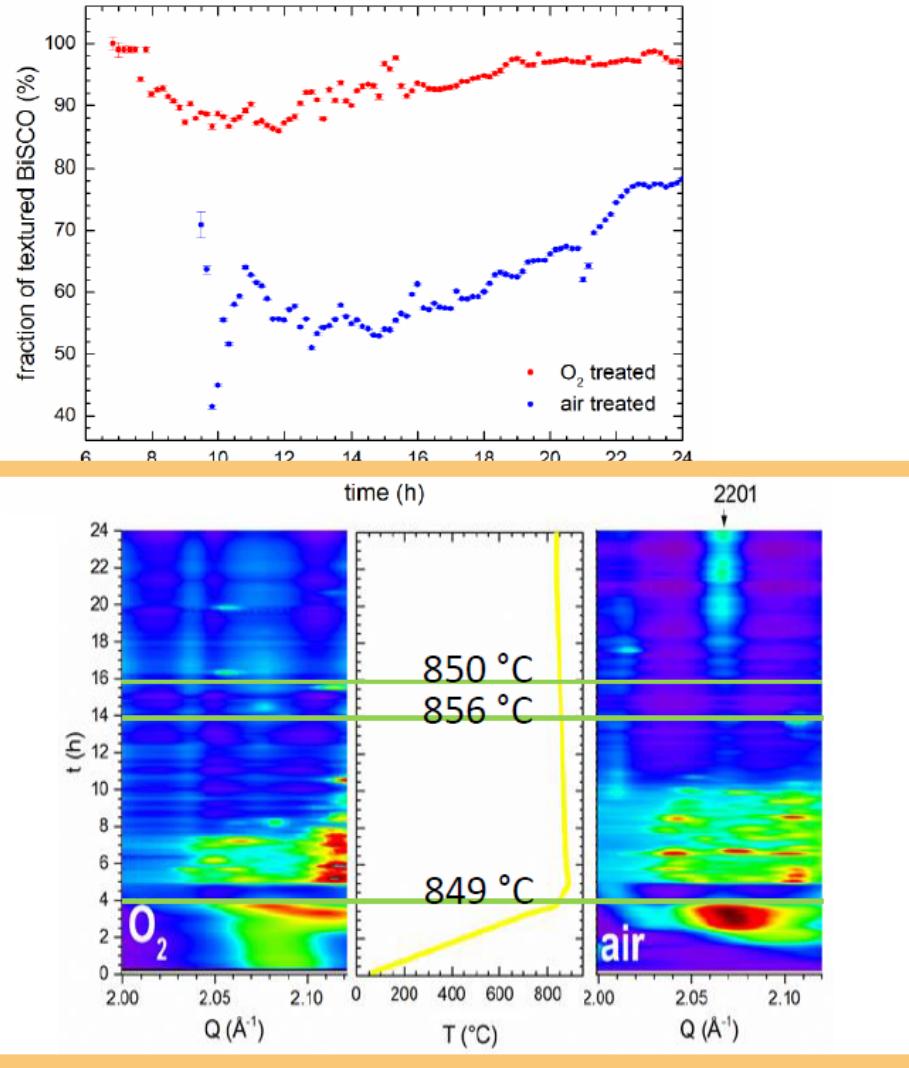


- In-situ X-ray diffraction of Bi(2212)-wire
- Aim: Bi(2212) phase evolution during heat treatment

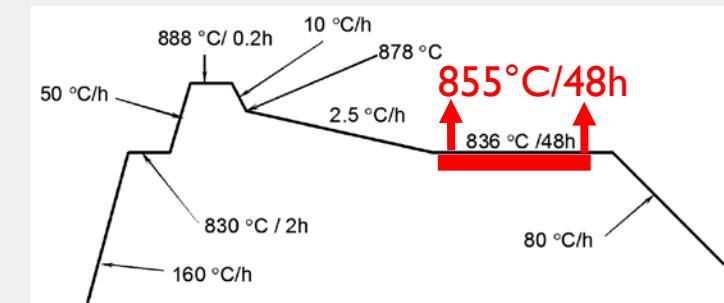


Heat treatment optimization

- Information about Bi(2212) phase evolution
 - Texturing
 - Role of the Oxygen
 - Secondary phase
- Result: Bi(2201) recrystallizes at T=850°C



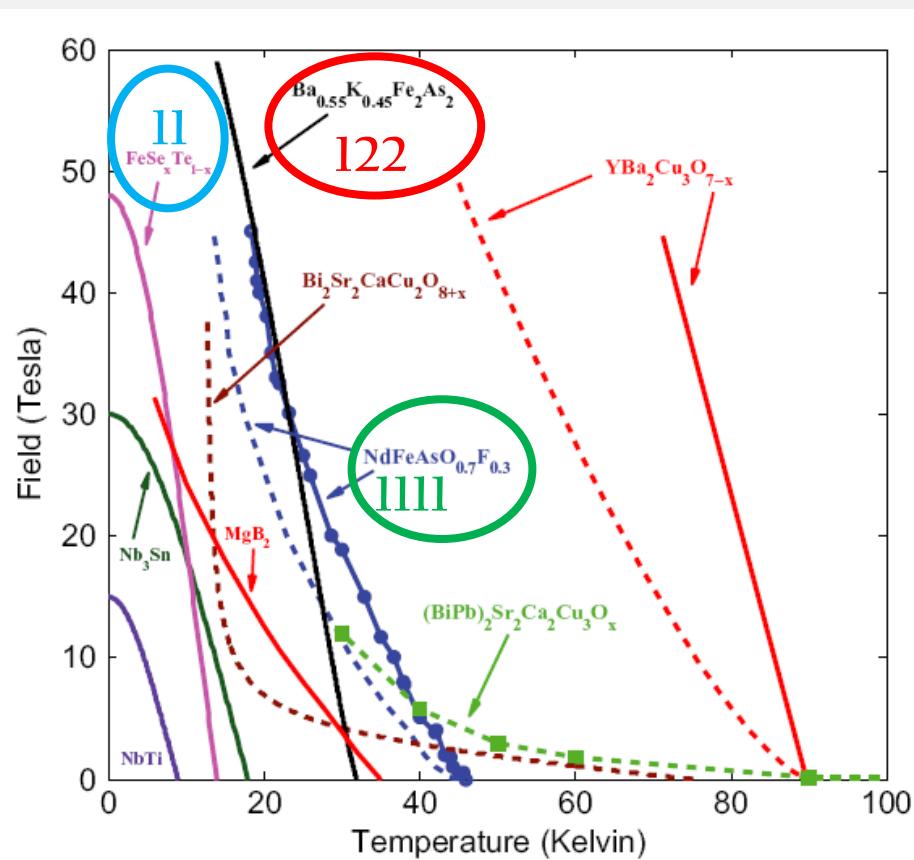
NEXT STEP:
Perform an innovative heat treatment to prevent Bi(2201) phase growth
(plateau 855°C/48h)



Iron based superconductors (IBS)

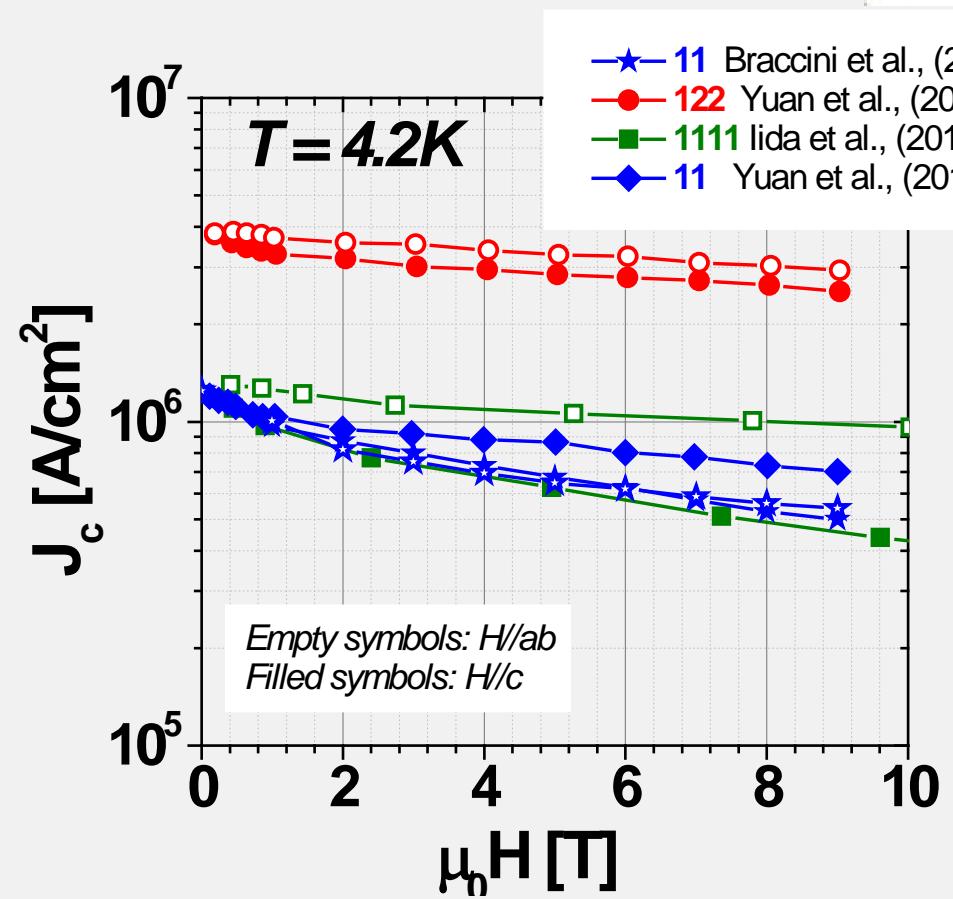
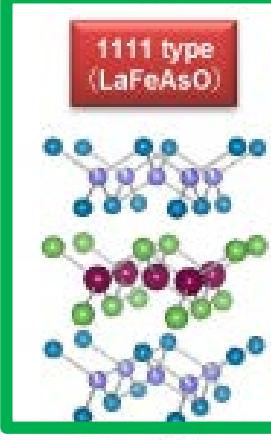
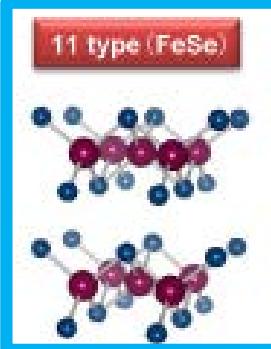
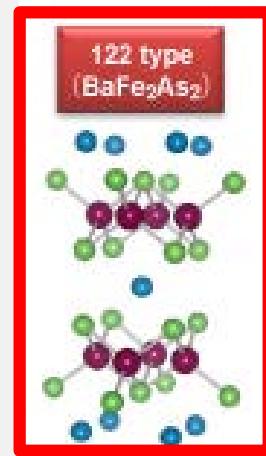
✓ Large H_{c2}

✓ H_{irr} close to H_{c2}



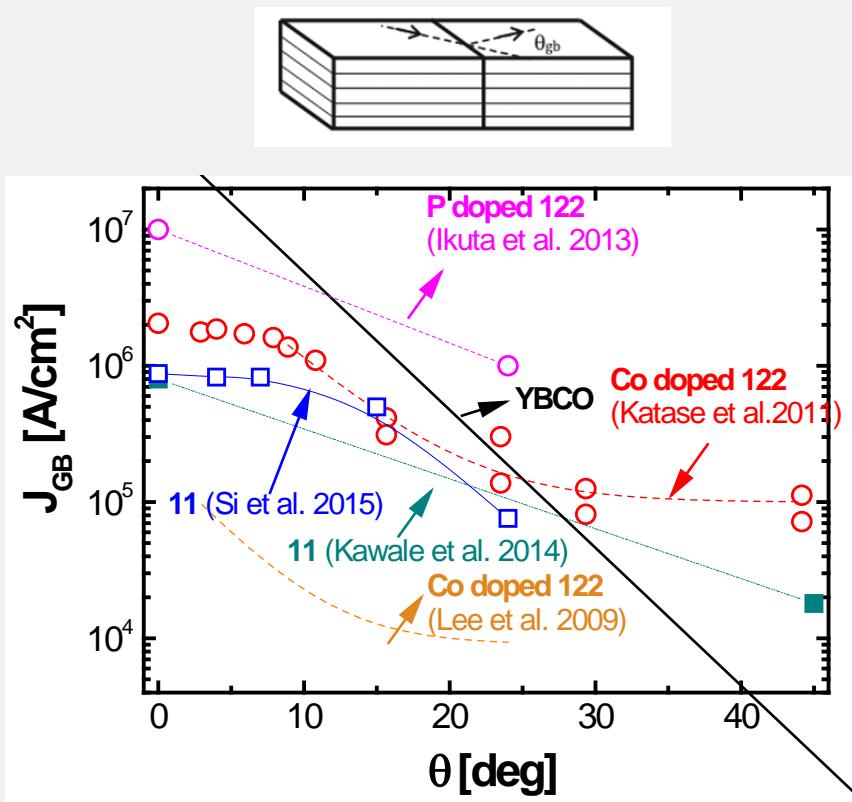
C. Tarantini et al., PRB 84, 184522 (2011)

Super⁺α
FIRST Program



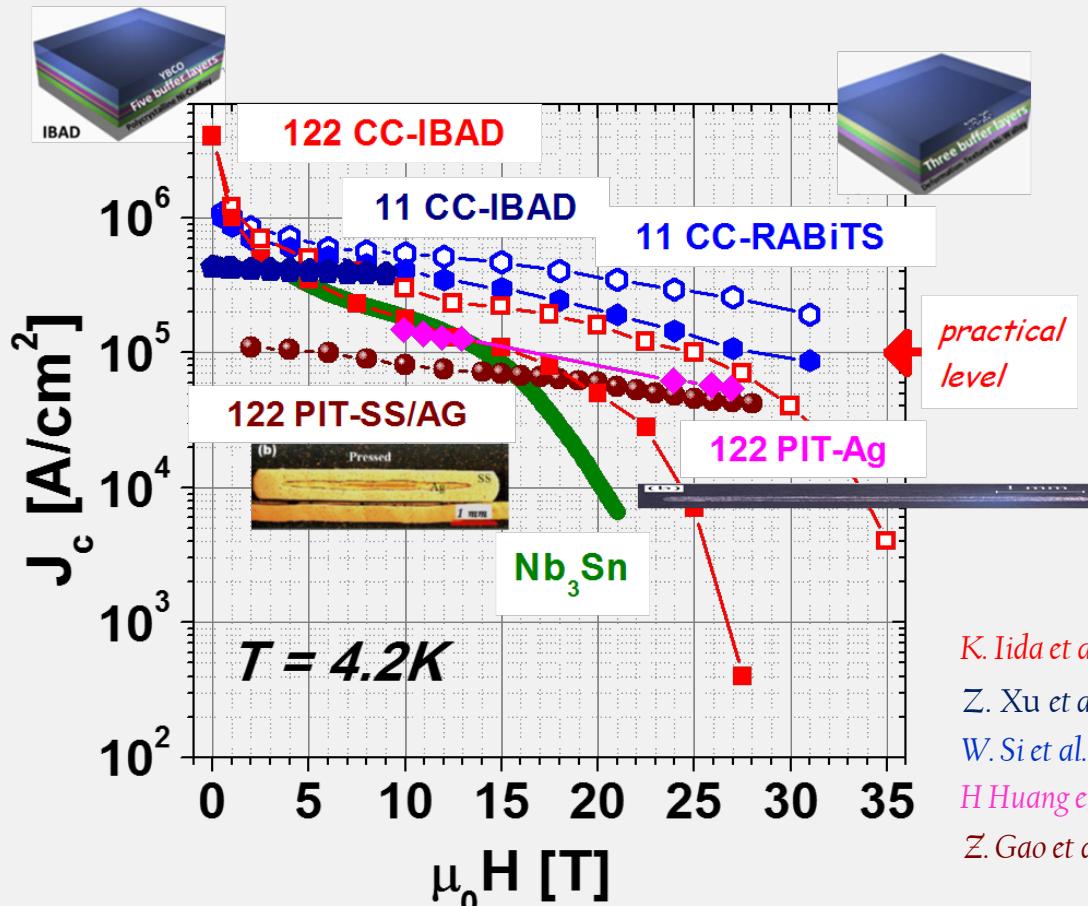
- ✓ Large
- ✓ Isotropic
- ✓ Field independent

✓ **Milde dependence of J_c on the misorientation angle**



IBS advantageous GB over HTS

✓ **J_c of technical conductors above the practical level**



**NEED OF DEVELOPING
SCALABLE PROCESSES FOR
MAKING LONG CONDUCTORS**

- K. Iida et al. Sci. Rep. 7 (2017) 39951
 Z. Xu et al. SuST 30 (2017) 035003
 W. Si et al. Nat. Comm. 4 (2013) 1347
 H Huang et al. SuST 31 (2017) 015017
 Z. Gao et al. SuST 28 (2015) 012001

IBS

to develop prototype IBS conductors through reliable, simpler and scalable techniques

Two routes:

PIT Ba-122

- Develop method for preparing a large amount of 122 powders*
- Optimization of mechanical-thermal treatments for increasing density*

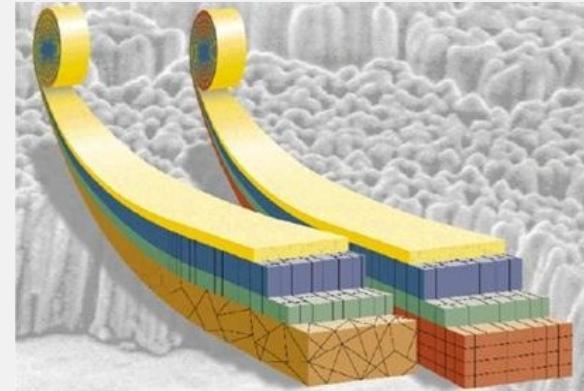


to develop prototype IBS conductors through reliable, simpler and scalable techniques

Two routes:

CC Fe(Te,Se)

- 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 J_e**



- ✓ 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)

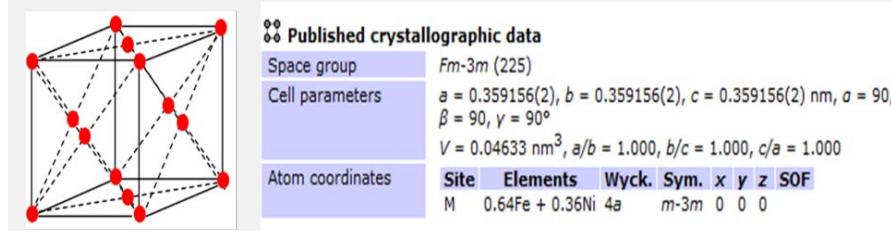
Ni alloys + buffer
(CeO₂, LaZrO₂, CZO)



Iron alloys (Fe/Ni)

INVAR:

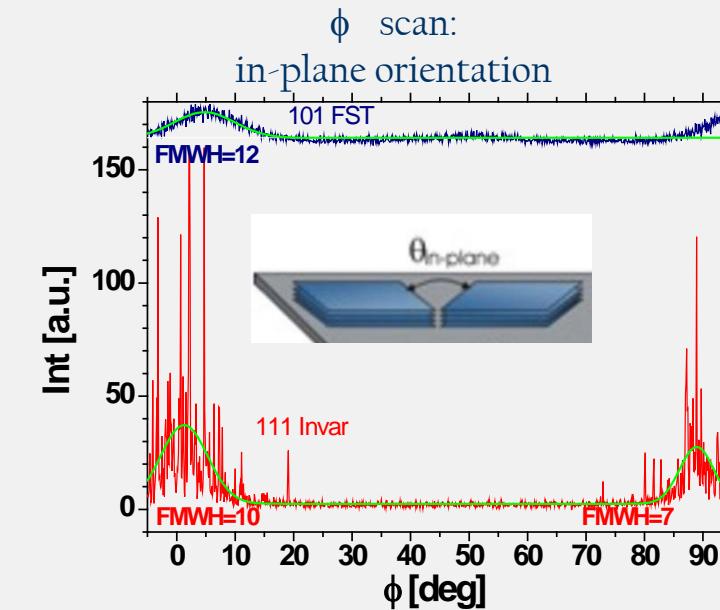
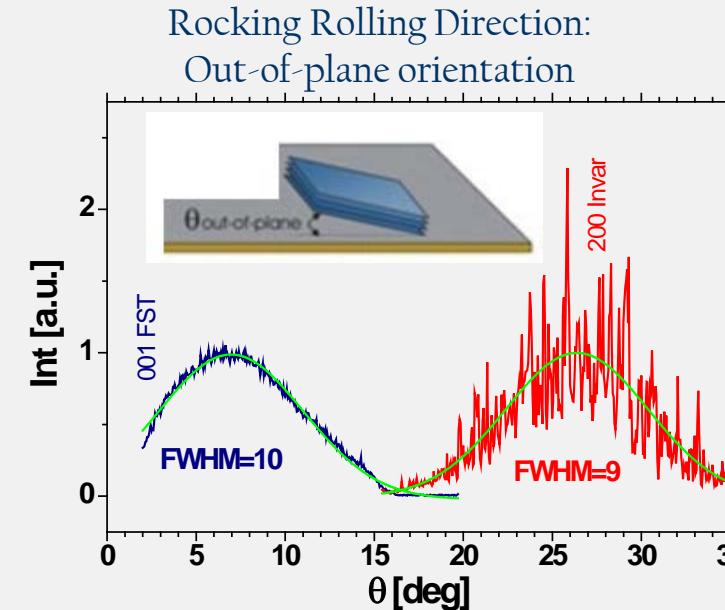
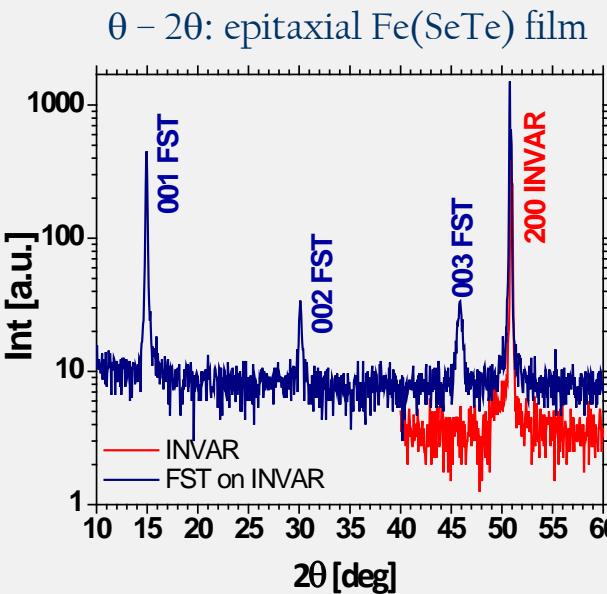
- Commercial alloy 64% Fe , 36% Ni
- Low cost
- FCC structure, compatible with Fe(Se,Te)



drawn / flat rolled $\Rightarrow 50 / 70 \mu\text{m} + \text{HT} @ 1000^\circ\text{C}$



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

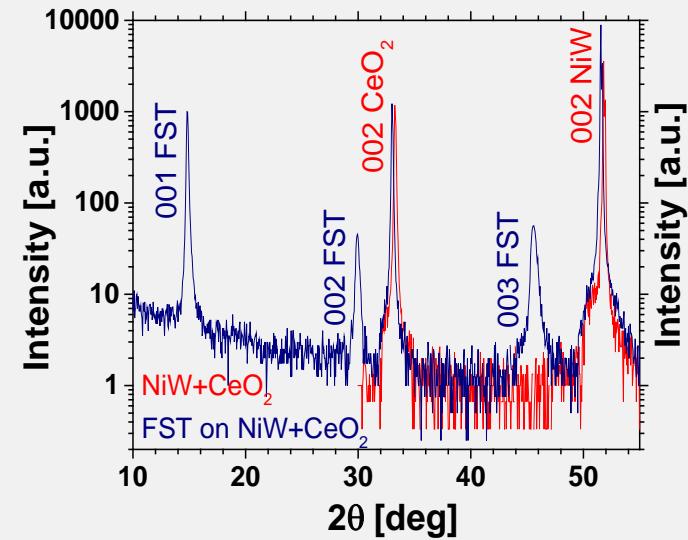
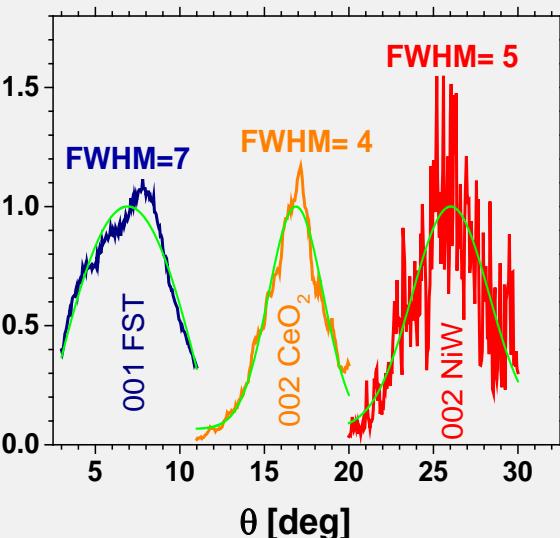
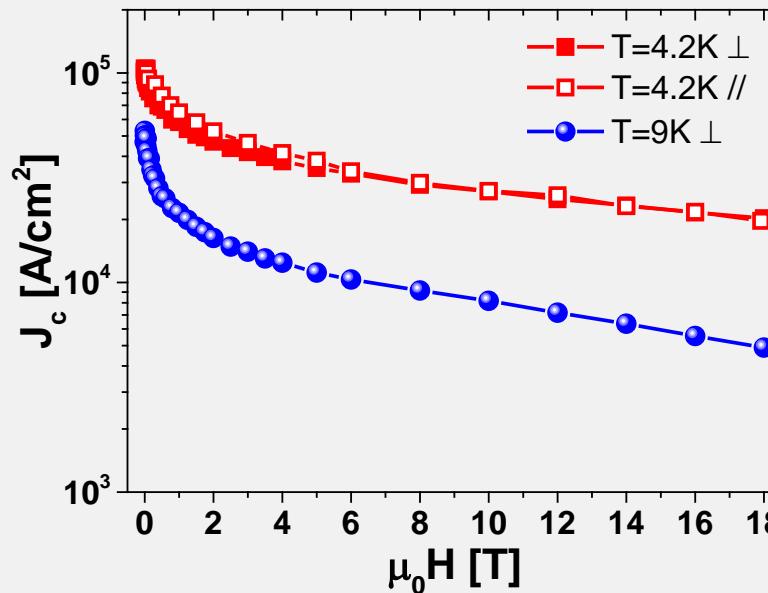
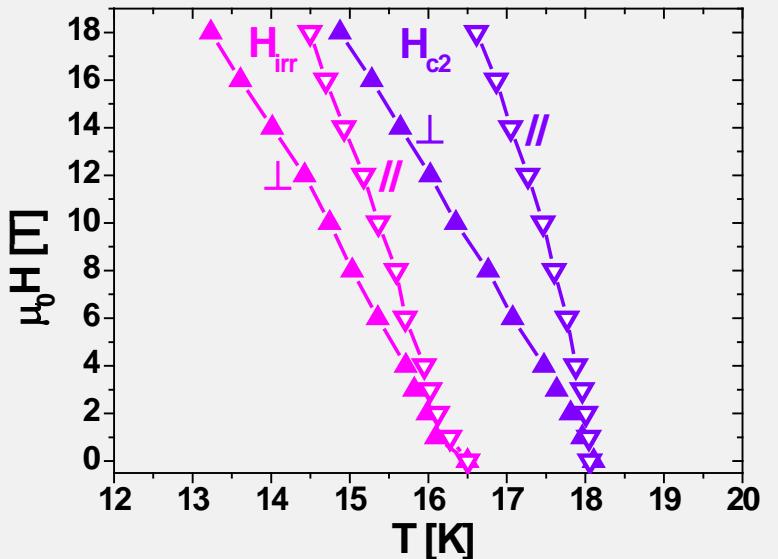
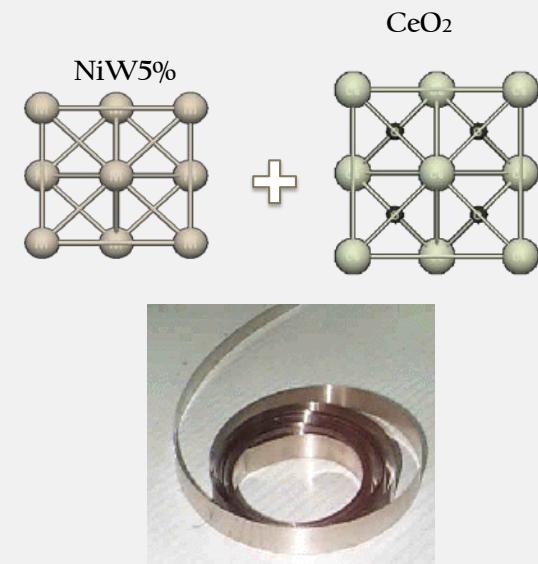
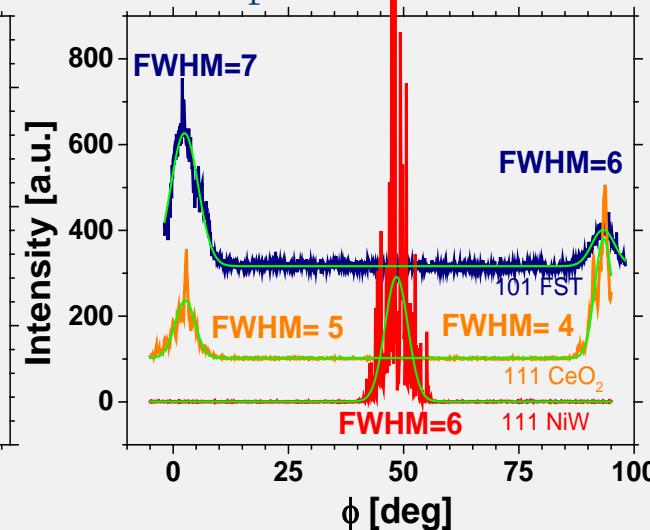


Growth of epitaxial thin films on INVAR



Superconducting properties not yet observed

Fe(SeTe) on NiW5% + CeO₂

 $\theta - 2\theta$: epitaxial Fe(SeTe) filmRocking Rolling Direction:
Out-of-plane orientation ϕ scan:
in-plane orientation

- ✓ Growth of epitaxial thin films on NiW5%+CeO₂
- ✓ $T_c \sim 18$ K, H_{c2} large and isotropic
- ✗ J_c isotropic but not yet optimized

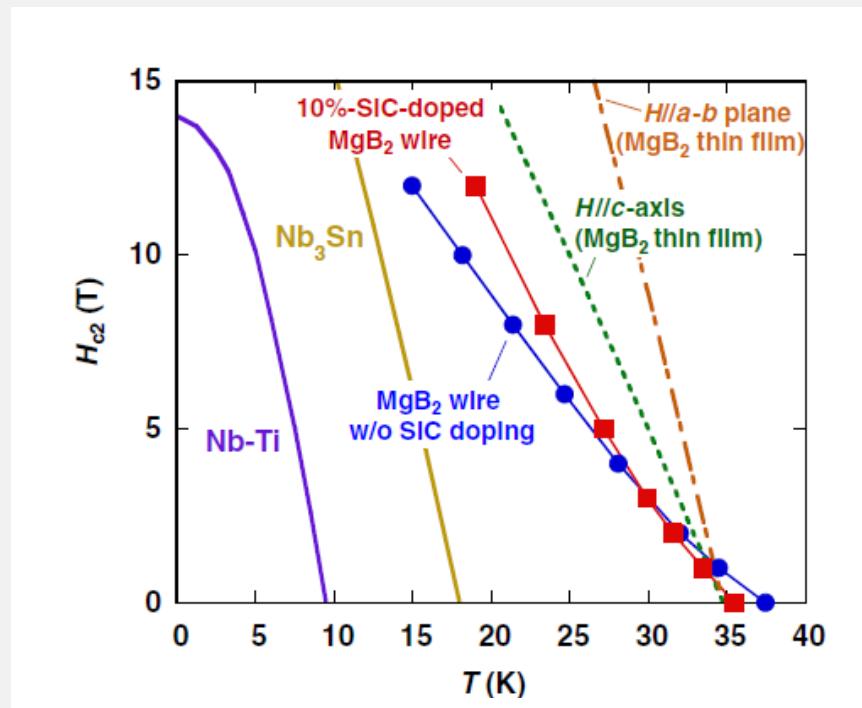


MgB₂



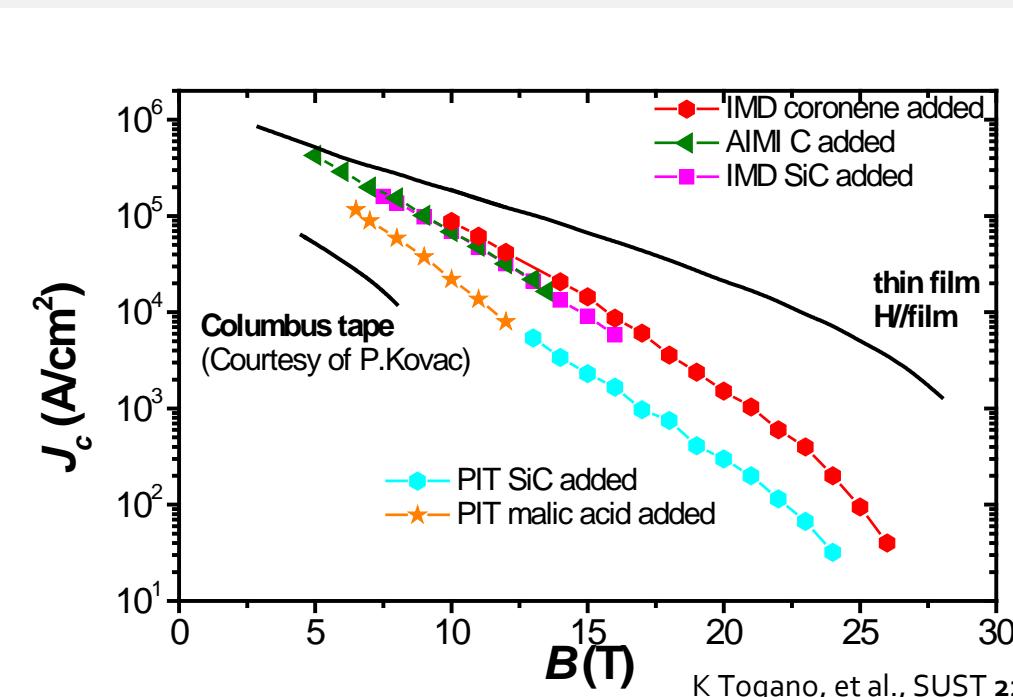
- ✓ $T_c = 39$ K
- ✓ Metallic system
- ✓ Low density
- ✓ Low cost elements
- ✓ No evidence of “weak link”
- ✓ $H_{c2}(0) > 70$ T in thin films

- ✗ $H_{c2}(0) \sim 18$ T in undoped MgB₂
- ✗ 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 MgB₂ is not a high field superconductor



Hiroaki Kumakura[†]

Jpn. J. Appl. Phys. 51 (2012) 010003



K Togano, et al., SUST 22 (2009) 015003

J.H. Kim , et al., SUST 23 (2010) 075014

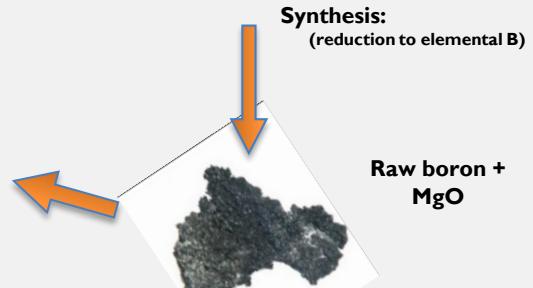
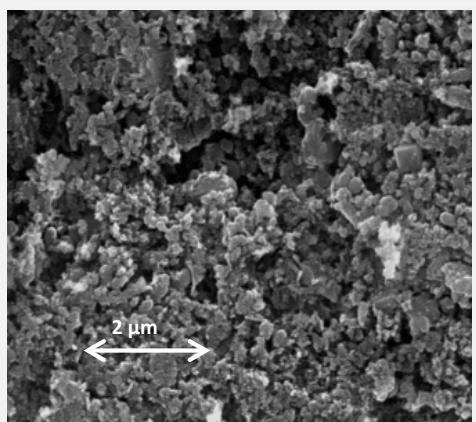
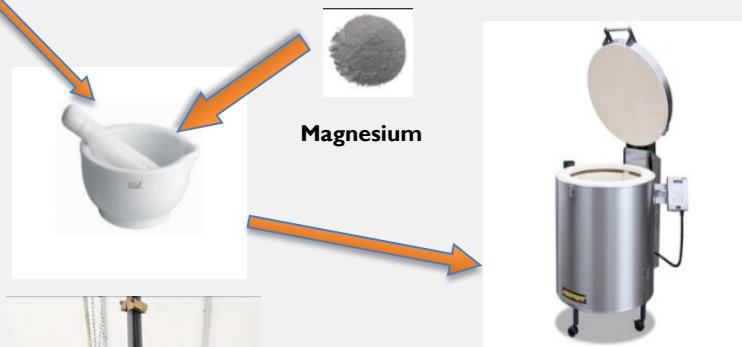
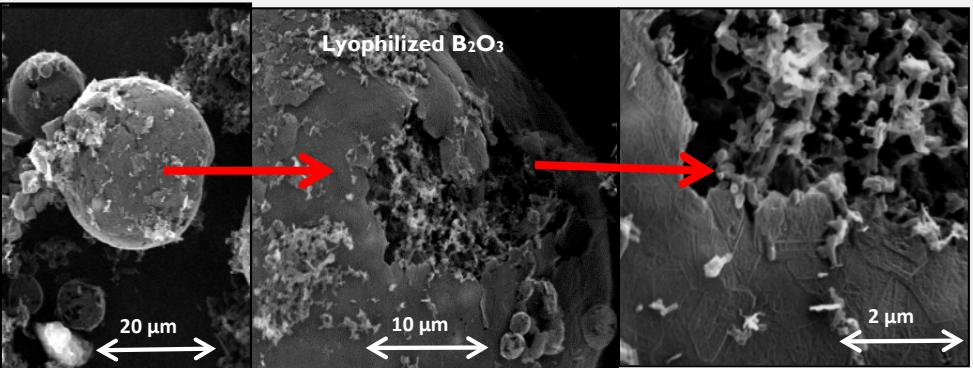
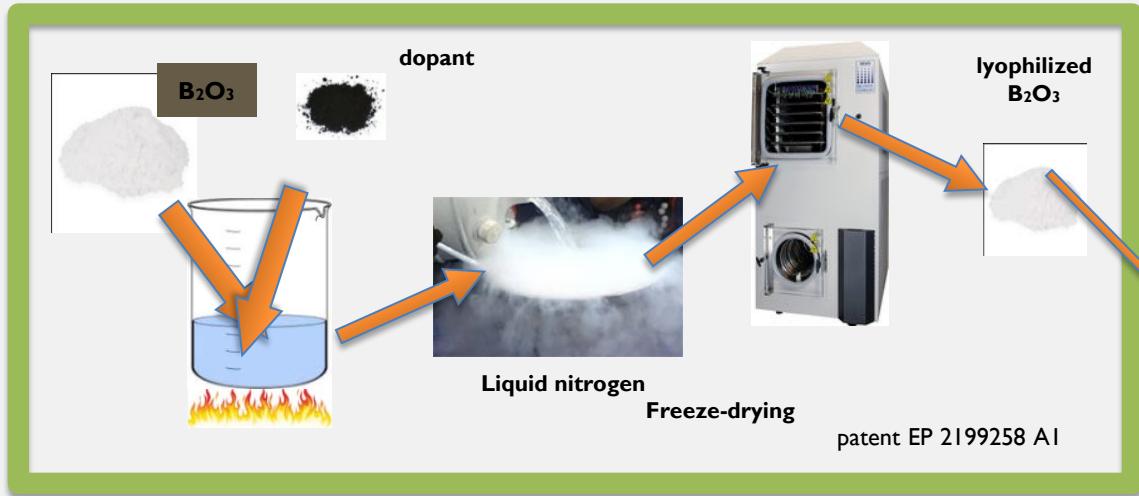
G Z Li et al.SUST 26 (2013) 095007

Shu Jun Ye, et al., SUST 27 (2014) 085012

MgB₂

To increase the operating field by adopting an original doping method

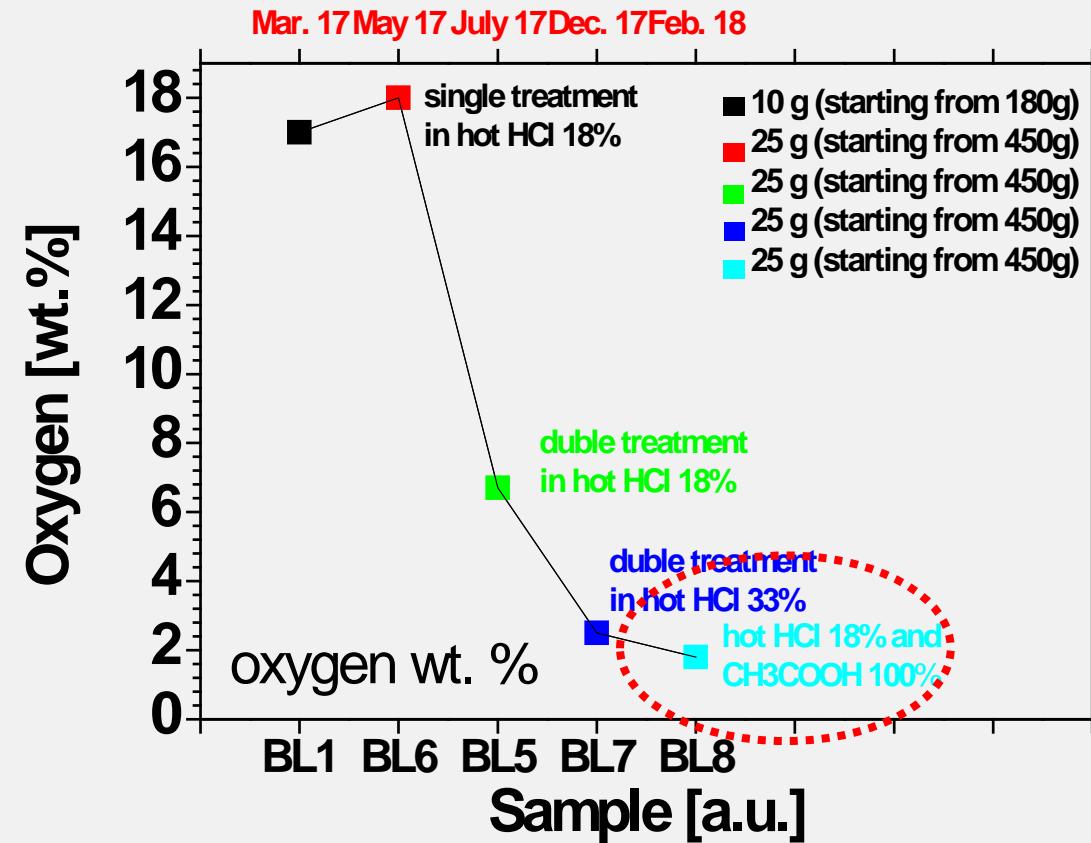
Synthesis of nano-boron



Scaling up the process has taken one year-work

100 gr (Rough material) \Rightarrow 500 gr

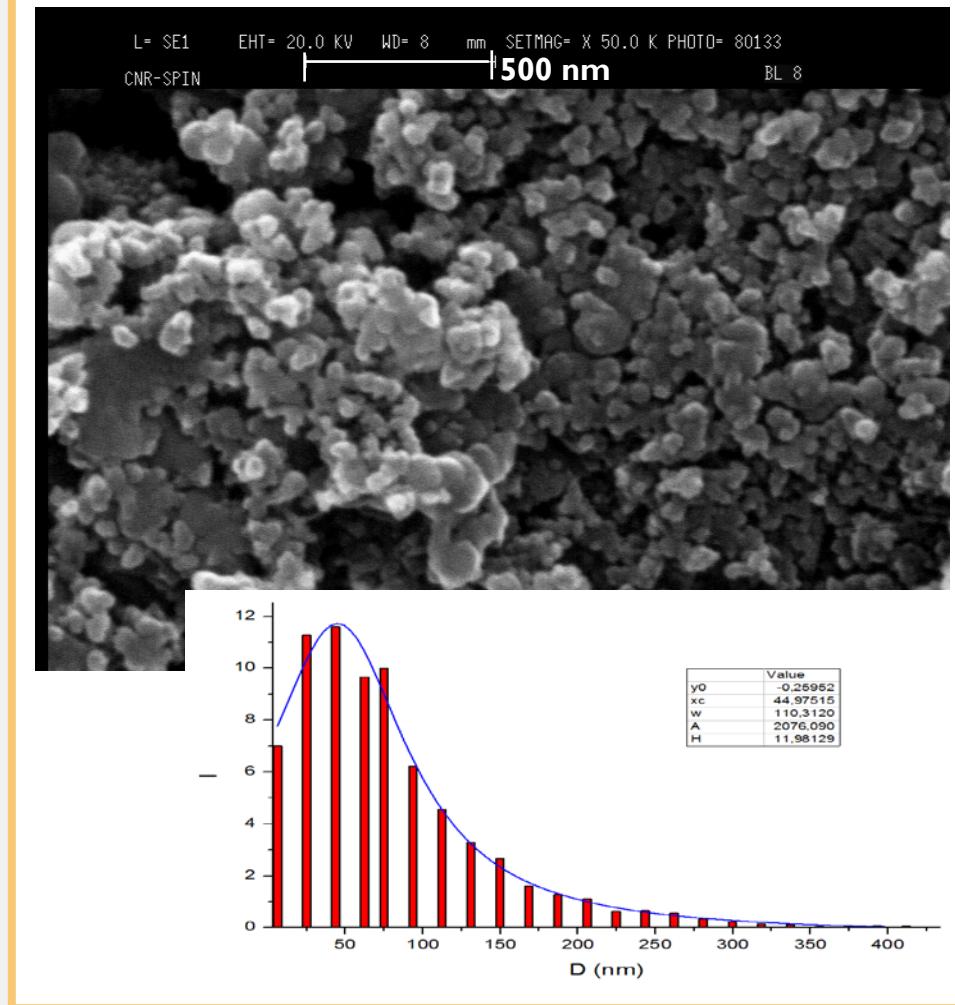
5 gr (Boron) \Rightarrow 25 gr



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