IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), January 2017.
Plenary presentation AT-4 given at 1st Asian ICMC – CSSJ 50th Anniversary Conference; Kanazawa, Japan, November 7 - 10, 2016.

中国科学院 CHINESE ACADEMY OF SCIENCES

中国科学院电工研究所 Institute of Electrical Engineering Chinese Academy of Sciences

Present status of development of superconducting materials in China

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Beijing, China

Outline

Overview: recent progress on conductors

1 LTS

2 HTS conductors

- Bi-2223 tapes
- Bi-2212 round wires
- Y or R.E. based coated conductor tapes

3 MgB_2 wires

4 Iron-based superconducting wires and tapes

5 Conclusions

Practical Wires & Tapes

- **Commercial production:**
  - Niobium alloys (NbTi, Nb_3Sn etc)
  - **Bi2223, Bi2212** / silver tape - 1st Generation HTS
  - **MgB_2**
- **Pre-commercial:**
  - **YBCO** 2nd Generation HTS "coated conductor"
- **Laboratory:**
  - **Fe-based superconducting wires**

Financial Supports for R&D of Superconducting Materials in China

1. Chinese Government

- MOST: 863, 973 plan;
- NSFC

2. Local Government

- Beijing, Shanghai

3. Industry Company

LTS Materials at Western Superconductor (WST)

Western Superconductor company in Xi'an now is the only institution to develop low Tc superconducting materials that are supplied for ITER project.

Capability of advanced Ti alloy and superconductor production lines: 6000 ton ingots of Ti alloy, 3000 ton rods of Ti alloy and 400 ton superconductor per year

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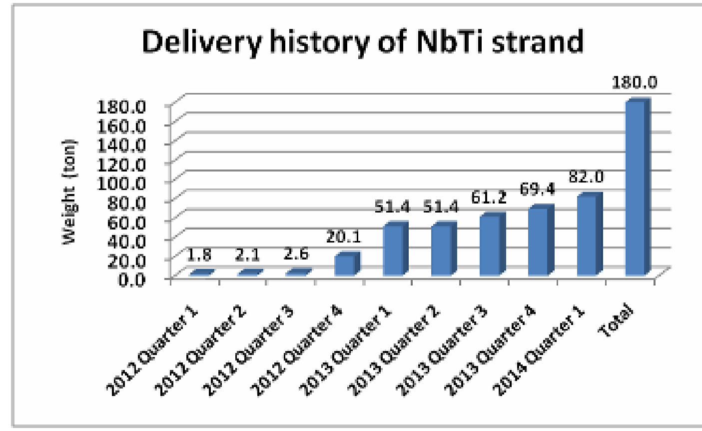
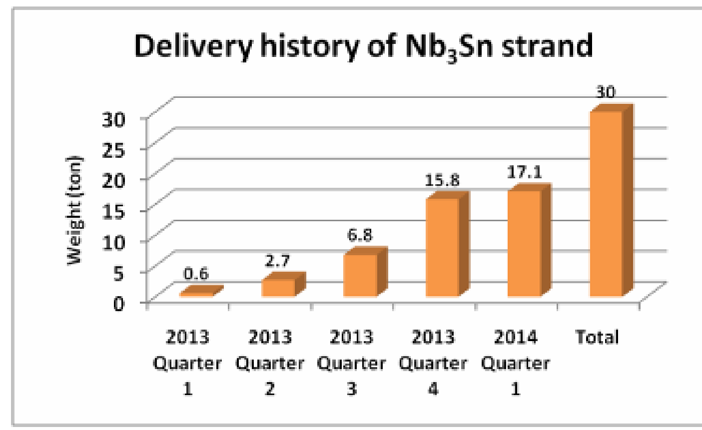
Overview of NbTi and Nb_3Sn Strands for ITER

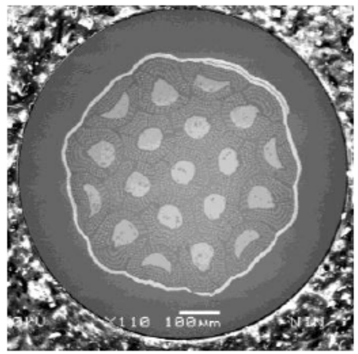
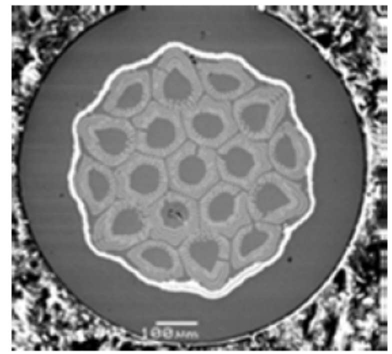
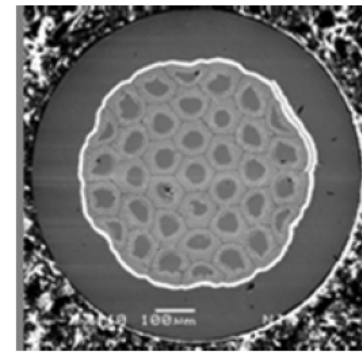




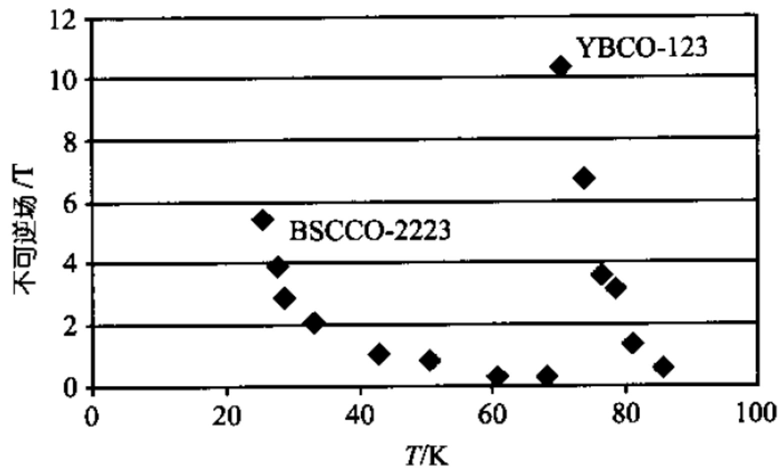
WST and NIN launched mass production of NbTi and Nb_3Sn strands for ITER in 2009 and delivered 180t NbTi and 30t Nb_3Sn strands until the end of 2015.

ITER project pushed the R&D and production of LTS in China

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

The system Bi-2223



Bi-2223

H*(77 K) ~ 0.2 T

Application:

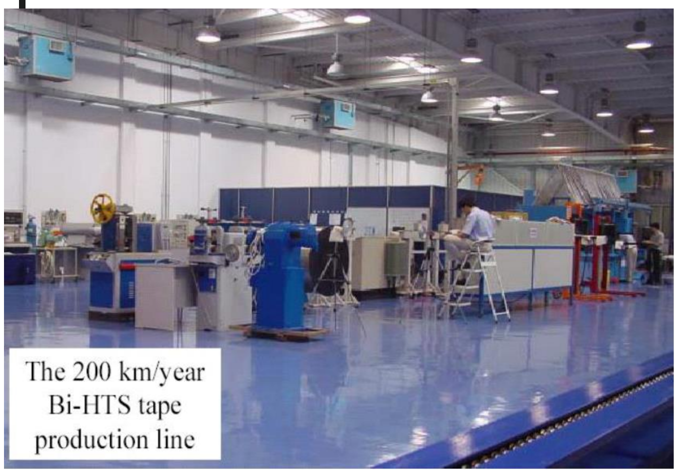
Mainly for cable

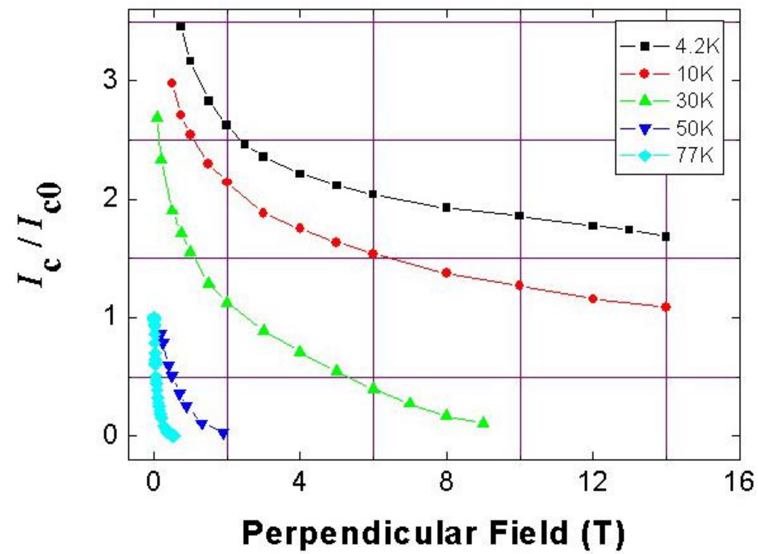
Well established PIT fabrication process

In china:

1. Innova Superconductor;
2. Northwest Institute for Nonferrous Metal Research (NIN)

Bi-2223 HTS tapes

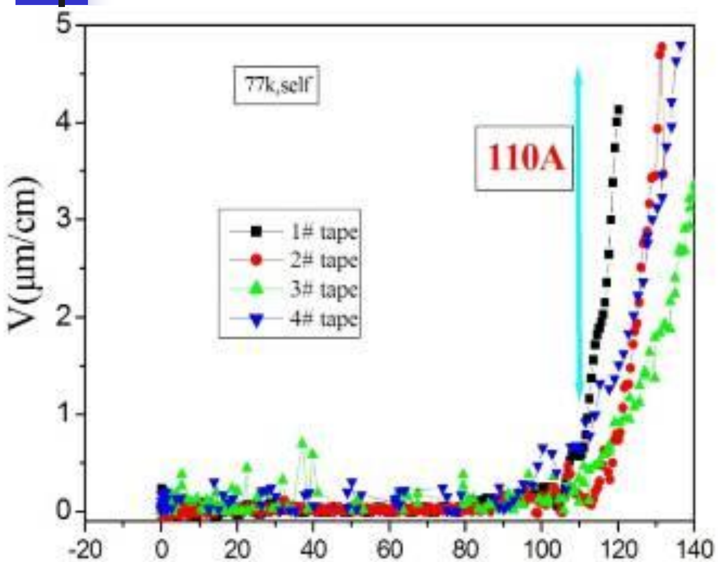


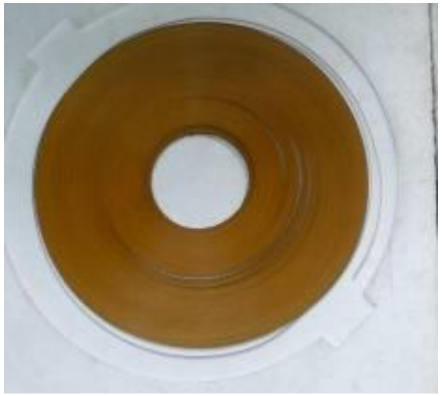


参数 \ 类型	临界电流 @77K, 0T	工程电流密度 @77K, 0T	当临界电流衰减5%，最大拉伸力	当临界电流衰减5%，临界弯曲半径	厚度，带±0.02mm公差	宽度，带±0.2mm公差	应用说明
标准型高温超导线材	120A-140A	12000A-14000A/cm^2	100MPa @77K	30mm	0.23mm	4.2mm	实验用线
绝缘型高温超导线材	120A-140A	12000A-14000A/cm^2	100MPa @77K	30mm	0.25mm	4.2mm	正面绝缘3kV并防止液氮深入起泡

Ic of long Bi2223 tapes
120~140 A (77 K, 0 T)

Bi-2223 HTS tapes





- **200-500 meter long Bi-2223 tapes can be fabricated in batches with the I_c of ~100A， $Jc=4\times10^4 A/cm^2$ (77K, s.f.).**
- **NIN is now developing AgAu-sheathed Bi-2223 tapes for the current lead used for the design and construction of CFETR in China.**

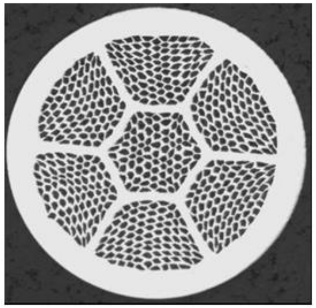
The system Bi-2212

Possible applications High field magnets 34 T (31T+3T insert)
Accelerator magnets??

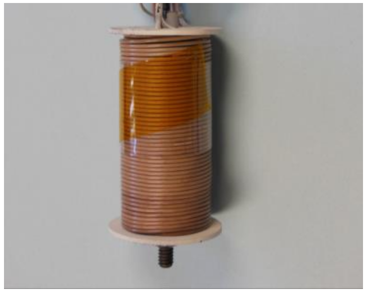
Advantage: Round wire, but * I_c still low
* mechanically weak

Main research units: Northwest Institute for Nonferrous Metal Research (NIN)

Round Bi-2212 wires



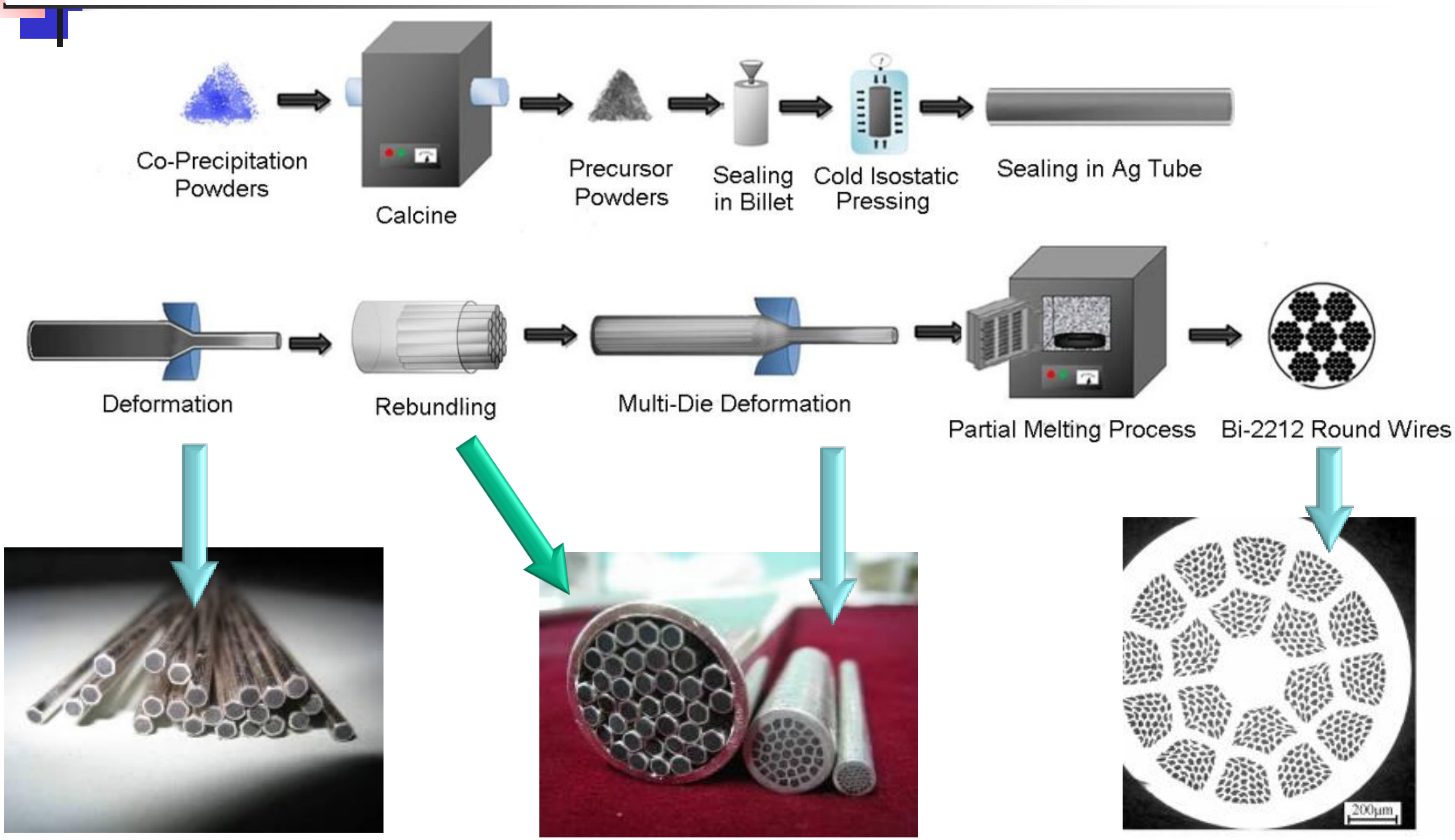
Larbalestier et al. Nature Mater., 2014, 13: 375



34T (in 31T)

Bi-2212 HTS wires

Powder in tube process is adopted in NIN for the fabrication of 200 m long Bi-2212 wires.

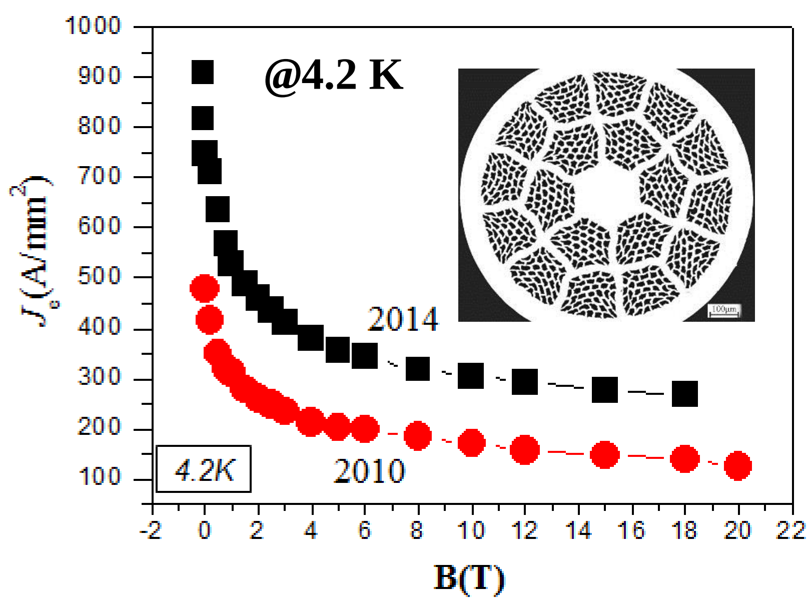


Bi-2212 wires in NIN

Batch production for 200-m long Φ1.0mm wires

4.2 K, 0 T: *Je* ~ 920A/mm², *Jc* ~ 4400 A/mm²
4.2 K, 20 T: *Je* ~ 270A/mm², *Jc* ~ 1200 A/mm²

Short samples:
*I*c=890 A
*J*ce=1100 A/mm²
*J*c=5200 A/mm²
(4.2 K, s.f.)

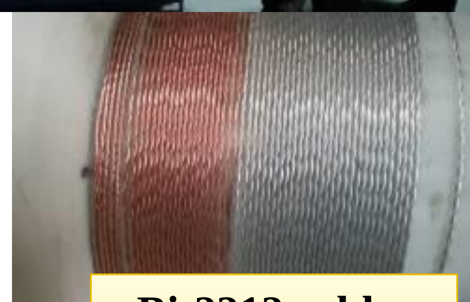


Bi-2212 wires

Bi-2212 wires can achieve *Jc* of > 1000 A/mm² @4.2 K, 20 T, which shows great potential for the application in high-field magnets or large current cables.

Fabrication of Bi-2212 CICC conductors

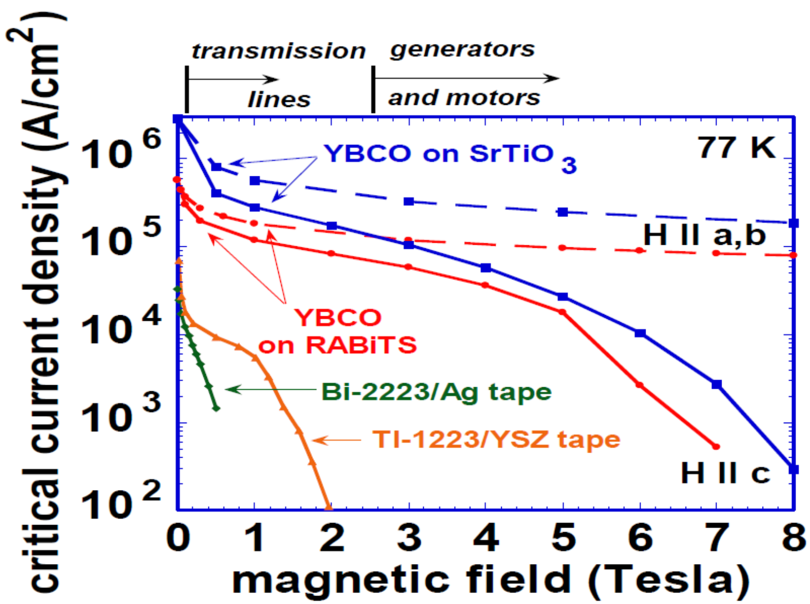
First stage	Number of Bi-2212 wires	2
	Tension	20 N
	Pitch	18-20 mm
Second stage	Number of Bi-2212 wires	2×3
	Tension	20 N
	Pitch	49 mm
Third stage	Number of Bi-2212 wires	2×3× 7
	Tension	30 N
	Pitch	90 mm



Bi-2212 cables

- NIN is now working with IPP-CAS on the fabrication of Bi-2212 CICC;
- 42 Bi-2212 wires were adopted for 5m long conductor;
- *Ic* measurement is on the way…

The system YBCO -- coated conductors



Applications at 77 K:

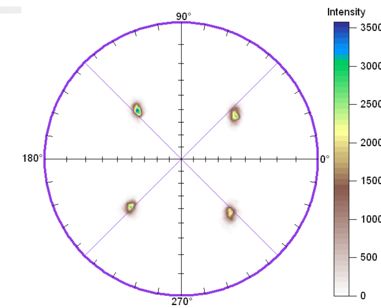
- Cables
- Generators
- Motors
- Transformers
- Wind generators

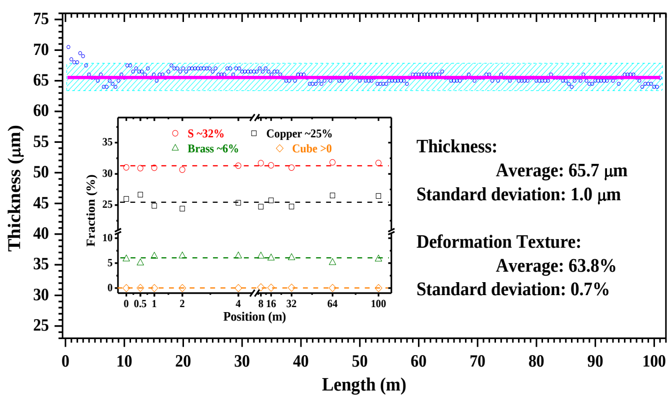
Research groups of 2G HTS tapes in China

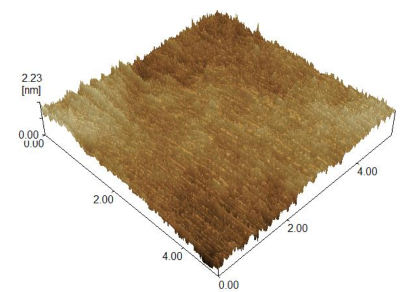
R2R: Reel-to-reel system for the fabrication of long tape

Enterprises and Institutions	Buffer layer		YBCO layer		
	On textured NiW	On untextured tape via IBAD	MOCVD	PLD	MOD
Tsinghua清华	√	√			√
BJTU北工大	R2R				√
NINM/XTU西北有色院/西安理工	√				√
SWJT西南交大	√				R2R
JLU吉林大学			√		
CAS中科院	√				√
UEST电子科大	R2R	√	√		
GRINM北京有色院	R2R			R2R	
SJTU-SC 交大-上超	R2R	R2R		R2R	
SHU-SCSC 上大-上创	R2R	R2R			R2R
SAMRI 苏州新材料-永鼎		R2R	R2R		

Long-length substrate production: NiW tapes





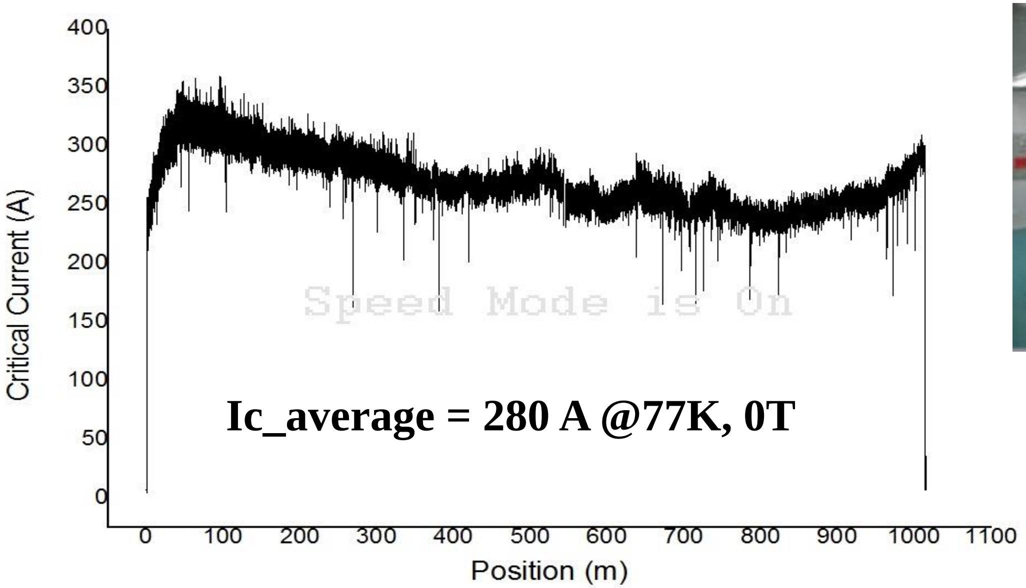


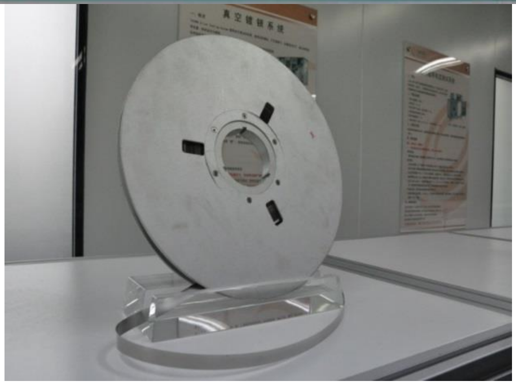
- ✓ Thickness~66 μm
- ✓ Width=10 mm
- ✓ Length>500 m

- ➢ **Highly cube textured Ni-5at.%W tapes of hundred meters with typical fraction of cube texture ~100% were fabricated by conventional metallurgy method.**
- ➢ **Content of cube texture in Ni7W and Ni9W tapes reaches 99.5%, 94% respectively.**

Long YBCO C.C. by IBAD-MOCVD

@ Suzhou SAMRI



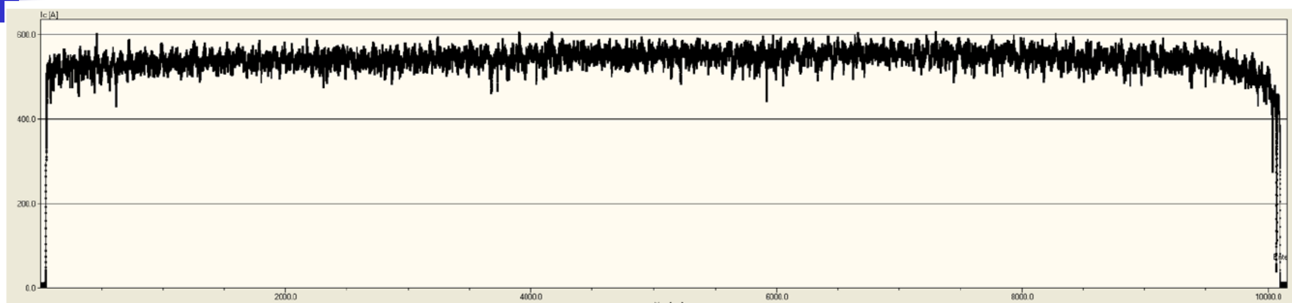


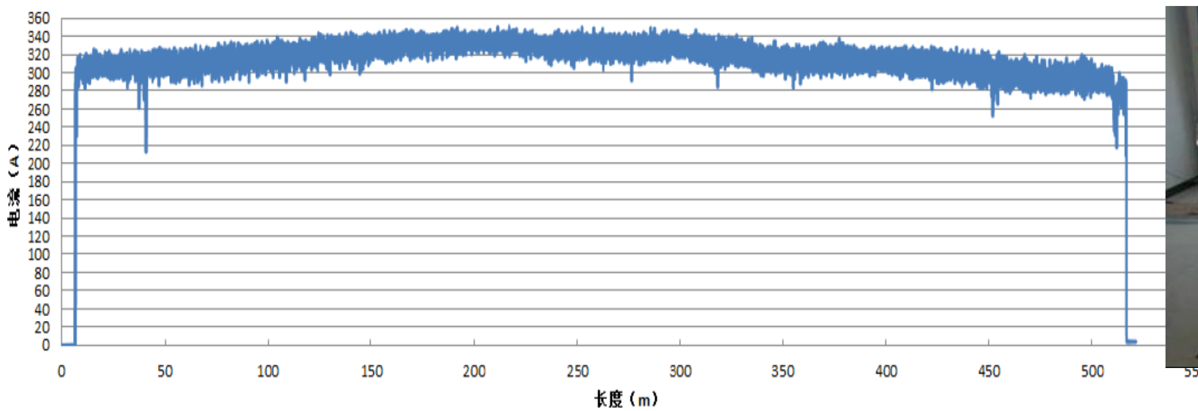
Production rate: 50 -100 m/h

- **1000 meter long YBCO tapes were fabricated by MOCVD, with the width of 12 mm and thickness of YBCO 1-3 μm.**

Long YBCO C.C. by IBAD-PLD

@ SJTU/Shanghai Supercond.



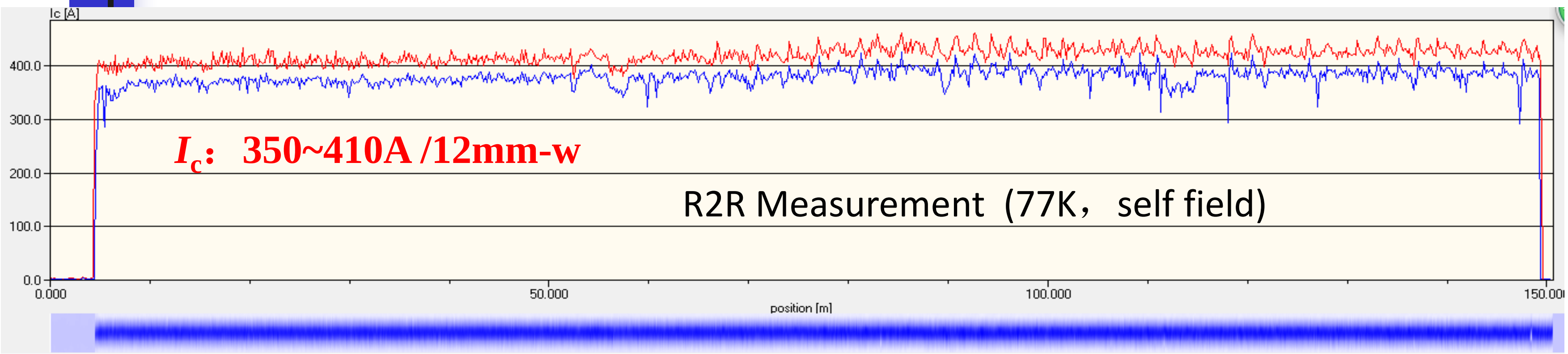


Magnetic, reel to reel TapeStar measurements:

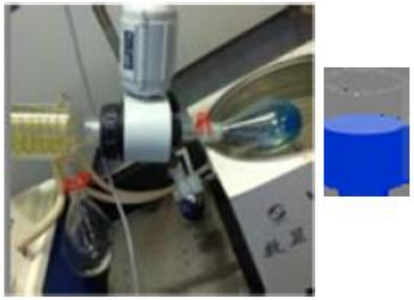
- ***I_c* is about 500A/cm for 100-300 m long tapes (77K, 0T).**
- ***I_c* is about 280-300A/cm for 1000 m long tapes (77K, 0T).**

Long ReBCO C.C. by IBAD-MOD

@ SHU/ShangChuang Supercond.



Industrial Process for MOD-ReBCuO Coated Conductors



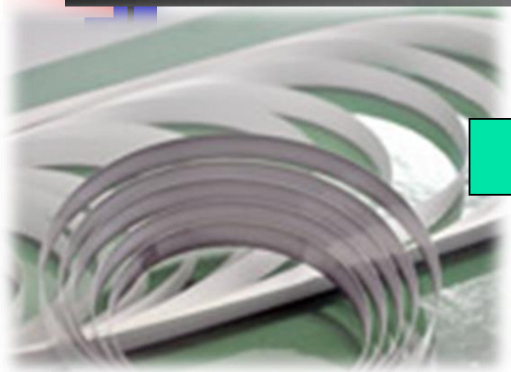
Solution Preparation

Coating + Low temperature Pyrolysis

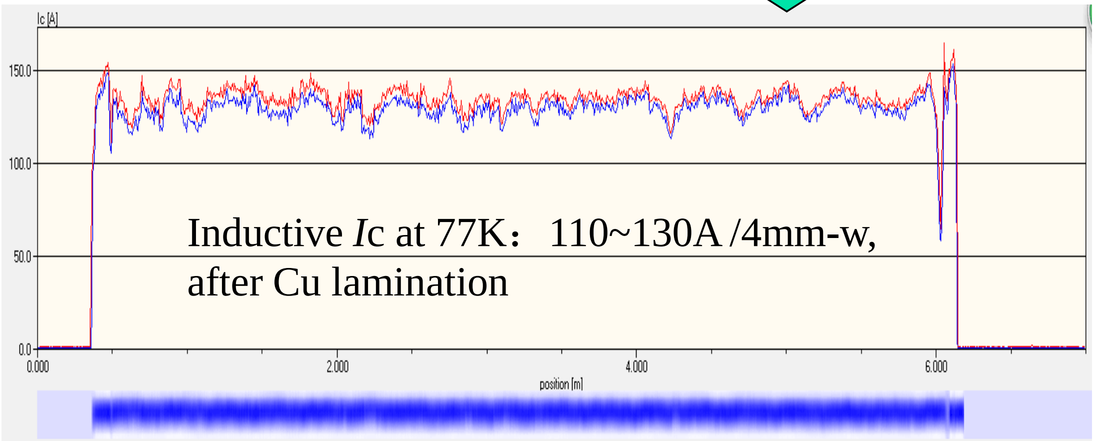
High-temperature Crystallization

Oxygenation

Laminated with Brass and Polyimide Insulating Tapes



Gold Medal from New Materials Expo



Key Issues for YBCO Coated Conductors

Industrial limitation factors: * Costs

In power equipment, Cu wires typically operate in the range of $15–25/kAm. This sets a benchmark for superconducting wire.

To improve performance, and reduce cost

- **Increased thickness of YBCO layer**
- **Enhanced flux pinning via doping**

MgB_2 wires and tapes

- **Northwest Institute for Nonferrous Metal Research (NIN)**
- **Institute of Electrical Engineering Chinese Academy of Sciences (IEE-CAS)**

MgB_2 – Magnesium diboride

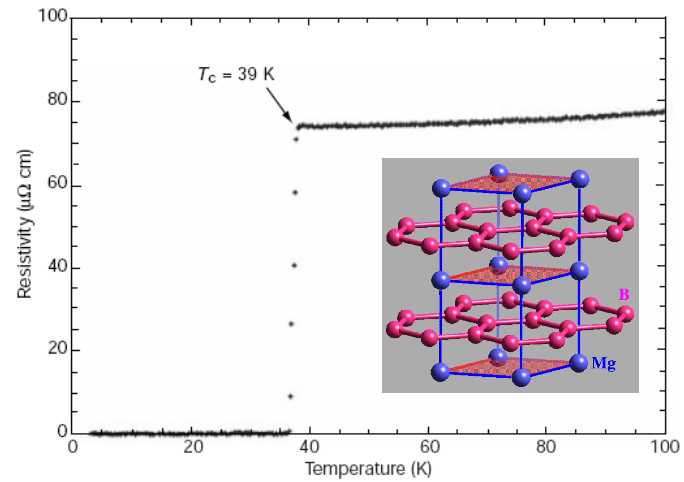
NATURE | VOL 410 | 1 MARCH 2001

Superconductivity at 39 K in magnesium diboride

Jun Nagamatsu*, Norimasa Nakagawa*, Takahiro Muranaka*, Yuji Zenitani* & Jun Akimitsu*†

* Department of Physics, Aoyama-Gakuin University, Chitosedai, Setagaya-ku, Tokyo 157-8572, Japan

MgB_2 was a well known material since the 1950s and commercially available in 2011!



J. Nagamatsu, et al. , Nature 410 (2001) 63

Advantage of MgB_2

- Highest T_c(~40K) among metallic superconductors
- No grain orientation required (Easy to fabricate long tape or wire)
- Low materials cost
- Good mechanical properties
- Light weight material

T_c=38 K

Low H_{c2}

Main Application:

1-2T MRI magnets at 15-20K

MgB_2: Barrier for applications

The in-field J_c of MgB_2 tapes and wires is still lower because of low upper critical field and poor flux pinning.

How to enhance J_c in MgB_2 wires?
Chemical doping is the most effective way !

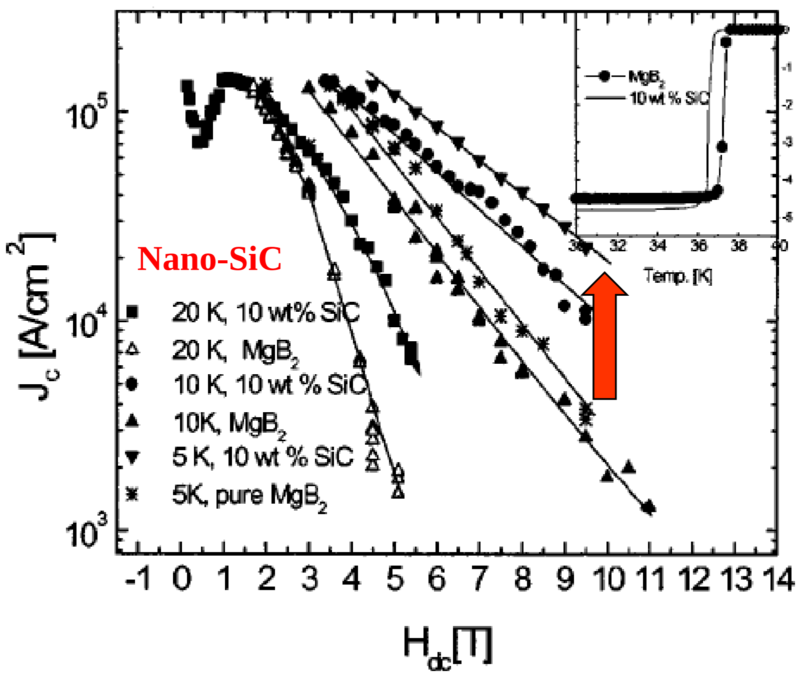
- Increasing H_{c2} with C doping
- Introducing pinning centers with nanopartical addition

Most effective additives are carbon (carbon-containing compounds): SiC, C, carbohydrates, etc.

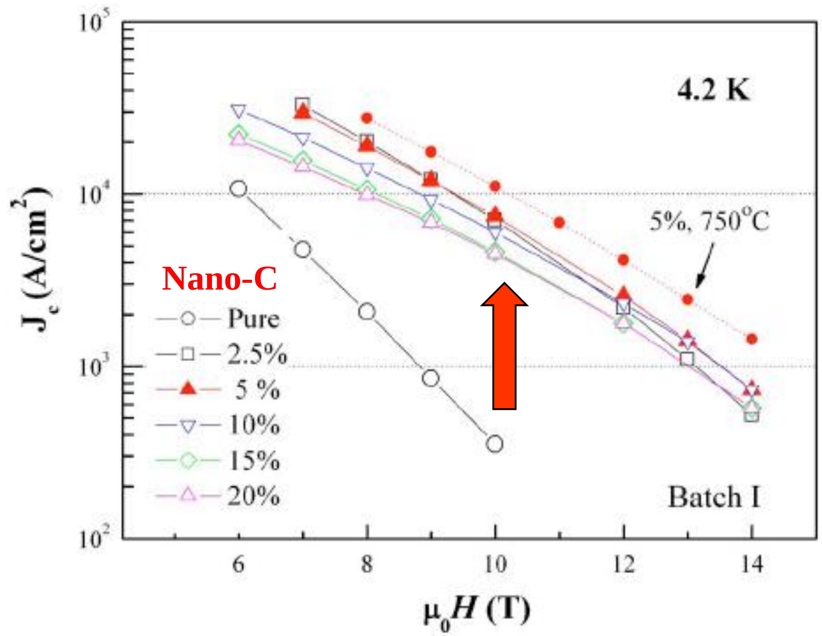
The most effective additives

Nano-SiC or nano-C doping to MgB_2 tapes

-- enhanced by more than an order of magnitude in high fields



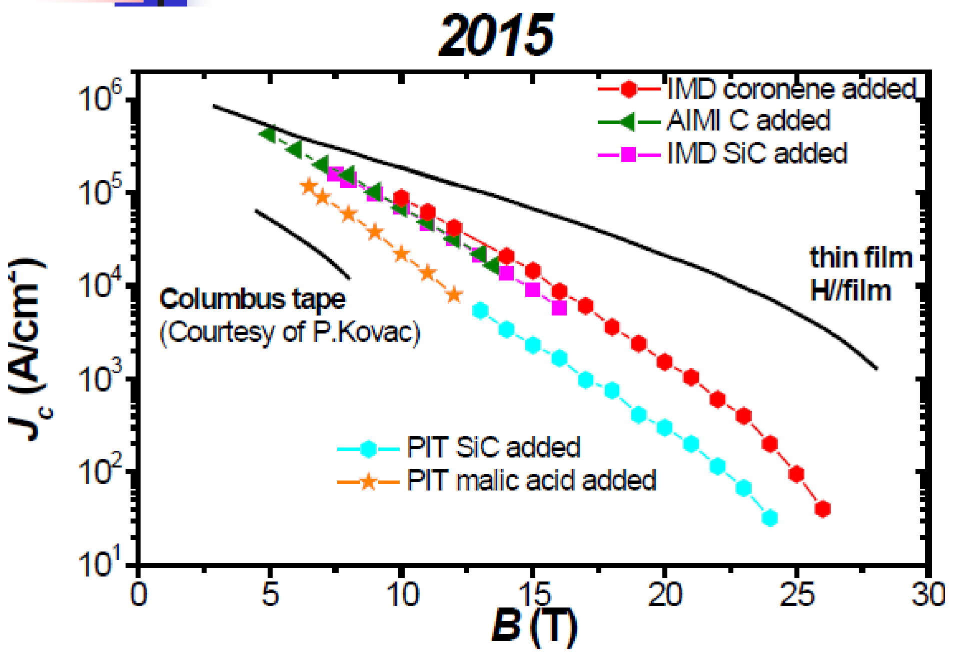
Dou et al. *APL* 81 (2002) 3419



Ma et al. *APL* 88 (2006) 072502

Fine grains in C doped MgB_2 ⟹ Large Jc

Latest critical current density J_c of MgB_2 wires



Putti presented at EUCAS2015

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

PIT tapes:
J_c= 6×10⁴ A/cm² (4.2 K, 10 T)

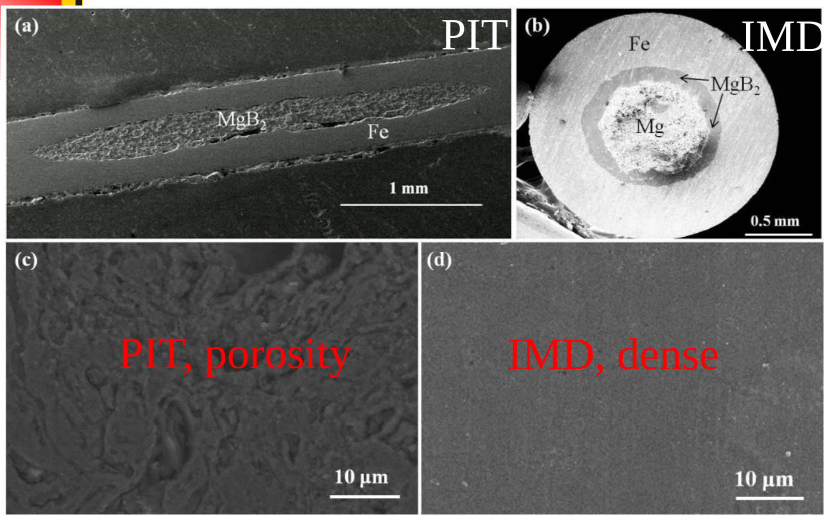
W. Hassler, ***SUST*** 21 (2008) 062001

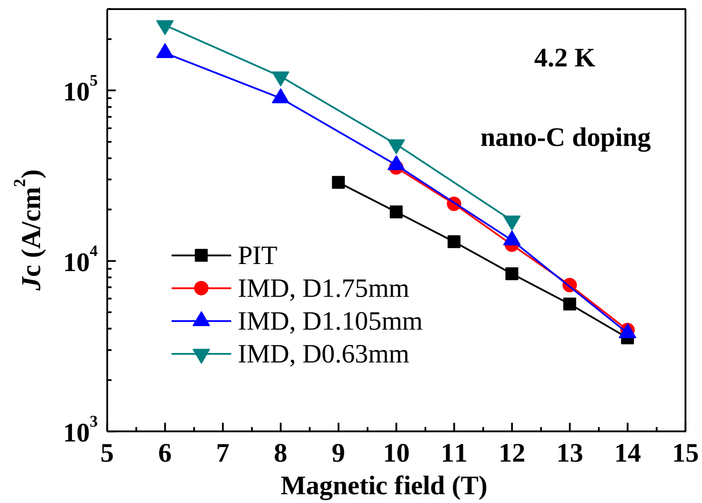
IMD wires:
J_c= 1.5×10⁵ A/cm² (4.2 K, 10 T)

Moving from 1G (PIT) to 2G (IMD) wires

IEE-CAS

IMD-processed MgB_2 wire with crystalline boron powders



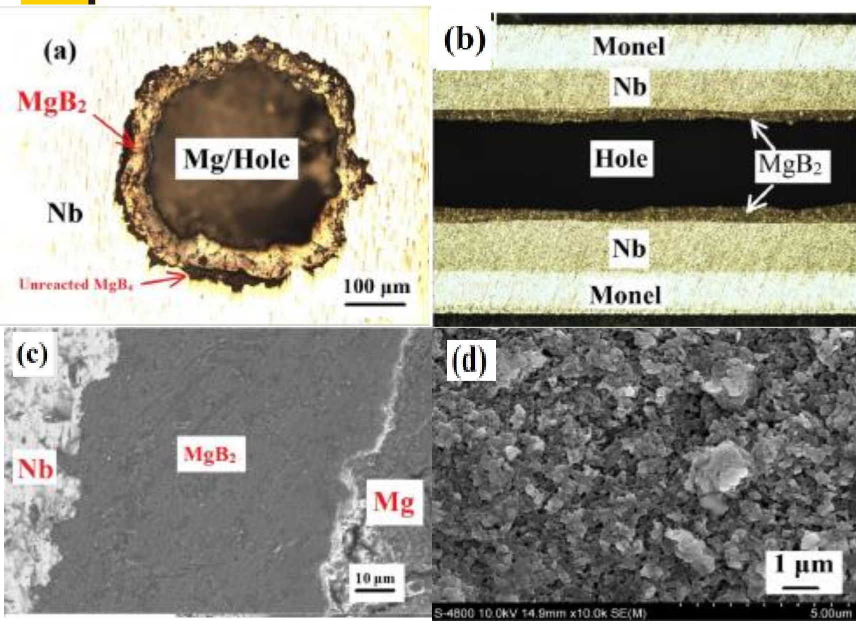


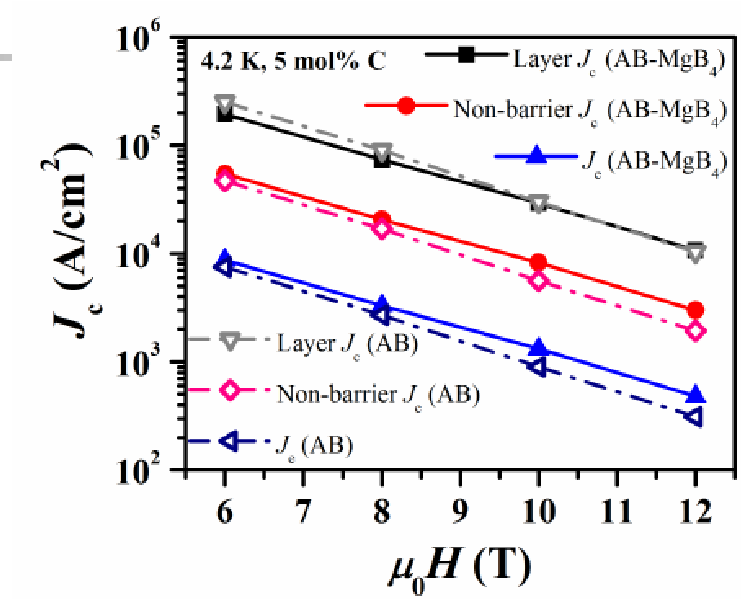
- ➢**The IMD process is found to be less sensitive to the purity of the boron powders, compared to the PIT method.**
- ➢**The layer J_c of 4.8×10^4 A/cm^2 at 10 T was achieved for IMD-processed MgB_2 wires fabricated with crystalline boron powders, which is almost comparable to that made by amorphous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

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

IEE-CAS

IMD-MgB_2 wires using MgB_4 precursors





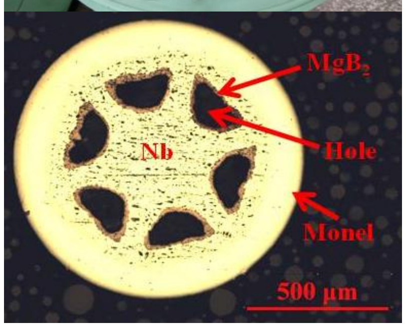
➢The engineering J_e of MgB_2 wire made using MgB_4 precursor were enhanced due to the improved grain connectivity and the enlarged fill factor.

➢MgB_4+Mg processing route offers an new opportunity in MgB_2 wire fabrication to enable a higher fill factor and to enable higher values of J_e, which is important for applications.

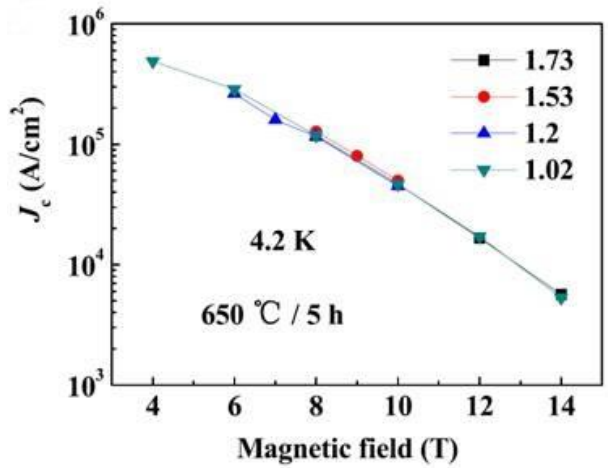
Xu et al., *Supercond Sci Technol.* 29 (2016) 105019

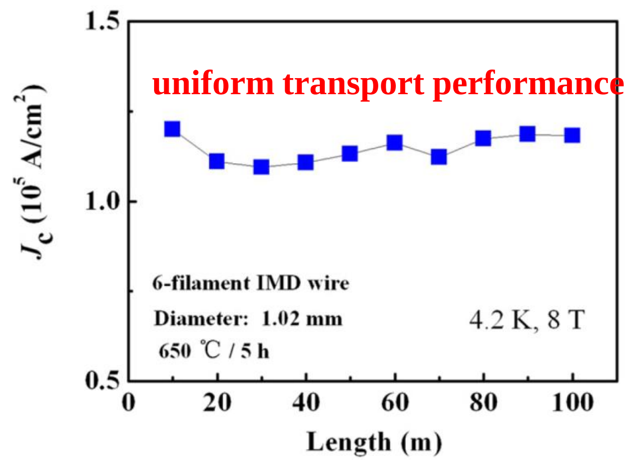
IEE-CAS

Fabrication of 100 m-class IMD-processed 6-filament MgB_2 wires



-- MgB_2/Monel/Cu



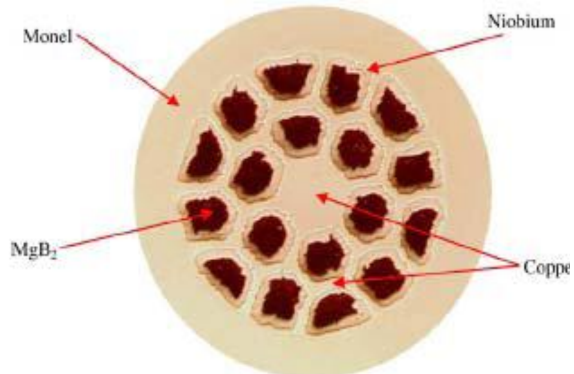


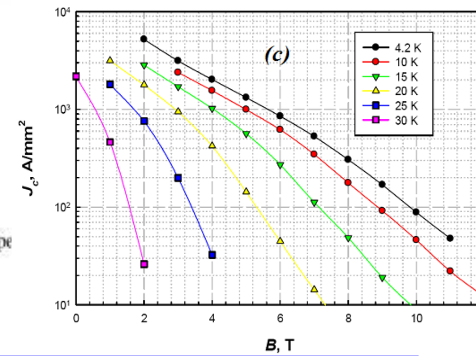
Wang et al., *SuST 29 (2016) 065003*

- ➢A 100-m long 6-filament MgB_2 wire was successfully fabricated **using internal magnesium diffusion (IMD) process.**
- ➢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.**
- ➢*The J_c has a fairly uniform distribution through-out the wire.*

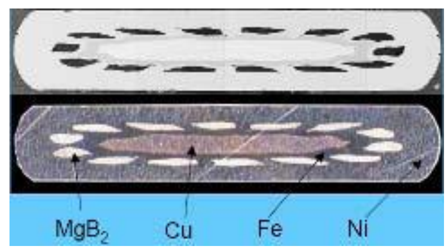
Fabrication of km-level PIT MgB_2 wires

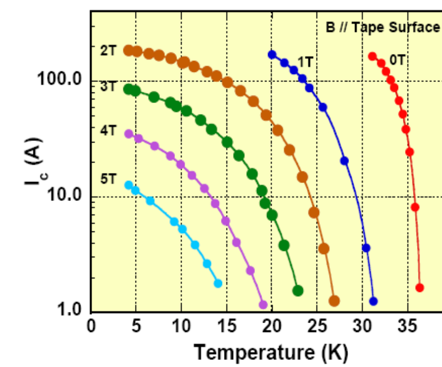
American Hyper Tech. Corporation



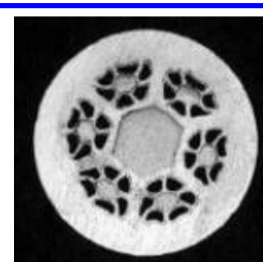


Italy Columbus Supercon. Corporation

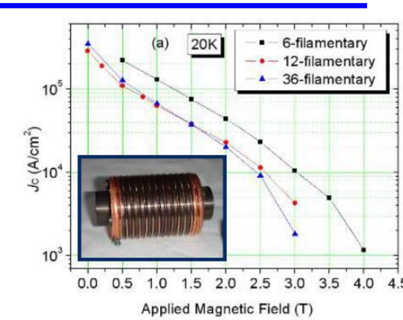




China Western Superconducting Technologies Corporation

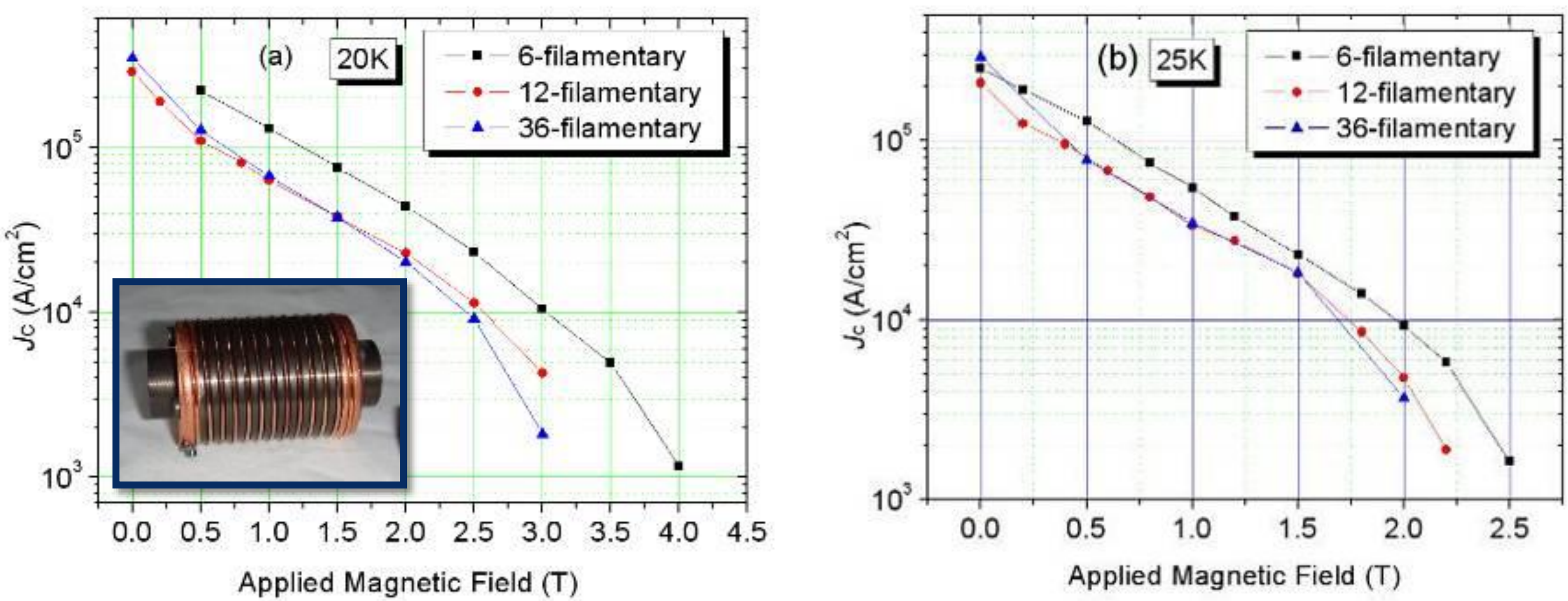


MgB_2/Nb/Cu



WST

Fabrication of *km*-level MgB_2 wires



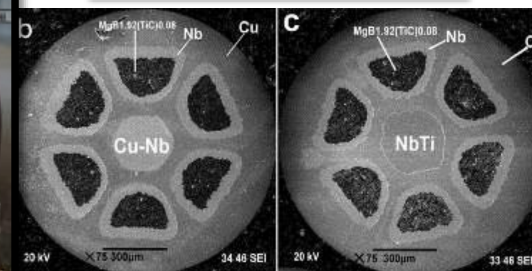
Critical current density of 1500 meter long MgB_2 wires

At 20 K, 2 T, J_c= 4.3×10^4 A/cm^2

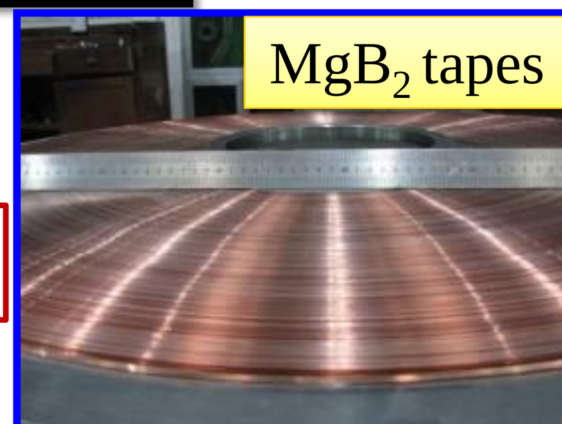
WST

Fabrication of *km*-grade MgB_2 wires

6-MgB_2 filaments +Nb/Cu or NbTi reinforcement



Capability



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

Iron-based wires and tapes

- **Institute of Electrical Engineering, Chinese Academy of Sciences (IEE-CAS)**

Iron-Based Superconductors (IBS)

J. Am. Chem. Soc., **130** (11), 3296 -3297, 2008. 10.1021/ja800073m
Web Release Date: February 23, 2008

Iron-Based Layered Superconductor La[$O_{1-x}F_x$]FeAs (x = 0.05-0.12) with T_c = 26 K

Yoichi Kamihara,*† Takumi Watanabe,‡ Masahiro Hirano,†§ and Hideo Hosono†‡§

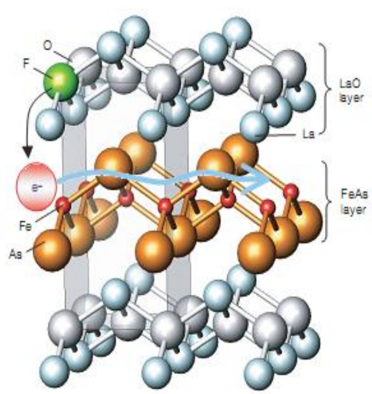
ERATO-SORST, JST, Frontier Research Center, Tokyo Institute of Technology, Mail Box S2-13, Materials and Structures Laboratory, Tokyo Institute of Technology, Mail Box R3-1, and Frontier Research Center, Tokyo Institute of Technology, Mail Box S2-13, 4259 Nagatsuta, Midori-ku, Yokohama 226-8503, Japan

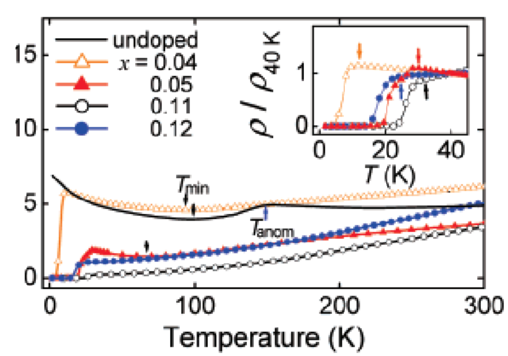
hosono@msl.titech.ac.jp

Received January 9, 2008

Abstract:

We report that a layered iron-based compound LaOFeAs undergoes superconducting transition under doping with F^- ions at the O^{2-} site. The transition temperature (T_c) exhibits a trapezoid shape dependence on the F^- content, with the highest T_c of ~26 K at ~11 atom %.

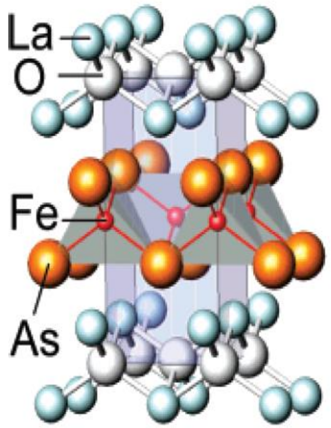




Main known IBS families

Among them, the three phases most relevant for wire applications are 1111, 122, and 11 types with a T_c *of 55, 38 and 8 K, respectively.*

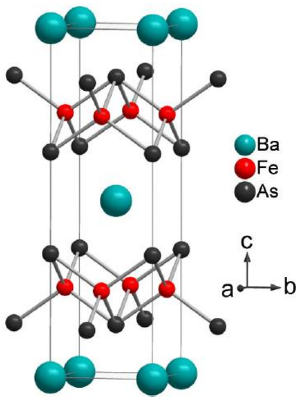
1111 Phase LnOFeAs



***T_c* ~55 K**

Z. A. Ren et al., ***Chin. Phys. Lett.*** 25, 2215 (2008)

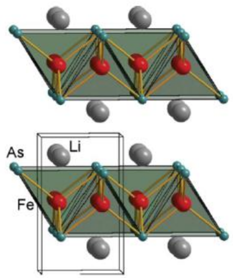
122 phase AFe_2As_2 (A=Ba, Sr, Ca)



***T_c* ~38 K**

M. Rotter, et al., ***Phys. Rev. Lett.*** **101**, 107006 (2008)

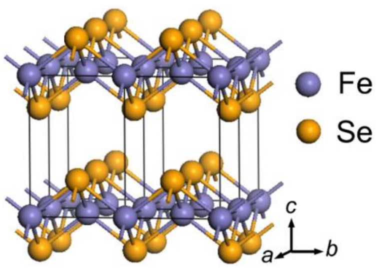
111 phase LiFeAs



***T_c* ~18 K**

X. C. Wang, et al., ***Solid State Commun***. **148**, 538 (2008).

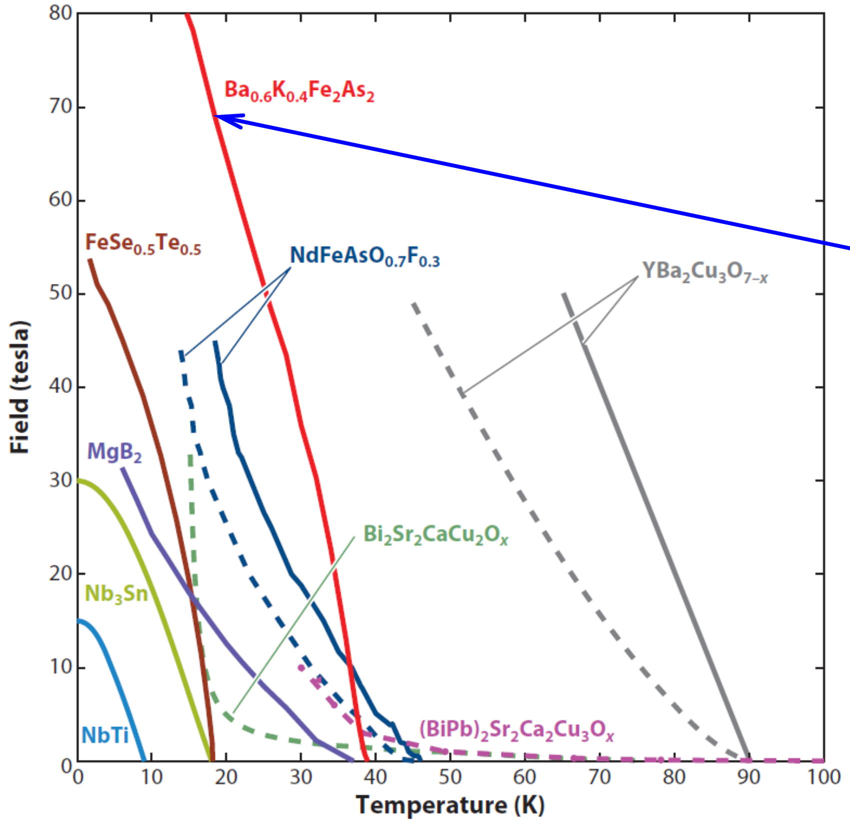
11 phase FeSe



***T_c* ~8 K**

F. C. Hsu, et al., ***Proc. Natl. Acad. Sci. U.S.A.*** **105**, 14262 (2008).

The extremely high H_{c2} in IBS



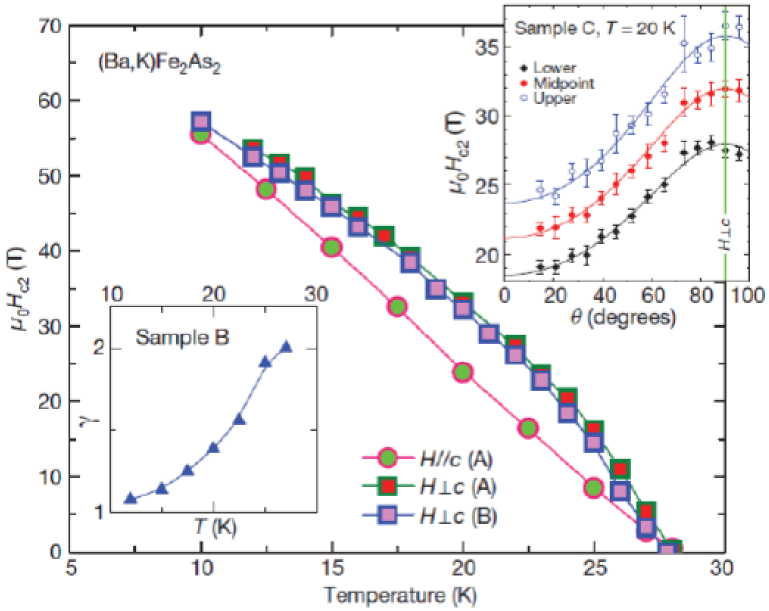
Gurevich, ***Nature Mater.*** 10 (2011) 255

At 20 K, the H_{c2} can be >70 T where IBS outperform both MgB_2 and Bi-2223.

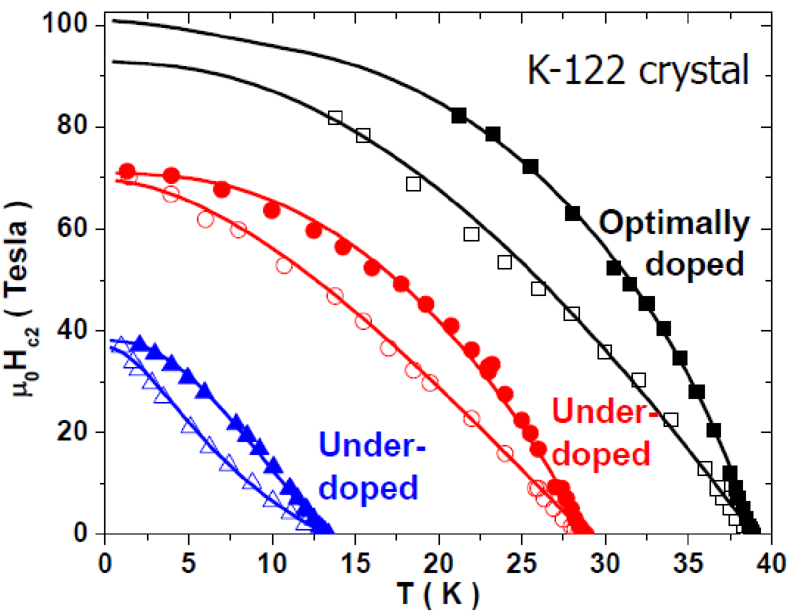
- **Interesting FBS have T_c: 38-55 K >> Nb-Ti and Nb_3Sn**
- **Operation at 4K >20T or 10-30 K at >10 T would be very valuable**

The extremely high H_{c2} in IBS shows a great potential for applications in high field magnets, e.g., H > 20 T, which cannot be achieved via LTS and MgB_2.

122 IBS - small anisotropy γ



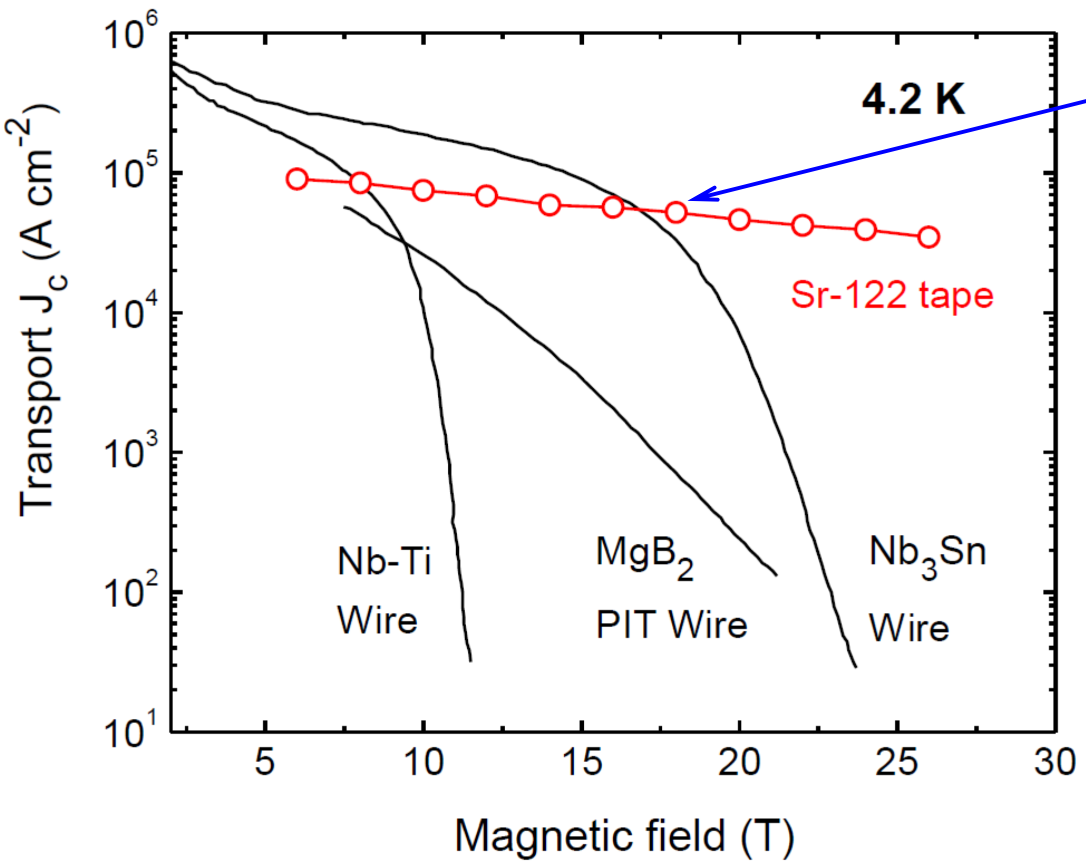
Yuan et al. Nature 457, 565 (2009)



Tarantini et al. PRB 86, 214504 (2012)

- γ ~1.1 for K-122, nearly isotropic
- γ is almost 1, clearly, vortices are much more rigid than in any cuprate-much easier to prevent depinning of any GB segment

The J_c of IBS wires: Very weak field dependence in high field region



122 IBS wire:
Large J_c, at H > 20T

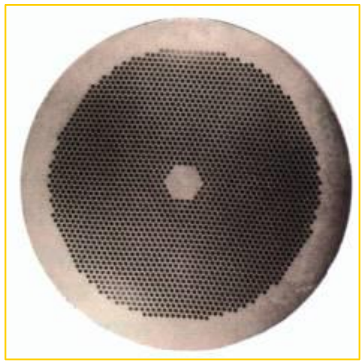
Fe-based wires potential for high-field applications

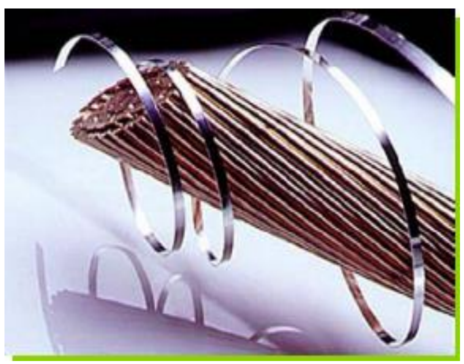
To apply superconducting materials to technologies related to magnets, they must be transformed into wires

Merits:

High H_{c2} (70T@20K),

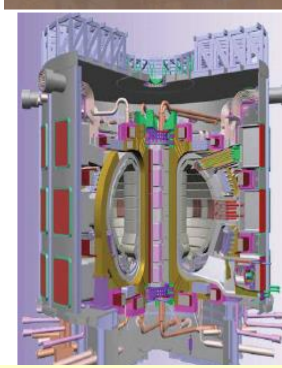
Low γ (<2)





MRI

NMR



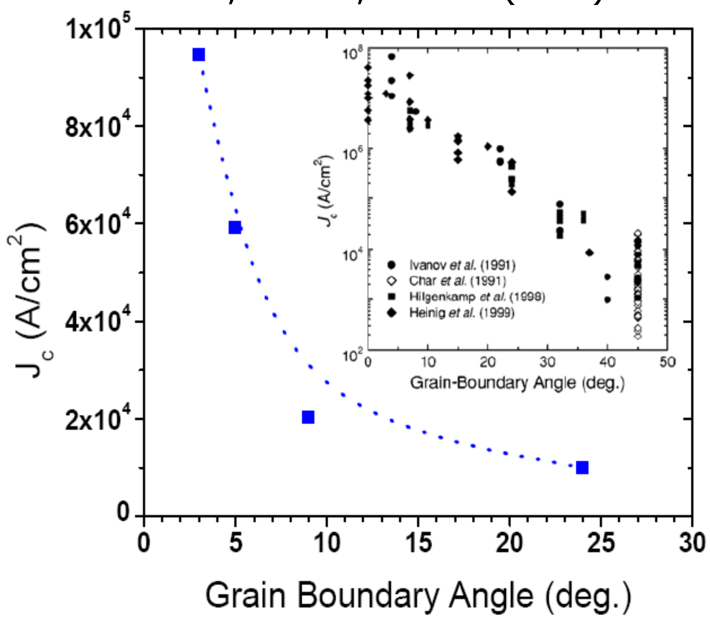
ITER

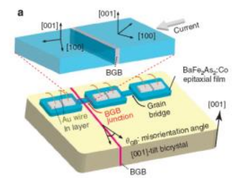
Development of high-performance wire conductors is essential

Grain boundary behavior in 122-type pnictides

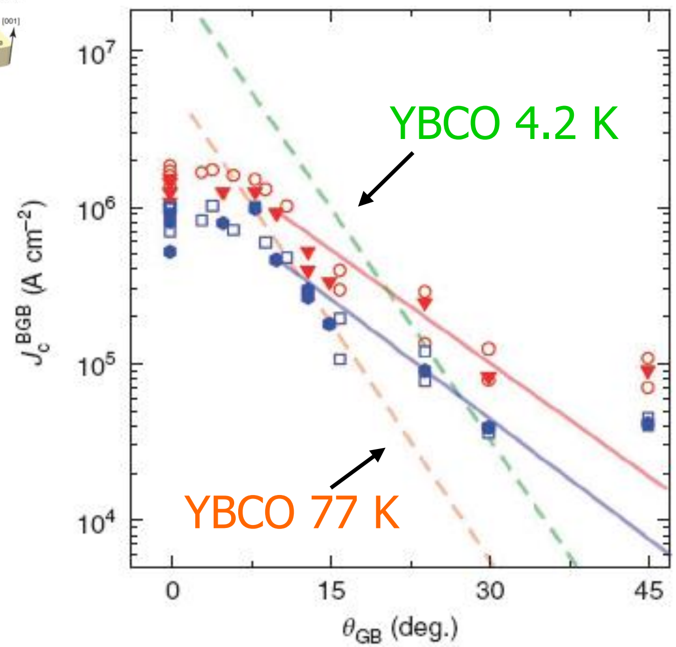
Co doped Ba-122 thin films on bicrystals

Lee et al., *APL* 95, 212505 (2009).





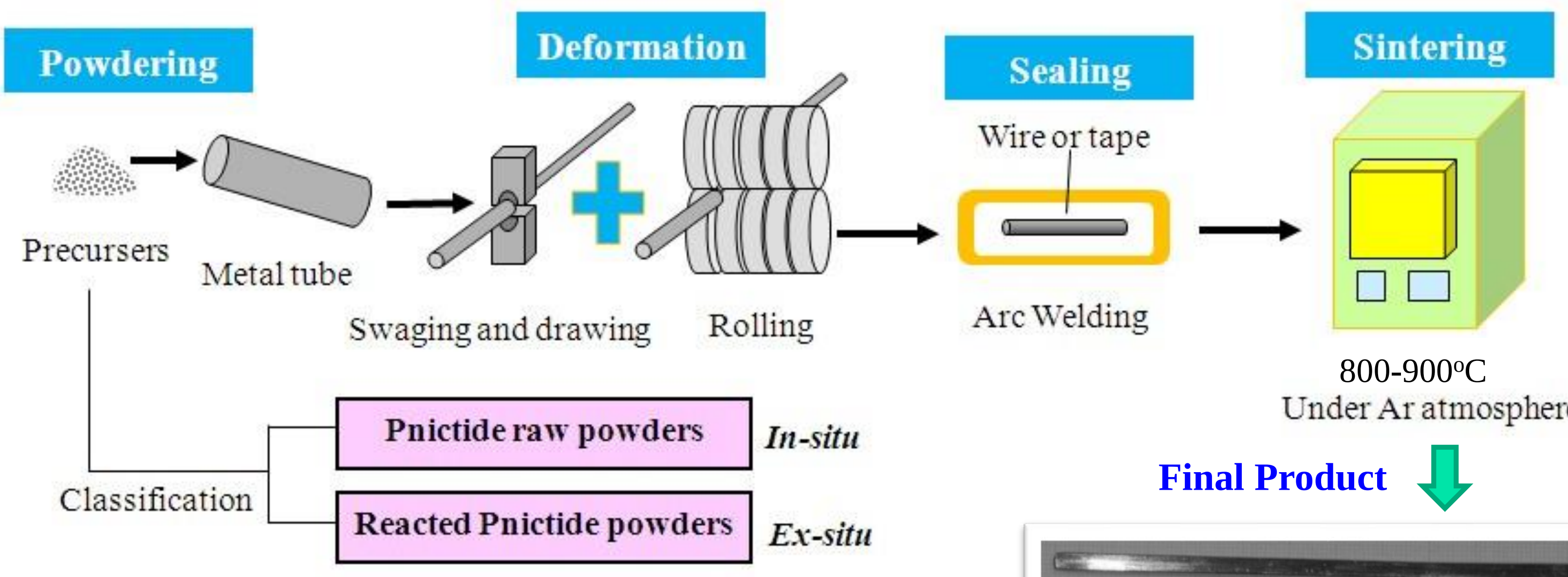
Katase et al., *Nat. Commun.* 2, 409 (2011)



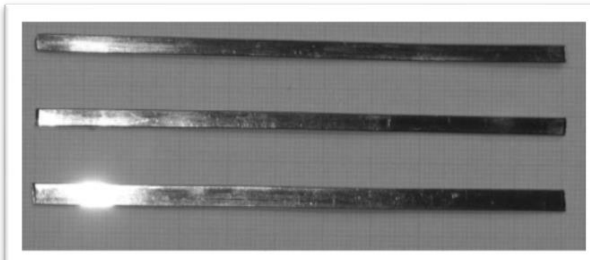
- **J_c decreases exponentially with GB angle, however, the critical angle GBs of pnictides is θ_c = 9º, larger than YBCO (θ_c~5º) .**
- **Weak link effect, the GBs do not degrade the J_c as heavily as YBCO.**
- **Advantageous GB over cuprates!** This is the reason why we can use the PIT method to make the pnictide wire and tapes, but PIT can not work for YBCO.

Fabrication process for $Sr(Ba)_{1-x}K_xFe_2As_2$ wires (*Powder-in-tube method*)

– Simple and scalable process, low cost



Final Product



Iron-based superconducting tapes

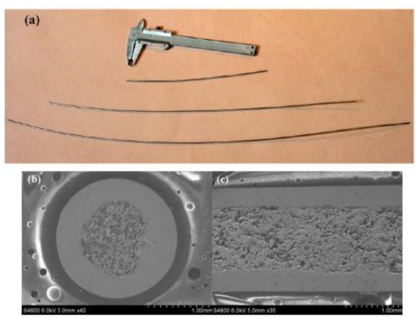
122 PIT wires:

1. The single phase can easily be obtained.
2. The sintering temperature is low.

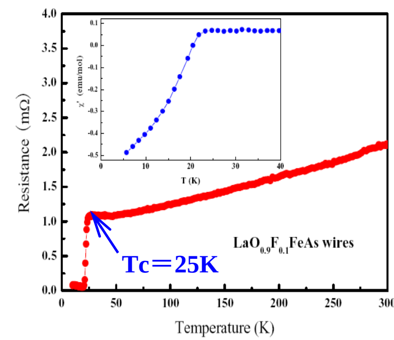
In April 2008, the first pnictide wire was fabricated by the powder-in-tube method

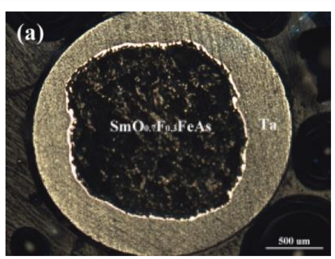
The early wires →

- **much low critical current density Jc!**
- **due to thick reaction layer, many impurities, and cracks.**

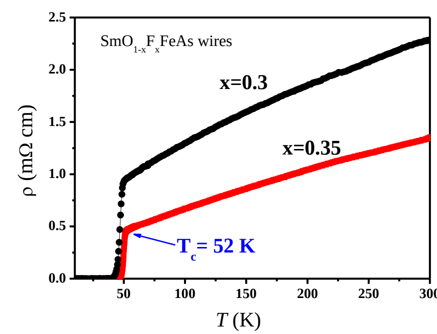


LaOFeAs →



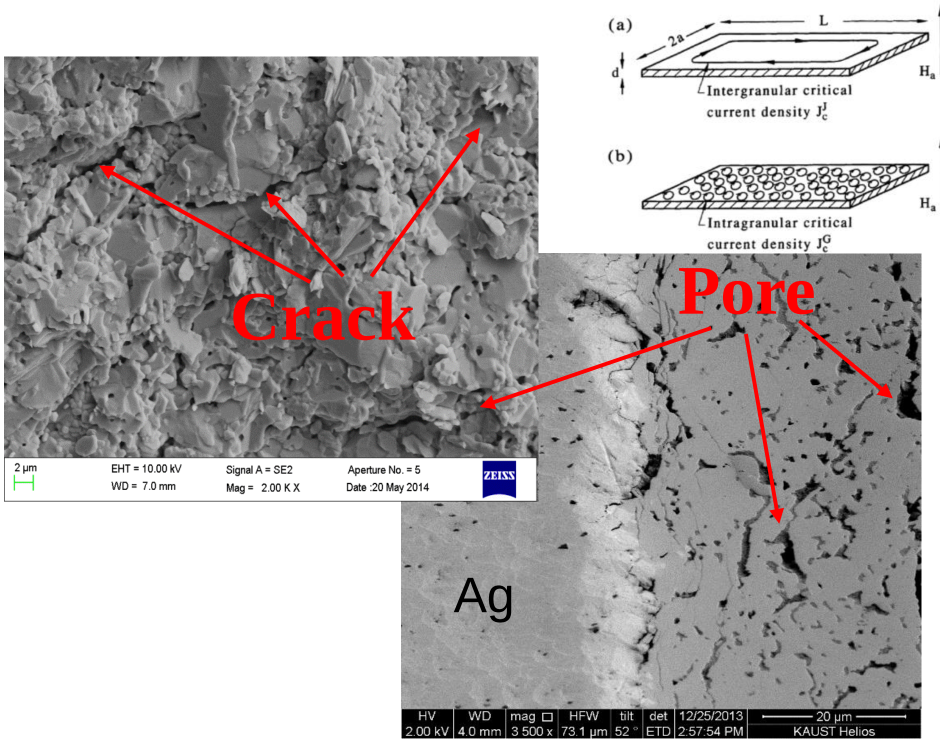


SmOFeAs →

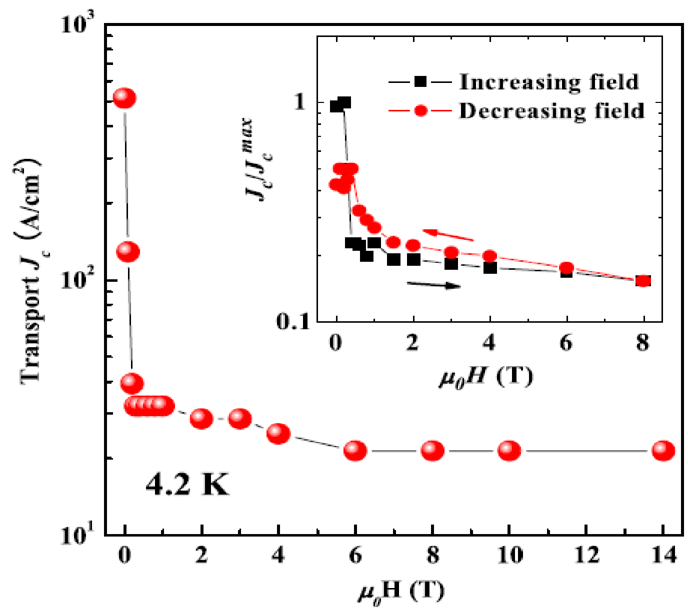


Our group: ***Supercond. Sci. Technol.*** *21 (2008) 105024*

Key problems for PIT wires: Low density and weak link



Good connectivity is desirable!



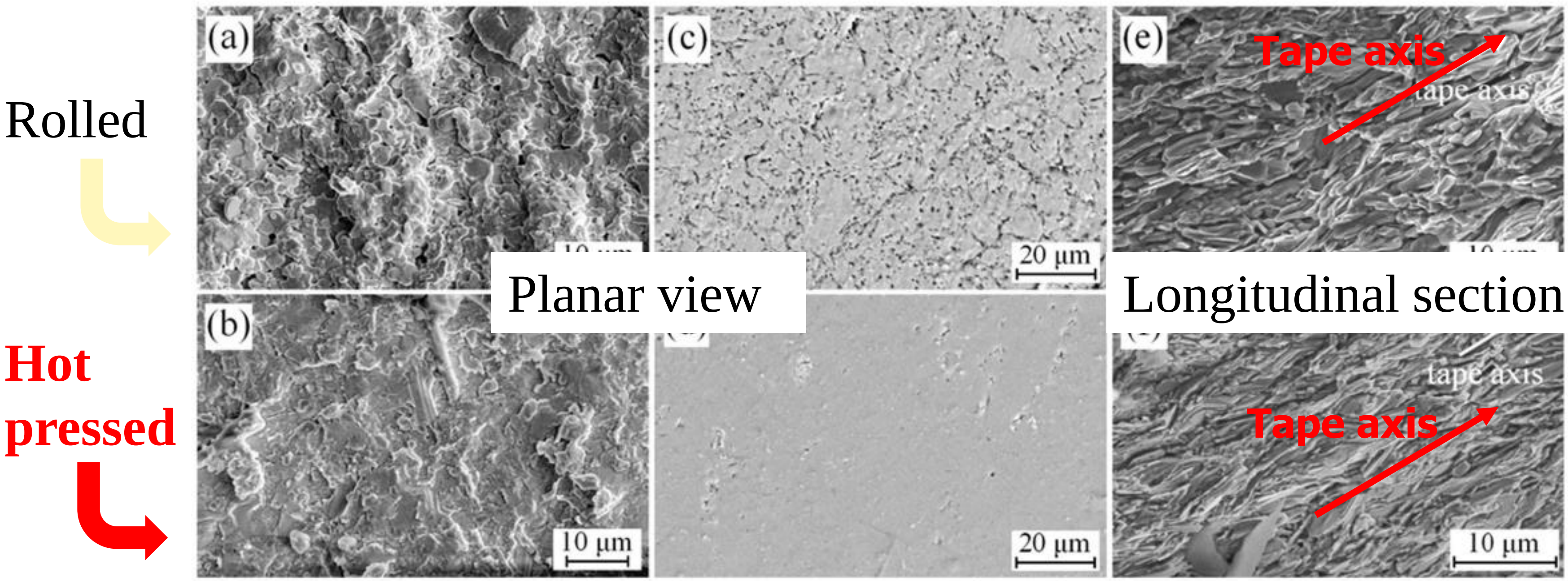
Low density: cracks and porosity

Hysteresis in transport J_c: signature of weak links

- Residual cracks and porosity always lead to poor grain connection, so suppress J_c in polycrystalline wires!
- A hysteretic phenomenon observed for transport J_c in an increasing and a decreasing field indicated a weak-linked behavior, similar to that of the cuprates.

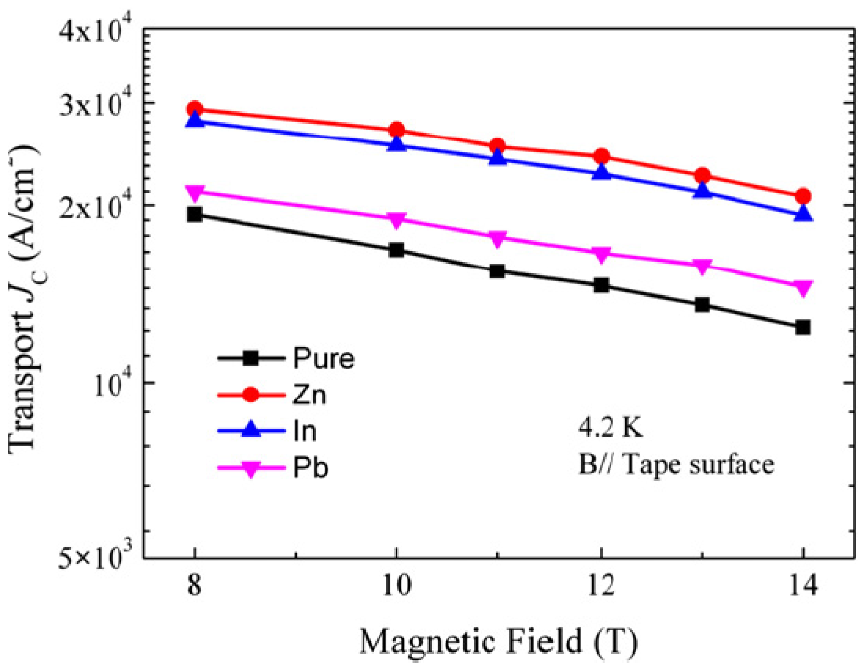
Solutions

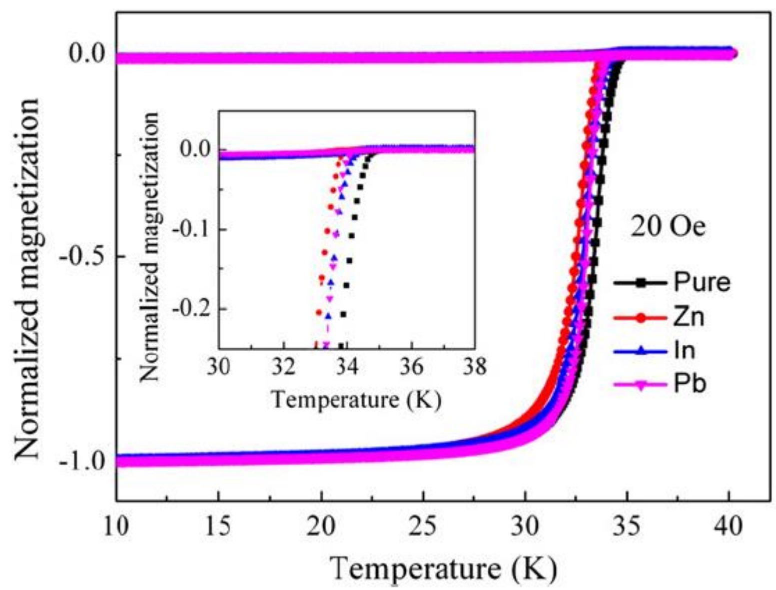
- ✓ **Add Sn** to improve the grain connectivity. (APL2011)
- ✓ **Large reduction rolling** to increase texture. (*Physica C* 2011, *APL* 2011)
- ✓ **Hot pressing** is effective to enhance the superconducting core density as well as grain alignment. (*APL*2014)



Zn and In additions are effective to enhance the J_c-B of 122/Ag tapes

Chemical addition has been confirmed as a simple and readily scalable technique for enhancing Jc.

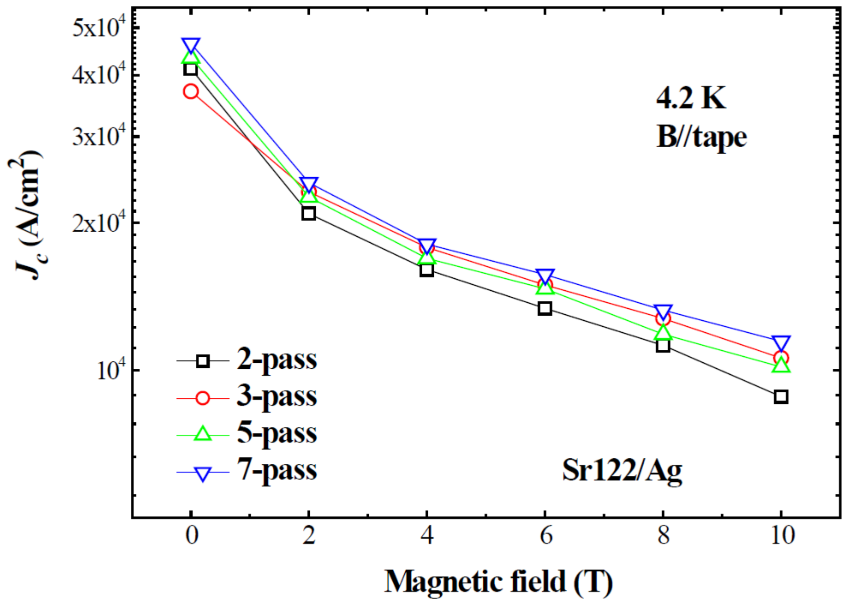


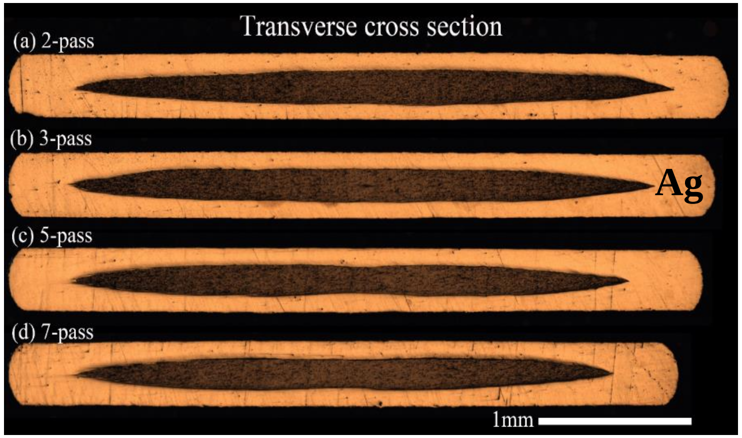


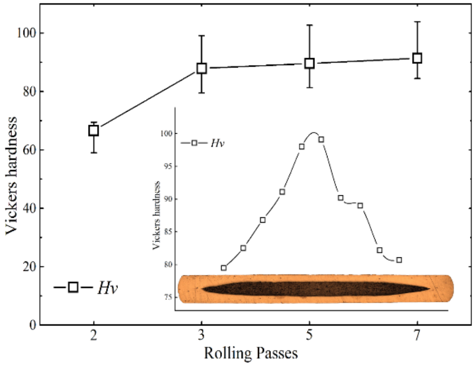
- The additions do not significantly affect the temperature transition Tc, and the Tc decreased only 0.4 K.
- the Jc enhancement in In or Zn-added samples may be attributed to the improved phase uniformity as well as the good grain connectivity

Lin et al., *Scripta Mater.* 112 (2016) 128

Optimized rolling process for 122/Ag tapes: 3-pass deformation is best







- The width of the tapes and the area of superconducting cores increase with decreasing the rolling pass, but the transport J_c seems close.
- We can fabricate tapes with 3 rolling passes to get the uniform and high-J_c 122 tapes.

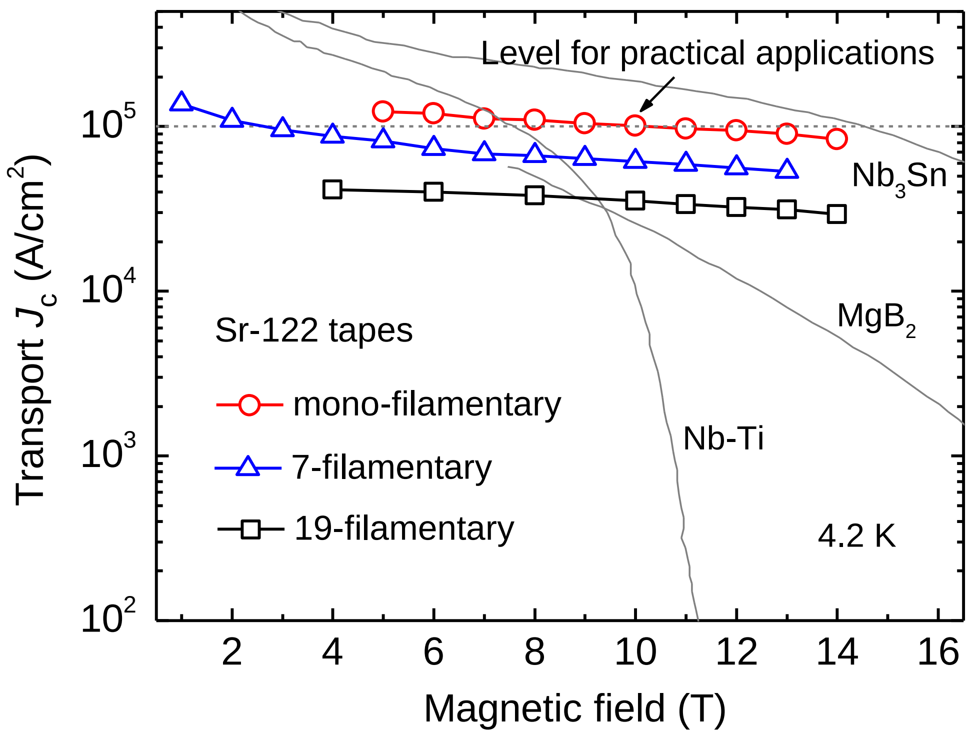
Huang, ***Physica C***, 2016

Breakthrough work

Very High transport J_c were achieved in 122/Ag tapes: $J_c > 10^5$ A/cm² (4.2 K, 10 T) - by hot pressing

The threshold for practical application:
$J_c = 10^5$ A/cm²@10 T

First to reach practical level J_c!



Later achieved

At 10 T, $J_c = 1.2\times10^5$ A/cm²

even in 14 T, J_c = ~10^5 A/cm²

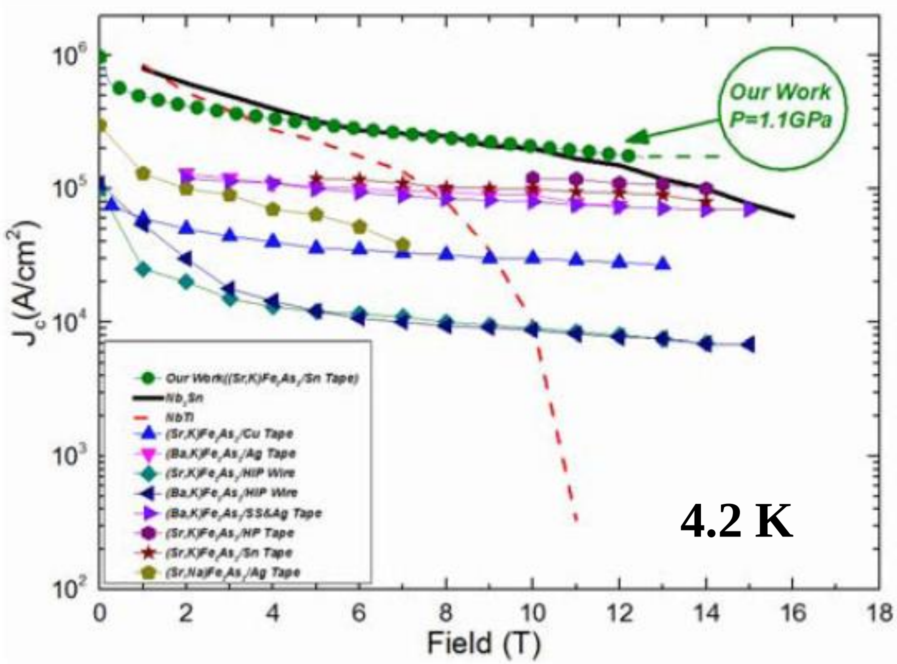
The superior J_c can be attributed to higher grain texture and improved densification.

Zhang et al., *APL* 104 (2014) 202601
Lin et al., *Sci. Rep.* 4 (2014) 6944

Latest result

Shabbir et al., *submitted*

J_c up to 3×10^5 A/cm^2 @ 4.2 K, 10 T can be achieved under Hydrostatic Pressure



-- Collaborated with Prof. Xiaolin Wang, S. X. Dou, Wollongong Univ.

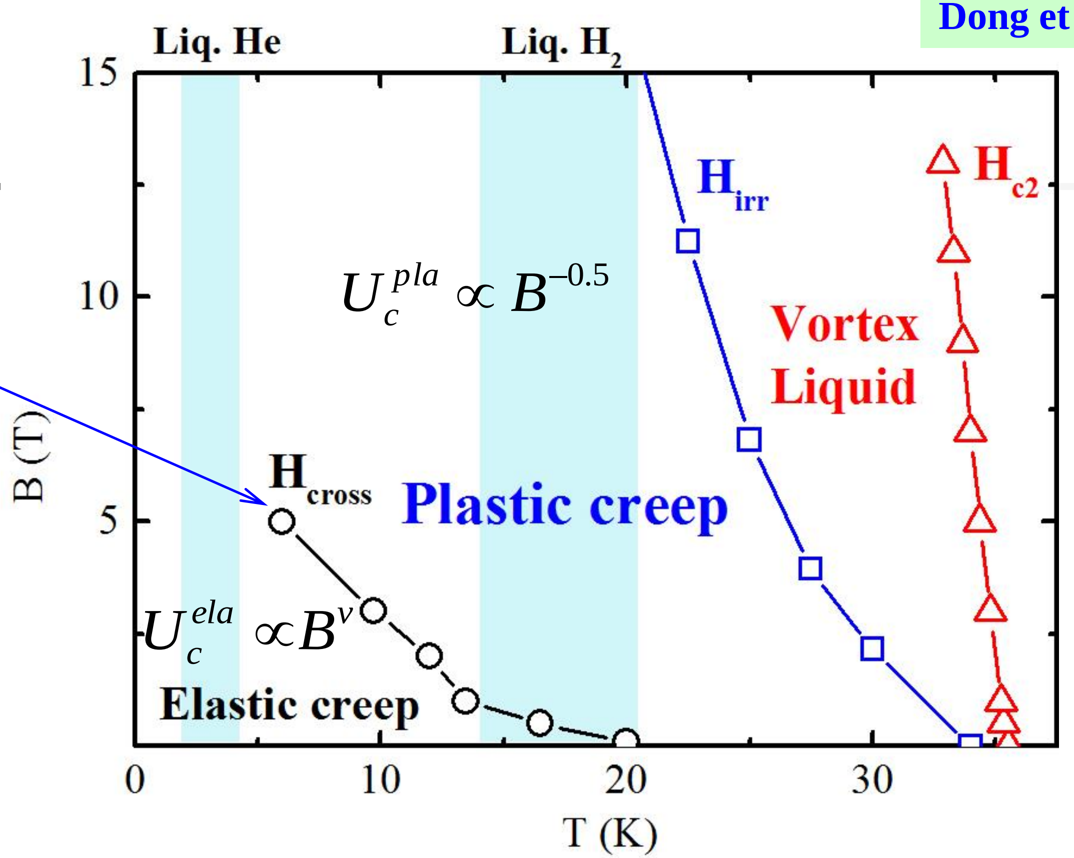
- ✓ **Using PPMS, HMD high pressure cell and Daphne 7373 oil as the medium for applying hydrostatic pressure on Sr-122/Ag tape samples.**
- ✓ **Tape samples were measured under pressure.**

- The hydrostatic pressure of 1GPa can significantly enhance J_c in Ag-clad $Sr_{0.6}K_{0.4}Fe_2As_2$ tapes at different temperatures, e.g., ~2×10^5A/cm^2 at 13T, 4.2 K.
- Pressure can improve the grain connectivity and increase the pinning number density.
- The result shows that the current IBS tapes/wires should have plenty of room to raise their J_c or I_c to higher levels.

Vortex phase diagram of high-J_c HP-122 tapes

Dong et al., *JAP*, 2016

H_{cross} is defined as the crossover field from elastic to the plastic creep regime.



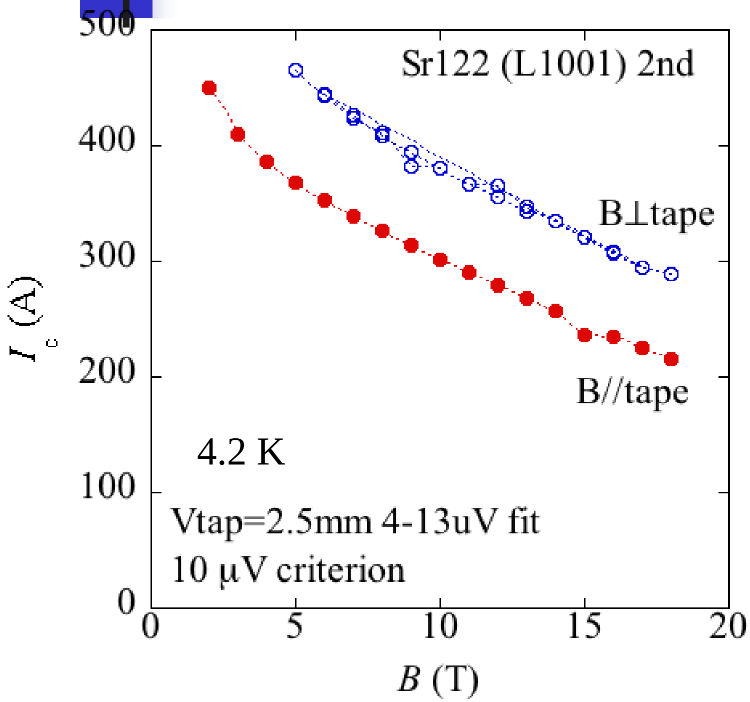
- More robust field dependence of J_c in the elastic creep regime.
- Weak field dependence of J_c in the liquid helium region, but J_c quickly decrease in the liquid hydrogen region.
- **To further increase flux pinning force: i)** decrease grain size to make more grain boundaries, ii) increase point pinning sites, *e.g.* radiation or nano-particle inclusion.

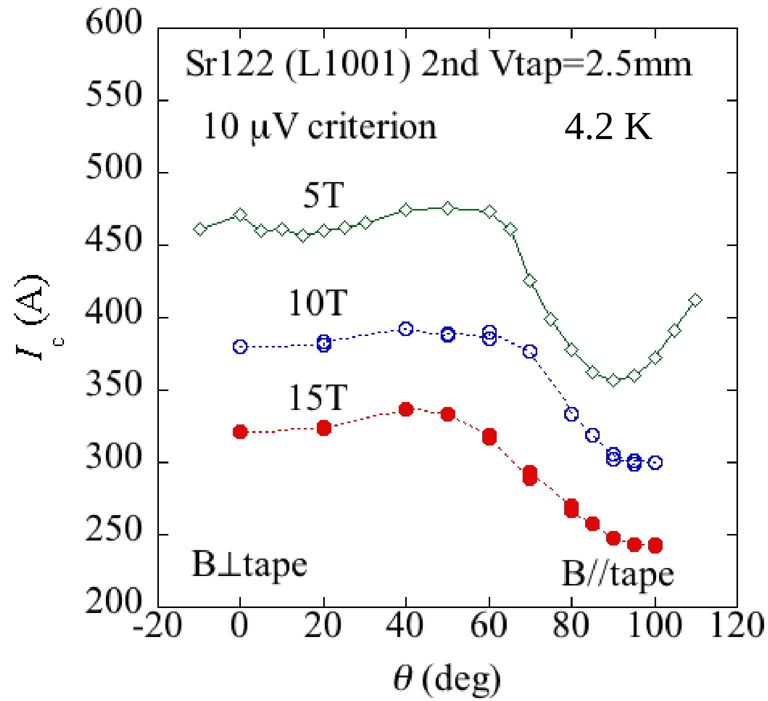
Small anisotropy

SuST, submitted

J_c properties at 4.2 K for HP Sr-122/Ag tapes

-- Measured by Dr. S. Awaji
HFLSM, Tohoku Univ.



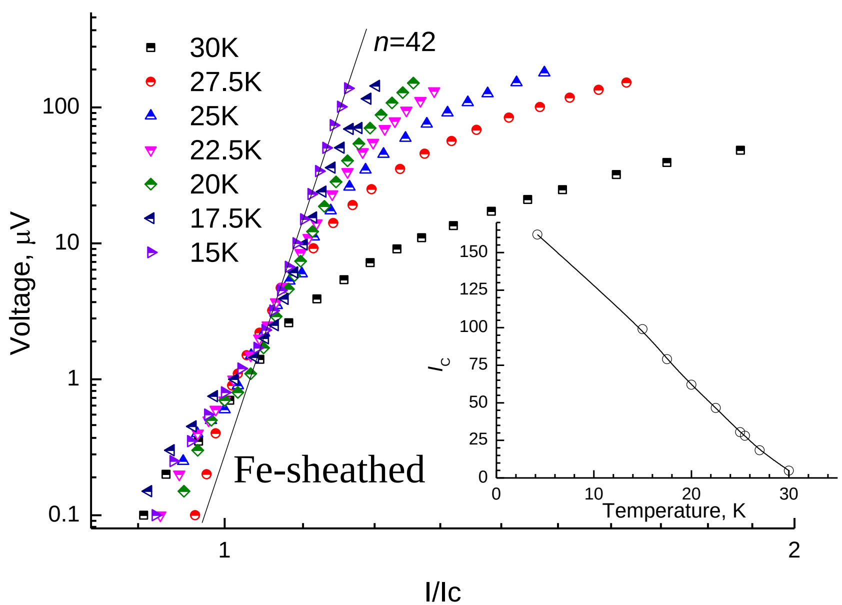


- **The I_c in applied magnetic fields is slightly higher in the perpendicular field ($I_c^{\perp}$) than in the parallel field ($I_c^{//}$).**
- **The anisotropy ratio ($\Gamma = I_c^{\perp}/I_c^{//}$) is less than *1.5*, quite small, very promising for applications.**

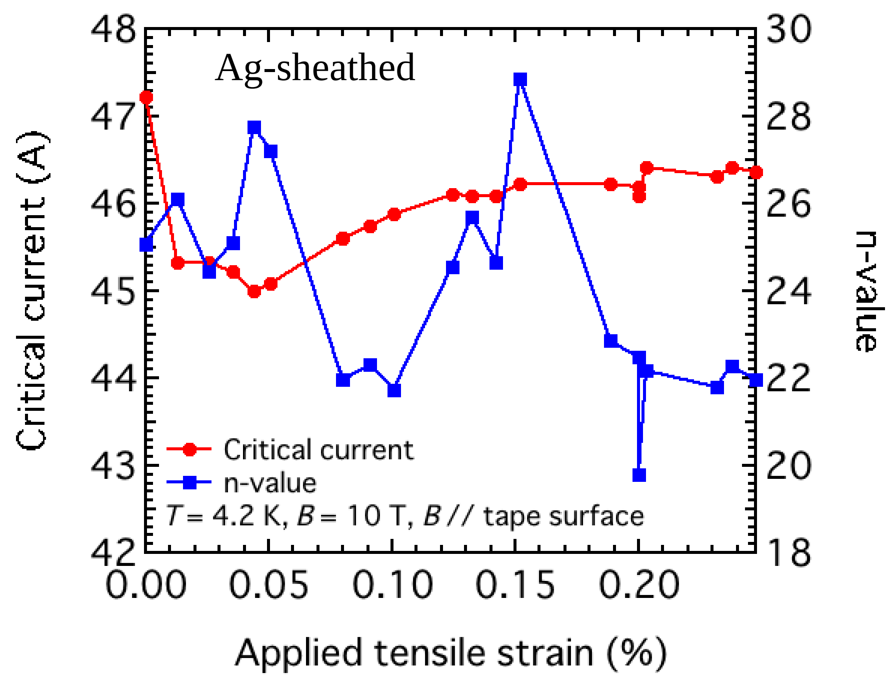
***n* value**

Temperature dependence of *n value* for Sr-122 tapes

-- Measured by Prof. Yang
Univ. of Southampton, UK



-- Measured by Dr. Oguro
HFLSM, Tohoku Univ., JP



At 20 K, the *n value* was over 30

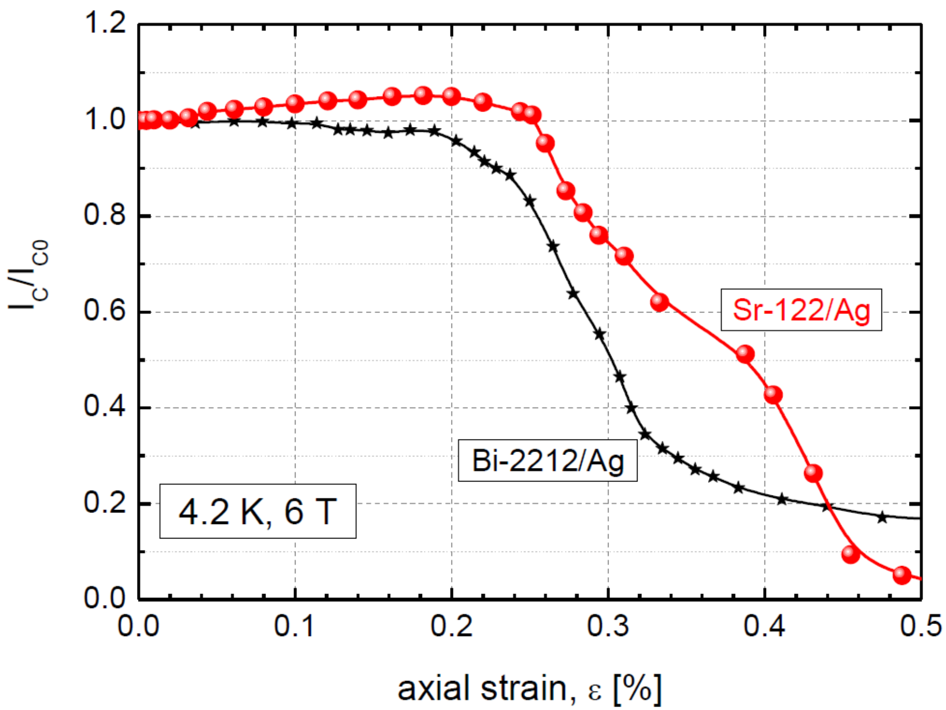
At 4.2 K, the *n value* was over 20

Strain property

Kovac et al., *SuST* 28 (2015) 035007

The first strain measurements of Sr-122/Ag tapes

-- Measured by Dr. Kovac
Slovak Academy of Sciences



At 4.2 K, 10 T: I_c >125A

Irreversible strains:

ε = 0.25%

which seems better than that of Bi-2212/Ag

The first observation of strain effects on the critical current of 122 wires

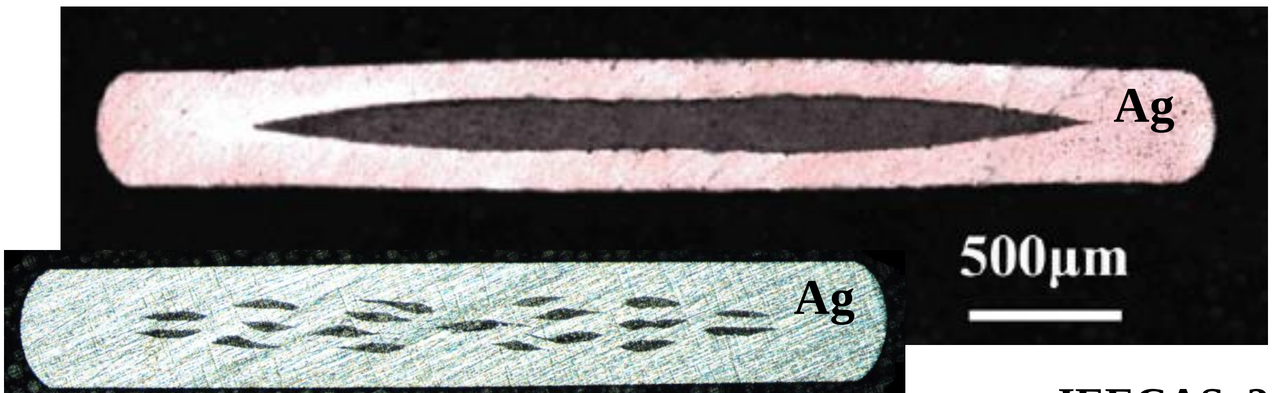
Next step:

Improvement of mechanical property of pnictide wires will be one of the major challenges for high field applications

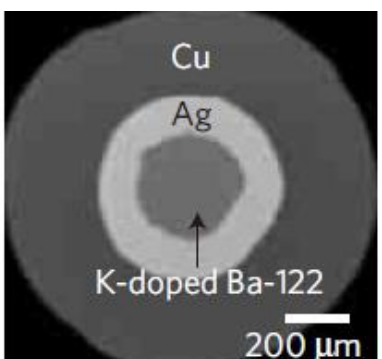
So far, all high-J_c pnictide wires and tapes were made by using Ag as sheath material

Ag is very expensive

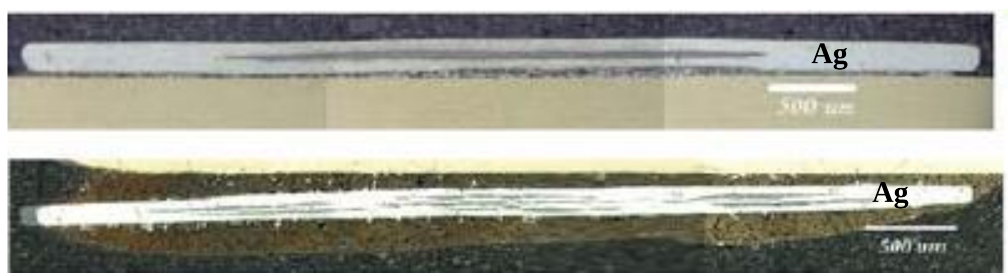
We should find other cheap materials, in order to reduce the cost!



IEECAS, 2014



Florida, 2012



NIMS, 2014

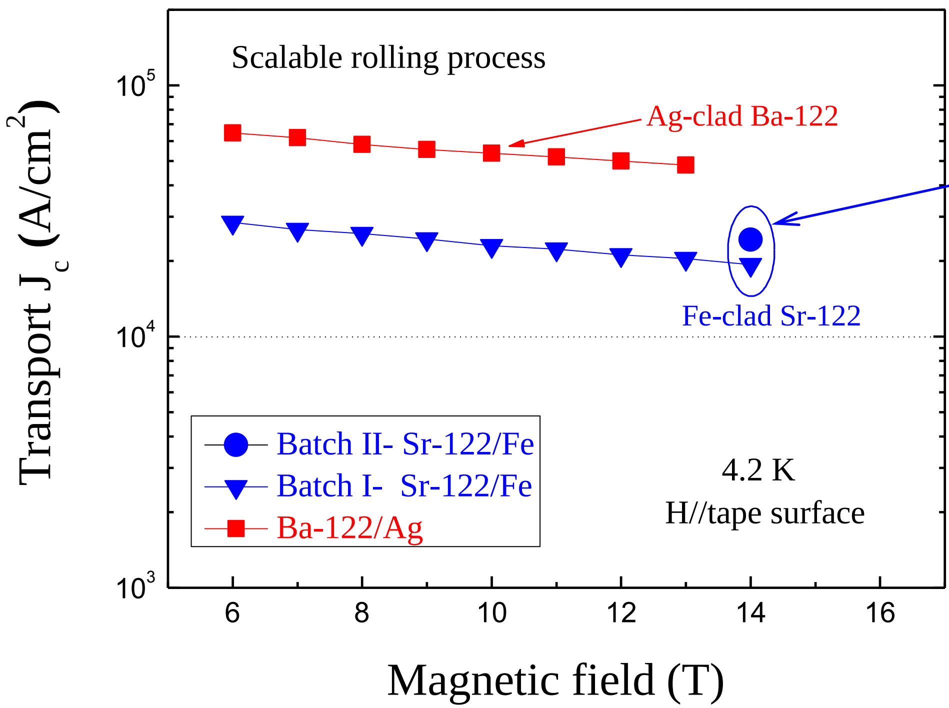
Fe sheath material

Ma , *Physica C* 516 (2015) 17

Fabrication of Fe-cladded 122 tapes

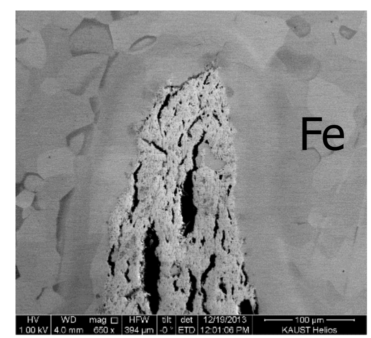
-- tape thickness=0.6 mm

-- by the scalable rolling



At 4.2 K and 14 T:

J_c **= 2.4×10⁴ A/cm²**

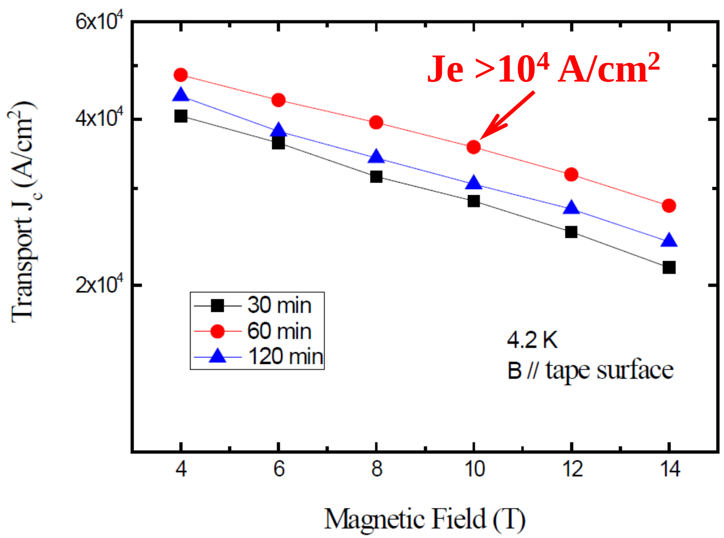


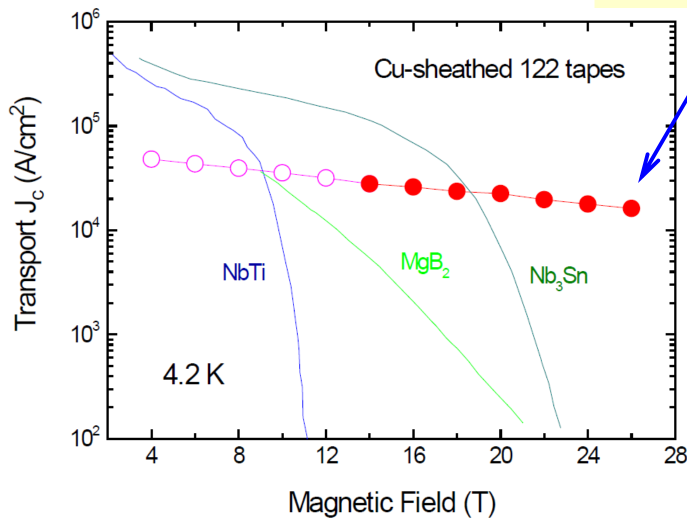
From an economic point of view, the Fe sheath is more attractive than the Ag sheath in fabricating Sr122/Ba122 tapes for practical applications.

Copper sheath material

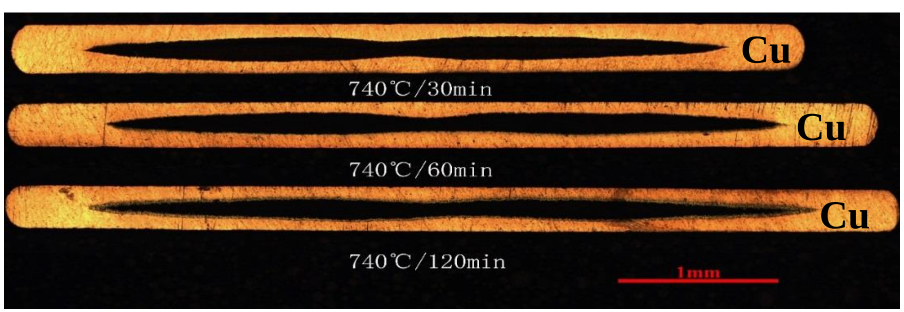
High J_c in Cu-sheathed Sr-122 tapes at low temperature 740°C

At **26 T**:
$J_c = 1.6\times10^4$ A/cm^2





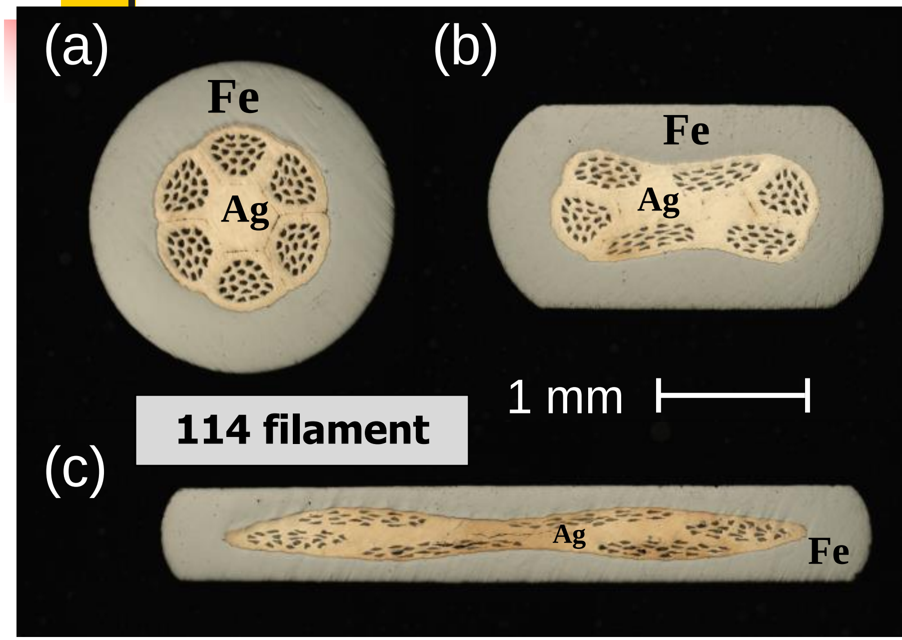
At 4.2 K, 10 T
Engineering J_e: $>10^4$ A/cm^2

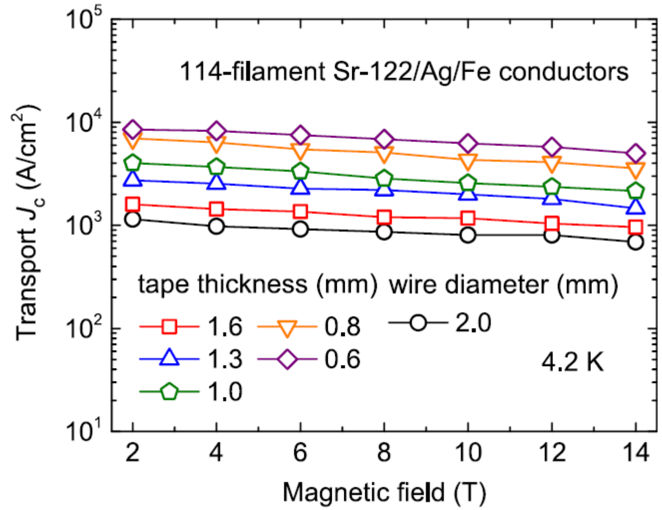


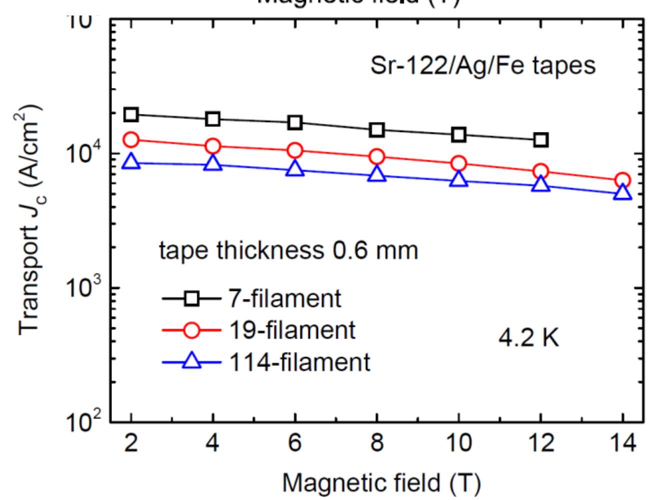
- The HP740/60 tape has a uniform and well connective superconducting phase and only a small amount of diffusion of Cu.
- The best transport J_c reaches 3.5×10^4 A/cm^2 at 10 T and keeps 1.6×10^4 A/cm^2 at 26 T.

Lin et al., *SuST* 29 (2016) 095006

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







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.

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

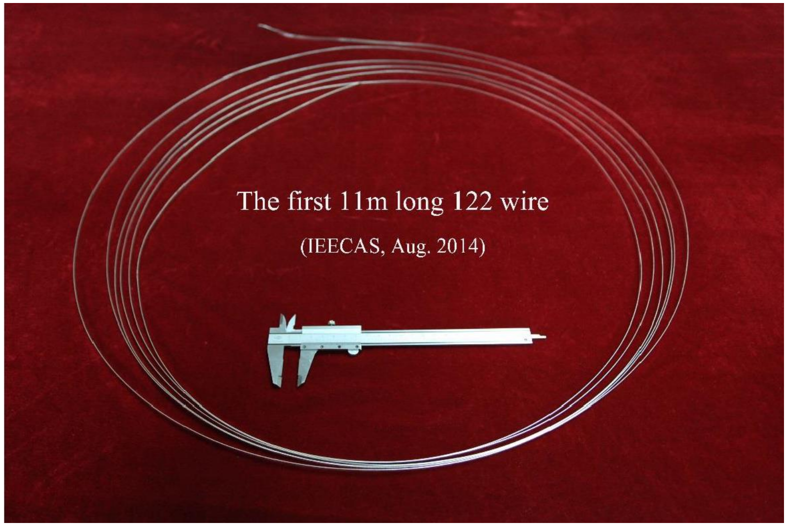
IEE-CAS

Ma , *Physica C* 516 (2015) 17

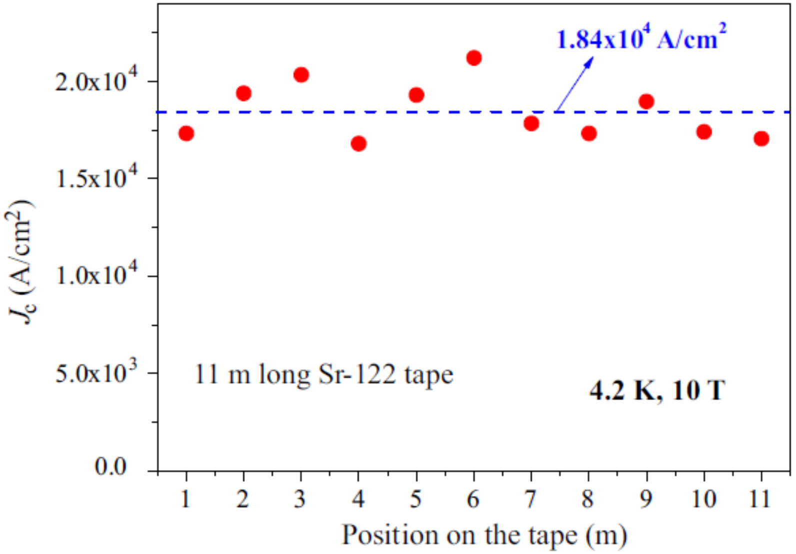
The first 11m long Sr-122 tape

-- by the scalable rolling process

The first long wire-- 11 m



Uniform wires can be fabricated



The average J_c of this long Sr122/Ag wire is ~ 18400A/cm^2
The fluctuations of the J_c is ~5%

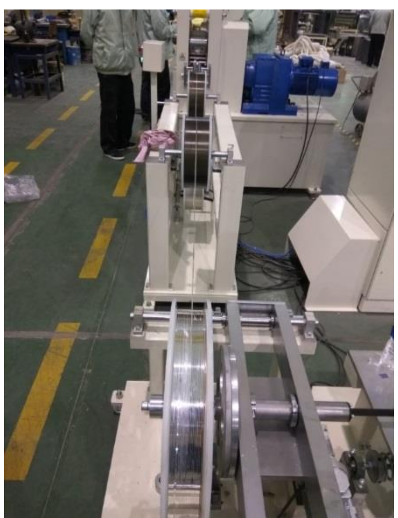
Significant breakthrough!

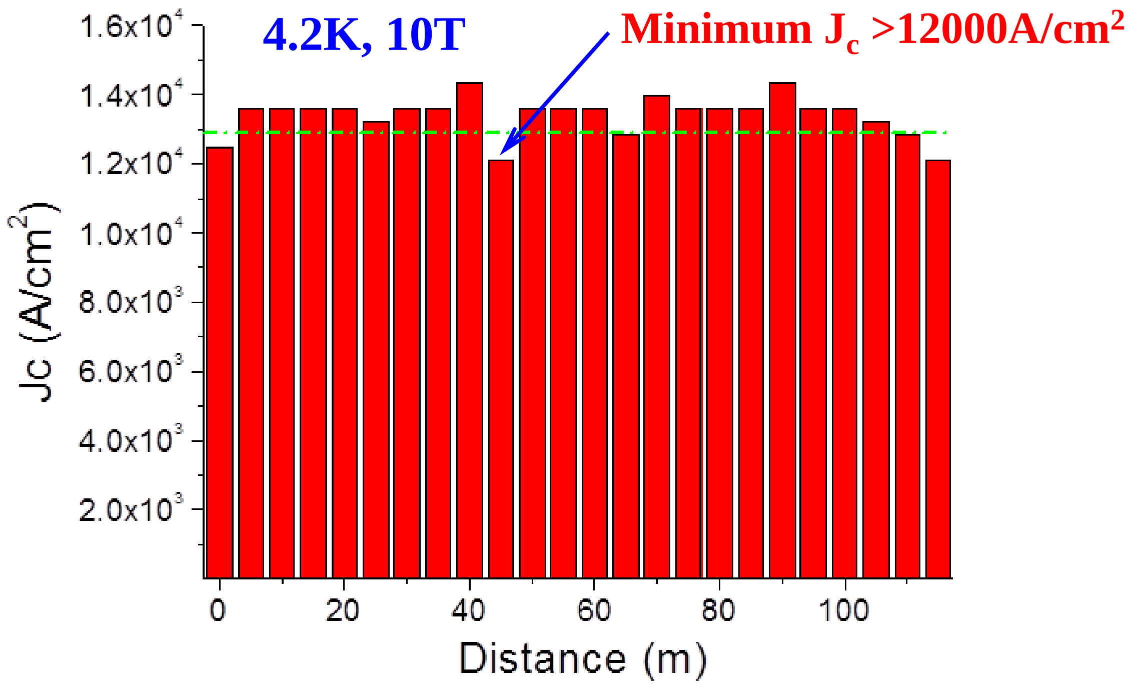
In Aug., 2016

The world's first 100 meter-class iron-based superconducting wire

-- Presented at ASC2016, Denver

115 m long **7-filamentary** wire



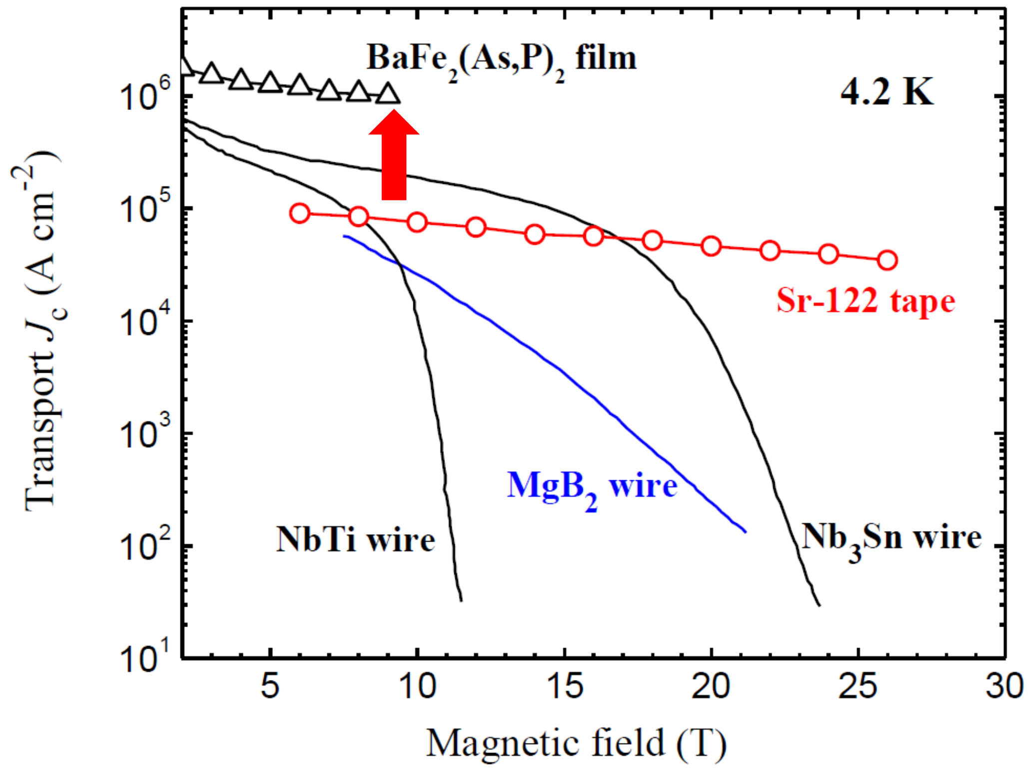


At 4.2 K, 10 T, transport Jc distribution along the length of the first 100 m long 7-filament Sr122 tape

http://snf.ieeecsc.org/pages/new-paper-and-result-highlights
e-print arXiv:1609.08301.

Prospects

Breakthrough work



Already reached practical level J_c at 10 T

+

Realization of the first 100 m long-length tape

Strong promising for high-field applications !

- **We believe that iron-based wires would be possible to operate at 4.2 K >20T or 20-30 K at >10 T.**
- **An scalable process is required to fabricate high performance long length tapes, e.g., *Rolling (hard sheath), Hot Rolling or Hot isostatic press (HIP)*…**

Summary

- **In the past 5 years, China has made significant progress in the development of LTS, YBCO C.C., Bi-2212, MgB_2 and iron-based superconducting wires and tapes.**
- **Further improvement of J_c is needed, in view of the high cost of present HTS conductors.**
- **There should be a place for Fe-based superconductors such 122 type with H_{c2} values exceeding 70 T @20 K, T_c =38 K and anisotropy of <1.5.**
- **We believe the R&D of superconducting materials in China will develop faster in the period of 13th Five-Year plan (from 2016).**

Acknowledgements

- **Institute of Electrical Engineering, Chinese Academy of Sciences (IEE-CAS)**
  Xianping Zhang, Dongliang Wang, Chao Yao, Chiheng Dong, He Huang, Qianjun Zhang, Kaili Lin
- **Northwest Institute for Nonferrous Metal Research (NIN)**
  G. Yan, C.S. Li, P.X. Zhang
- **Western Superconducting Technologies Co., Ltd. (WST)**
  Y. Feng
- **Suzhou Advanced Materials Research Institute (SAMRI)**
  H.W. Gu
- **Shanghai Univ./ShangChuang Superconductor Co., Ltd.**
  C.B. Cai
- **Shanghai JiaoTong Univ./Shanghai Superconductor Technology Co., Ltd.**
  Y.J. Li
- **Innova Superconductor Technology Co., Ltd. (Inno ST)**
  Z. H. Han

Thank you for your attention