ASC2024 Salt Lake City

Status of Iron Based Superconductors: characteristics and relevant properties for applications

Kazumasa Iida, Nihon University

2024.9.3, Salt Lake City

superconductivity

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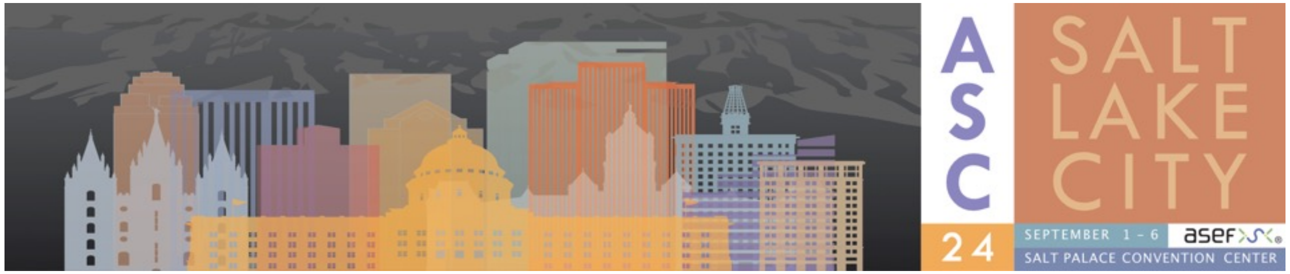
Superconductor Science and Technology

IOP Publishing



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Overview

1. **Iron-based superconductors (IBSs)**
   - Physical properties
2. **Tuning of the superconducting properties**
   - SC transition temperature (strain, monolayer, intercalation, EDLT)
   - Grain boundary, GB
   - Critical current density (natural defects, APC, thermodynamic approach)
3. **Progress Toward applications**
   - Use of IBS wires and bulks in magnets, and perspective

Discover of Iron based superconductors (IBSs)

First Fe-based superconductor in 2006

JACS COMMUNICATIONS
Published on Web 07/15/2006

Iron-Based Layered Superconductor: LaOFeP

Yoichi Kamihara,† Hidenori Hiramatsu,† Masahiro Hirano,†,‡ Ryuto Kawamura,§ Hiroshi Yanagi,§ Toshio Kamiya,†,§ and Hideo Hosono*,†,‡

ERATO-SORST, JST, Frontier Collaborative Research Center, Tokyo Institute of Technology, Mail Box S2-13, 4259 Nagatsuta, Midori-ku, Yokohama 226-8503, Japan, Frontier Collaborative Research Center, Tokyo Institute of Technology, Mail Box S2-13, 4259 Nagatsuta, Midori-ku, Yokohama 226-8503, Japan, and Materials and Structures Laboratory, Tokyo Institute of Technology, Mail Box R3-4, 4259 Nagatsuta, Yokohama 226-8503, Japan

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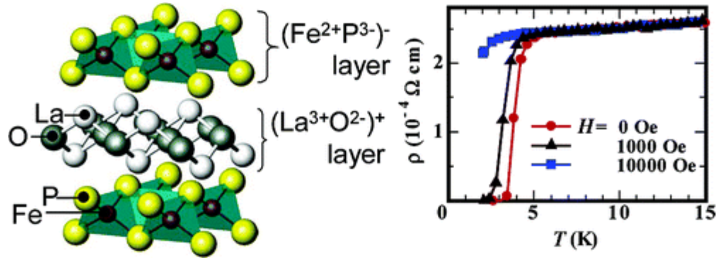


P -> As

O -> $O_{1-x}F_x$

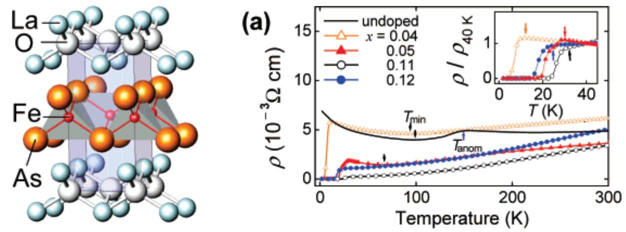
JACS COMMUNICATIONS
Published on Web 02/23/2008 **In 2008**

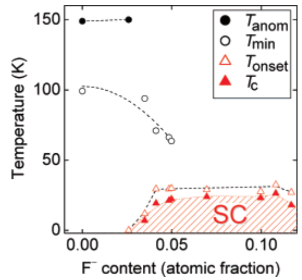
Iron-Based Layered Superconductor La[$O_{1-x}F_x$]FeAs (x = 0.05−0.12) with T_c = 26 K

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

Received January 9, 2008; E-mail: hosono@msl.titech.ac.jp



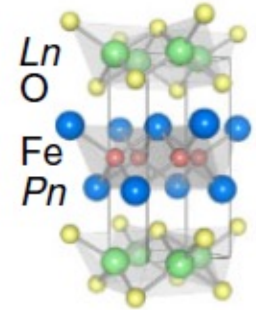


Superconducting dome

Iron based superconductors (IBSs): FeAs or Fe*Ch* tetrahedron

1111

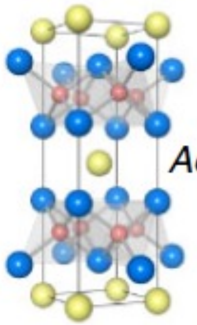
T_c=55 K



*Ln*Fe*Pn*O
*Ae*Fe*Pn*F
(*Ln*=La, Ce
Ae=Ca, Sr
Pn=P, As)

122

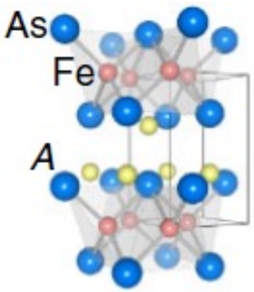
T_c=38 K



$AeFe_2Pn_2$
(*Ae*=Ca, Sr, Ba, K, Eu)

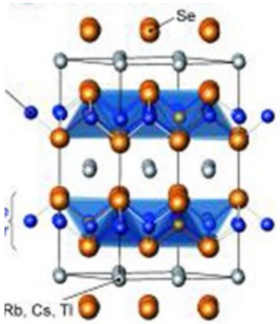
111

T_c=18 K



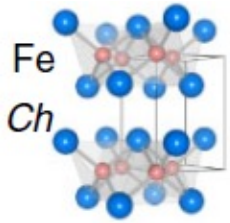
*A*FeAs
(*A*=Li, Na)

245



11

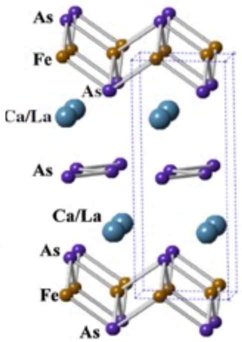
T_c=14 K



Fe*Ch*
(*Ch*=S, Se, Te)

112

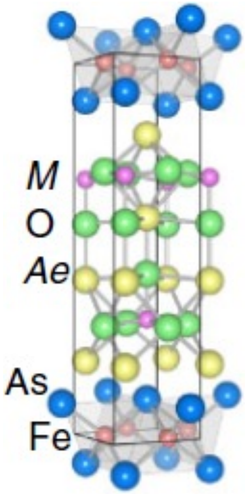
T_c=34 K



$AeFeAs_2$
(*Ae*=Ca, Sr, Ba)

21113

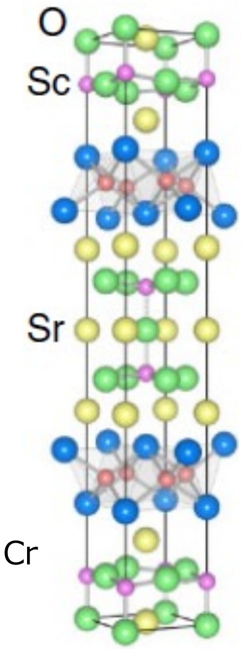
T_c=37 K



$Ae_2MFePnO_3$
(*M*=Sc, Ti, V, Cr
Ae=Ca, Sr
Pn=P, As)

32225

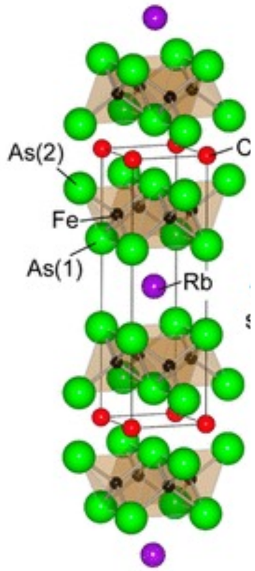
T_c=45 K



$Sr_3Sc_2Fe_2As_2O_5$

1144*

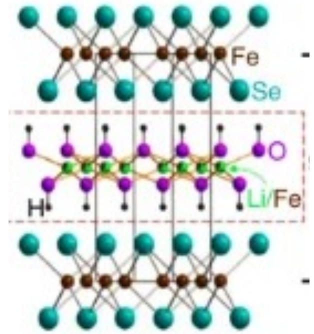
T_c=36 K



$CaRbFe_4As_4$

11111

T_c=41 K



FeAs and Fe*Ch* tetrahedron: common structure

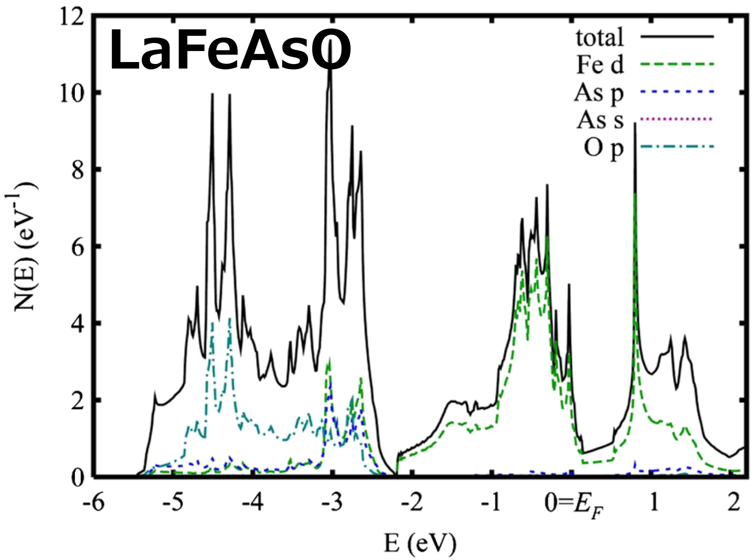
*A. Iyo *et al.*, *J. Am. Chem. Soc.* **138** 3410 (2016).

K. Tanabe and H. Hosono, *Jpn. J. Appl. Phys.* **51** 010005 (2012).

Electronic structure: Multiband superconductors

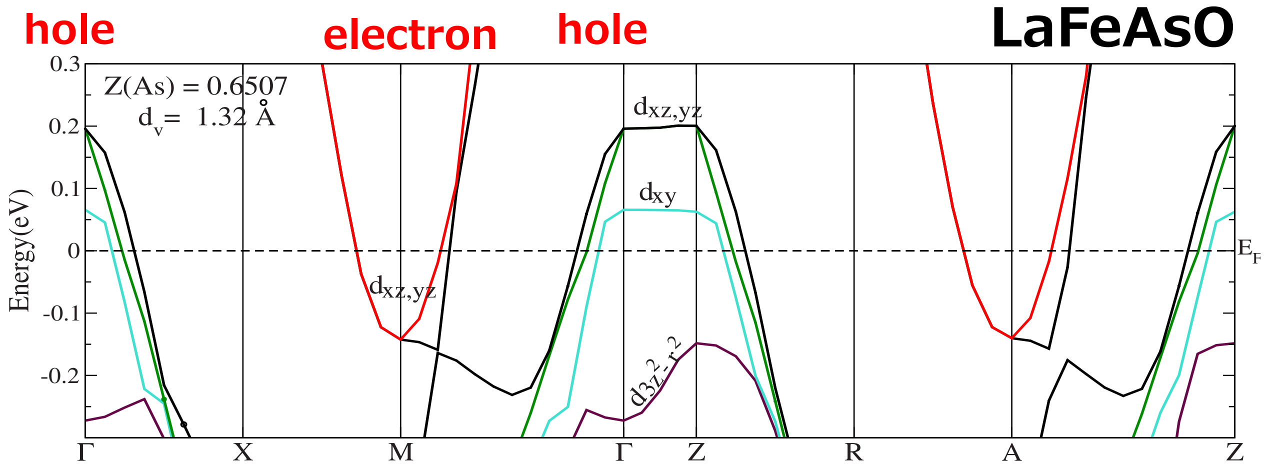
Fe3*d* orbitals play an important role for superconductivity

Fe 3*d* orbitals dominate the total DOS around E_F



D. J. Singh and H.-M. Du, *Phys. Rev. Lett.* **100** 237003 (2008).

Five Fe 3*d* bands across E_F
→ Multiband superconductors



V. Vildosola *et al*., *Phys. Rev. B* **78** 064518 (2008).

IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 57, Oct 2024. Plenary presentation given at ASC 2024, Sept 2024, Salt Lake City, Utah, USA.

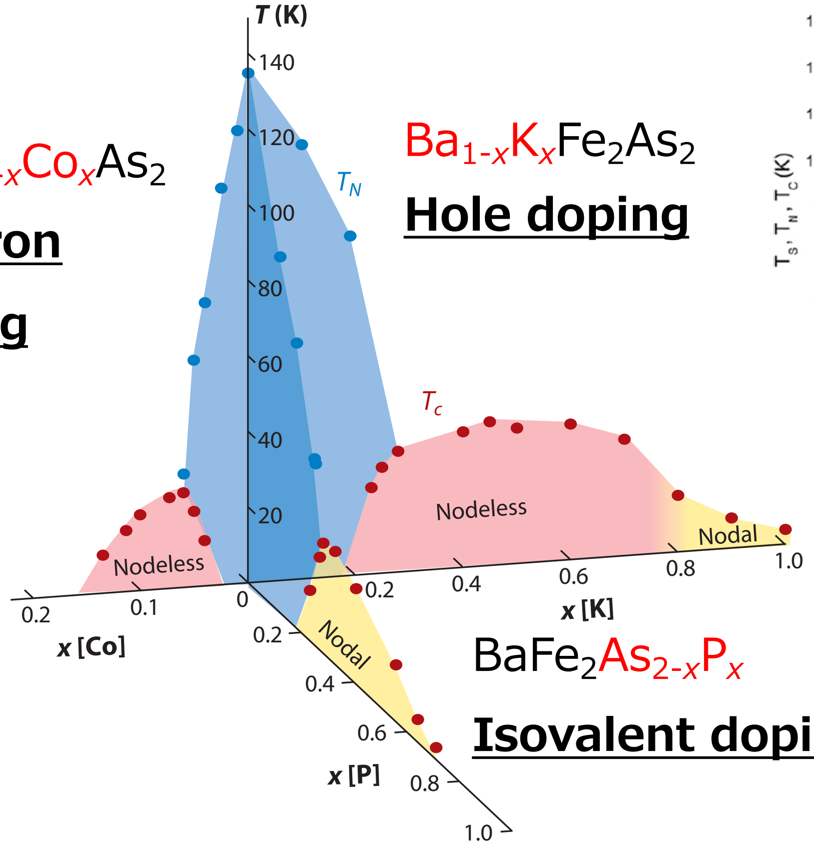
Mganetic phase diagrams of 122, 1111 and 11

$BaFe_2As_2$ (Ba122) system

$BaFe_{2-x}Co_xAs_2$
Electron doping

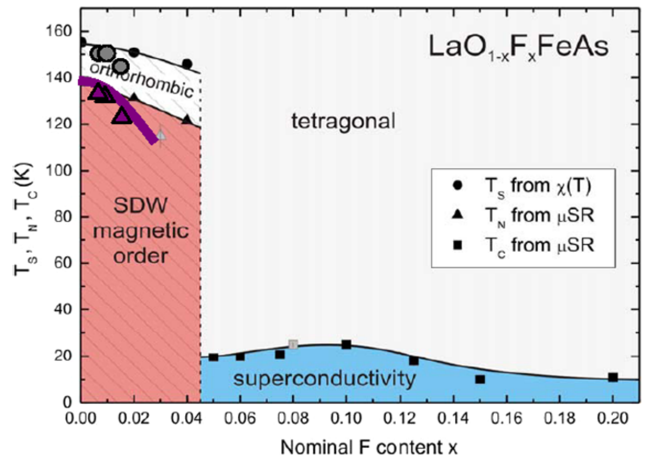
$Ba_{1-x}K_xFe_2As_2$
Hole doping

$BaFe_2As_{2-x}P_x$
Isovalent doping



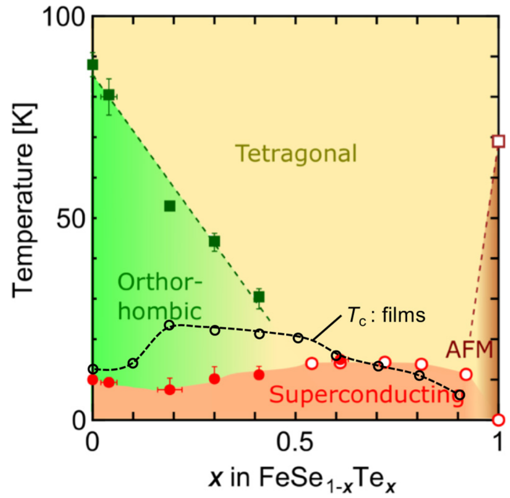
T. Shibauchi *et al.*, *Annu. Rev. Condens. Matter Phys.* **5** 113 (2014).

$LaFeAsO_{1-x}F_x$



A. Köhler *et al.*, *J. Supercond. Nov. Magn.* **22** 565 (2009).

$FeSe_{1-x}Te_x$

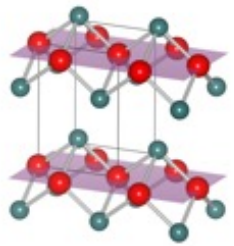


K. Terao *et al.*, *Phys. Rev. B.* **100** 224516 (2019).

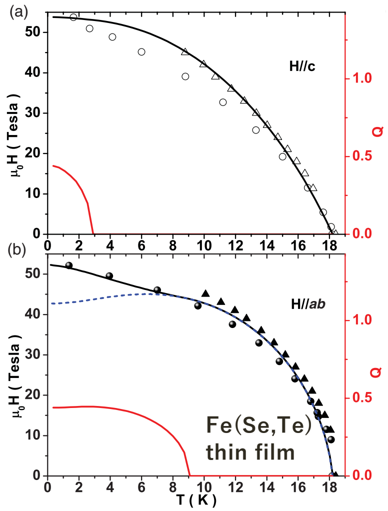
- **AFM is suppressed by doping**
- **Presence of the SC domes**
- **Direct doping to the FeAs layer is not harmful to SC (c.f. Cuprates)**

High upper critical field, H_{c2}, and low anisotropy

11

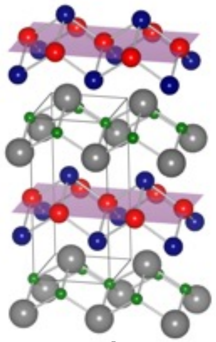


Fe(Se,Te)

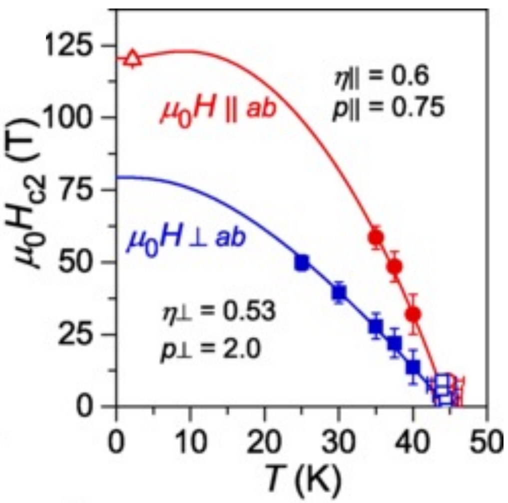


C. Tarantini *et al.*, *Phys. Rev. B* **84** 184522 (2011).

1111

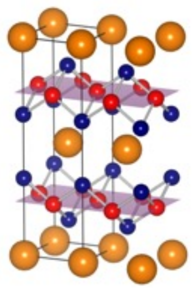


*Ln*FeAs(O,F or H)
[*Ln*=Nd, Sm,…]

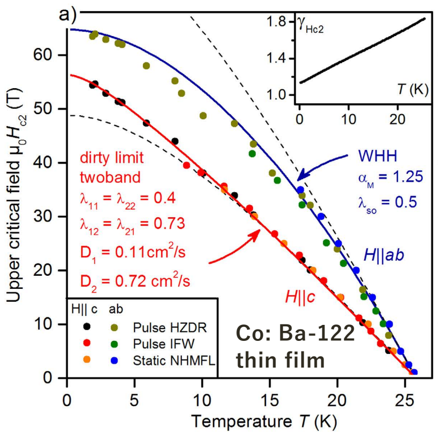


K. Hanzawa *et al.*, *Phys. Rev. Materials* **6** L111801 (2022).

122



AeFe_2As_2
[*Ae*=Ca, Ba,...]



J. Hänisch *et al.*, *Sci. Rep.* **5** 17363 (2015).

	11	122	1111
γ_{Hc2}	1-2	1-2	1-5

- Large H_{c2} over 50 T at low *T* even *H*||*c*
- Low anisotropy

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Comparison between cuprates and IBSs

	Cuprates	IBSs
Degree of freedom in material design	high (many compounds)	high (many compounds)
Parent compound	Mott insulator	AFM bad metal
Gap symmetry	d-wave, single band	extended s-wave (s± or s++), 5 bands
Doping	Hole: T_c=154 K[i)] Electron: T_c=30 K[ii)]	Hole: T_c=38 K[iii)], isovalent: T_c=31 K[iv)] Electron: T_c=55 K[v)], 65 K[vi)]
H_{c2} anisotropy	~5: RE-123 ~150: Bi-2223	1~2: 11 and 122 1~5: *Ln*-1111
Pairing mechanism	spin fluctuations?	spin fluctuations? orbital fluctuations?

i) $HgBa_2Ca_2Cu_3O_{8+\delta}$ w/pressure
ii) $La_{1-x}Ce_xCuO_4$
iii) $Ba_{0.6}K_{0.4}Fe_2As_2$
iv) $BaFe_2(As_{0.66}P_{0.33})_2$
v) *Ln*FeAs(O,F) (*Ln*=Nd, Sm)
vi) FeSe monolayer

Overview

1. Iron-based superconductors (IBSs)

- Physical properties

2. Tuning of the superconducting properties

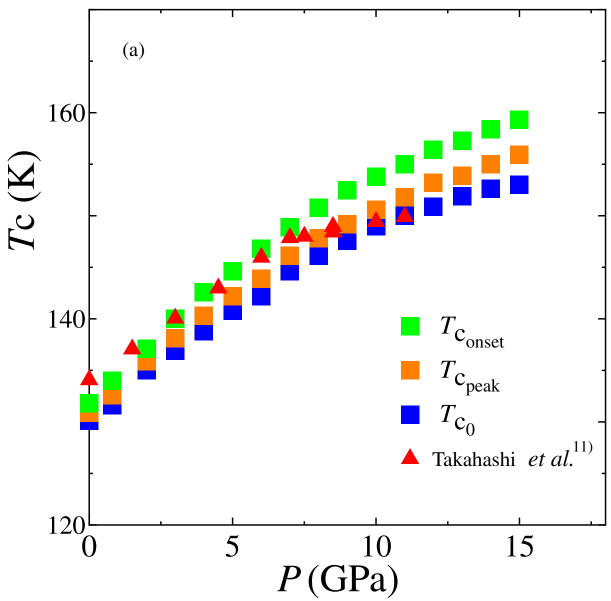
- SC transition temperature (strain, monolayer, intercalation, EDLT)
- Grain boundary, GB
- Critical current density (natural defects, APC, thermodynamic approach)

3. Progress Toward applications

- Use of IBS wires and bulks in magnets, and perspective

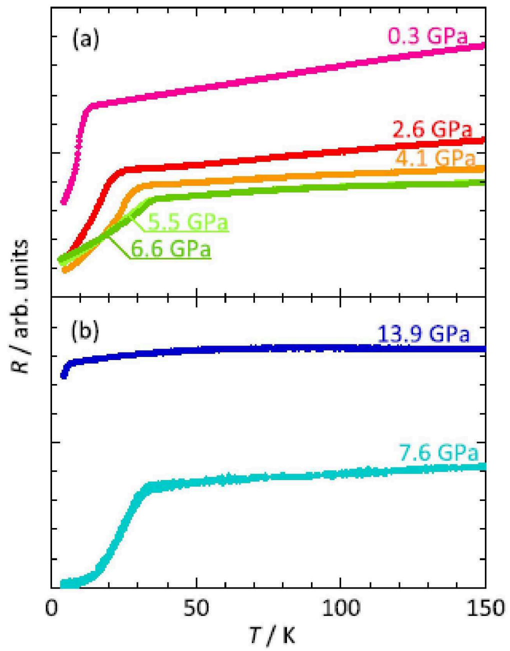
A significant jump of T_c by pressure

$HgBa_2Ca_2Cu_3O_{8+\delta}$:
130 K -> 153 K (15 GPa)



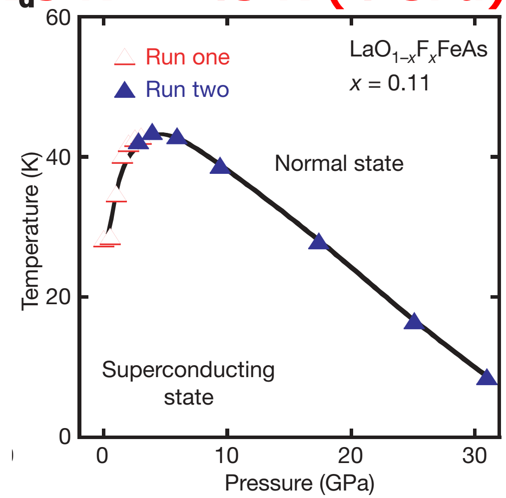
N. Takeshita *et al.*, *J. Phys. Soc. Jpn.* **82** 023711 (2013).

FeSe:
9 K -> 37 K (7 GPa)

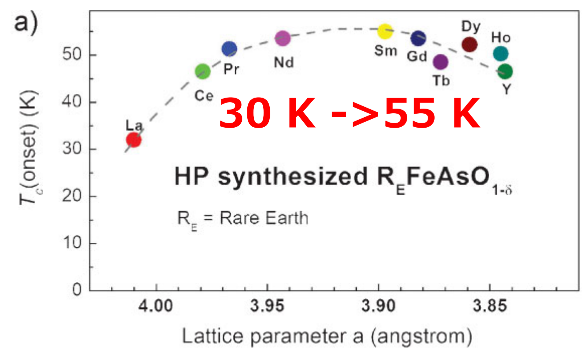


S. Margadonna *et al.*, *PRB* **80** 064506 (2009).

$LaFeAsO_{0.89}F_{0.11}$:
25 K -> 43 K (4 GPa)



H. Takahashi *et al.*, *Nature* **453** 376 (2008).

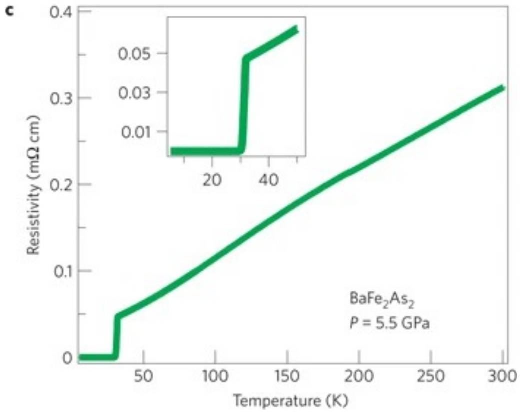


Z. Ren, Z. Zhao, *Adv. Mater.* **21** 4584 (2009).

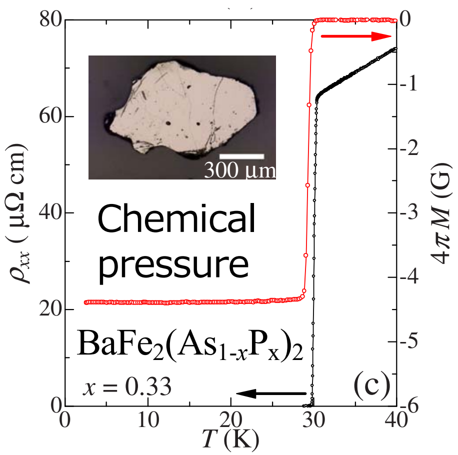
- ➢ Isotropic pressure enhances T_c
- ➢ Chemical pressure also enhances T_c

Pressure & strain induced superconductivity in Ba122

Bulk



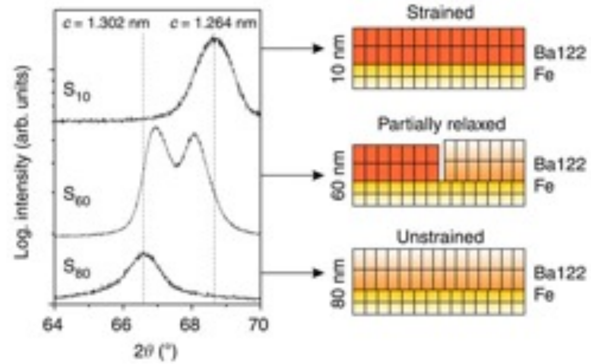
S. J. A. Kimber *et al.*, *Nat. Mater.* **8**, 471 (2009).

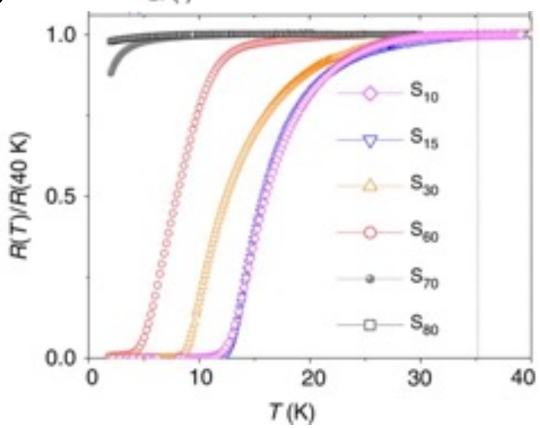


S. Kasahara *et al.*, *PRB* **81** 184519 (2010).

Bilayer

Fe: 30 nm/Ba122: 10~80 nm

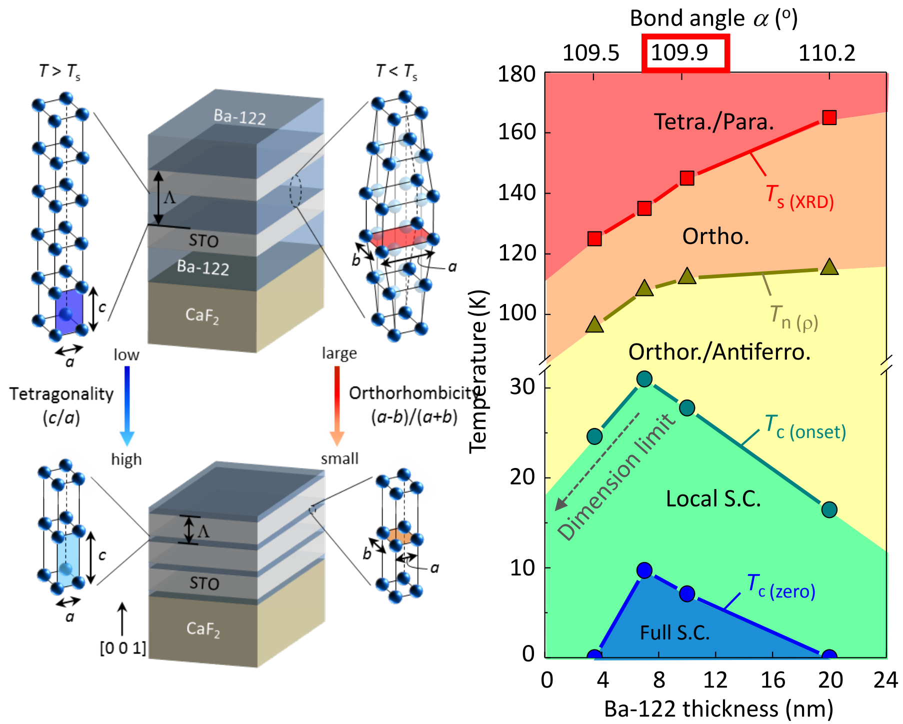




J. Engelmann, K.I. *et al.*, *Nat. Commun.* **4** 2877 (2013).

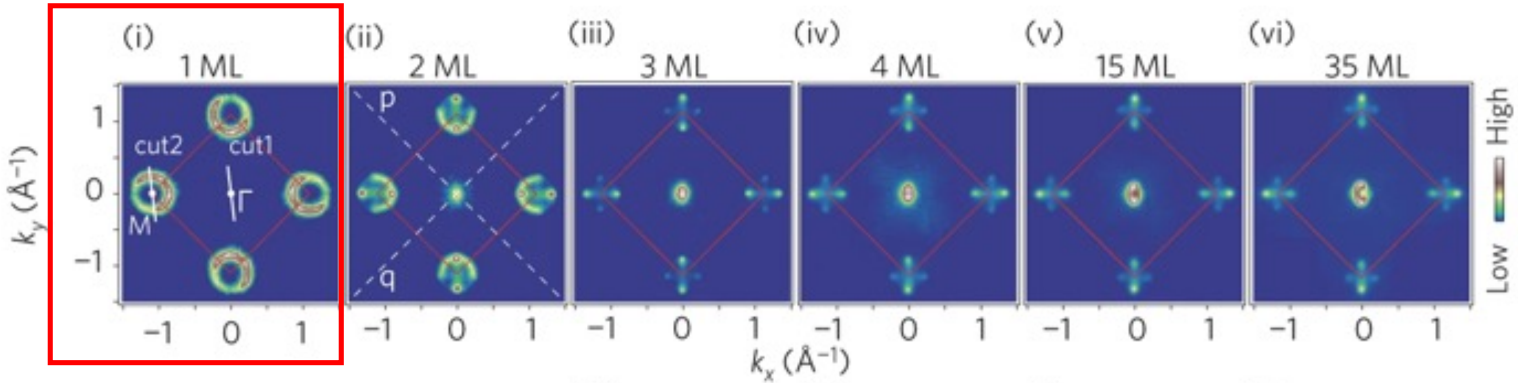
Superlattice

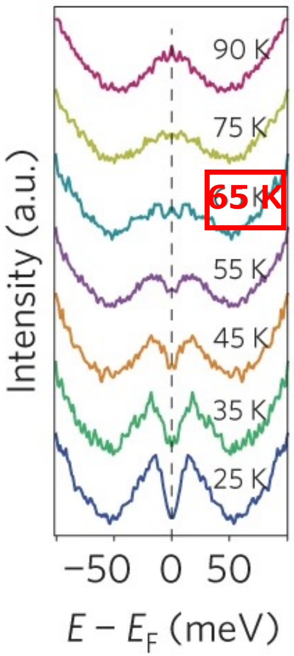
SrTiO$_3$: 14 nm/Ba122: 4~20 nm



J. Kang *et al.*, *PNAS* **117** 21170 (2020).

T_c =65 K in a monolayer of FeSe





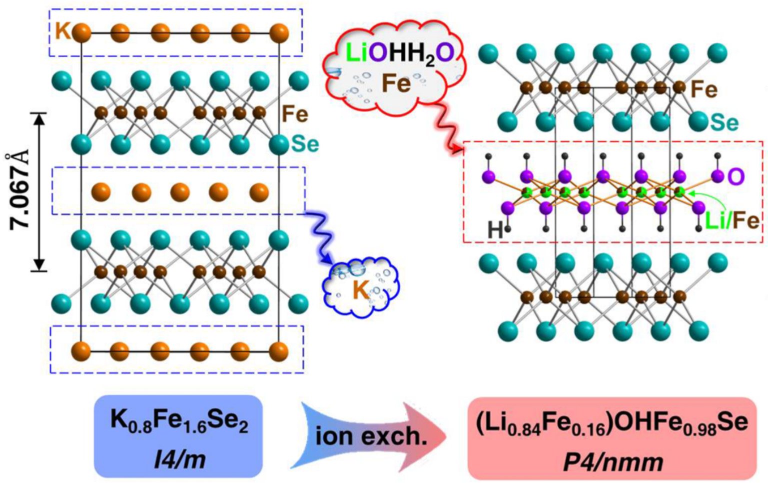
- SC gap opened at between 55 K $\leq T \leq$ 65 K for 1 ML
- Only electron-like pockets appeared at M-point for 1 ML
- Hole-like pocket started to appear at Γ-point for over 2 ML
- FeSe ML is very sensitive to air -> quickly degraded

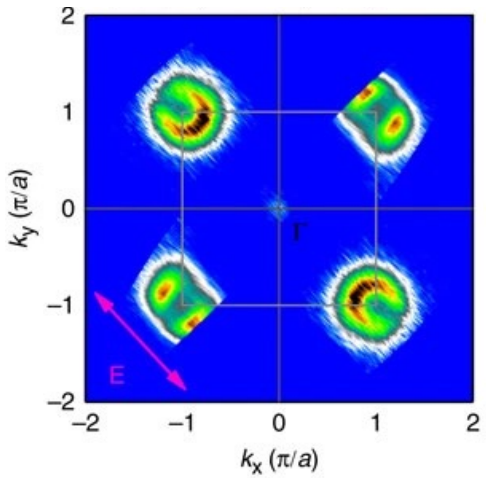
Wang *et al*., *Chin. Phys. Lett*. **29** 037402 (2012).

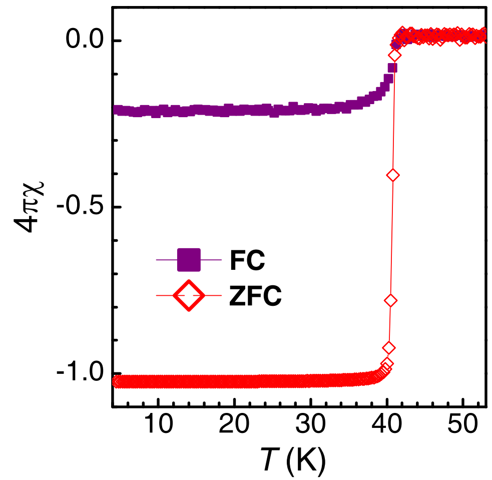
Tan *at al*., *Nat. Mater*. **12** 634 (2013).

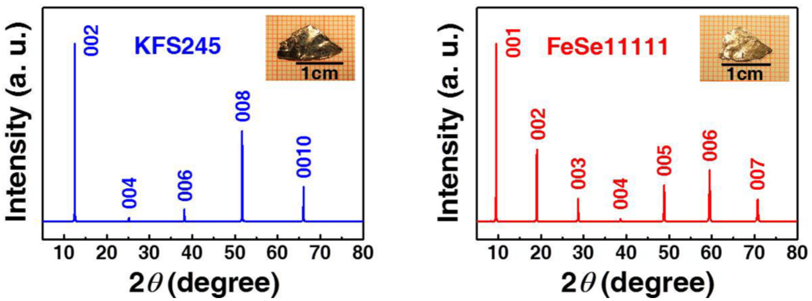
Tuning superconducting properties, T_c, by intercalation

(Li,Fe)OHFeSe (11111) single crystal





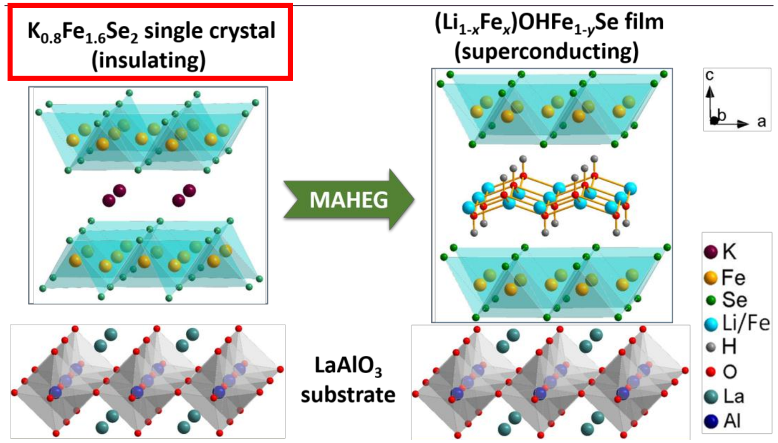




Dong *et al*., *Phys. Rev*. B, **92** 064515 (2015).

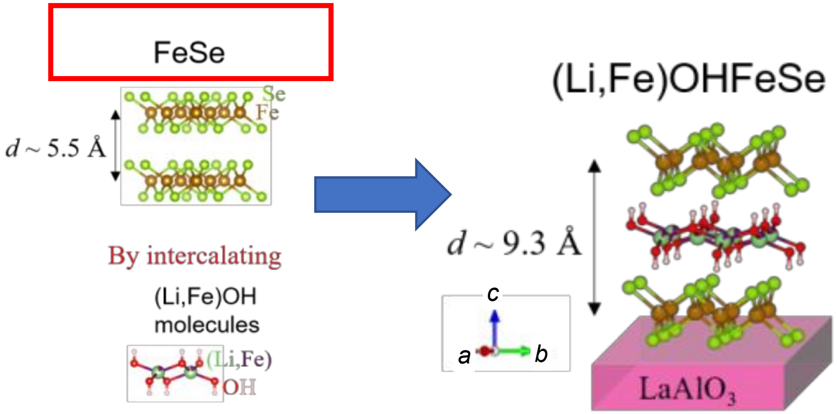
- (Li,Fe)OHFeSe single crystals grown by ion exchange
- Electronic structure is very similar to the FeSe ML (T_c ~ 42 K)

Tuning superconducting properties, T_c, by intercalation



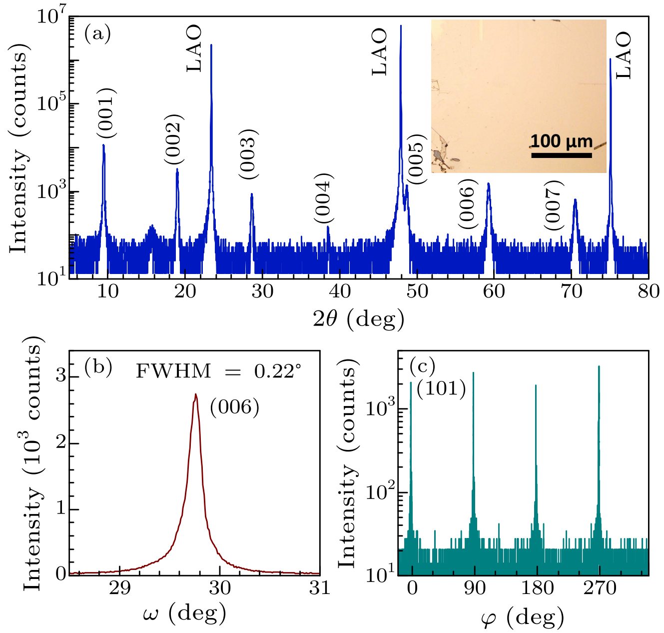
matrix-assisted hydrothermal epitaxial growth

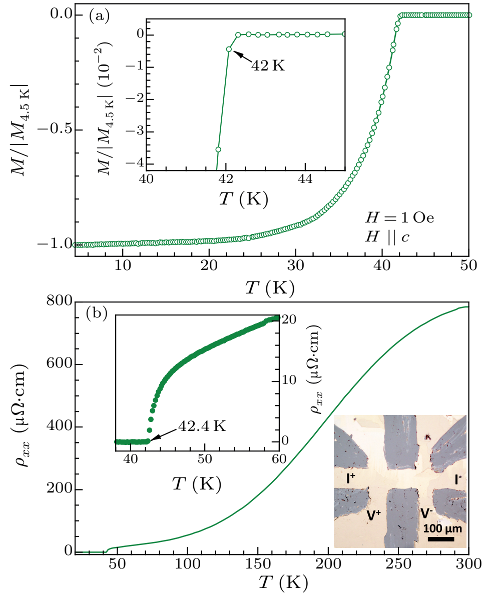
Huang *et al.*, *arXiv:1711.02920* (2017).



Dong *et al.*, *Chinese Phys. Lett.* **39** 127402 (2022).

Epitaxial (Li,Fe)OHFeSe thin film





- ➢ (Li,Fe)OHFeSe epitaxial thin films
- ➢ $T_c \sim 42$ K, comparable to single crystal

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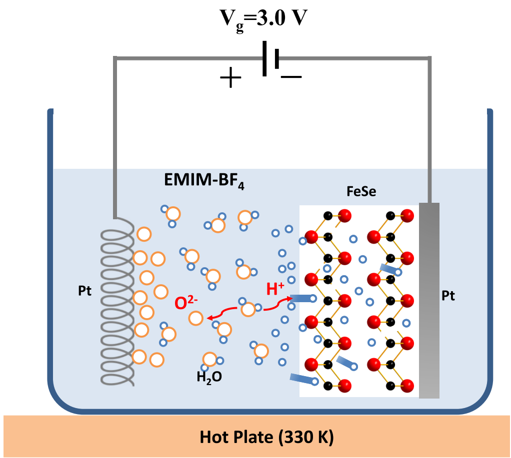
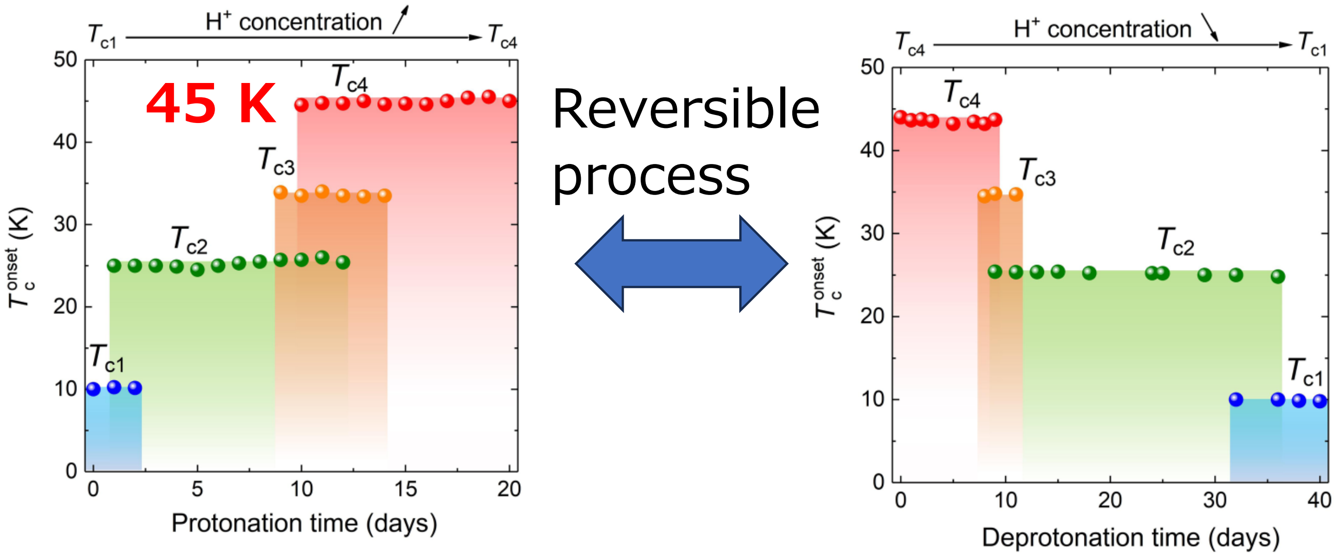
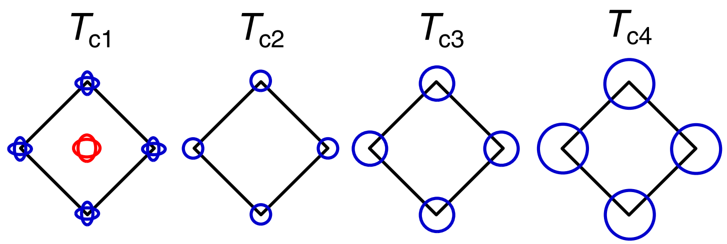
Tuning superconducting properties, T_c, by protonation

Protonation-induced SC in FeSe



H_2O in an ionic liquid



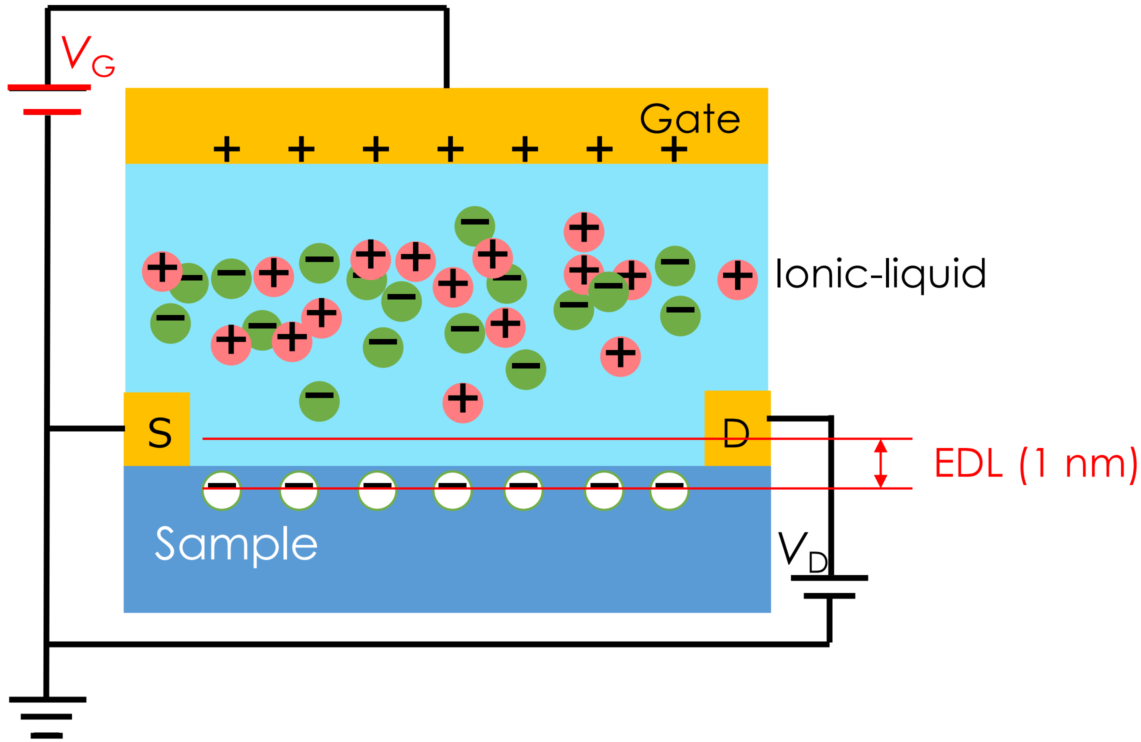


Heavily electron doping induces high T_c

H+ concentration

Y. Meng *et al*., *Phys. Rev. B* **105** 134506 (2022).

Electric double layer transistor (EDLT)



Electro-static carrier doping

V_G>0…electron doping
V_G<0…hole doping

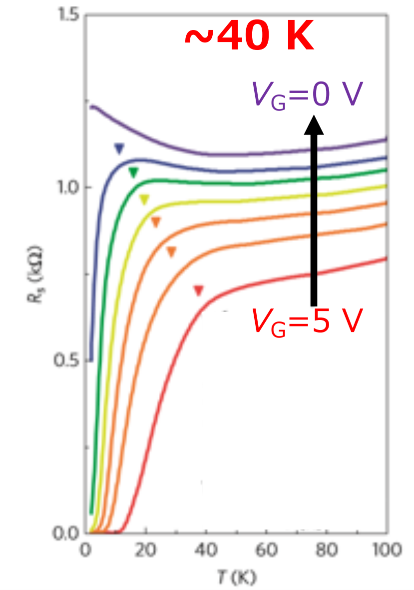
Tuning superconducting properties by EDLT

SC induced by EDLT

first demonstration

in IBS [**FeSe~0.6nm]**

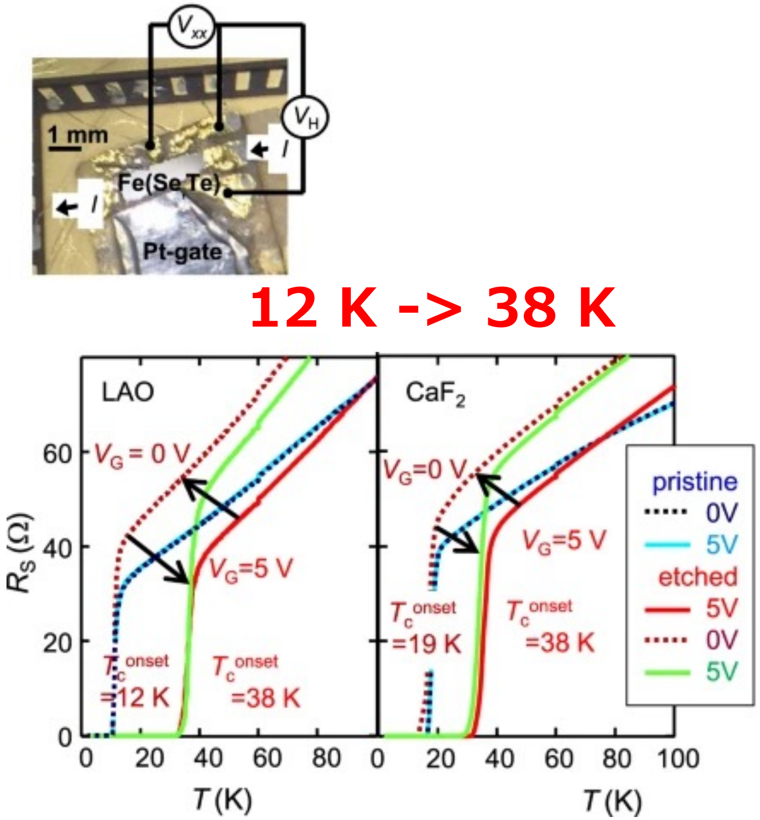
J. Shiogai *et al*., *Nat. Phys.* **12** 42 (2016).



***T*c enhancement** by EDLT

$FeSe_{0.8}Te_{0.2}$ (>10 nm)

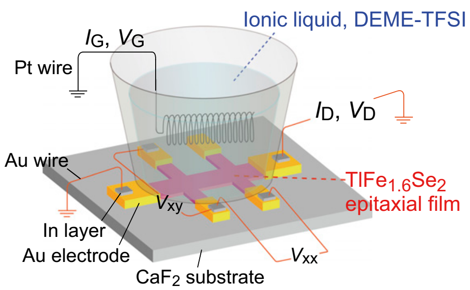
S. Kouno *et al*., *Sci. Rep.* **8** 14731 (2018).

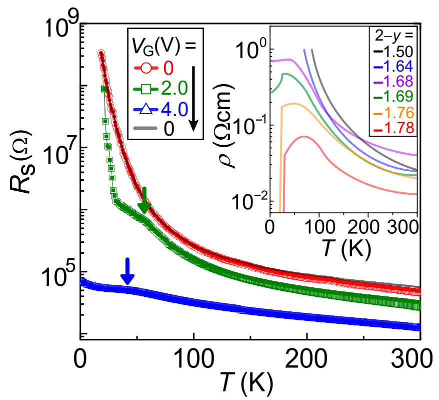


So far, enhancement of T_c by EDLT only for FeSe & Fe(Se,Te)

$TlFe_{1.6}Se_2$ (~20 nm)

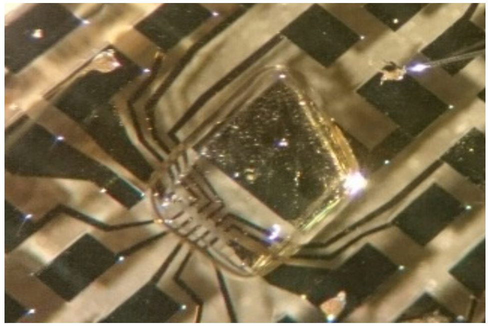
T. Katase *et al*., *PNAS* **111** 3979 (2014).

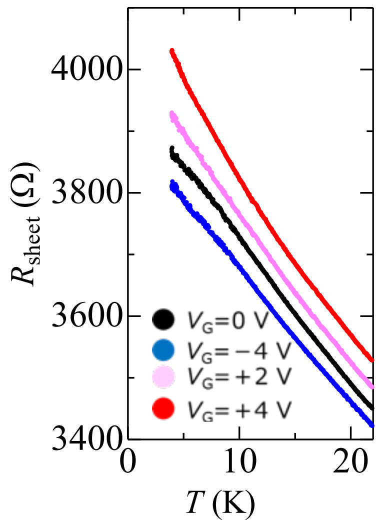




NdFeAsO (~7 nm)

K. Iida *et al*., *unpublished*

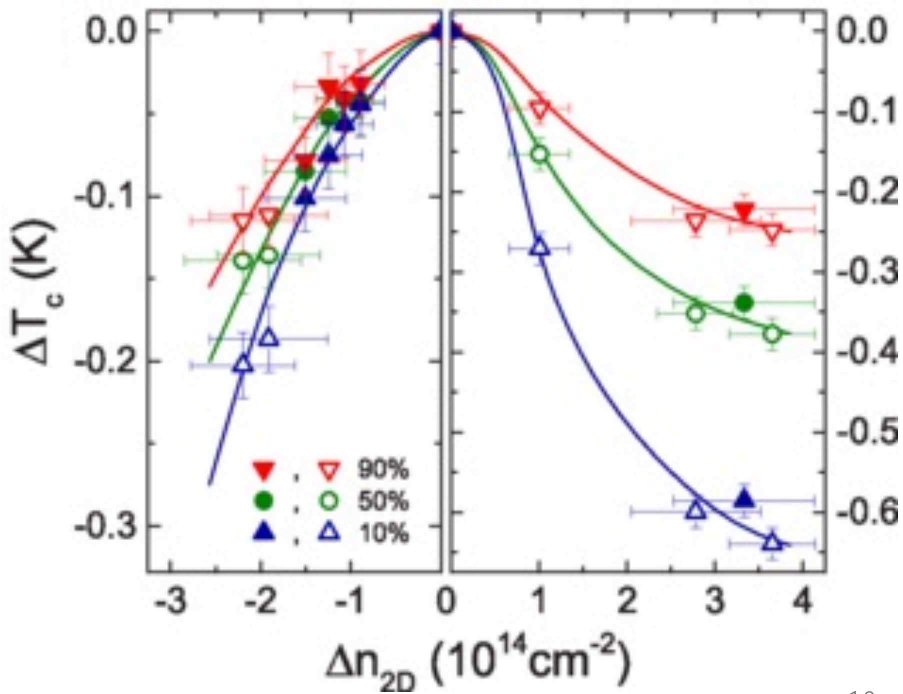




Ambipolar suppression of T_c

$BaFe_2(As,P)_2$ (~10 nm)

E. Piatti, K.I. *et al*., *Phys. Rev. Mater.* **3** 044801 (2019).



IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 57, Oct 2024. Plenary presentation given at ASC 2024, Sept 2024, Salt Lake City, Utah, USA.

Overview

1. Iron-based superconductors (IBSs)

- Physical properties

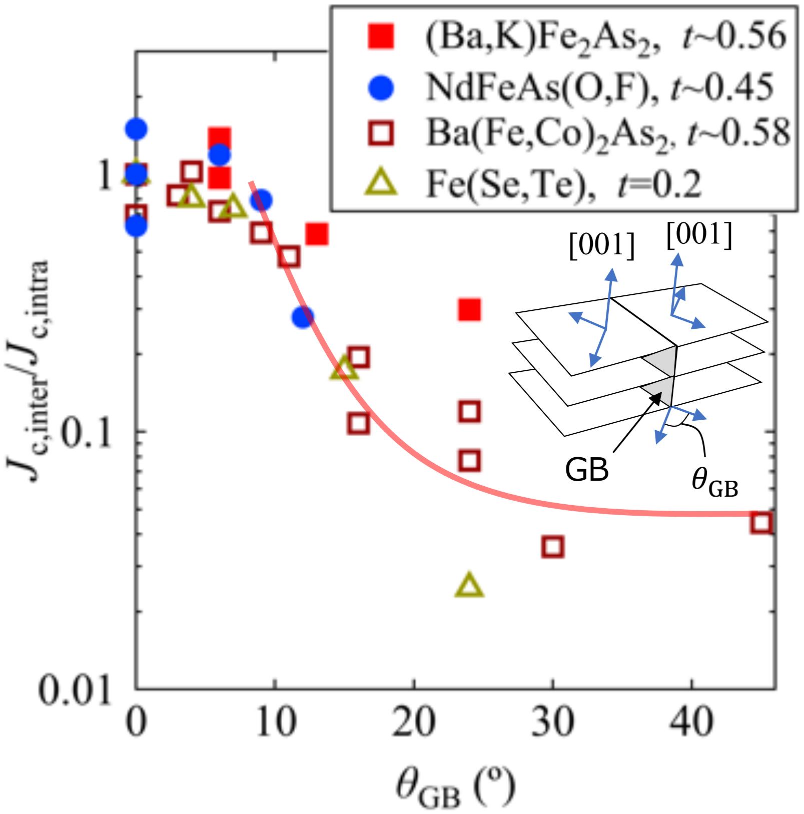
2. Tuning of the superconducting properties

- SC transition temperature (strain, monolayer, intercalation, EDLT)
- Grain boundary, GB
- Critical current density (natural defects, APC, thermodynamic approach)

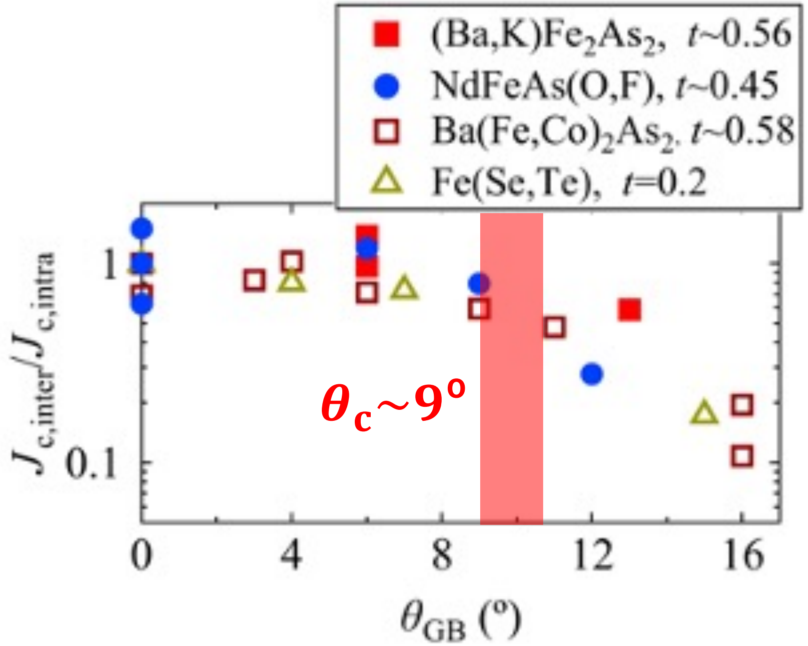
3. Progress Toward applications

- Use of IBS wires and bulks in magnets, and perspective

Large critical angle θ_c & constant $J_{c,inter}$ ($\theta_{GB} > \sim 15^o$)



T. Hatano, K.I. *et al*., *NPG Asia Mater.* **16** 41 (2024).
K. Iida *et al*., *Supercond. Sci. Technol*. **32** 074003 (2019).
T. Katase *et al*., *Nat. Commun*. **2** 409 (2011).
W Si *et al*., *Appl. Phys. Lett*. **106** 032602 (2015).
E. Sarnelli *et al*., *IEEE Trans. Appl. Supercond*. **27** 7400104 (2017).

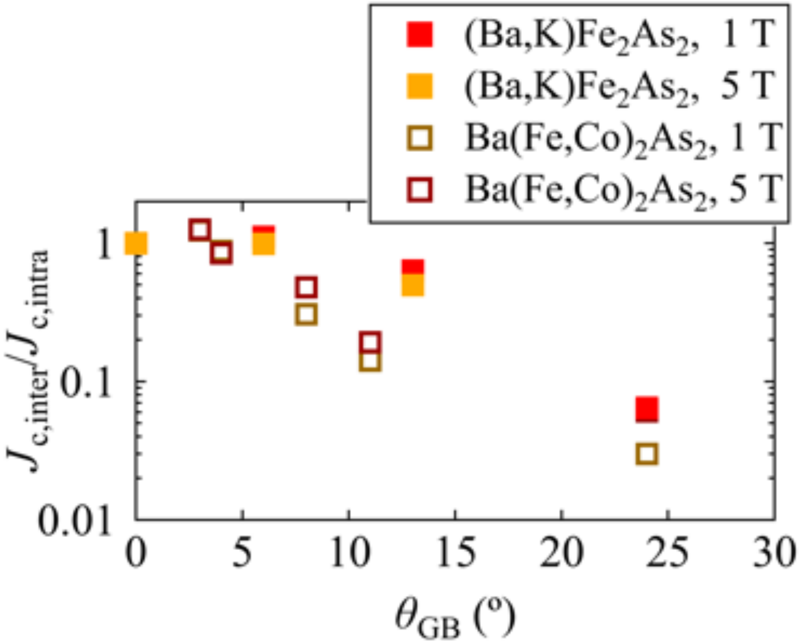


- A critical angle θ_c of 9º, which is larger than cuprate
- The $J_{c,inter}$ is constant at $\theta_{GB} > \sim 15^o$

IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 57, Oct 2024. Plenary presentation given at ASC 2024, Sept 2024, Salt Lake City, Utah, USA.

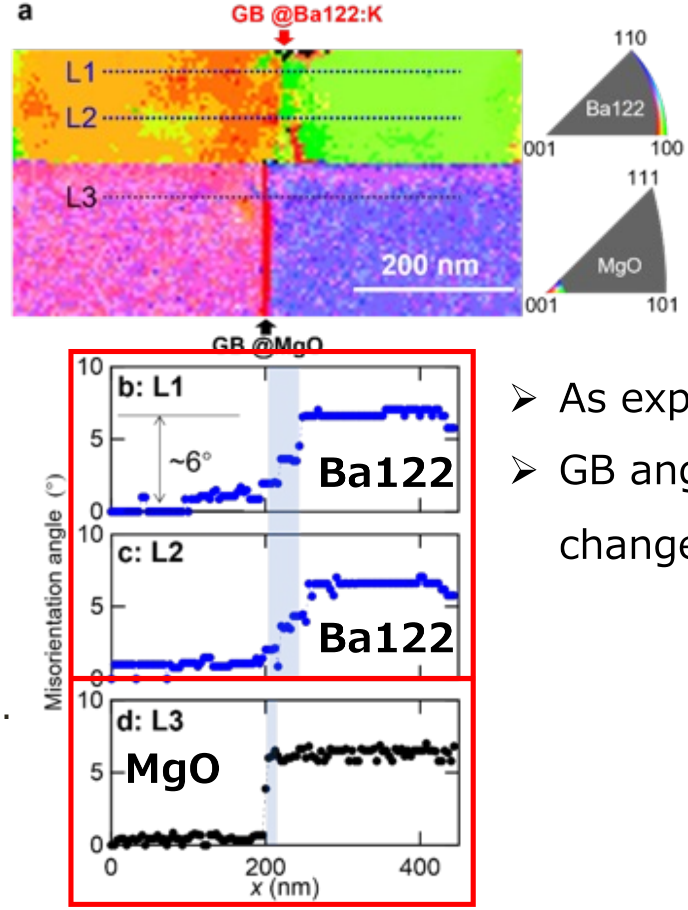
Excellent GB properties in (Ba,K)122

Unchanged θ_c for (Ba,K)122 even in field



T. Hatano, K. I. *et al*., *NPG Asia Mater.* **16** 41 (2024).

SPED (scanning precision electron diffraction)

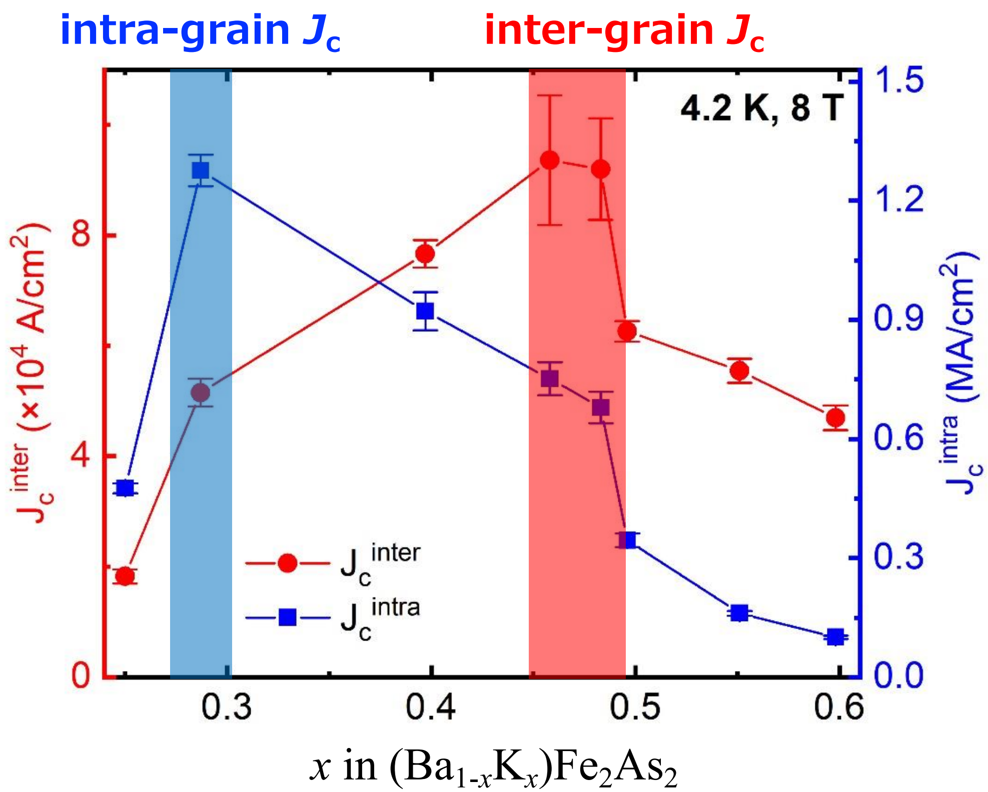


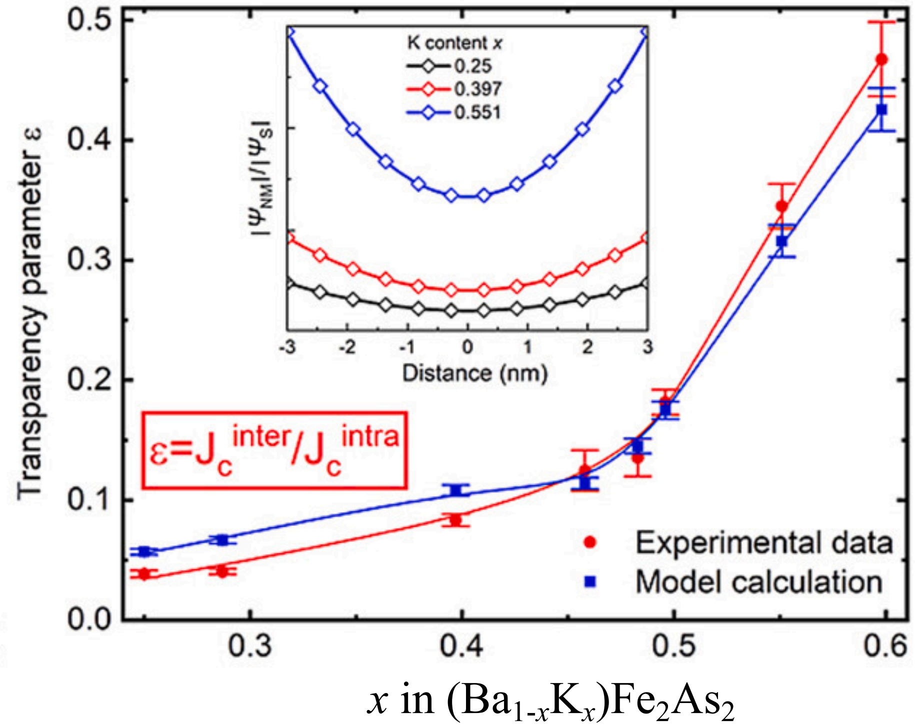
(Ba,K)122 having θ_{GB}=6º

- As expected, GB is sharp for MgO
- GB angles of K:Ba122 gradually change

IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 57, Oct 2024. Plenary presentation given at ASC 2024, Sept 2024, Salt Lake City, Utah, USA.

GB transparency is increased by over-doping (Ba,K)122





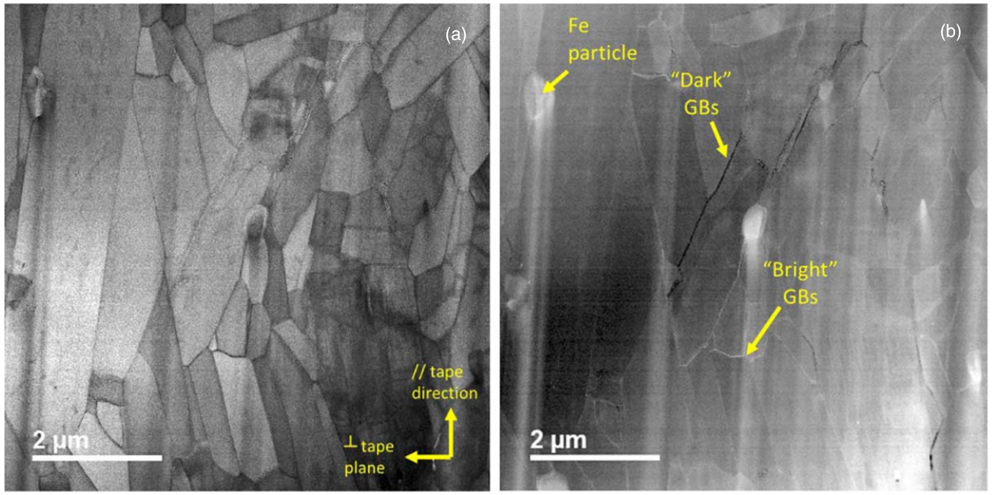
- Over-doped grains enhanced the proximity effect
- SNS JJ model described the data

Z. Cheng *et al*., *Mater. Today Phys*. **28** 100848 (2022).

IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 57, Oct 2024. Plenary presentation given at ASC 2024, Sept 2024, Salt Lake City, Utah, USA.

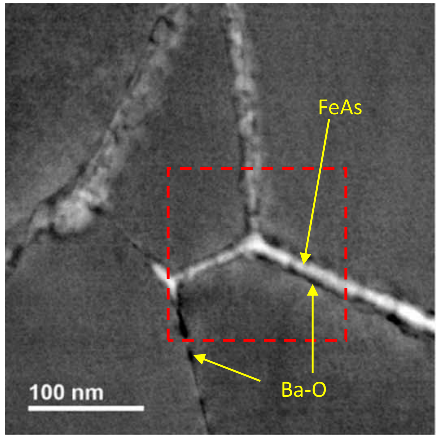
Detailed analyses on polycrystalline (Ba,K)122

Hot-pressed (Ba,K)122 tape



FeAs wetting phase and BaO

(Blocking the supercurrent flow)



- Grain alignment is important (GB connectivity)
- Clean GB is important (the number of GB connections)

Detailed in 4MOr2A-01
by F. Kametani (4/9)

F. Kametani *et al*., *Appl. Phys*. Express **17** 013004 (2024).

Overview

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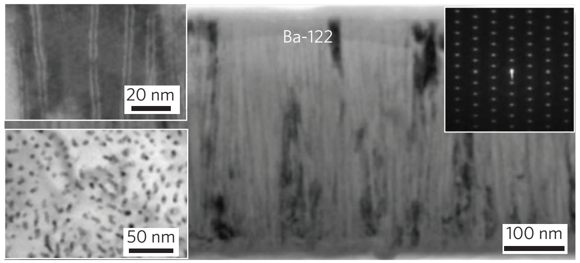
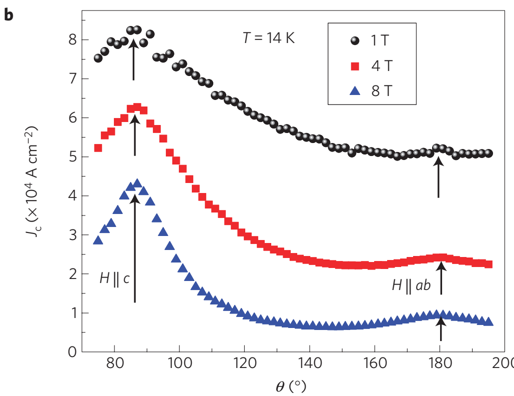
Natural defects in IBS thin films

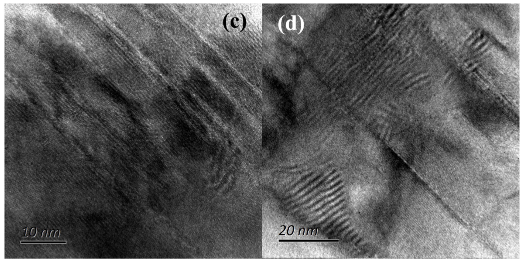
- **Co-doped Ba-122** on $SrTiO_3$ template
  Ba-Fe-O nano pillar (columnar defects)

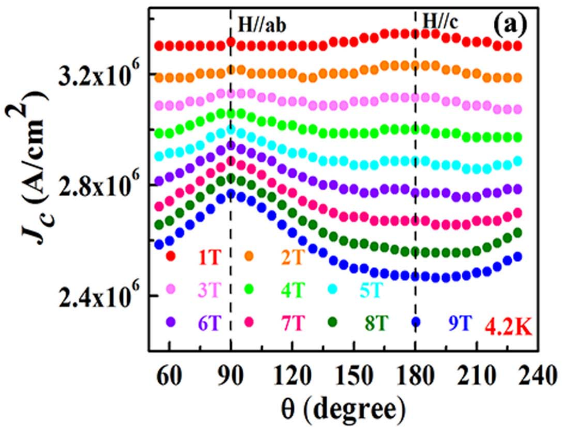




S. Lee *et al.*, *Nat. Mater.* **9** 397 (2010).

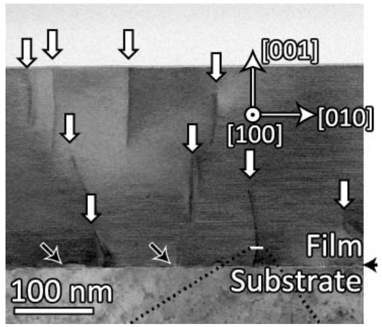
- **Co-doped Ba-122** on CaF_2
  Stacking faults

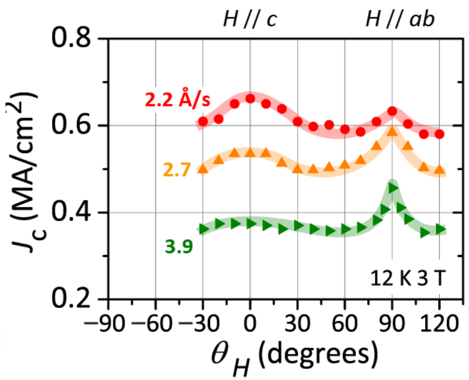




P. Yuan *et al.*, *SuST* **30** 025001 (2017).

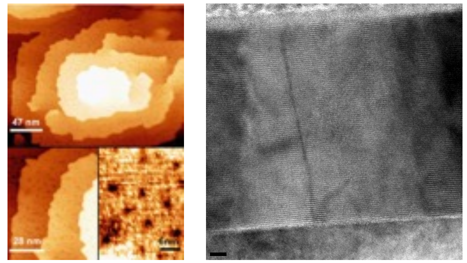
- **P-doped Ba-122** on MgO
  Dislocations

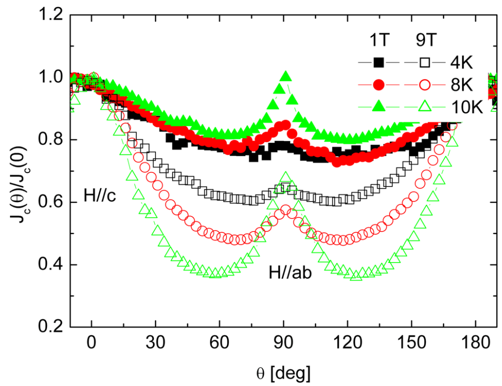




H. Sato *et al.*, *APL* **104** 182603 (2014).

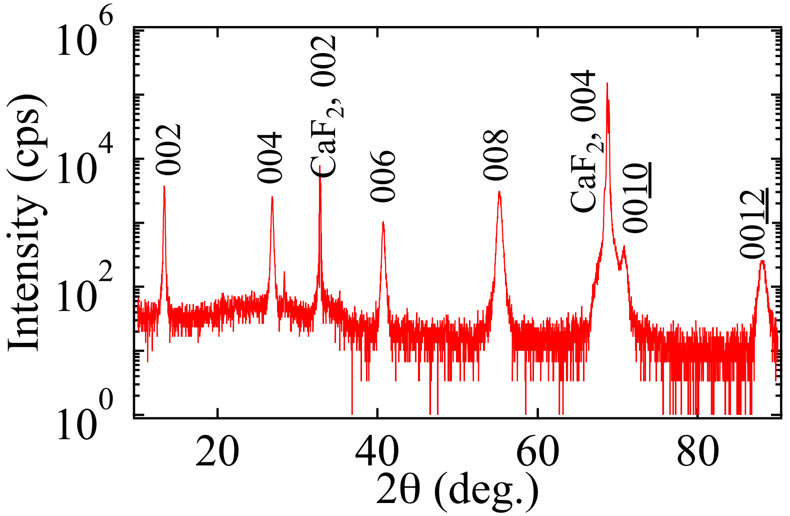
- **Fe(Se,Te)** on $SrTiO_3$
  Threading dislocations

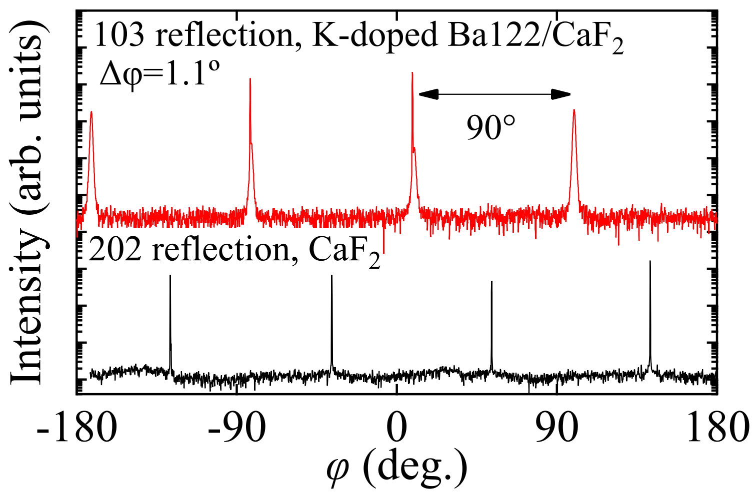


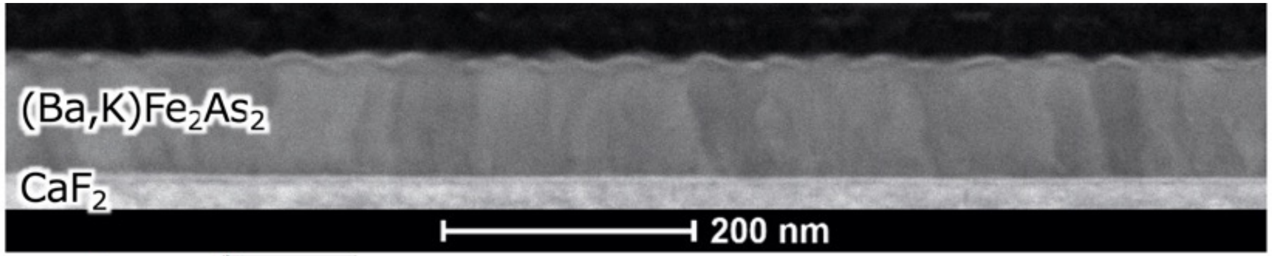


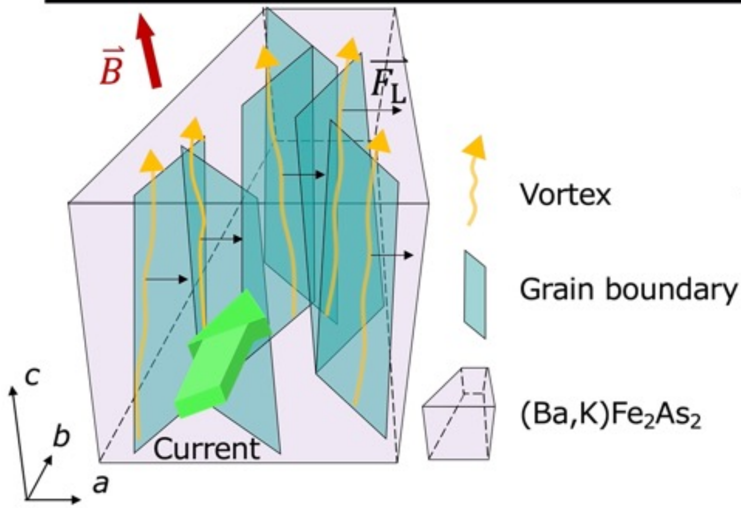
E. Bellingeri *et al.*, *APL* **100** 082601 (2012).

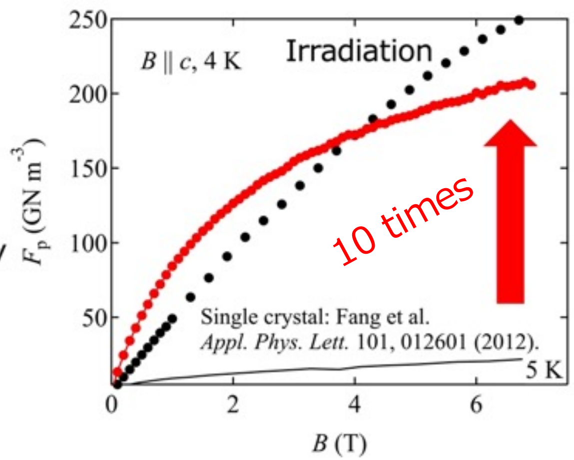
Natural defects in IBS thin films











Fluoride sub. & **low growth temperature** (~400°C) **are the key to epitaxial growth**

D. Qin, KI *et al*., *Phys. Rev. Materials* **5** 014801 (2021).

K. Iida *et al*., *NPG Asia Materials* **13** 68 (2021).

APC in IBS thin films

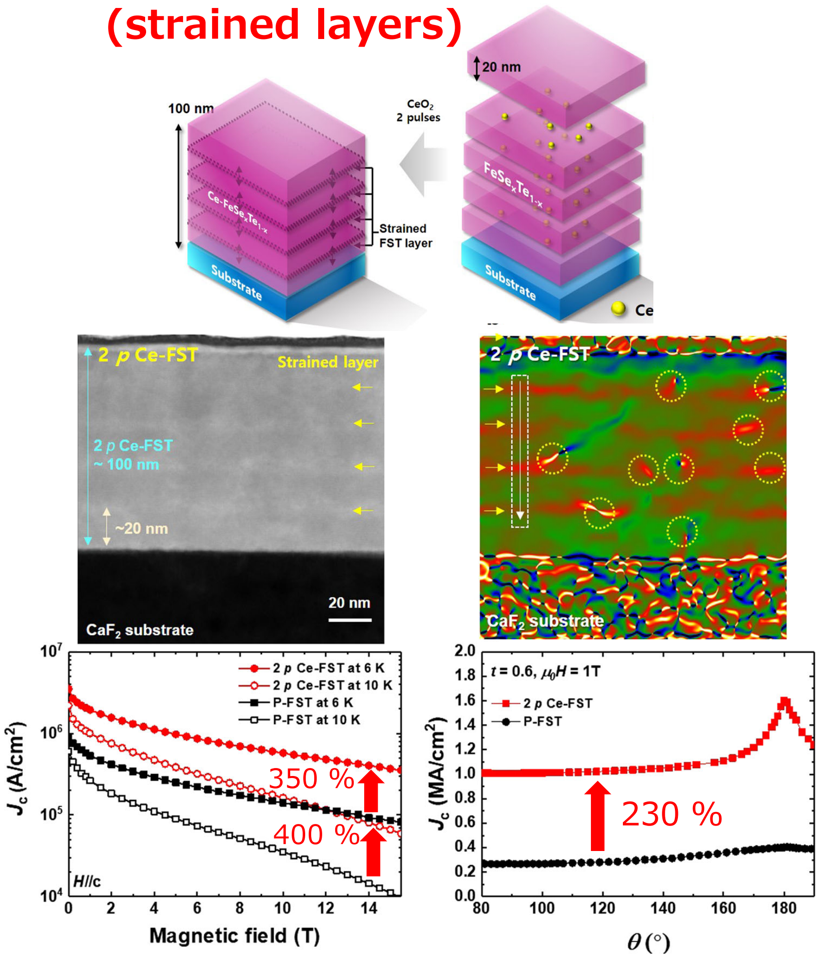
Materials	Methods	Microstructure	T_c (K)	Refs.
Co-doped Ba122	Multilayer or Quasi-multilayer	Ba122 or $SrTiO_3$ insertion	25.4 -> 26.0	[1], [2]
Fe(Se,Te)		CeO_2 insertion, strain	21.3 -> 20.4	[3]
Co-doped Ba122	$BaZrO_3$ addition to PLD targets	Nano $BaZrO_3$ rods	27.1 -> 24.6 (2 mol% BZO)	[4]
P-doped Ba122		Nano $BaZrO_3$ particles	26.3 -> 25 (3 mol% BZO)	[5]
Co-doped Ba122	$BaHfO_3$ addition to PLD targets	Nano $BaHfO_3$ particles	22.0 -> 19.5 (1 mol%BHO)	[6]
FeSe	$SrTiO_3$ addition to PLD targets	Nano $SrTiO_3$ rods	not shown	[7]
Fe(Se,Te)	Proton irradiation	Splayed cascade defects	18 -> 18.5 (1×10^{15} cm^{-2})	[8]
NdFeAs(O,F)	α −particle irradiation	No microstructure	49 -> 46 (5×10^{15} cm^{-2})	[9]
(Li,Fe)OHFeSe	TM (Mn) doping	No microstructure	42 -> 37	[10]

- ✓ Unlike cuprates, IBSs are robust against irradiation (disorder)
- ✓ For Ba-122, T_c decreases with -1 K/mol% (cf. -0.2~-0.1 K/mol% for REBCO)

[1] S. Lee *et al.*, *Nat. Mater*. **12** 392 (2013).
[2] C. Tarantini *et al.*, *Sci. Rep.* **4** 7305 (2014).
[3] S. Seo *et al.*, *NPG Asia Materials* **12** 7 (2020).
[4] J. Lee *et al.*, *SuST* **30** 085006 (2017).
[5] M. Miura *et al.*, *Nat. Commun*. **4** 2499 (2013).
[6] S. Meyer *et al.*, *J. Phys.: Conf. Ser*. **1559** 012052 (2020).
[7] T. Horide *et al.*, *Thi. Sol. Films* **733** 138802 (2021).
[8] T. Ozaki *et al.*, *Nat. Commun*. **7** 13036 (2016).
[9] C. Tarantini *et al.*, *SuST* **31** 034002 (2018).
[10] D. Li et al., *Sust* **32** 12LT01 (2019).

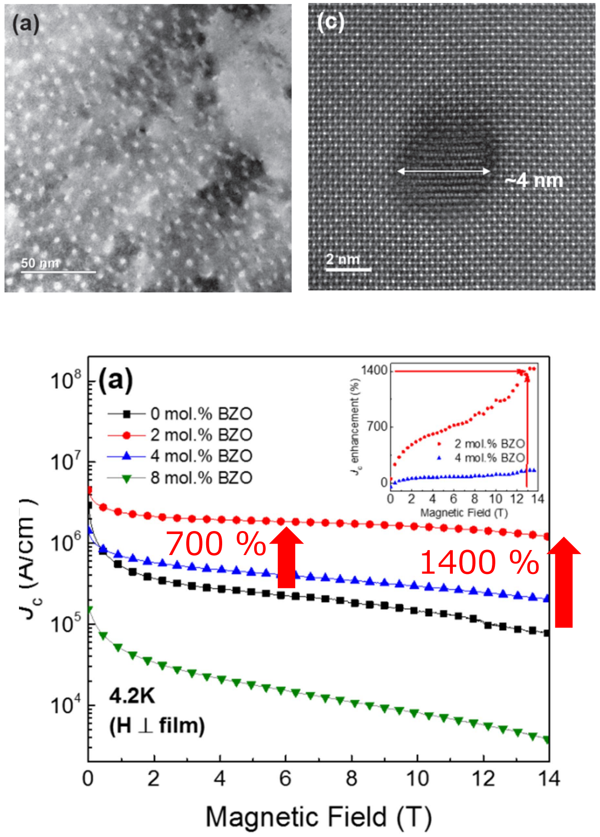
APC in IBS thin films

Quasi-multilayer
(strained layers)



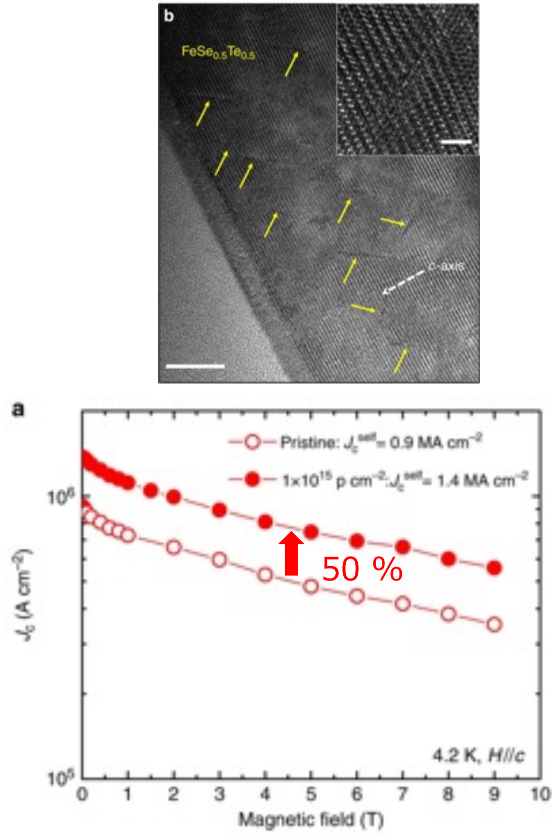
S. Seo *et al.*, NPG *Asia Materials* **12** 7 (2020).

Target modifications
(BZO nano cylinders)



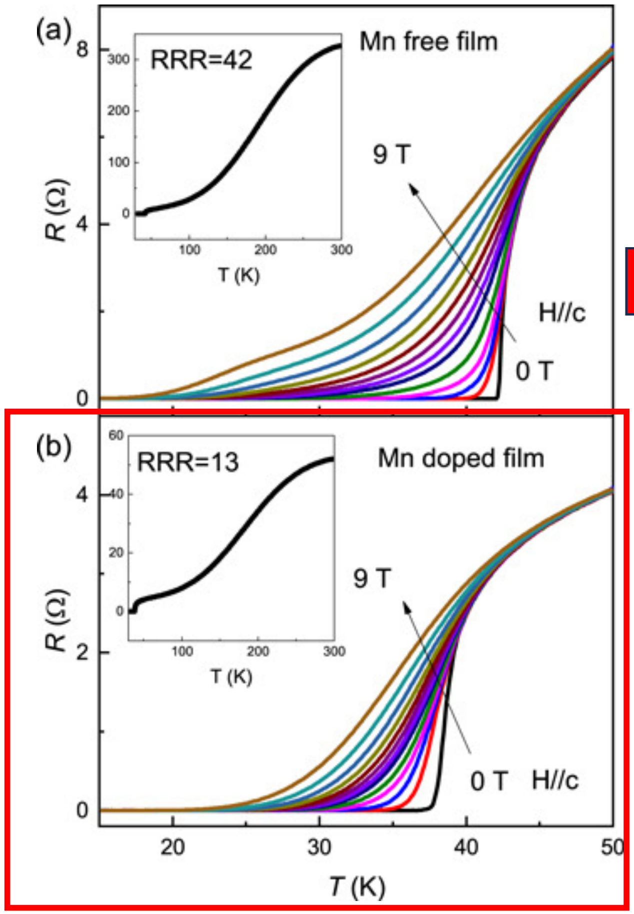
J. Lee *et al.*, *SuST* **30** 085006 (2017).

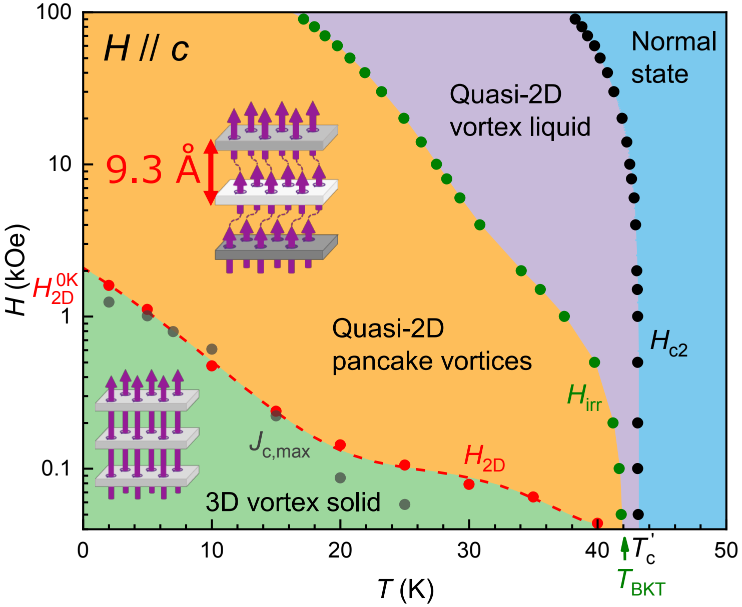
Proton irradiation
(splayed cascade defects)

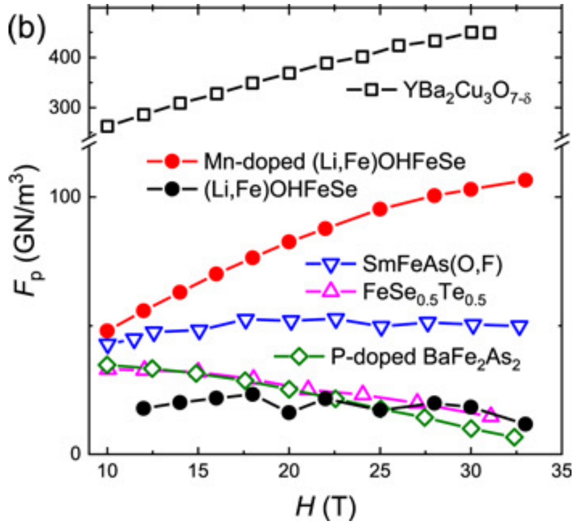


T. Ozaki *et al.*, *Nat. Commun*. **7** 13036 (2016).

Mn-doped (Li,Fe)OHFeSe (11111) thin films







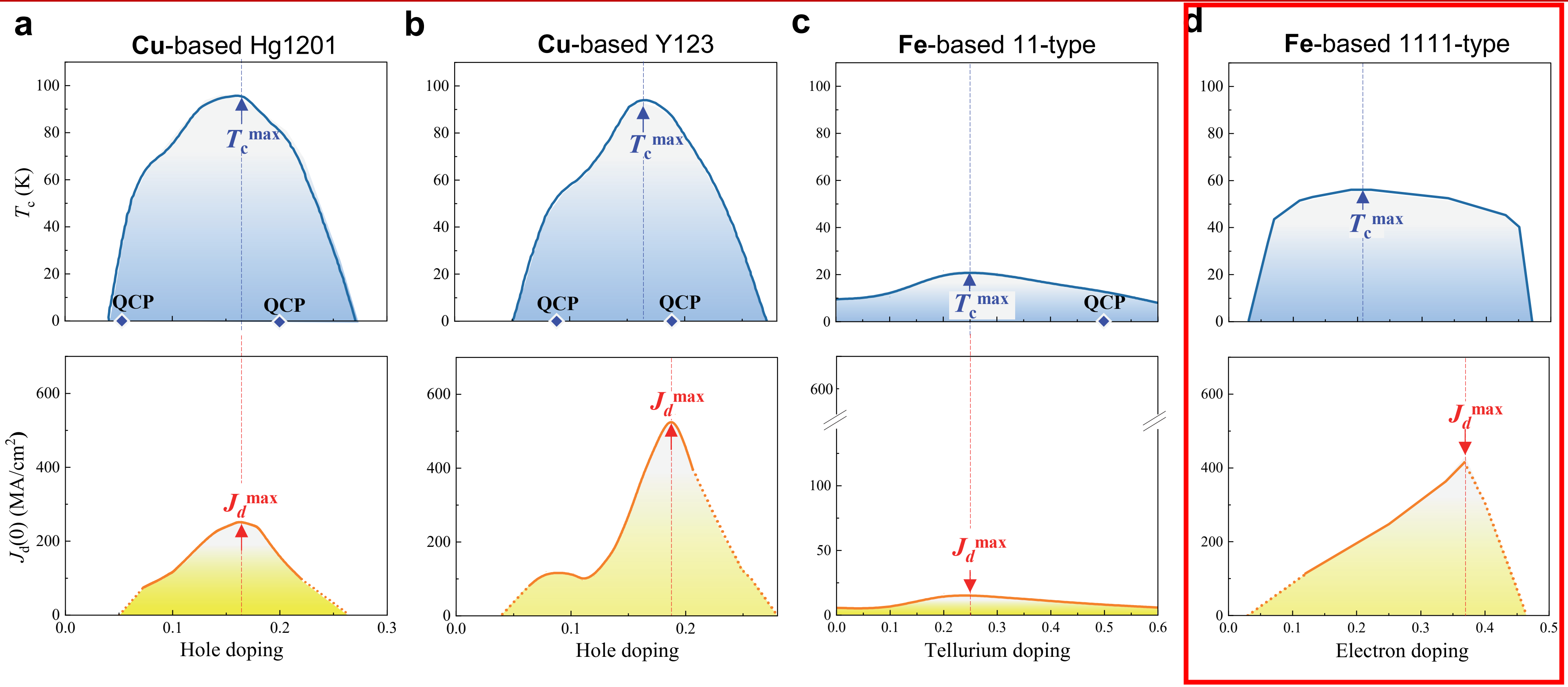
Li *et al*., *Supercond. Sci. Technol.* **32**, 12LT01 (2019).

Mn-doping
($Fe_{1-x}Mn_x$, x~0.1)

- Suppression of broadening
- Significant enhancement of F_p
- Decrease in T_c (42 K -> 37 K)
- Low RRR (42 -> 13)

IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 57, Oct 2024. Plenary presentation given at ASC 2024, Sept 2024, Salt Lake City, Utah, USA.

Thermodynamic approach + APC



The doping levels of $T_{c,\,max}$ is different from that of $J_{d,\,max}$

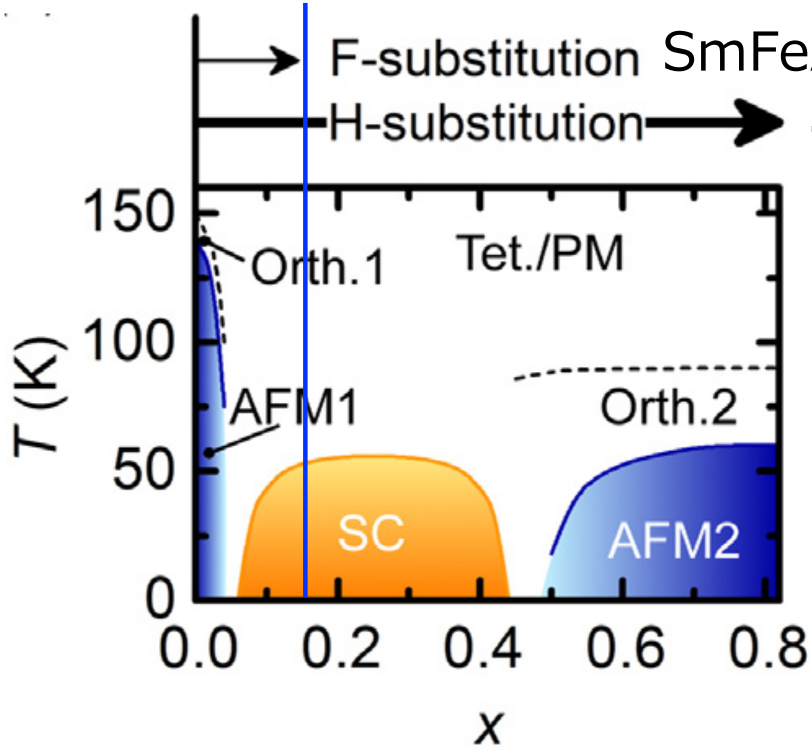
$$J_d(T) = \frac{\phi_0}{3\sqrt{3}\pi\mu_0\lambda^2(T)\xi(T)}$$

M. Miura, K. I. *et al.*, Nature Materials (2024).

Solubility limit in SmFeAsO

*Ln*FeAsO (*Ln*: lanthanoide)

$O^{2-} \rightarrow F^{-}$ or $H^{-} + e^{-}$ (electron doping)

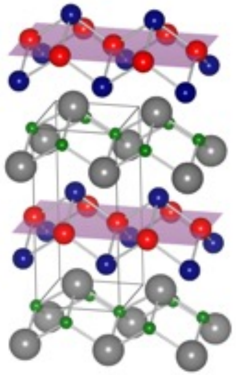


- Substitution level is limited **up to ~0.2** (For $SmFeAsO_{1-x}F_x$)
- For H, the substitution level is increased **up to ~0.8**
- Heavily electron doping can be achieved

S. Iimura *et al*., *J. Asia Ceramic Societies* **5**, 357 (2017).

Thermodynamic approach + APC for SmFeAs(O,H)

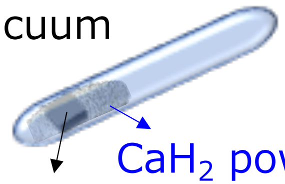
Topotactic reaction



LnFeAsO grown by PLD or MBE

H⁻ O^{2-}

vacuum

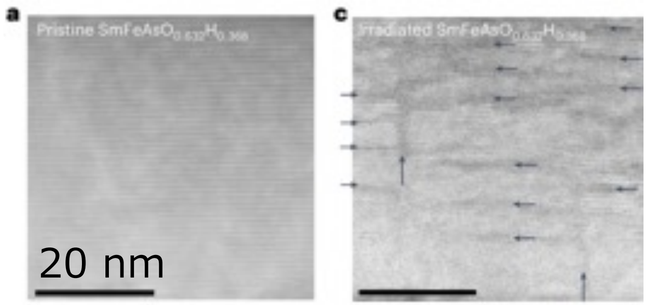


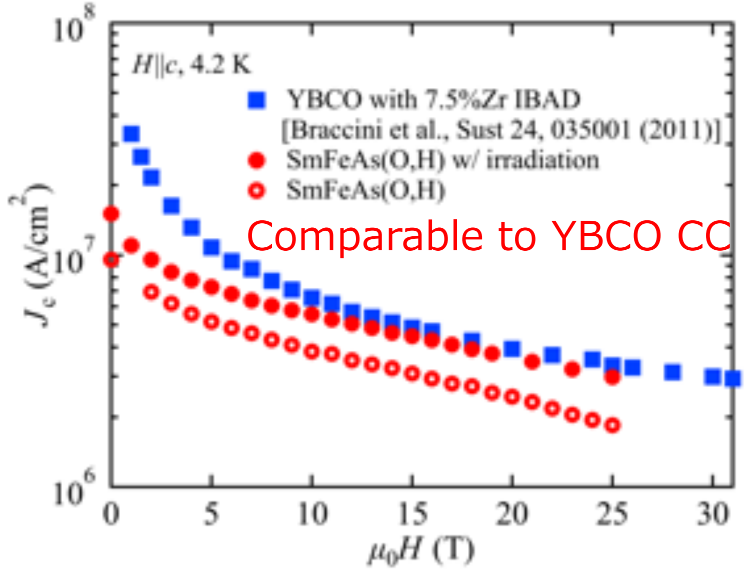
annealing

~450°C
up to 72 h

K. Kondo, K.I. *et al*., *SuST* ***33***, 09LT01 (2020).

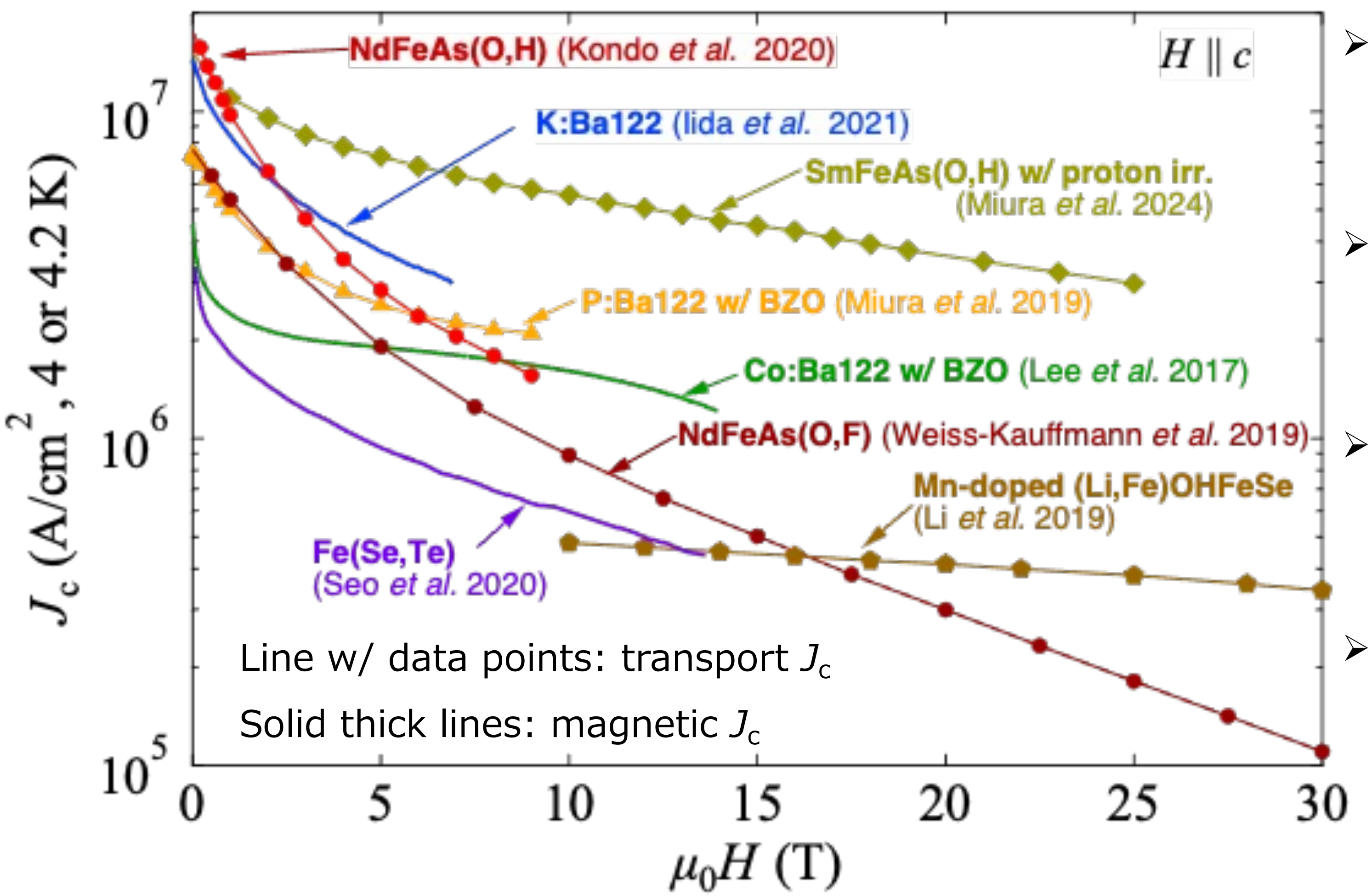
Pristine | Proton irradiation





M. Miura, K. I. *et al*., *Nature Materials* (2024).

Current status of the best-performing J_c-H (single xtal. sub.)



- Self-field J_c for all IBS exceed 3 MA/cm^2, even for Fe(Se,Te) with T_c=20 K
- The highest self-field J_c of over 17 MA/cm^2 was achieved with NdFeAs(O,H)
- In-field J_c was remarkably improved in SmFeAs(O,H) w/ proton irradiation
- Constant J_c of 0.4 MA/cm^2 up to 30 T for Mn-doped (Li,Fe)OHFeSe

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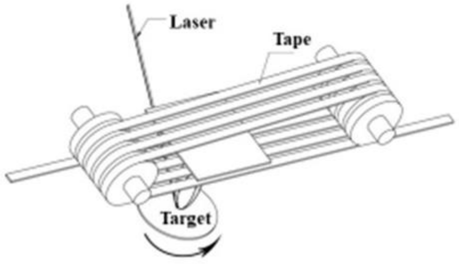
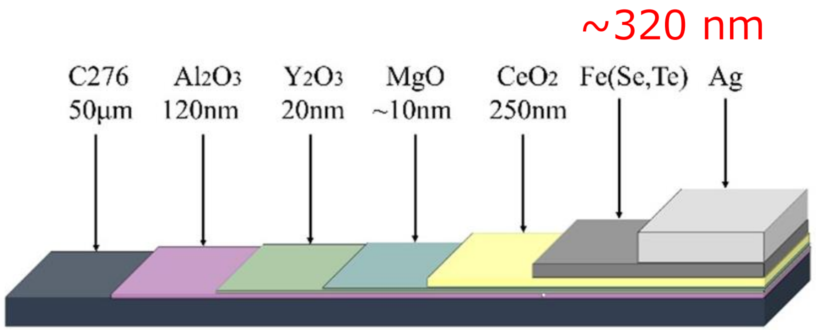
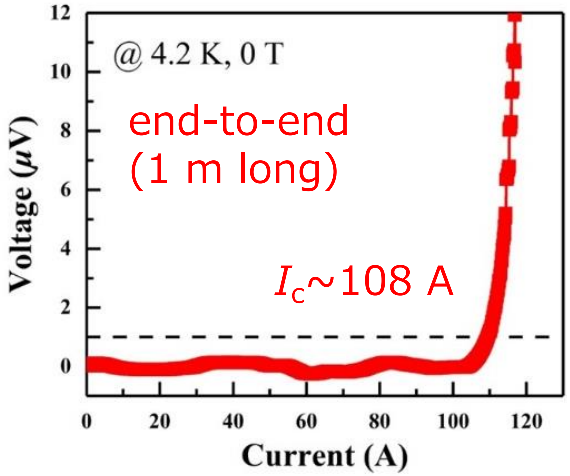
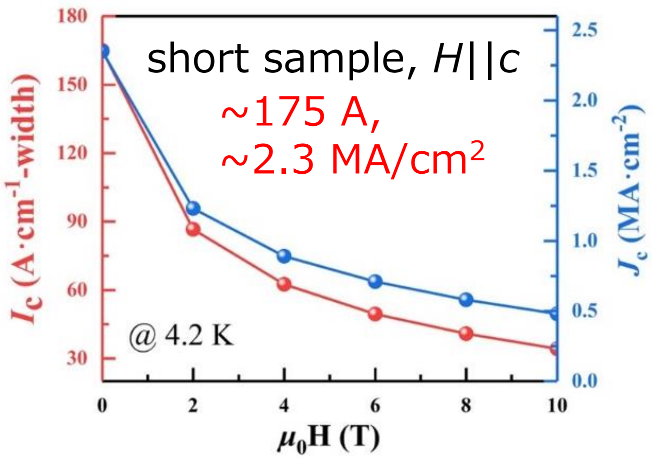
Fe(Se,Te) tapes

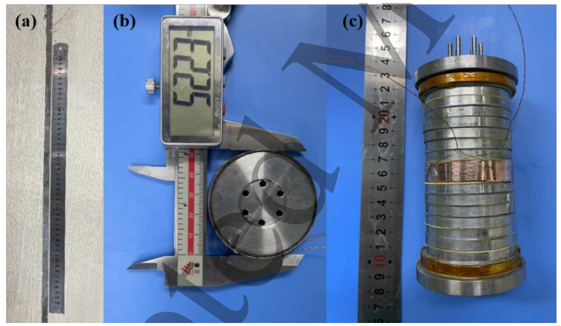
1 m long Fe(Se,Te) coated conductor











- multi turn PLD system, operating at f=20-60 Hz
- $FeSe_{0.4}Te_{0.6}$ target, $\phi = 60$ mm, $t = 8$ mm
- Self-field I_c~108 A @ 4.2 K (1 m tape, T_c=17.5 K)
- Short sample: Self field I_c~175 A corresponding to J_c~2.3 MA/cm^2

L. Liu *et al*., *Adv. Eng. Mater*. **25** 2201536 (2023).

S. Wei *et al*., *Sust* **36** 04LT01 (2023).

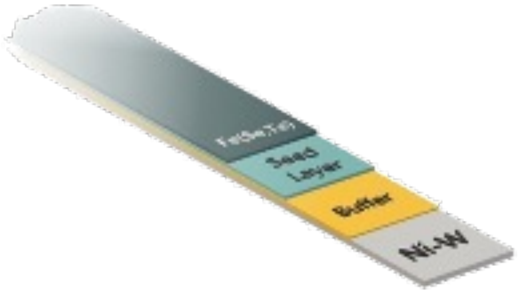
Detailed in 2MOr2A-06,-07 by H. Liu & Y. Li

Fe(Se,Te) tapes

Realising a cheap, Fe(Se,Te) Coated Conductor

courtesy by M. Putti & V. Braccini

- **Thick films** of Fe(Se,Te) by e-depo



Reported by L. Piperno

(1MOrB-02, 2/9)

- **Irradiation effects** on Fe(Se,Te) films

Reported by M. Iebole & F. Rizzo

(1MOr1B-03, -04, 2/9)

- **Pinning mechanism**

Microwave vortex motion in FeSe

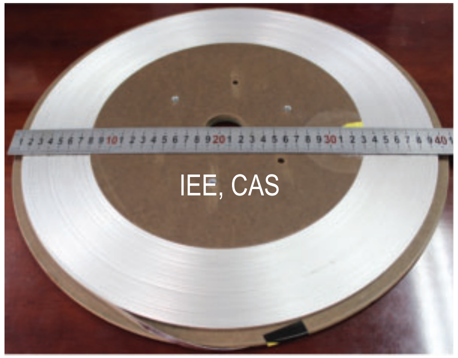
Reported by N. Pompeo

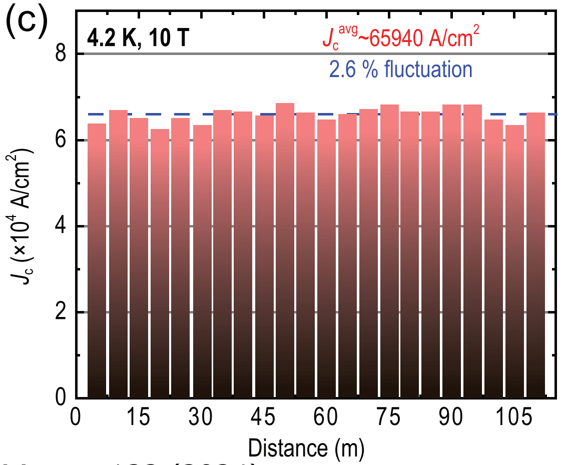
(1MOr1B-05, 2/9)

IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 57, Oct 2024. Plenary presentation given at ASC 2024, Sept 2024, Salt Lake City, Utah, USA.

(Ba,K)122 wires and magnets

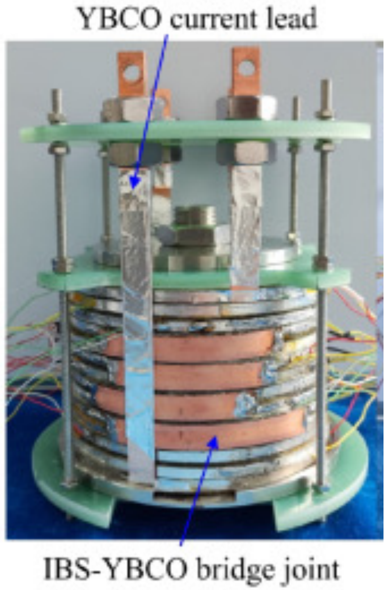
100 m-long, 7-core Ba122 tapes



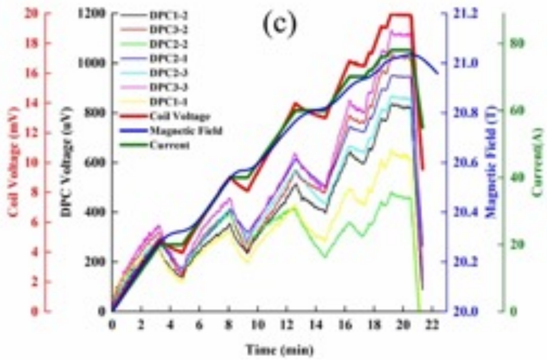


C. Dong *et al.*, *National Science Rev.* ***11*** nwae122 (2024).

(Ba,K)122 high field insert coil



Measured field: 21.03 T
Background field: 20 T



H. Ding *et al.*, *Sust* **36** 11LT0101 (2023).

Double Pancake Coils

7 DPCs

- DPC 1-1 Ic ≥100A
- DPC 3-3 Ic ≥ 85A
- DPC 2-3 Ic ≥ 90A
- DPC 2-1 Ic ≥ 100A
- DPC 2-2 Ic ≥ 90A
- DPC 3-2 Ic ≥ 85A
- DPC 1-2 Ic ≥ 100A

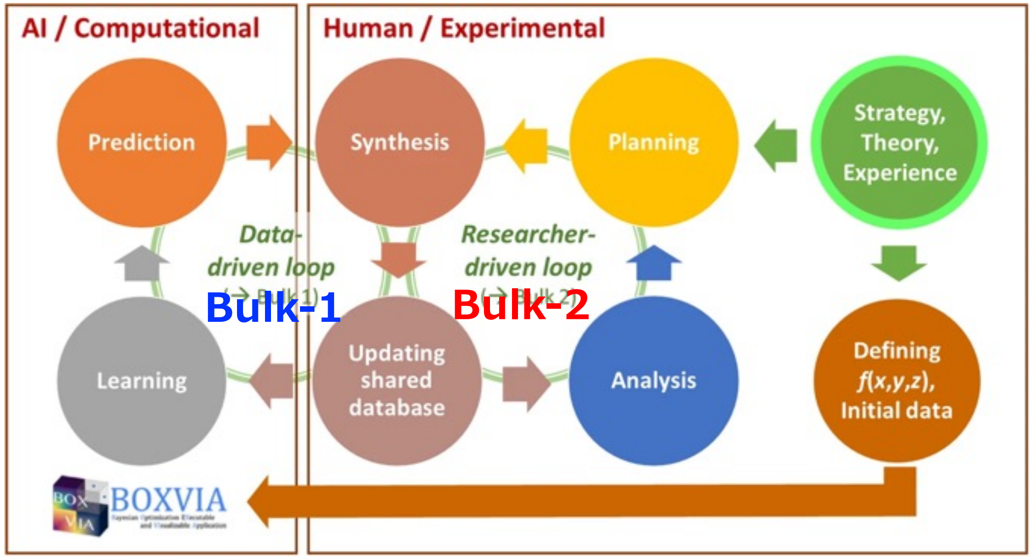
Courtesy by Prof. Dr. Yanwei Ma

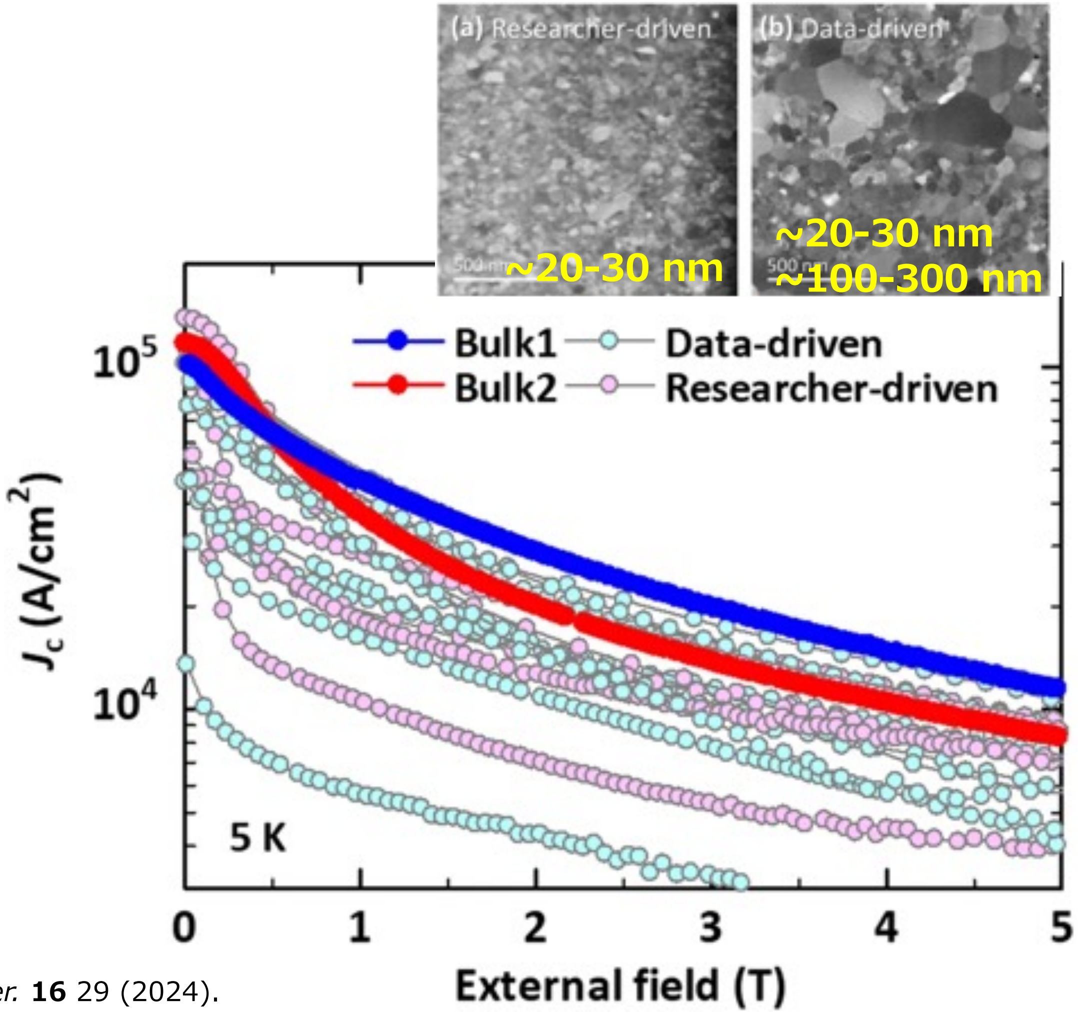
World first Tesla class coil using IBSs

Detailed in 5MOr1B-04 by C. Dong

(Ba,K)122 bulks fabricated by data- & researcher driven process design

Conceptual schematic of the complementary data- and researcher-driven process designs



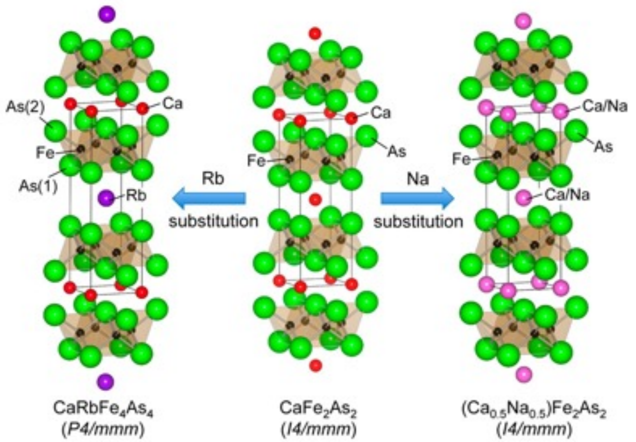


Detailed in 2MOr2A-01 by A. Yamamoto

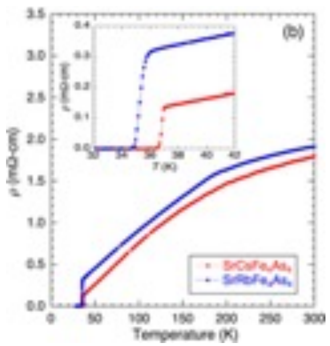
A. Yamamoto *et al.*, *NPG Asia Mater.* **16** 29 (2024).

$CaKFe_4As_4$ (1144) bulk samples

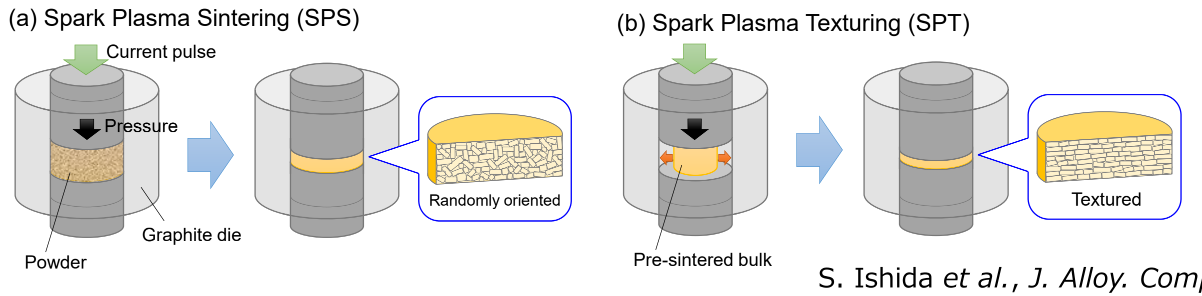
Hybrid phase between $AeFe_2As_2$ (Ae = Ca, Sr) and AFe_2As_2 (A=K, Rb, Cs)



T_c~36 K **w/o doping**

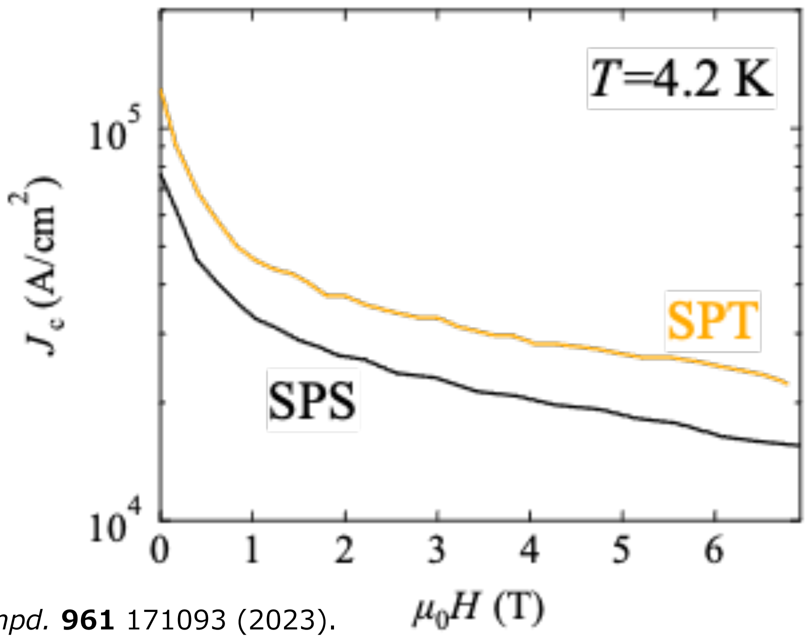


A. Iyo *et al.*, *J. Am. Chem. Soc.* **138** 3410 (2016).

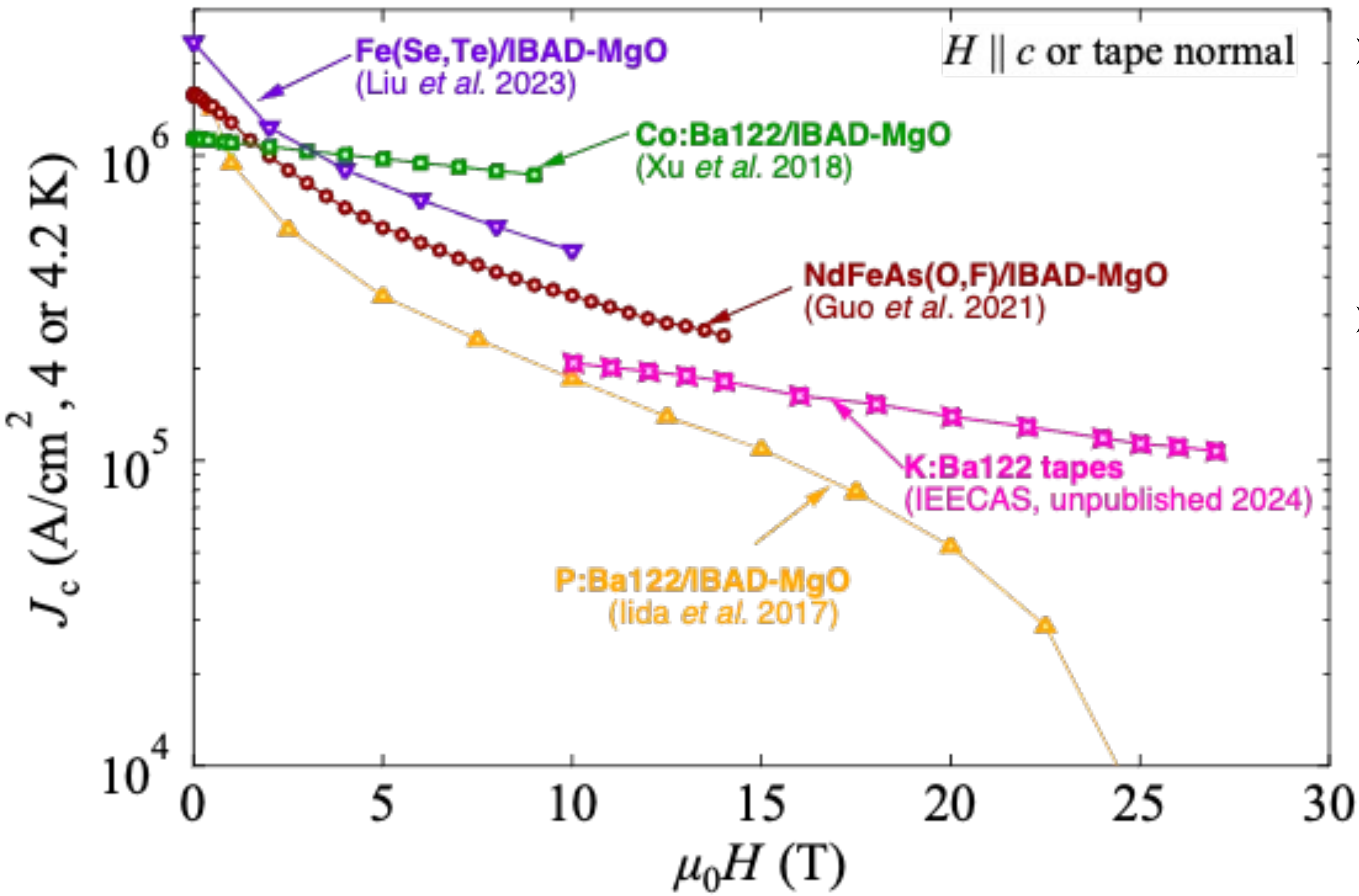


S. Ishida *et al.*, *J. Alloy. Compd.* **961** 171093 (2023).

- The *c*-axis textured 1144 was realized
- A self-field J_c of reached 12 kA/cm^2, which is comparable to that of K:Ba122 bulks

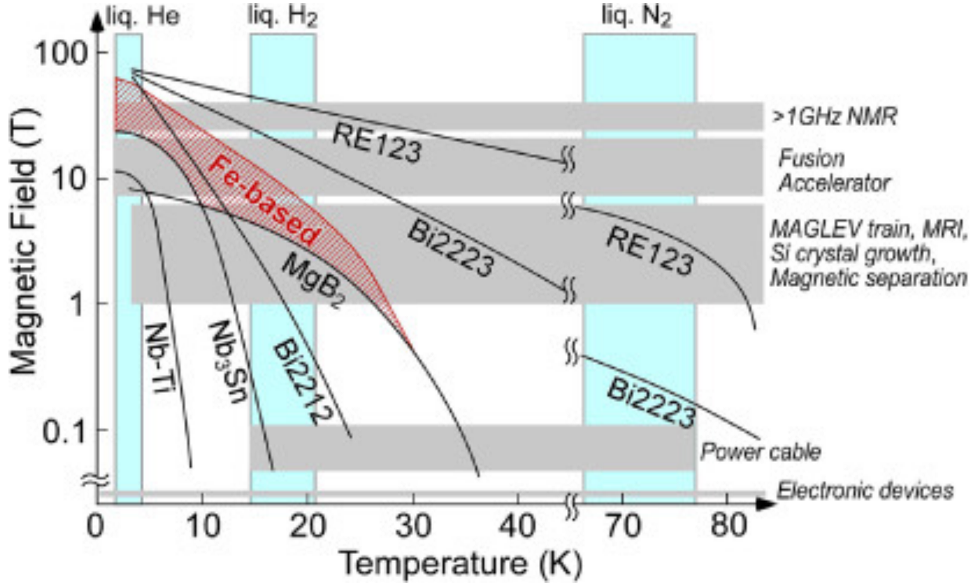


Current status of J_c-H plots for IBSs tapes (short samples)



- Fe(Se,Te)/IBAD-MgO showed the highest J_c in low field regime although T_c is the lowest
- In-field J_c of K-doped Ba122 tape was superior to that of the P-doped Ba122/IBAD-MgO

Perspective (still mature··· but)



J. Shimoyama *Sust* **27** 044002 (2014).

>20 T at 4.2 K   or >10 T at 20-30 K

IOP Publishing   Superconductor Science and Technology

Supercond. Sci. Technol. **32** (2019) 070501 (3pp)   https://doi.org/10.1088/1361-6668/ab1fc9

Viewpoint   J. Jaroszynski

CrossMark

Constructing high field magnets is a real tour de force

Moreover, the cost of IBS wire can be four to five times lower than that of Nb_3Sn, making it more expensive than NbTi, but with much higher critical parameters than Nb_3Sn. Attempts to make a superconducting wire started immediately, using either the powder-in-tube (PIT) [11–13] or coated conductor [14, 15] methods.

The cost of IBS wire can be four to five times lower than that of Nb_3Sn, making it more expensive than NbTi, but with much higher critical parameters than Nb_3Sn.

Summary

1. A review of the current status of IBSs has been conducted.
2. A review of various techniques for tuning T_c has been conducted.
3. High-angle grain boundaries (GBs) do block supercurrent flow, but not as severely as in the cuprates. This is a driving force for magnet applications using polycrystalline wires and bulk materials.
4. A strategy for improving the polycrystalline tapes and bulks of K-doped Ba122 has been proposed.
5. J_c-B performances have been improved significantly by APC and thermodynamic approach combined with APC (films).
6. Long length wires and tapes have been developed significantly.

Thank you for your attention!