The Research Program on Applied Superconductors in Geneva

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Archamps, 23.3.04

Outline

* Research Goals and Facilities in Geneva
* Bi,Pb(2223): Fundamental and Applied Research
* MgB_2: Wires Produced by the *Ex Situ* Technique
* Nb_3Sn: Multifilamentary Bronze Wires
* Conclusions

Research Goals and Facilities at GAP/DPMC

Mechanisms and Development of High Field Wires and Tapes

® **NMR, Laboratory Magnets, Accelerator Magnets**

Studies on Single Crystals: Bi,Pb(2223), MgB_2

Tape and Wire Preparation: Bi,Pb(2223), MgB_2, Nb_3Sn

Magnetization, Relaxation Effects

Strain Effects on J_c at Fields > 17 T (Walters Spiral)

Facilities at GAP in Geneva

Wire and tape preparation

* Hot Isostatic Extrusion machine: 250 ton, 47 mm dia.

* Deformation machines

Processing and analysis

* HIP machine: 2 kbar, up to 400 bar O_2 pressure, 20 l.

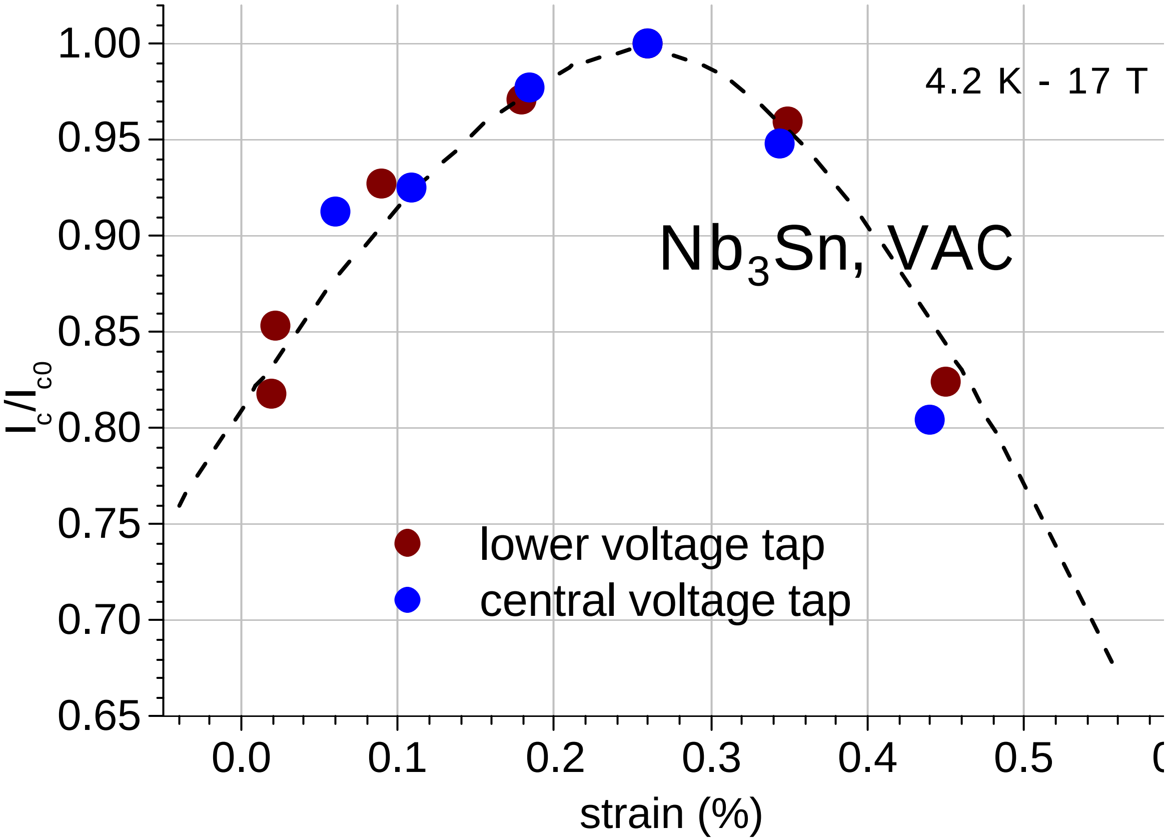
* DTA, up to 2 kbar

High field laboratory

Walters Spiral (WASP) for j_c (e) measurement

Strain rig at University Geneva:

- **1'000 A**
- **17 T (actually)**
- **21 T (June 04)**
- **800 mm length**



The Bi,Pb(2223) System

E. Giannini

X.D. Su

G. Witz

N. Clayton

N. Musolino

The system Bi,Pb(2223)

Phase Formation by Nucleation and Growth

(J.C. Grivel et al., 1995)

Proof for « transient liquid » by neutron diffraction

(E. Giannini et al., 1997)

Growth of Bi(2223) and Bi,Pb(2223) single crystals

(E. Giannini et al., 2003)

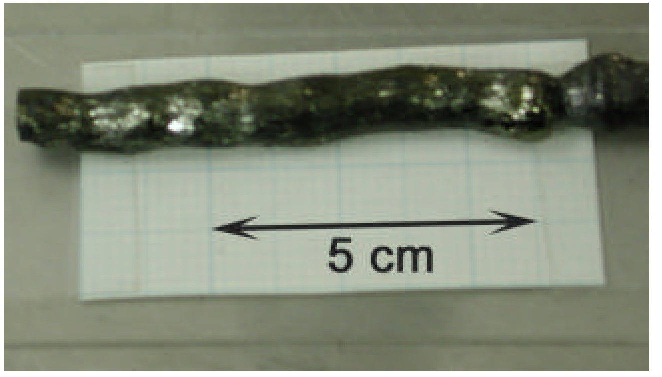
Relaxation Rate on Bi(2223) and Bi(2212)

(N. Clayton et al., 2004)

Travelling Solvent Floating Zone (TSFZ) in Image Furnace

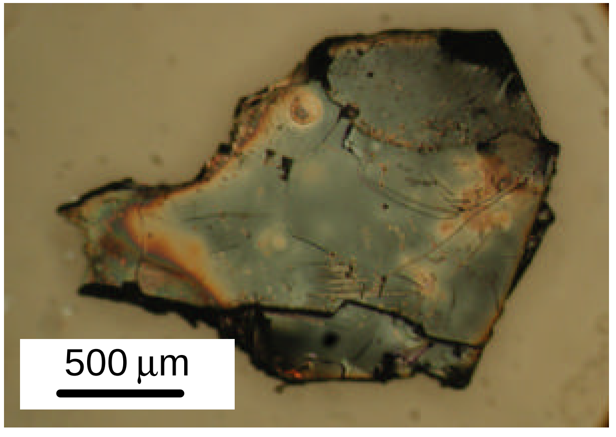
Bi(2223)

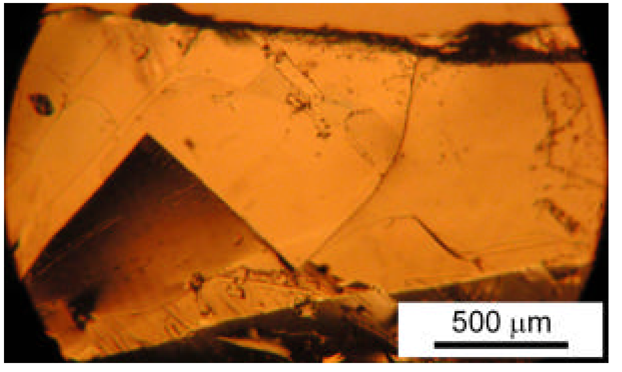
Single crystals

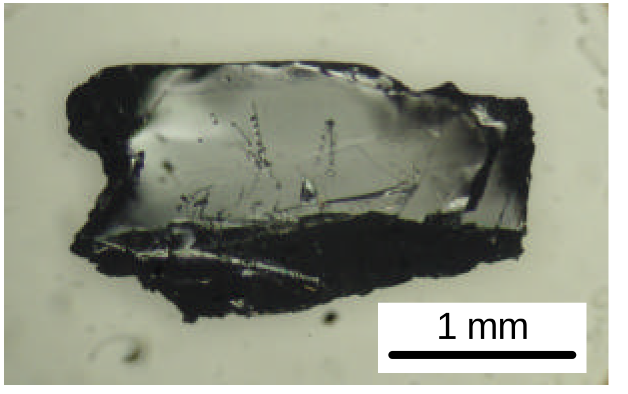


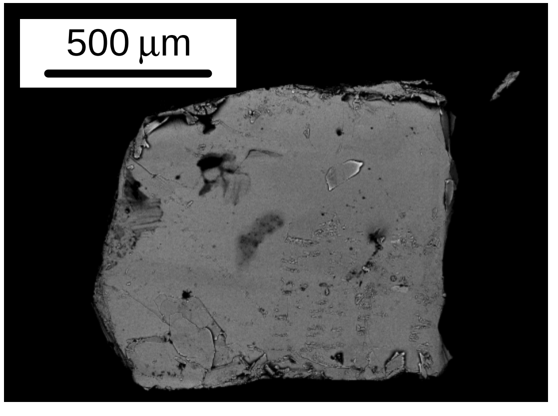
E. Giannini et al.

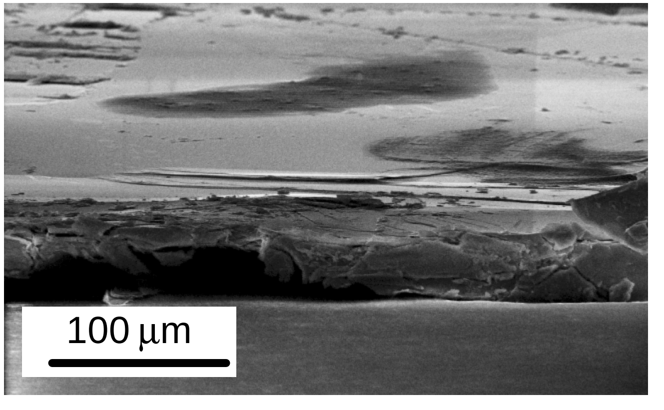
DPMC, Geneva



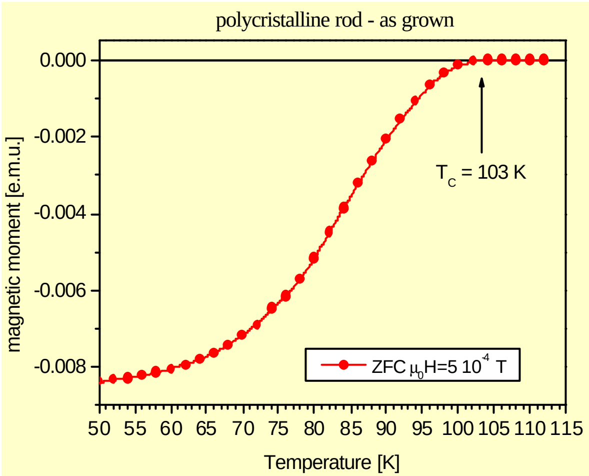


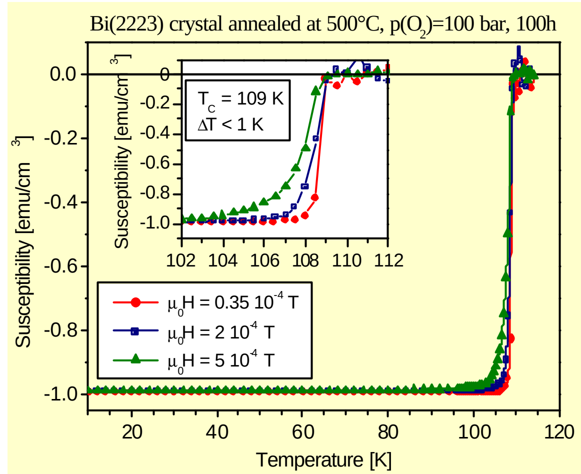


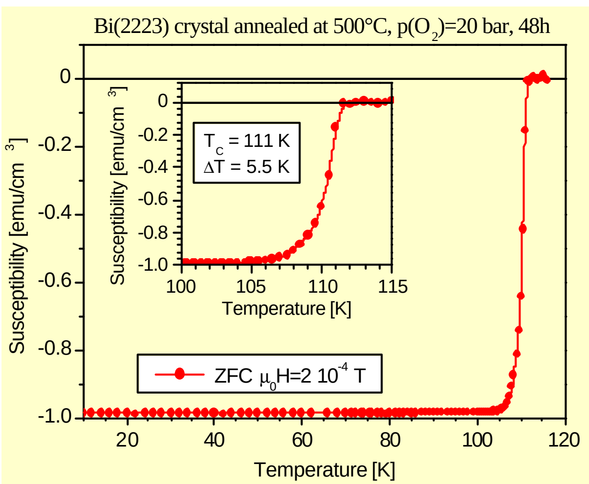


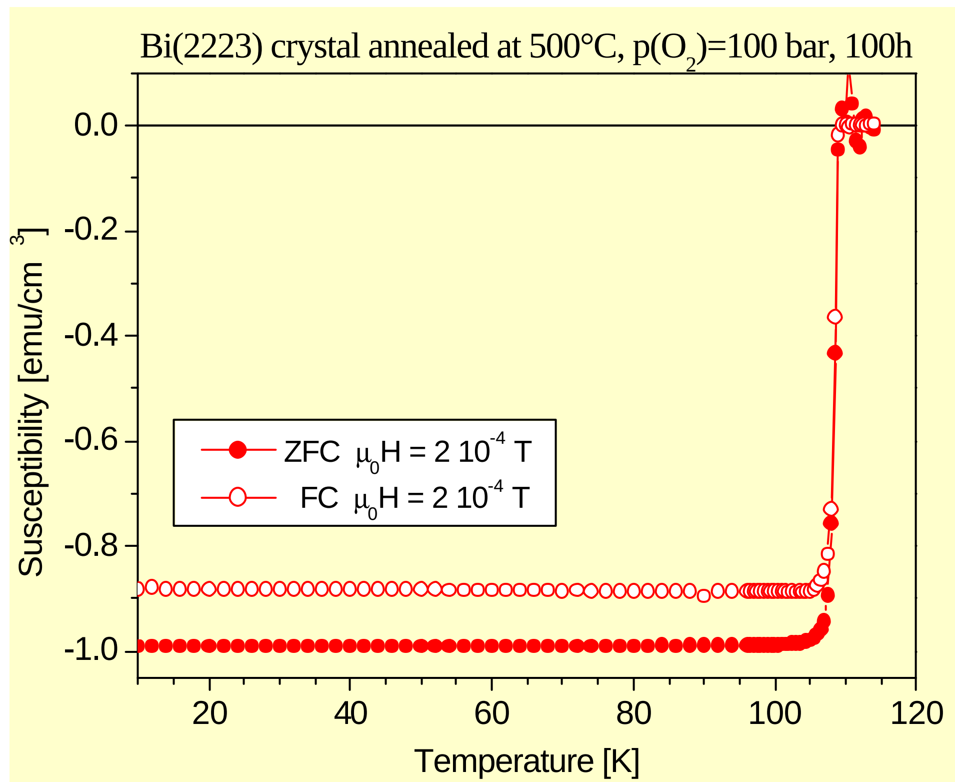


Magnetic characterisation





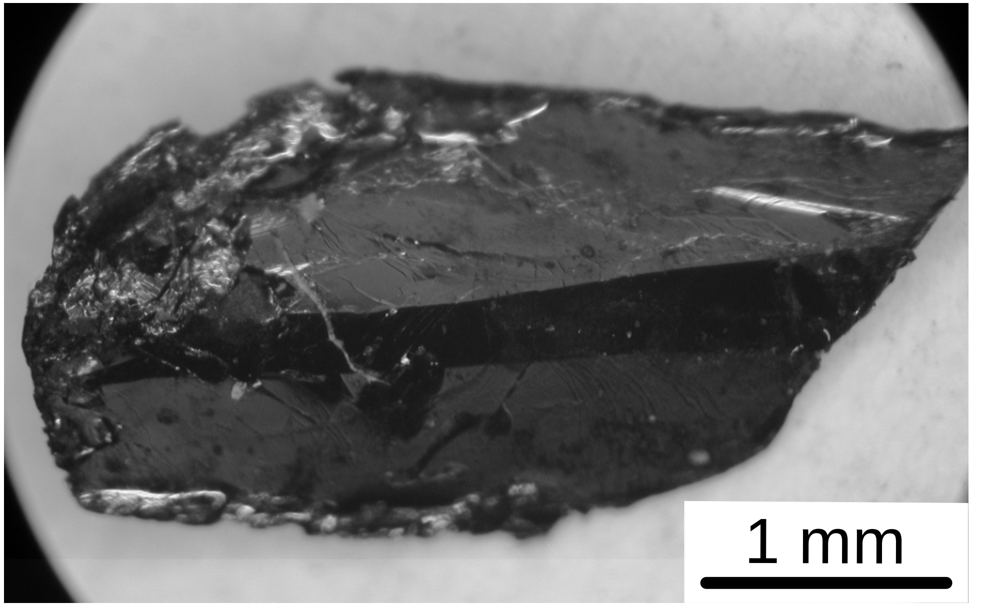


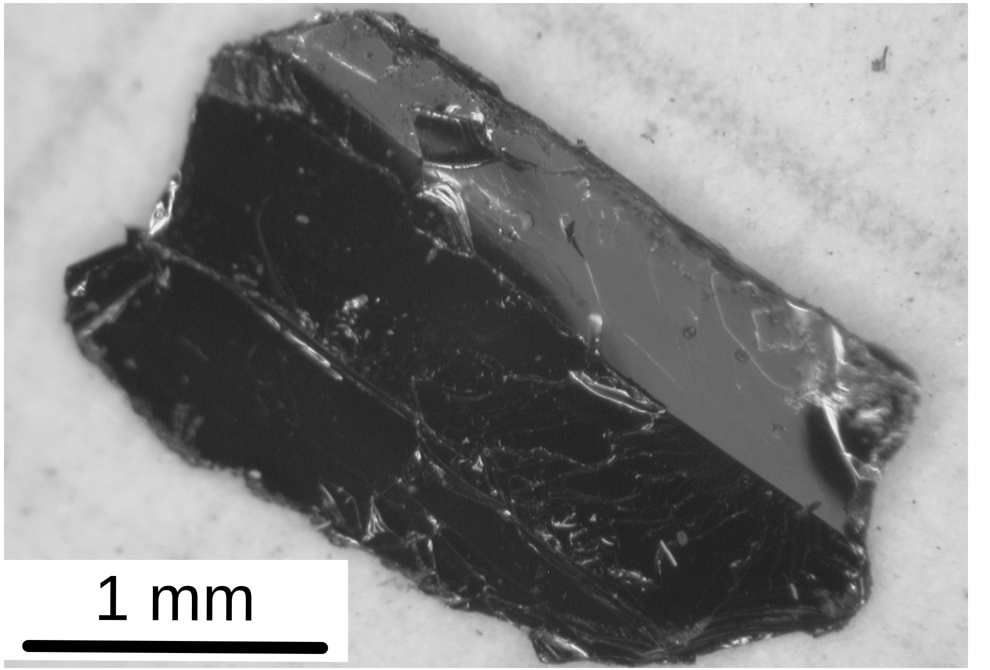


Bi,Pb(2223)

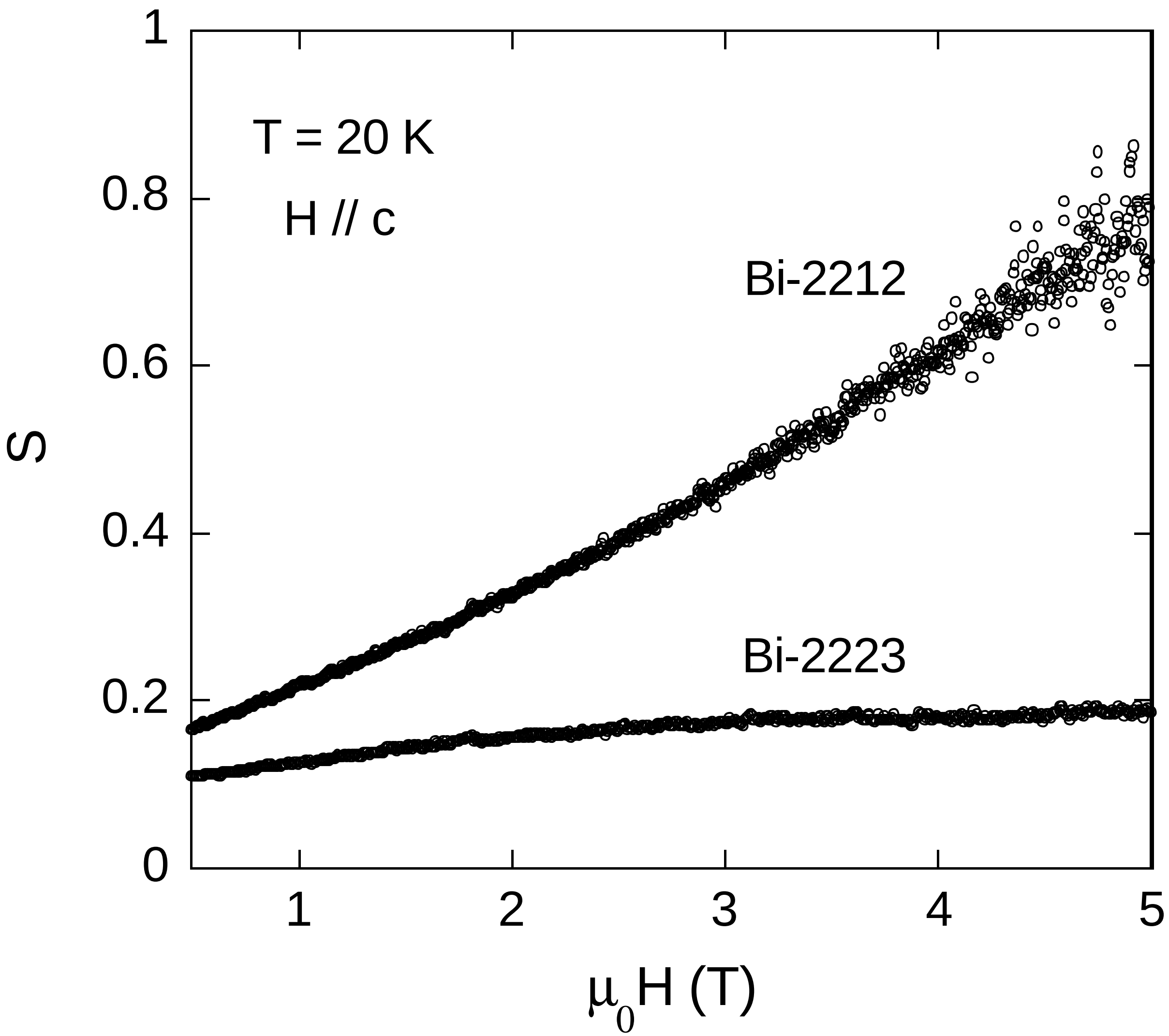
Single Crystals

E. Giannini et al., SuST Jan. 04





Relaxation Rate



N. Clayton, N. Musolino, E. Giannini, R.Flükiger., ICMC 2004, Wollongong

Bi,Pb(2223): Problems to be solved

Density, Homogeneity (microscale):

High pressure experiments (Hellstrom et al.)

Texture:

Texture in the *a,b* plane: not obtained so far.

This is the really limiting factor for Bi,Pb(2223) tapes

MgB_2 Tapes

« Ex Situ » Technique; Limitations

Paola Lezza

HongLi Suo

Roman Gladyshevskii

Archamps, 23.3.04

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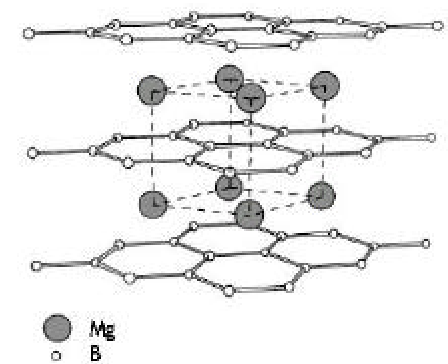
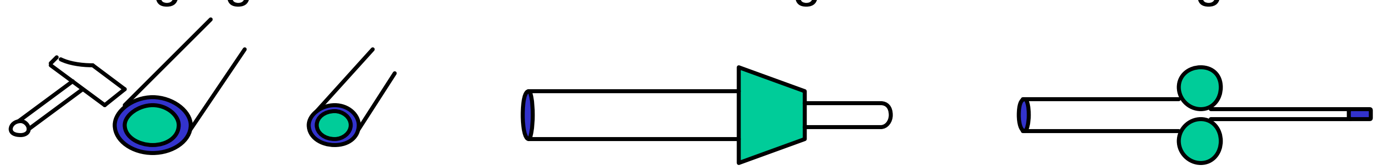
Sample preparation

- T_c = 40 K
- Ex-situ technique → pre-reacted powde
- Powder milling



- Deformation steps:

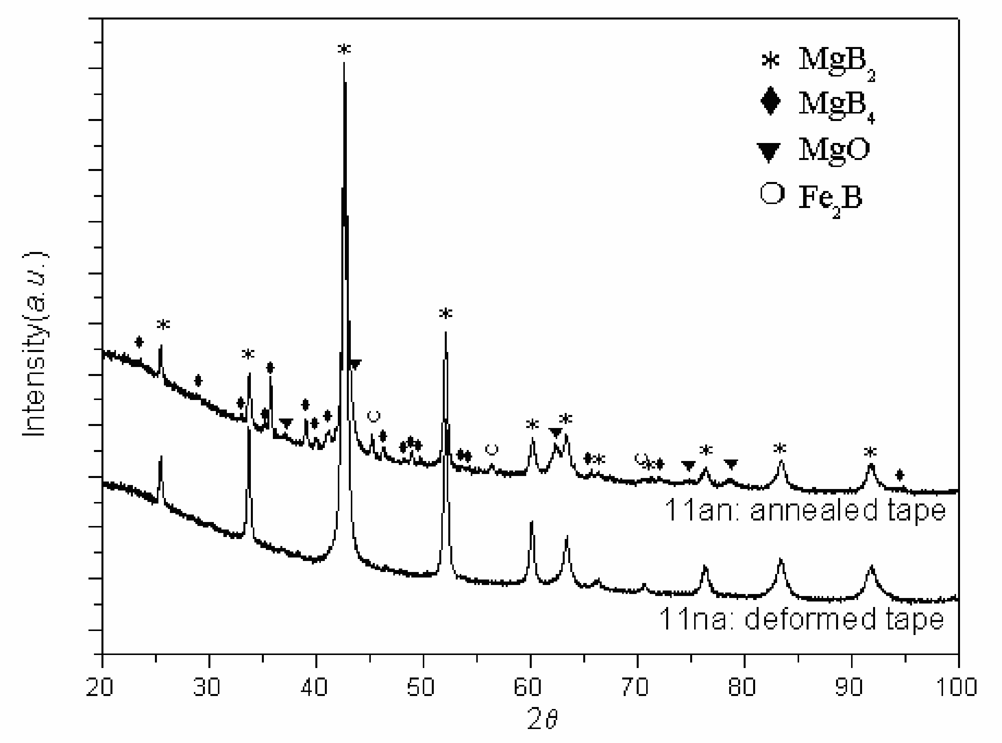
swaging | cold drawing | rolling



- Heat treatment at 920°C, 30 min

X-ray diffraction

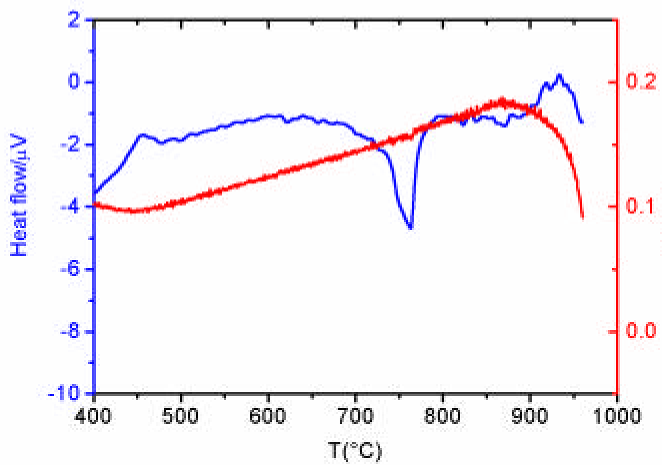
MgB_2/Fe tape after deformation and annealing



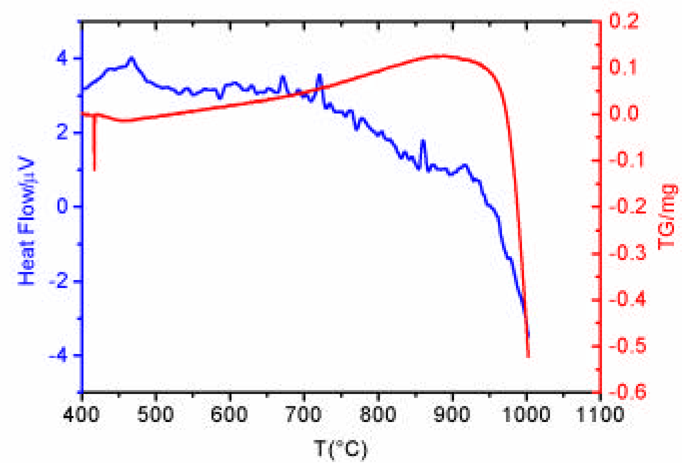
Phase/Space group	Site	Wyckoff Position	x	y	z
MgB_2 P6/*mmm*	Mg	1(a)	0	0	0
	B	2(d)	1/3	2/3	1/4

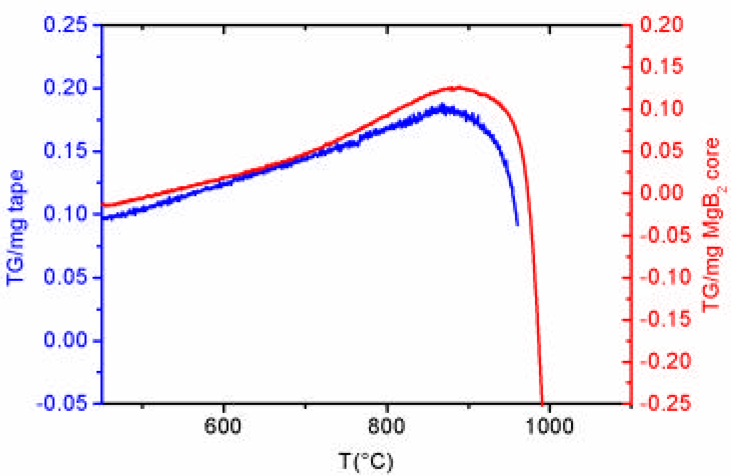
Differential thermal analysis

- MgB_2/Fe



- MgB_2 core





- Onset of evaporation changes, due to the presence of Fe (sheath)

Initial Powder Size

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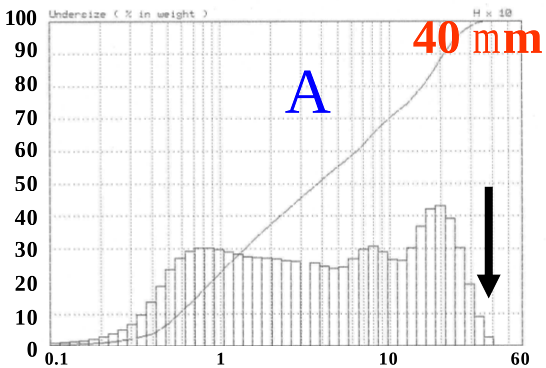
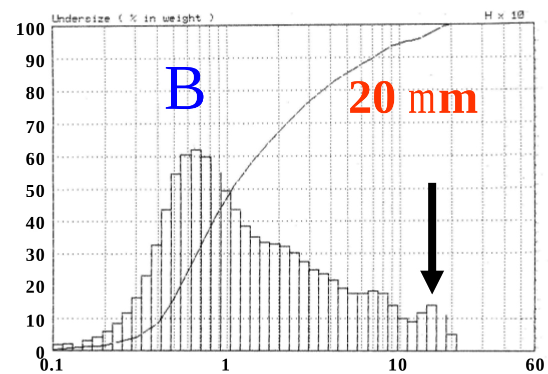
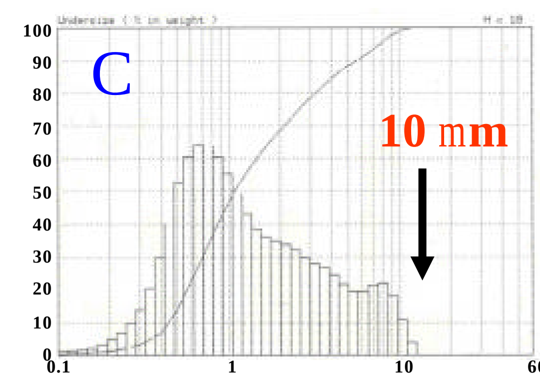




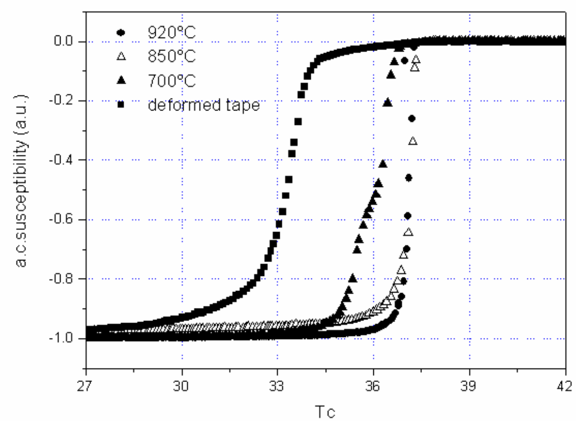


Impurities (wt.%)

Sample/ %	H	C	O
A	0.10	0.13	1.05
B	0.14	0.21	2.12
C	0.15	0.14	1.54

MgB_2/Fe wires

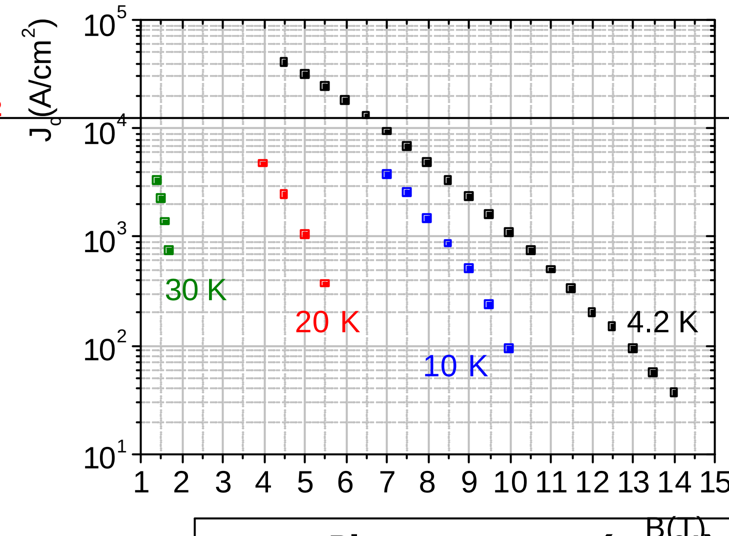
920°C/30 min., in vacuum

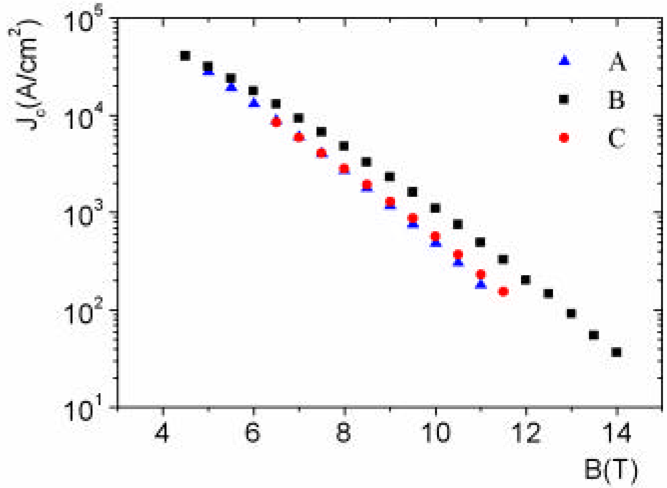


Present data

In Situ

10^4 A/cm²





Phase content (wt.%)

Sample/ PMS	MgB_2	MgB_4	MgO	Fe_2B
A/40 mm	**75.8(6)**	8.9(5)	12.7(3)	2.60(5)
B/20 mm	**73.5(5)**	8.4(4)	16.0(2)	2.10(4)
C/10mm	**75.1(4)**	10.8(3)	12.0(1)	1.10(3)

Domains and grain size

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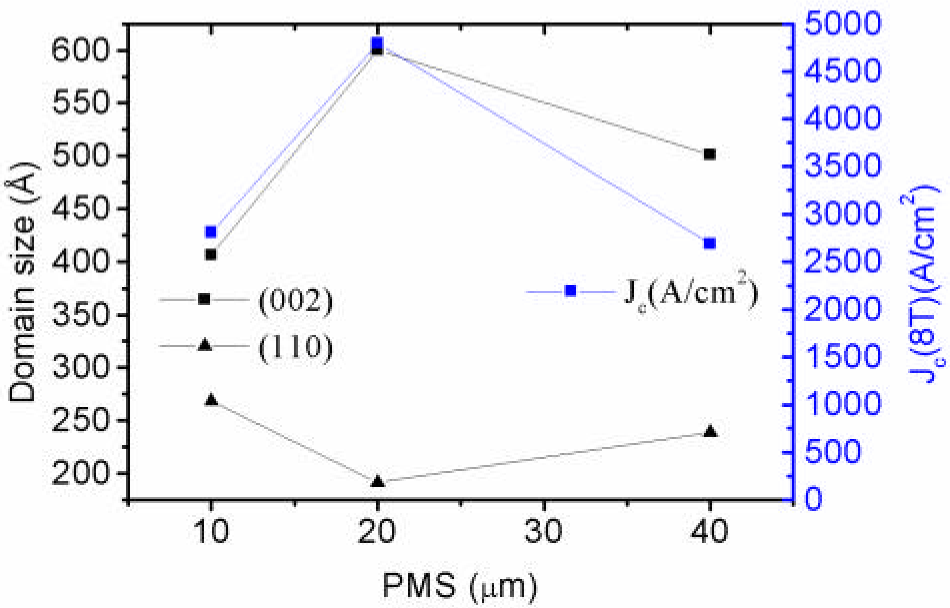
hkl	Sample /PMS	Domain size (Å)
After deformation		
(002)	B/20 mm	219.84
	C/10 mm	338.32
(110)	B/20 mm	305.67
	C/10 mm	144.16

hkl	Sample /PMS	Domain size (Å)
After annealing 920°C 30 min		
(002)	A/40 mm	501.04
	B/20 mm	600.23
	C/10 mm	405.83
(110)	A/40 mm	238.47
	B/20 mm	191.37
	C/10 mm	268.22



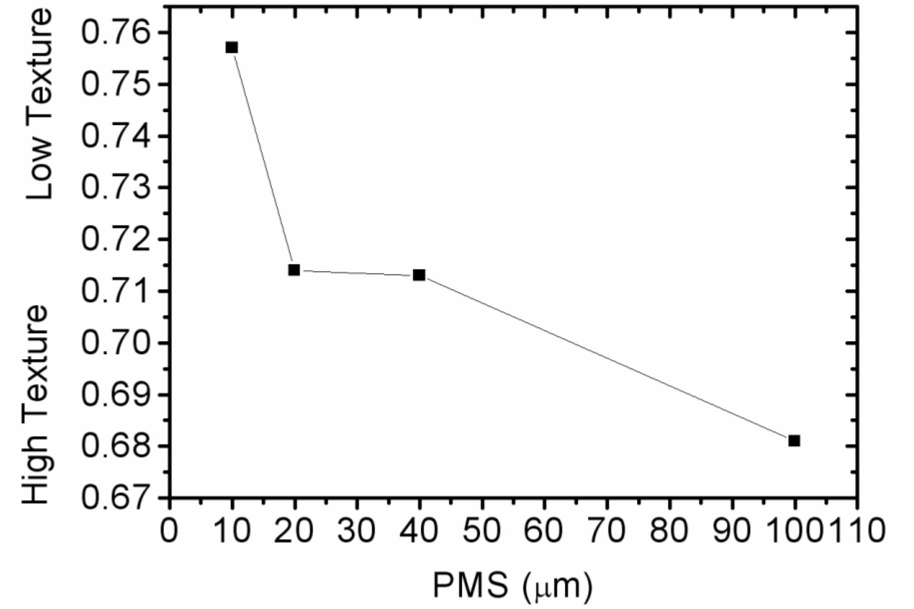
- Best sample: the one with the larger domain size on c-axis and medium particle size
- Particle size not dominant

Texture

Sample/ PMS	MgB_2	MgB_4	MgO	Texture
A/40 mm	75.8(6)	8.9(5)	12.7(3)	0.713
B/20 mm	73.5(5)	8.4(4)	16.0(2)	0.714
C/10mm	75.1(4)	10.8(3)	12.0(1)	0.757
			N/100mm	0.681

Low degree of texturing

Highest degree for largest particle size



Residual Strain

hkl	Sample /PMS	2q(°)	Breadth (°2q)	FWMH (°2q)	Strain (e*10^{-3})
After deformation					
(002)	B/20 mm	52.0	0.602	0.436	2.40
	C/10 mm	52.0	0.551	0.436	3.09
(110)	B/20 mm	60.0	0.605	0.475	2.78
	C/10 mm	60.0	0.747	0.489	2.07

hkl	Sample /PMS	2q(°)	Breadth (°2q)	FWMH (°2q)	Strain (e*10^{-3})
After 920°C 30 min					
(002)	A/40 mm	52.06	0.392	0.314	2.28
	B/20 mm	52.12	0.400	0.331	2.56
	C/10 mm	52.03	0.413	0.320	2.15
(110)	A/40 mm	60.13	0.531	0.373	1.53
	B/20 mm	60.21	0.608	0.413	1.37
	C/10 mm	60.11	0.574	0.430	2.24

→ Residual strain is released after final annealing

MgB_2: Conclusions

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* MgB_2 domain sizes have been determined by means of X ray diffraction ® J_c is correlated to the domain size

* A low degree of texturing has been found; highest for the largest particle sizes (analogy: Bi systems)

Study will be extended to: * "*in situ* " wires

* C or SiC added wires

Future perspectives

MgB_2 is perfectly ordered: limitation of B_{irr}

Analogy to Nb_3Sn

® Main research goal:

Find a way to slightly decrease the order parameter.

*** Additives: SiC, C,….** Dou et al.

*** Inclusions: MgO,…** Only in thin films (?)

*** Innovative growth processes**

Multifilamentary Nb_3Sn Wires

Bronze route

V. Abächerli

D. Uglietti

B. Seeber

Motivation for bronze route

Currently used for high field NMR magnets

(persistent mode)

Small filament diameter, $\leq 5\ \mu m$

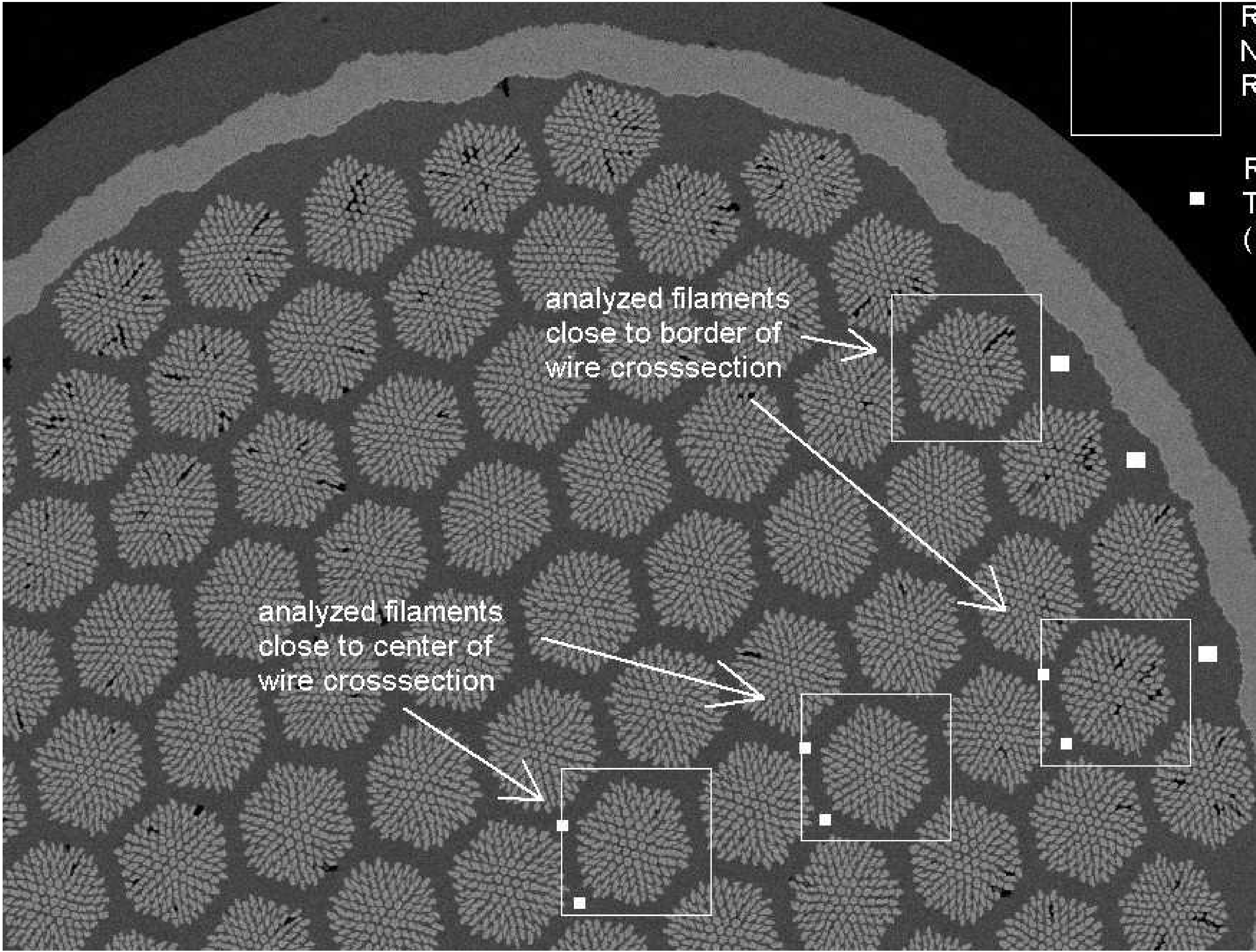
Small effective diameter, $\leq 20\ \mu m$

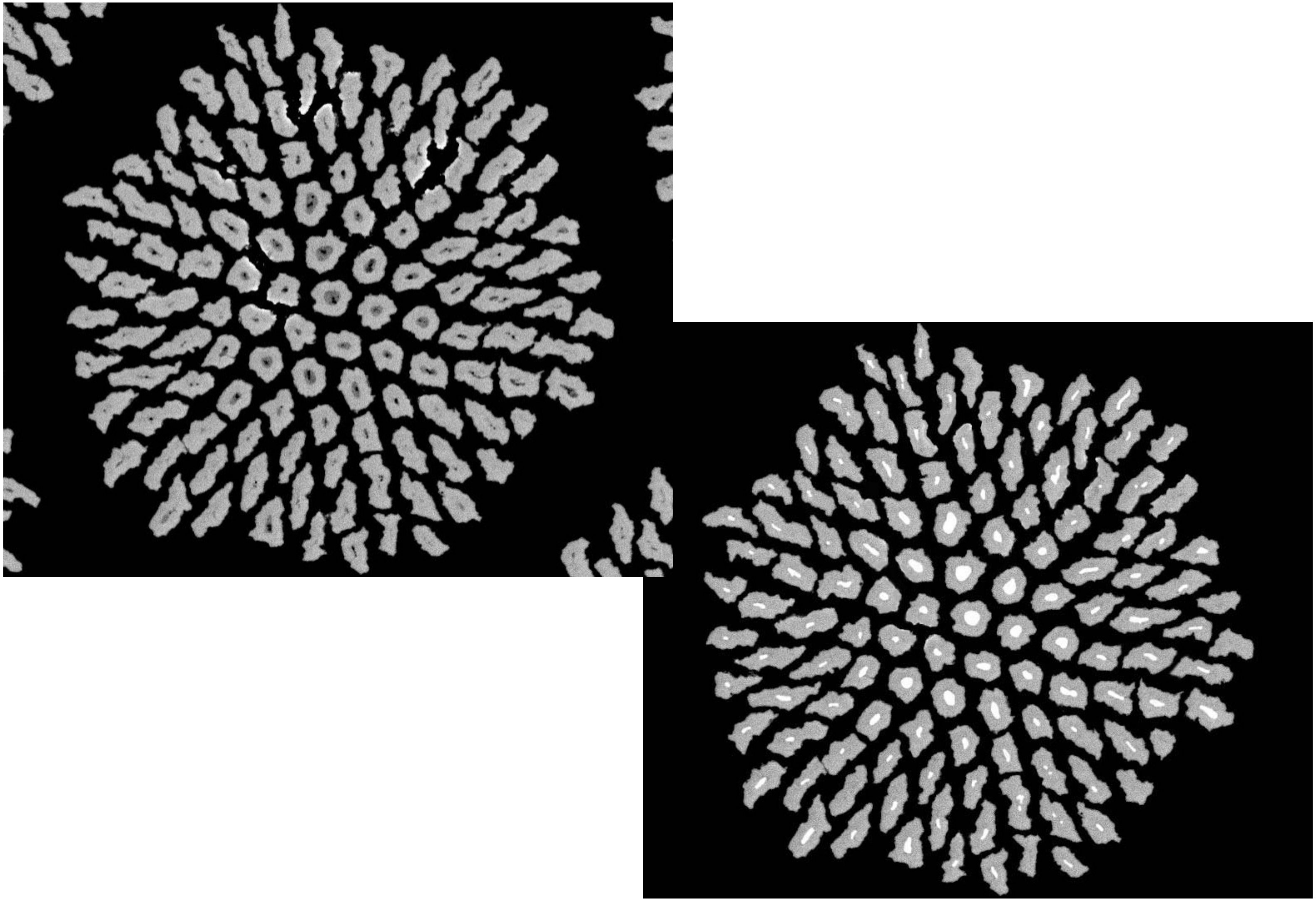
Higher mechanical stability: ε_m (after many cycles)

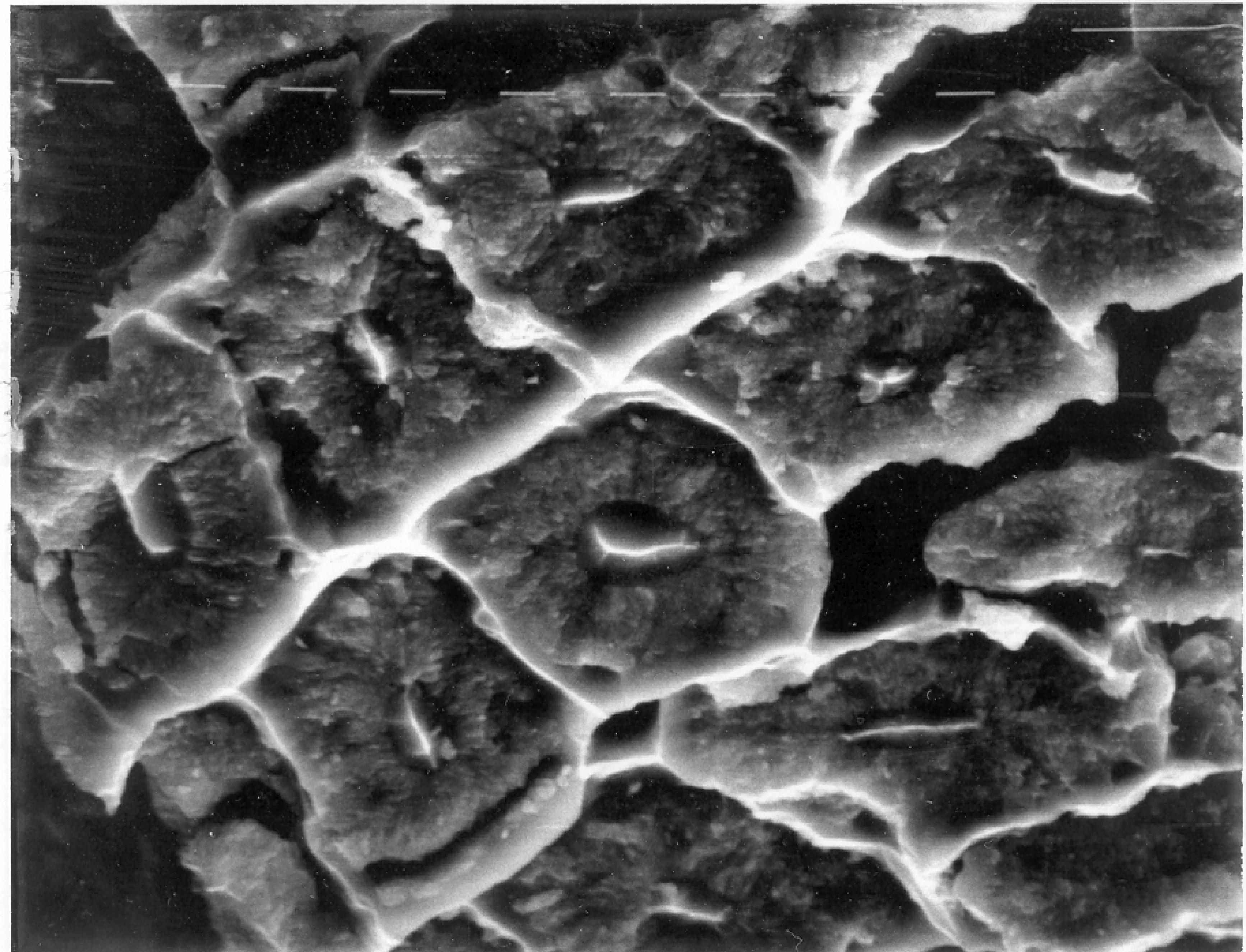
No voids (compressive stresses)

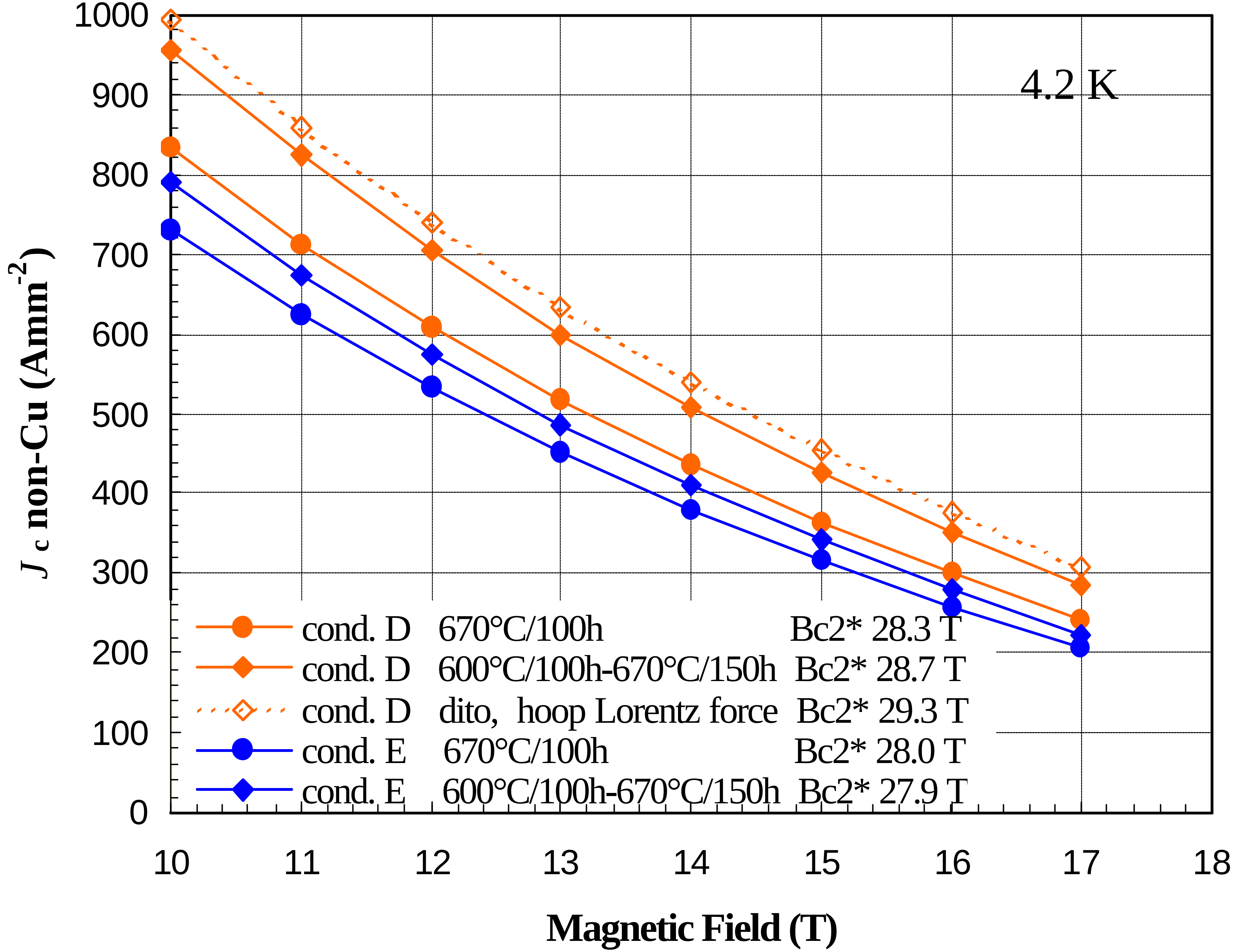
Limitation

Nb content is markedly lower than for other techniques

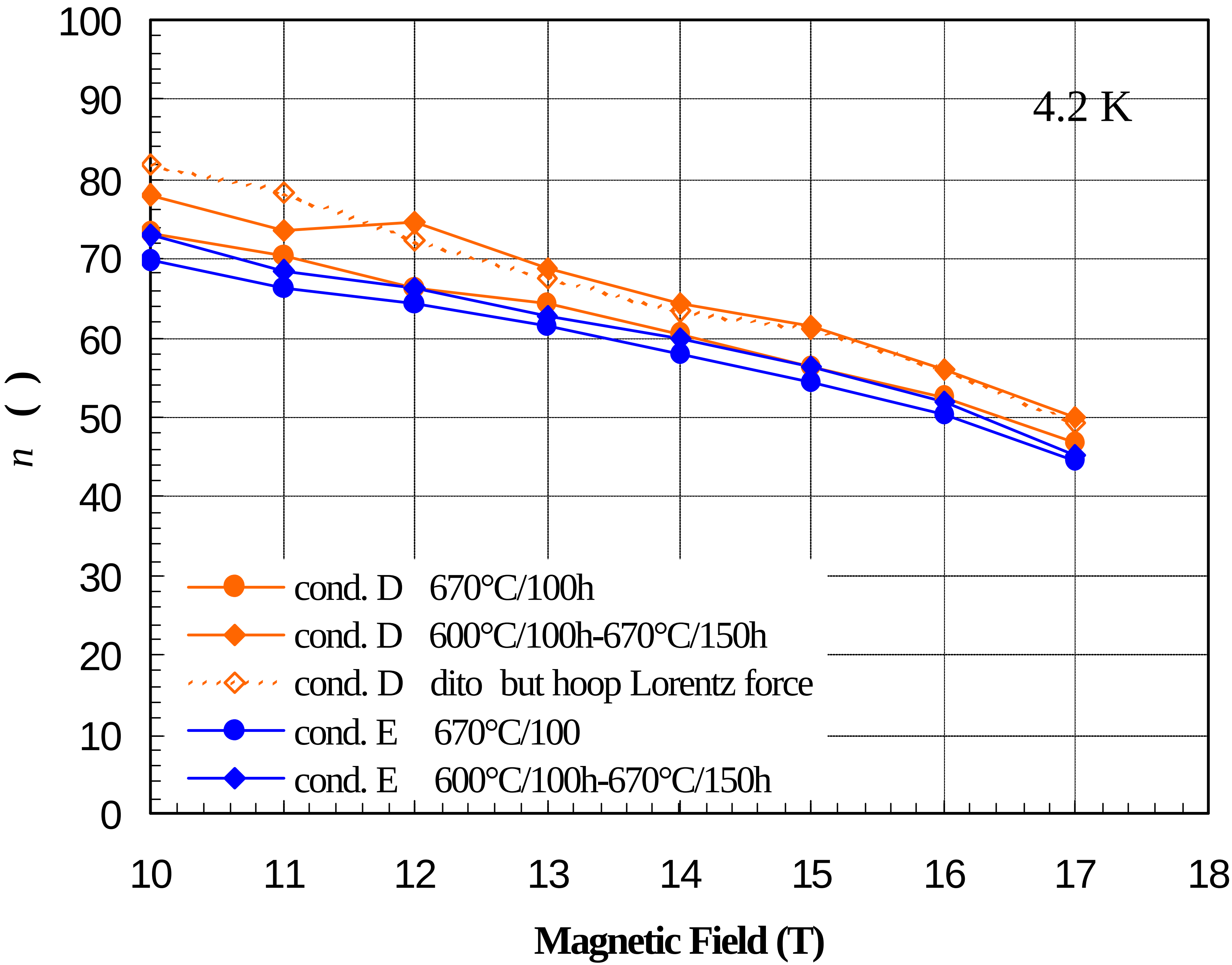

analyzed filaments close to border of wire crosssection
analyzed filaments close to center of wire crosssection







4.2 K
cond. D 670°C/100h Bc2* 28.3 T
cond. D 600°C/100h-670°C/150h Bc2* 28.7 T
cond. D dito, hoop Lorentz force Bc2* 29.3 T
cond. E 670°C/100h Bc2* 28.0 T
cond. E 600°C/100h-670°C/150h Bc2* 27.9 T
J c non-Cu (Amm-2)
Magnetic Field (T)



100
90
80
70
60
50
40
30
20
10
0
n ( )
4.2 K
cond. D 670°C/100h
cond. D 600°C/100h-670°C/150h
cond. D dito but hoop Lorentz force
cond. E 670°C/100
cond. E 600°C/100h-670°C/150h
10
11
12
13
14
15
16
17
18
Magnetic Field (T)

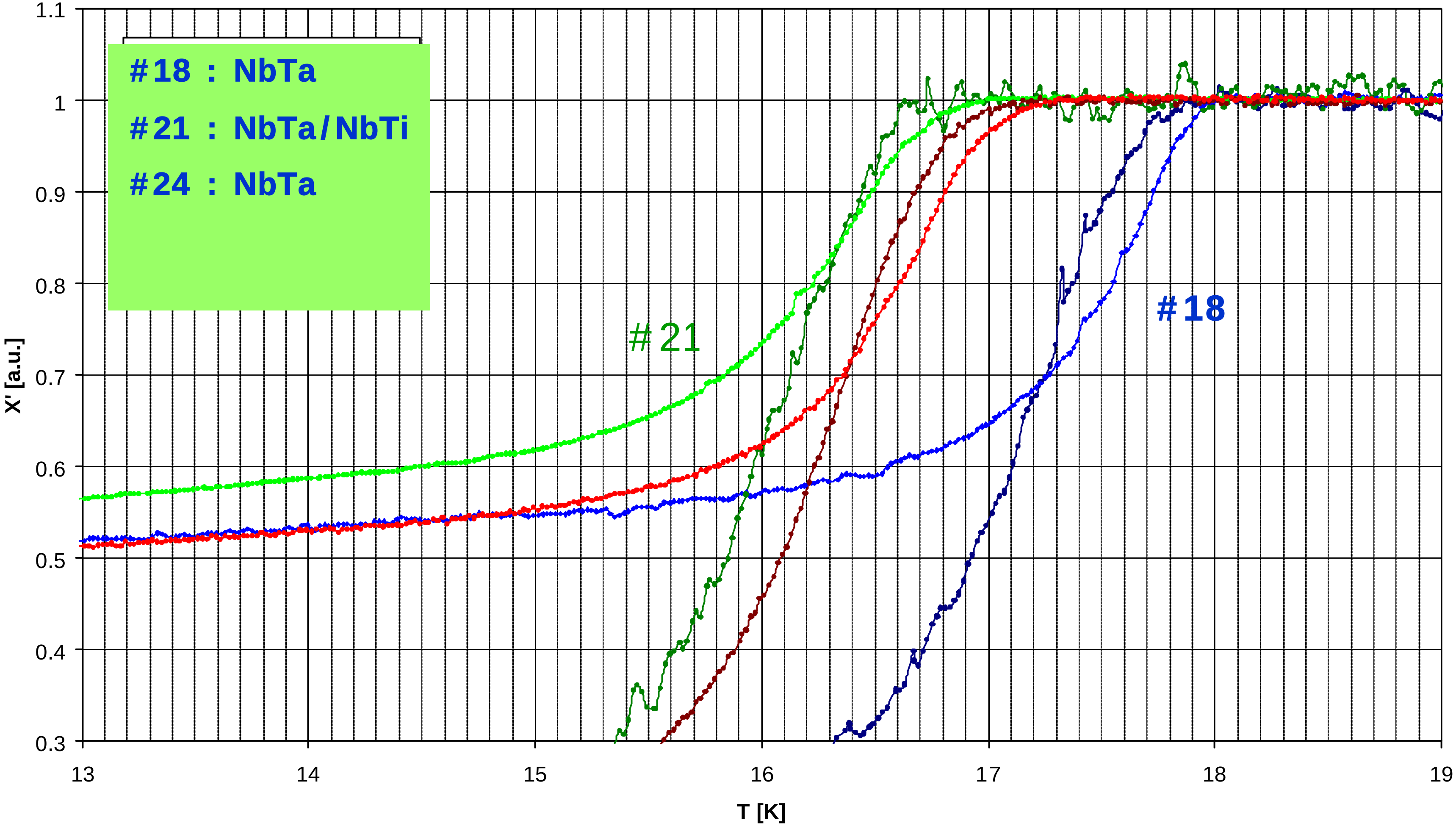
These results of J_c and *n* clearly reveal the Ti doping by the bronze as more performing

The analysis of the residual niobium ratio of the filaments and residual tin content in the bronze does not show a significant difference compared to the filament doping method.

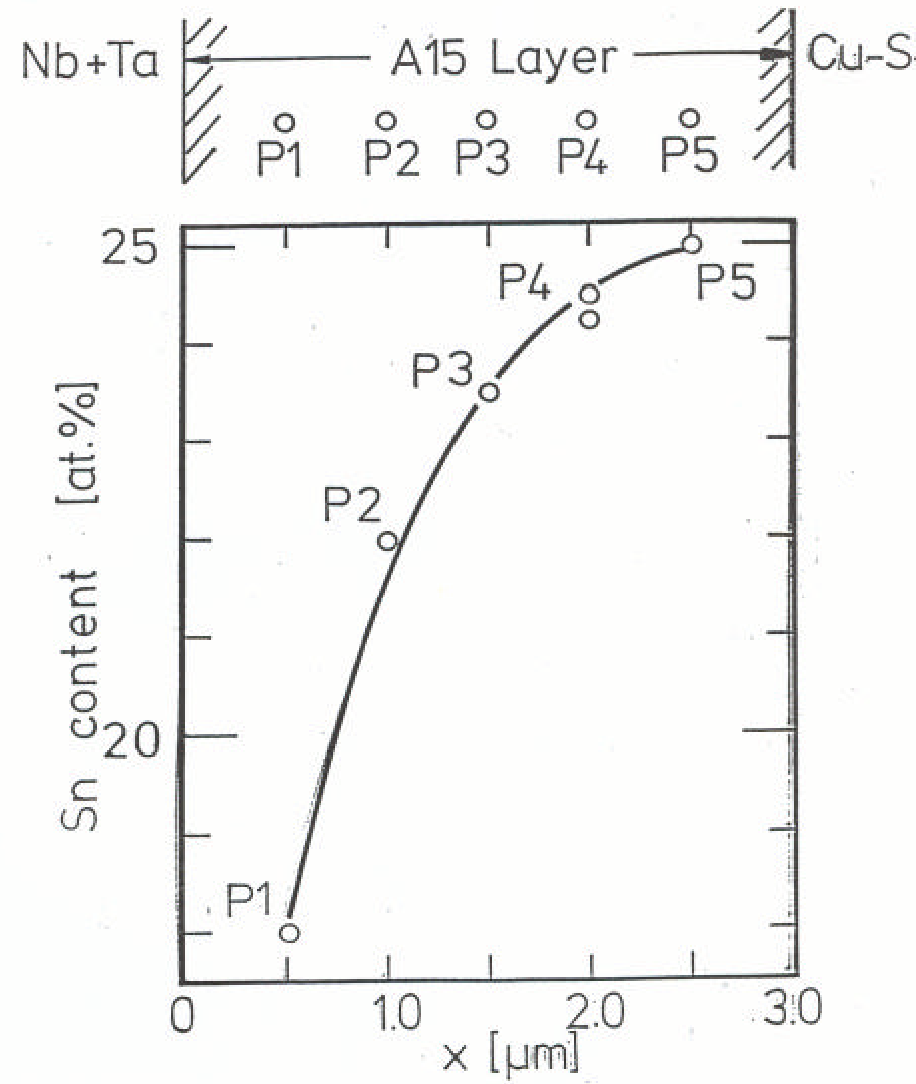
Further high resolution analysis has to be done on the nanostructure of the A15 phase (grains, grain boundaries).

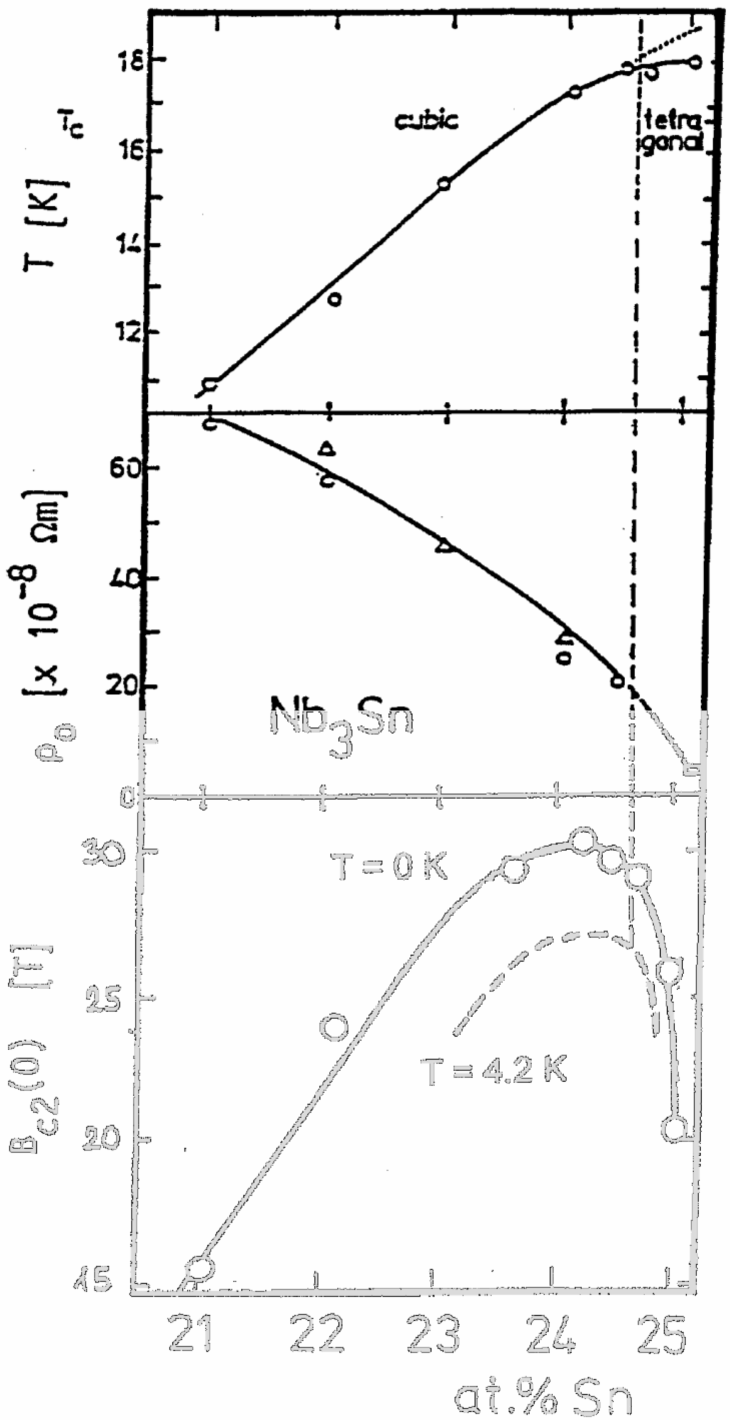
Nb_3Sn Wires: effect of Ti additives

600°C/100h-670°C/150h

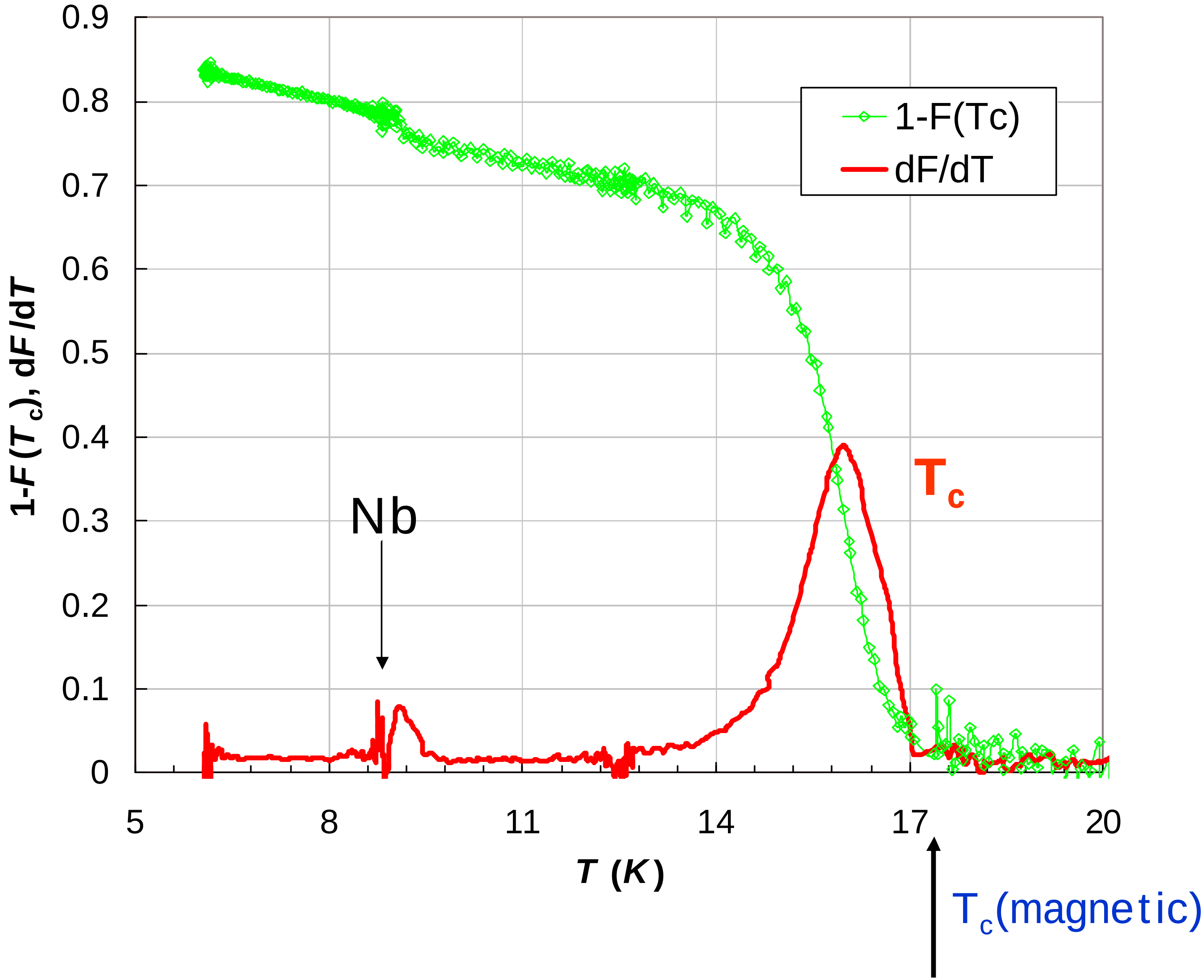


Bronze route wires: distribution of Sn in a filament

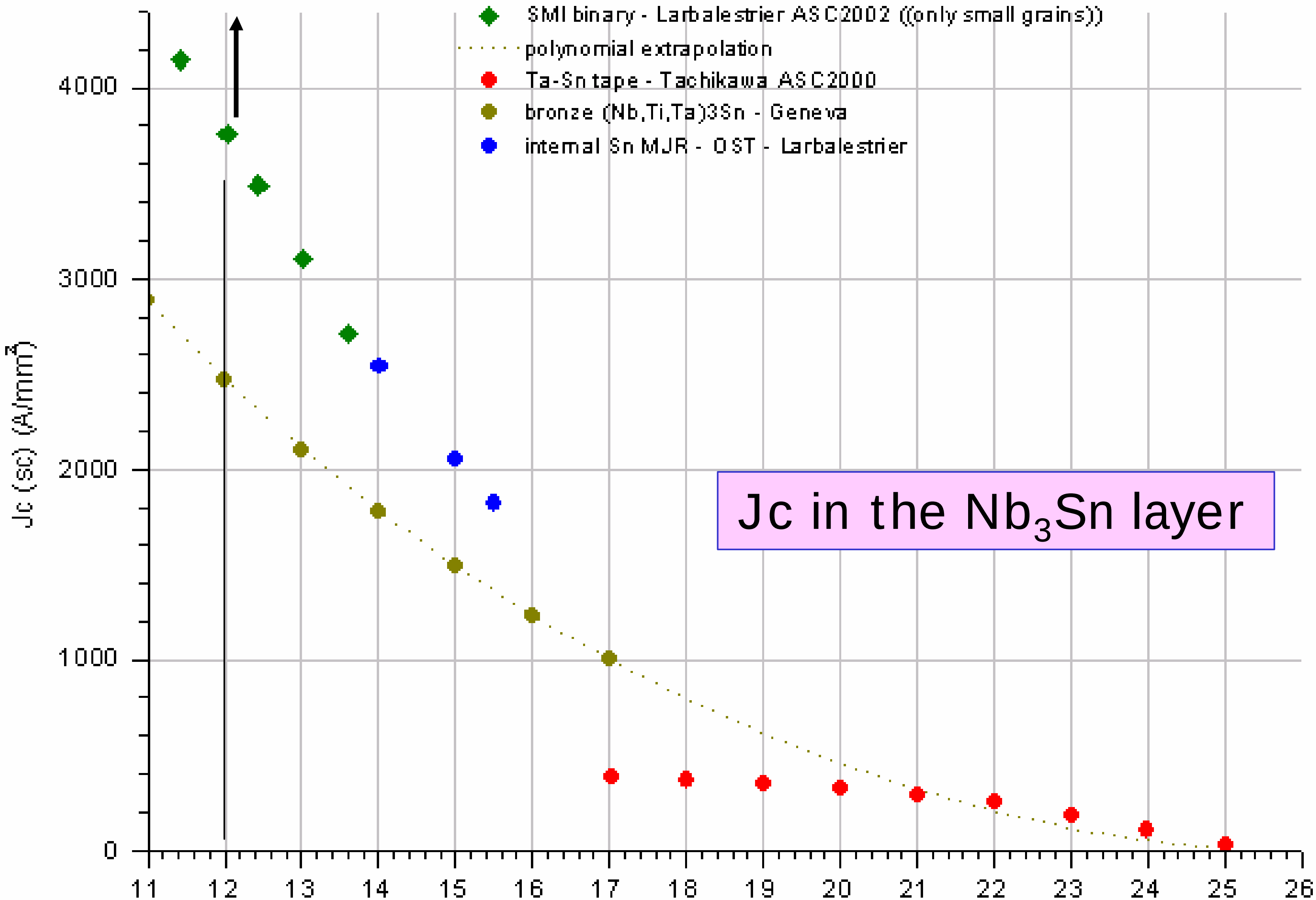




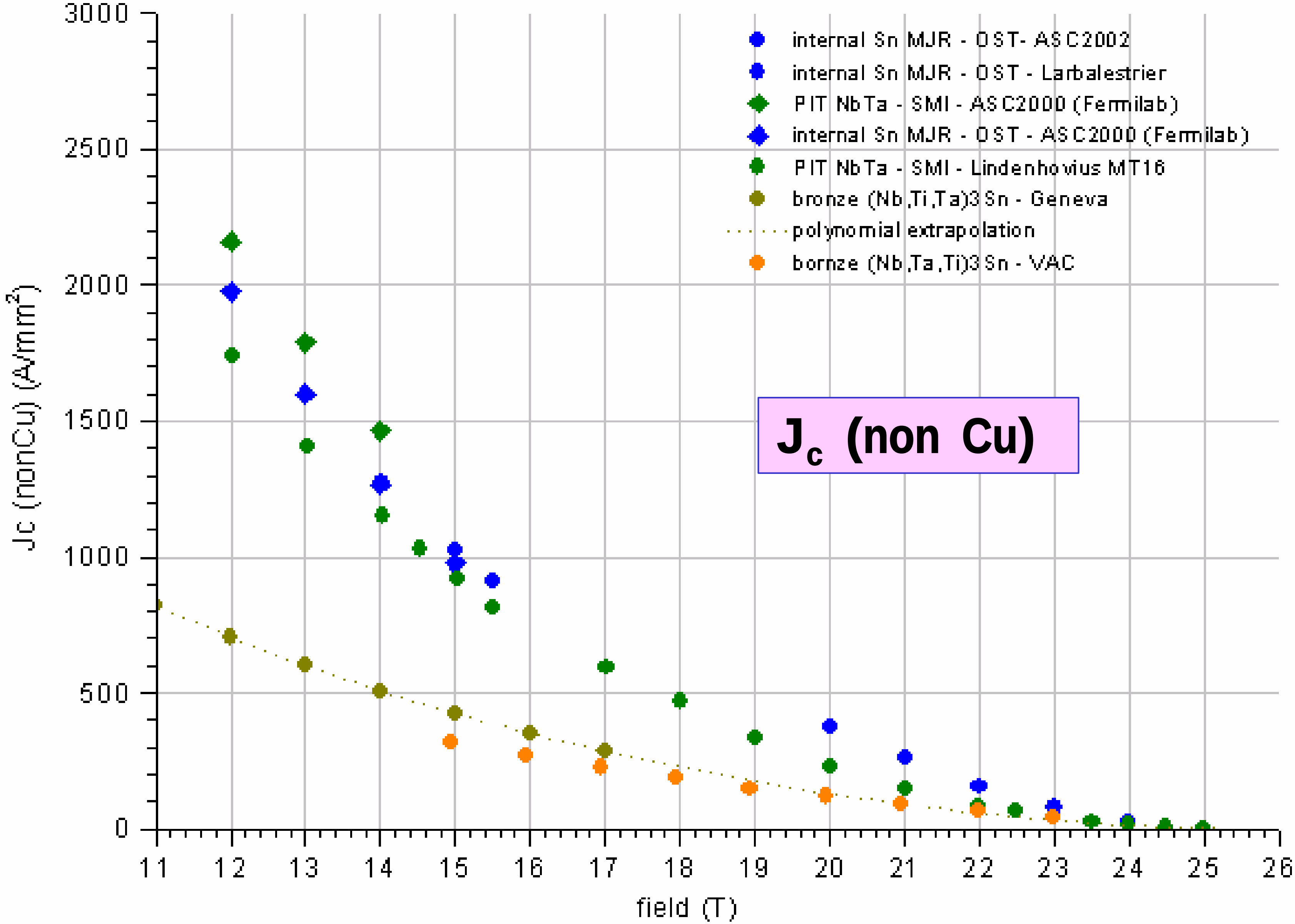
$B_{c2} \sim T_c \ \gamma \ \rho_o$



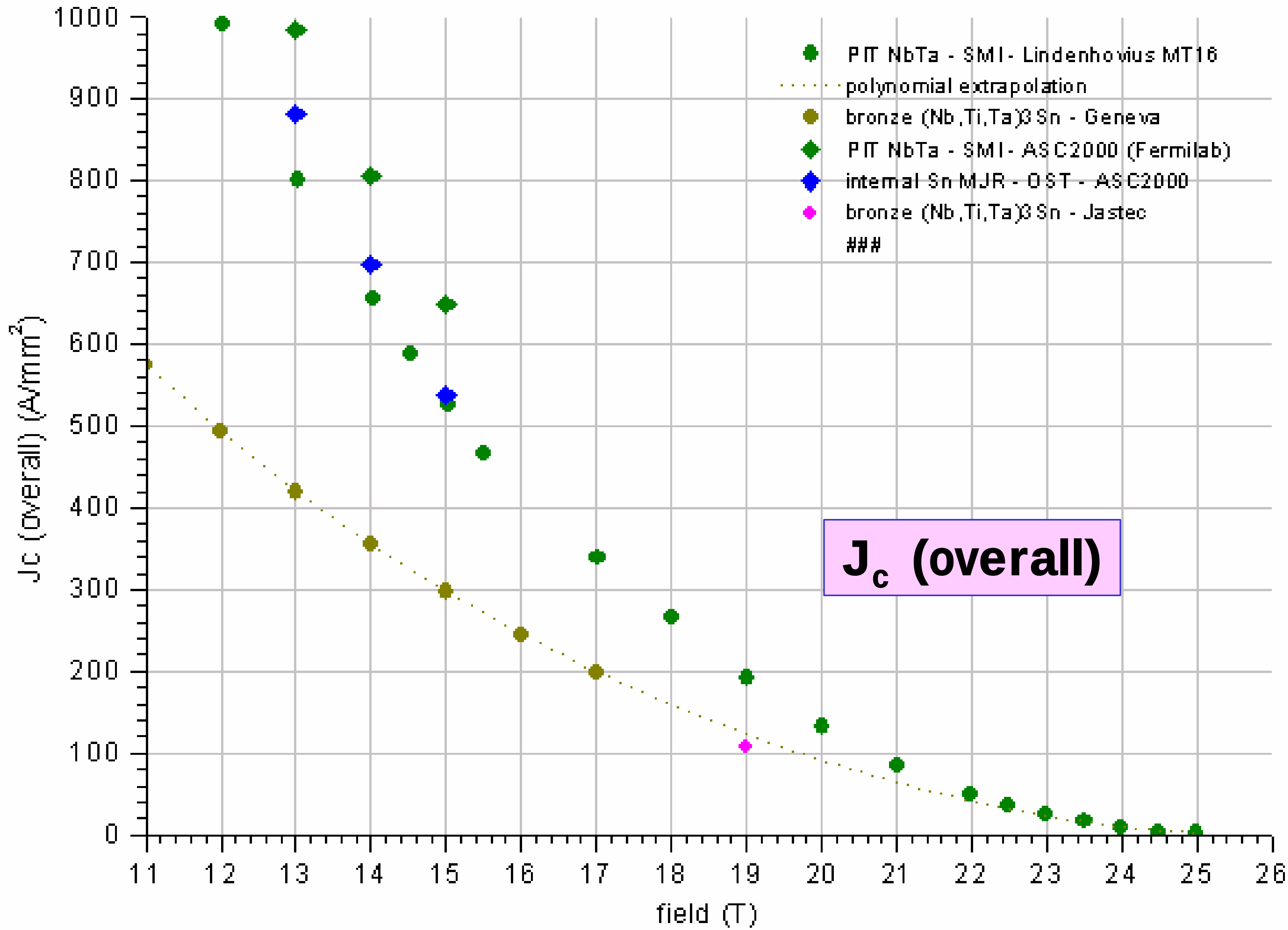
T_c distribution from by specific heat in $(Nb,Ti)_3Sn$ multifilamentary wire
(Y. Wang, A. Junod, Geneva)



SMI binary - Larbalestrier ASC2002 ((only small grains))
polynomial extrapolation
Ta-Sn tape - Tachikawa ASC2000
bronze (Nb,Ti,Ta)3Sn - Geneva
internal Sn MJR - OST - Larbalestrier
Jc in the Nb_3Sn layer
Jc (sc) (A/mm²)
0
1000
2000
3000
4000
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26



Jc (nonCu) (A/mm^2)
3000
2500
2000
1500
1000
500
0
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
field (T)
internal Sn MJR - OST- ASC2002
internal Sn MJR - OST - Larbalestrier
PIT NbTa - SMI - ASC2000 (Fermilab)
internal Sn MJR - OST - ASC2000 (Fermilab)
PIT NbTa - SMI - Lindenhovius MT16
bronze (Nb,Ti,Ta)3Sn - Geneva
polynomial extrapolation
bornze (Nb,Ta,Ti)3Sn - VAC
J_c (non Cu)



PIT NbTa - SMI - Lindenhovius MT16
polynomial extrapolation
bronze (Nb,Ti,Ta)3Sn - Geneva
PIT NbTa - SMI - ASC2000 (Fermilab)
internal Sn MJR - OST - ASC2000
bronze (Nb,Ti,Ta)3Sn - Jastec
###
Jc (overall)
Jc (overall) (A/mm2)
field (T)
0
100
200
300
400
500
600
700
800
900
1000
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26

Actually, bronze route only competitive for very high fields (NMR applications: B > 21 T), where other factors are important:

Mechanical stability

(uniaxial and transverse stress)

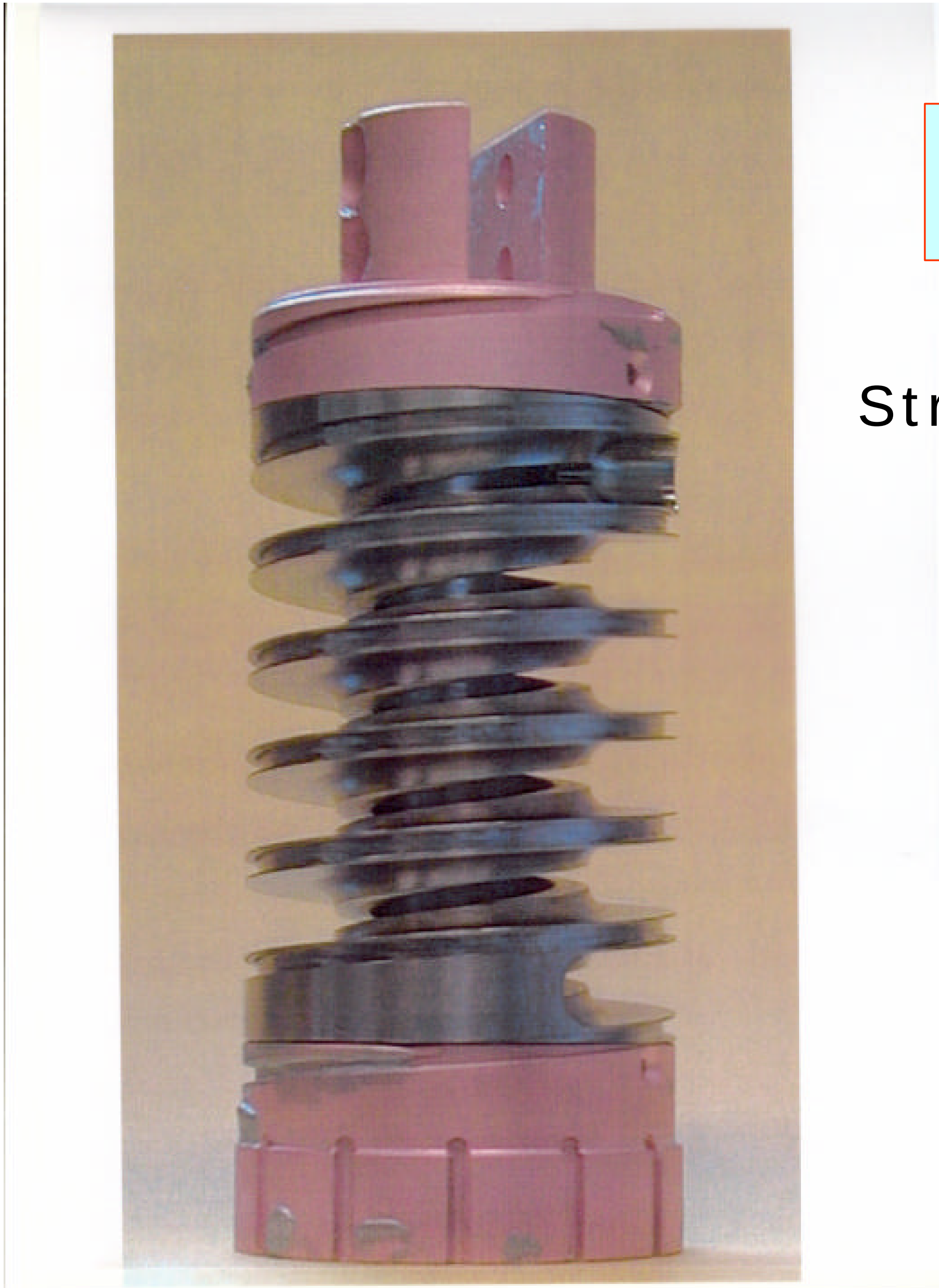
Joint techniques

Thermal stability

Small filament diameters: positive influence on all these properties

Next goals

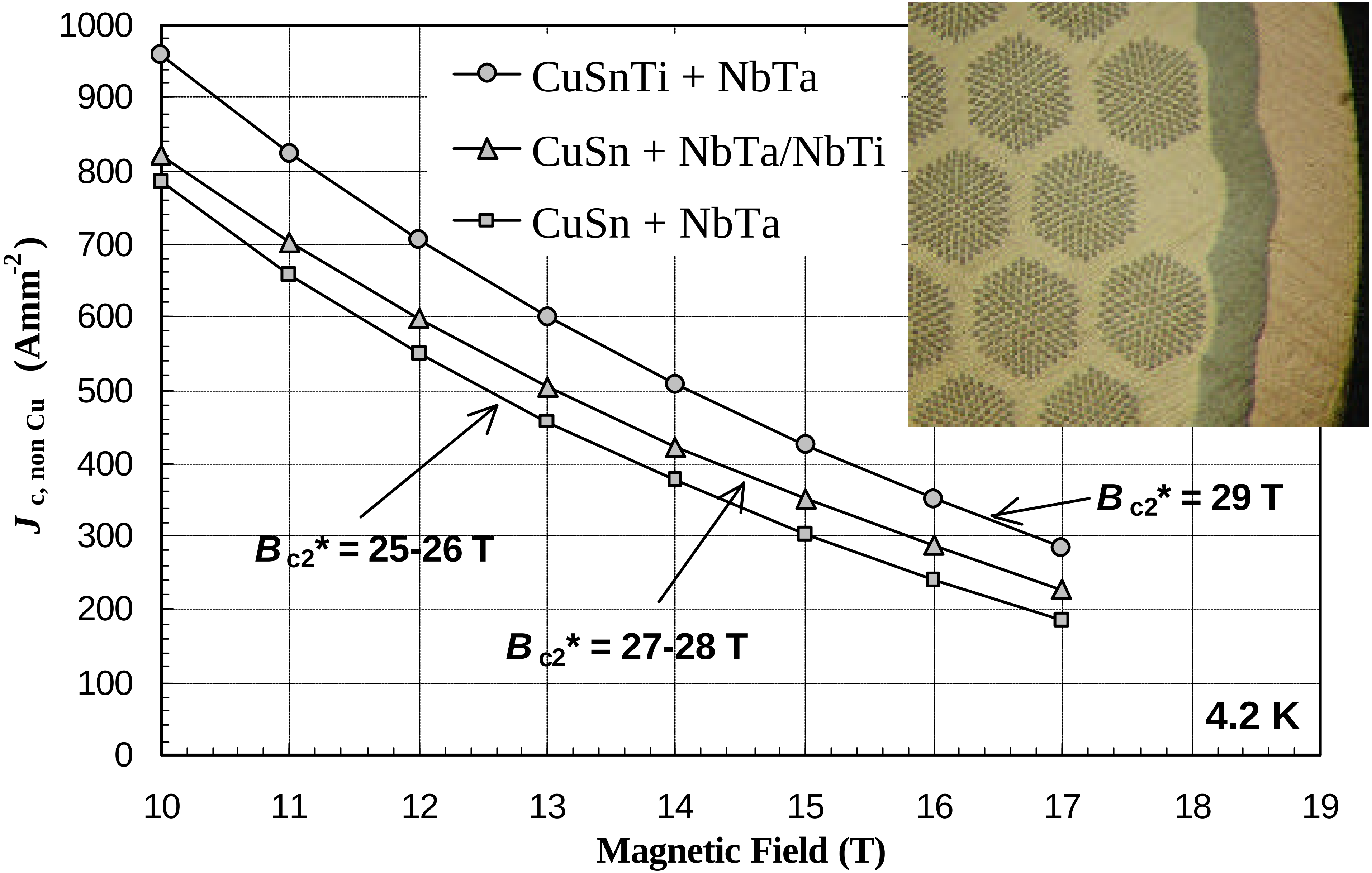
New investigation by means of specific heat, in view of narrower T_c distributions ® higher J_c values



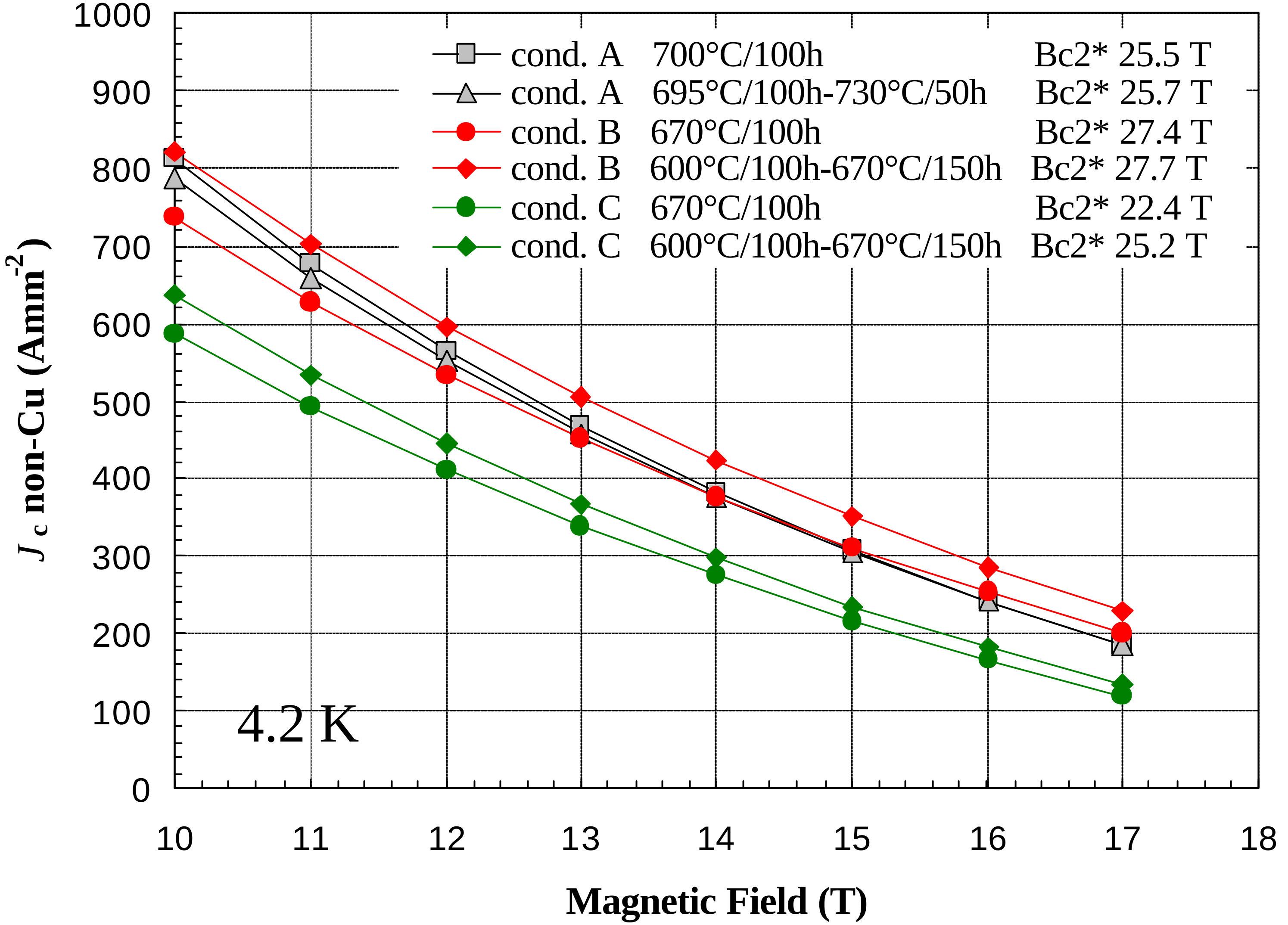
Walters Spiral (WASP)
for j_c (e) measurement

Strain rig at University Geneva:

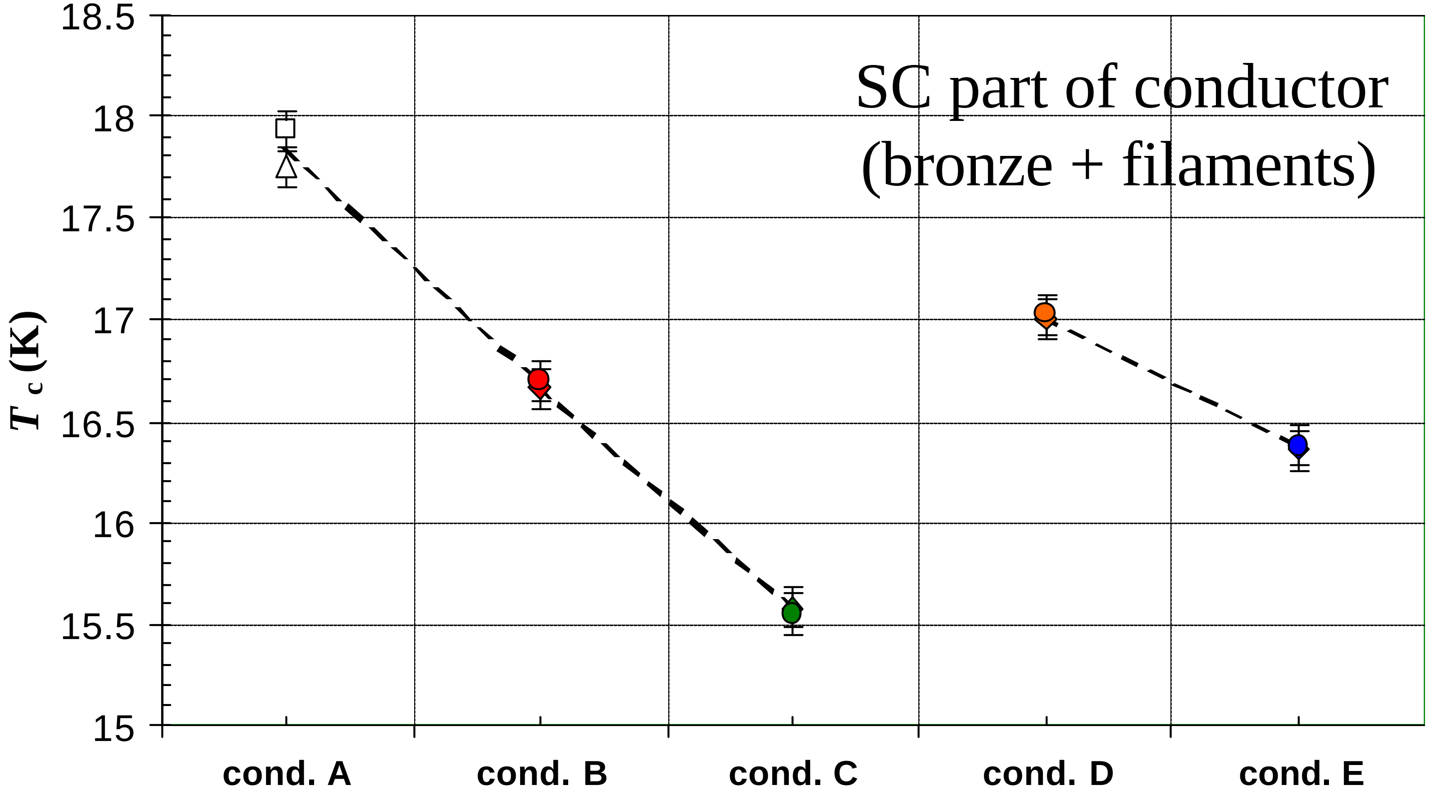
- £ **1’000 A**
- £ **17 T (actually)**
- **21 T (June 04)**
- £ **800 mm length**
- ³ **0.01 mV/cm**



Nb_3Sn wires with Ta and Ta + Ti additives, GAP/Univ. Geneva



cond. A 700°C/100h Bc2* 25.5 T
cond. A 695°C/100h-730°C/50h Bc2* 25.7 T
cond. B 670°C/100h Bc2* 27.4 T
cond. B 600°C/100h-670°C/150h Bc2* 27.7 T
cond. C 670°C/100h Bc2* 22.4 T
cond. C 600°C/100h-670°C/150h Bc2* 25.2 T
4.2 K
Jc non-Cu (Amm-2)
Magnetic Field (T)
0
100
200
300
400
500
600
700
800
900
1000
10
11
12
13
14
15
16
17
18


SC part of conductor
(bronze + filaments)
T_c (K)
18.5
18
17.5
17
16.5
16
15.5
15
cond. A
cond. B
cond. C
cond. D
cond. E