Columbus Superconductors

GRUPPO MALACALZA

MgB_2 wire performance

Giovanni Grasso

May 20th, 2008

Coworkers

- BASIC R&D
  CNR-INFM: A. Malagoli, V. Braccini, C. Bernini, C. Fanciulli, M. Tropeano, M. Vignolo, C. Ferdeghini, M. Putti

- CONDUCTOR DEVELOPMENT
  Columbus Superconductors: S. Brisigotti, A. Tumino, D. Pietranera, E. Demencik, S. Berta, R. Penco

- POWDERS DEVELOPMENT
  Ferrania Technologies: S. Magnanelli, A. Gunnella

- MAGNET DEVELOPMENT
  ASG Superconductors: R. Marabotto, M. Modica, D. Damiani, D. Nardelli

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Preamble

- MgB_2: this new material represents the natural evolution for applied superconductivity of today and tomorrow
- Superconductivity in MgB_2 was publicly announced in January 2001 by Japanese scientists
- From then on MgB_2 represents the known binary material showing superconductivity at the highest temperatures to date
- As virtually all superconductors used in large-scale industrial applications are binary materials (NbTi, Nb_3Sn), it appeared immediately evident that MgB_2 might have represented a new option
- So far researchers worldwide produced literally hundreds of scientific manuscripts focused on this surprising discovery
- Helium (liquid) is a natural resource available in limited quantities and it represents a bottleneck to industrial developments using superconductivity : MgB_2 is a convenient solution to that

Important parameters for industrial applications

Material	T_c	H_{c_2} (T= 4.2 K)	ξ (nm)	Mass Density
Nb-Ti	9 K	10 T	5	6.0 g/cm^3
Nb_3Sn	18 K	28 T	5	7.8 g/cm^3
MgB_2	39 K	60 T	5	2.5 g/cm^3
YBCO	90 K	> 50 T	<< 1 [c]	5.4 g/cm^3
BSCCO	110 K	> 50 T	<< 1 [c]	6.3 g/cm^3

World market

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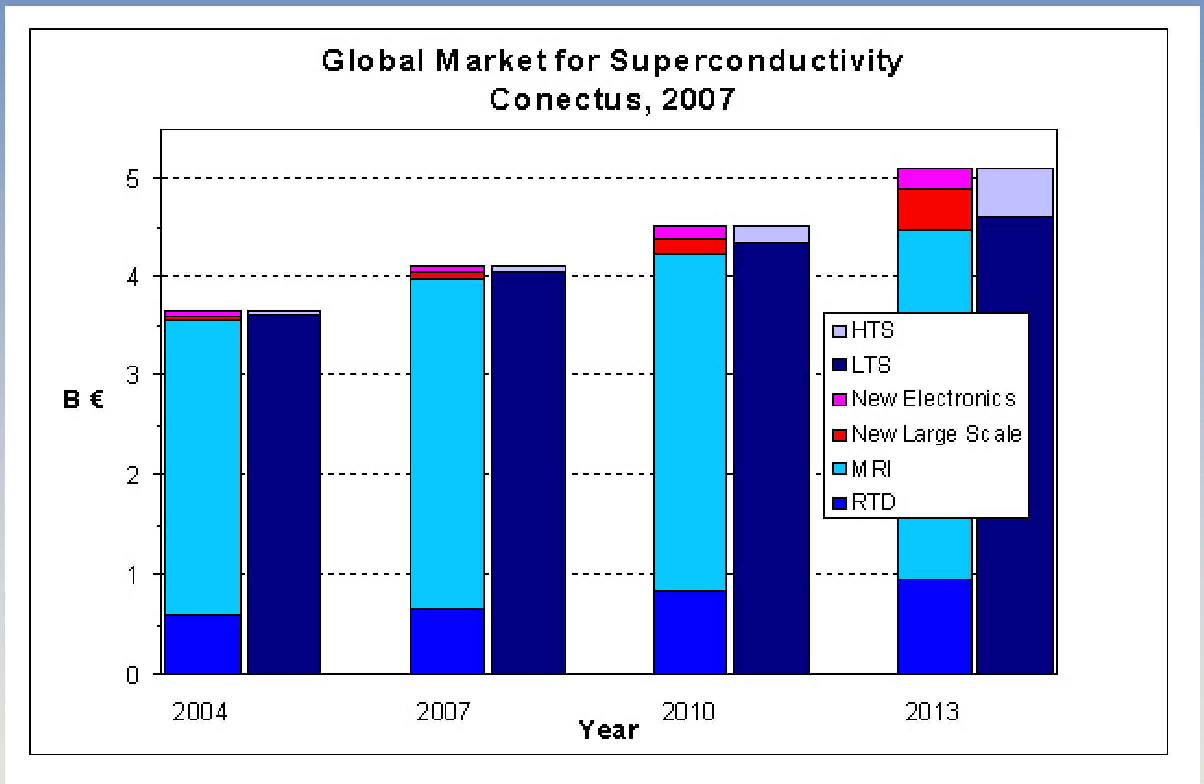
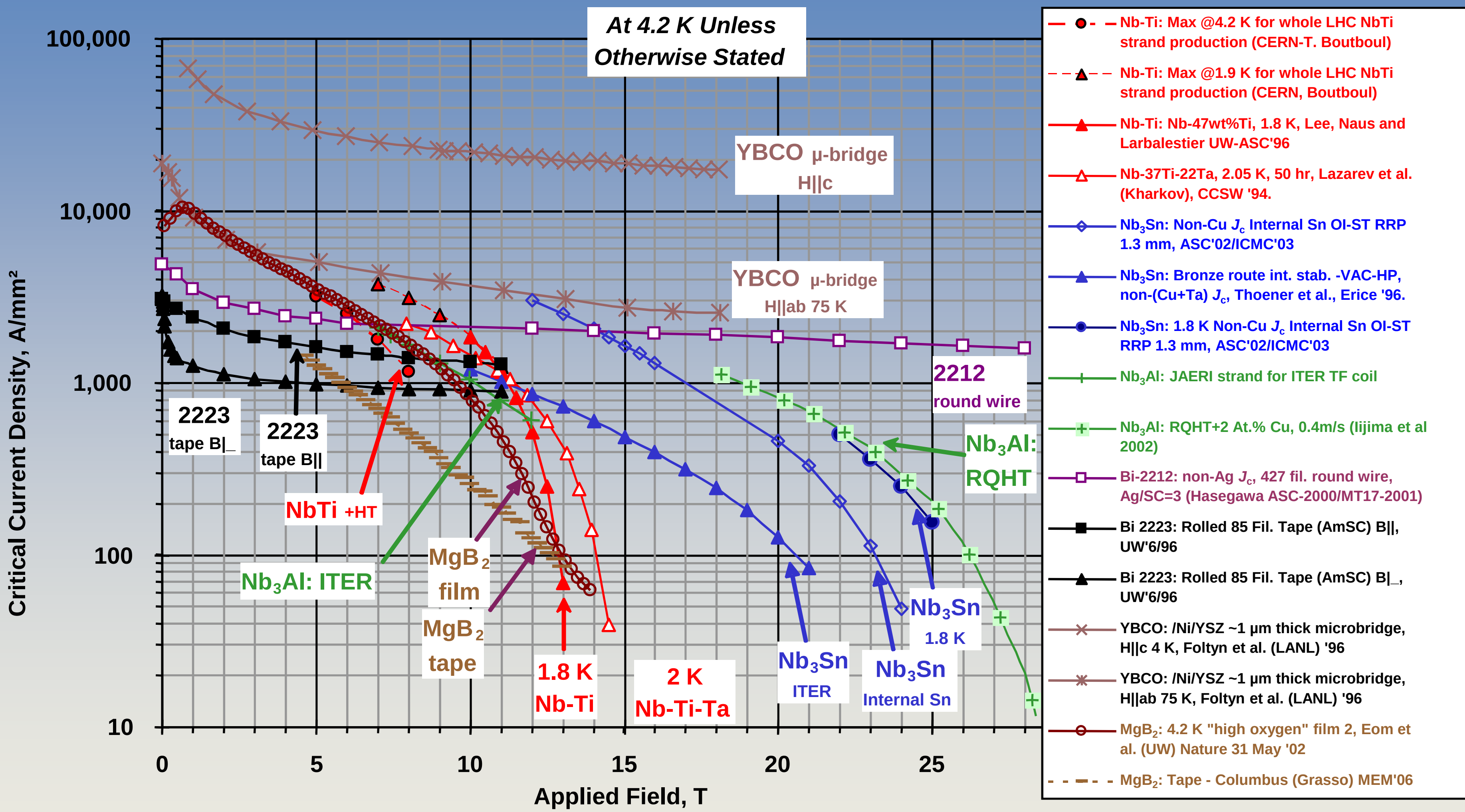


MgB_2 is an HTS with properties and price more near to an LTS

The questions are: how much of the current and future LTS and HTS market MgB_2 will grab?
and how big will the new market generated by MgB_2 be?

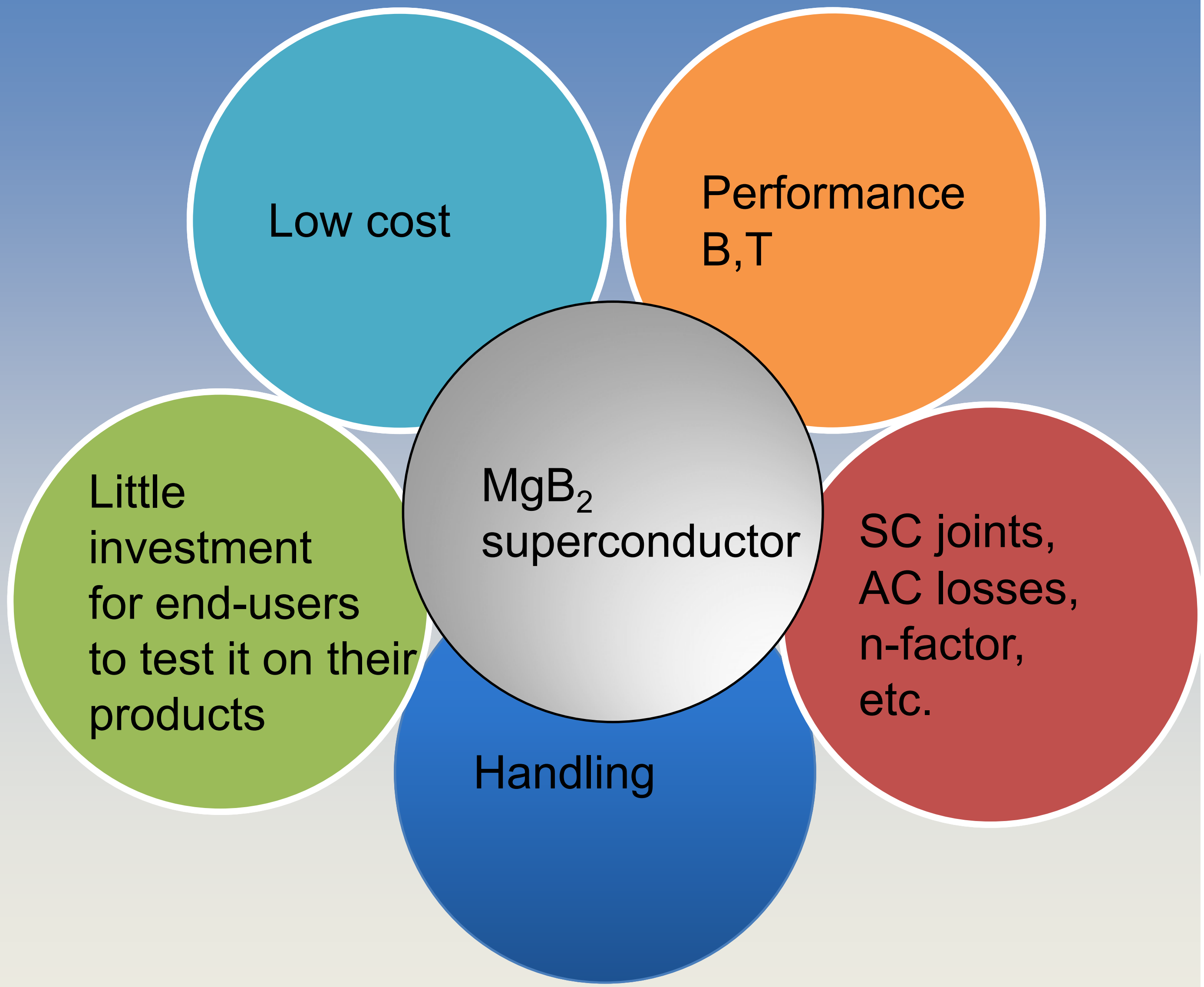
Critical currents of technical superconductors at 4.2 K



Superconductors choice is ‘in principle’ quite wide,but j_c is not the only important parameter for selection

Driving forces for MgB_2

- Low cost and wide availability of the raw materials, particularly in Europe
- Excellent chemical and mechanical compatibility with various elements (Ni, Fe, Ti, Nb, Ta, Cr, although not with Cu)
- Potential for very good performance at high fields (thin films show H_{c2} > 60 T !)
- Low anisotropy and potential for persistent mode operation (high n-value, low current decay at medium magnetic fields)



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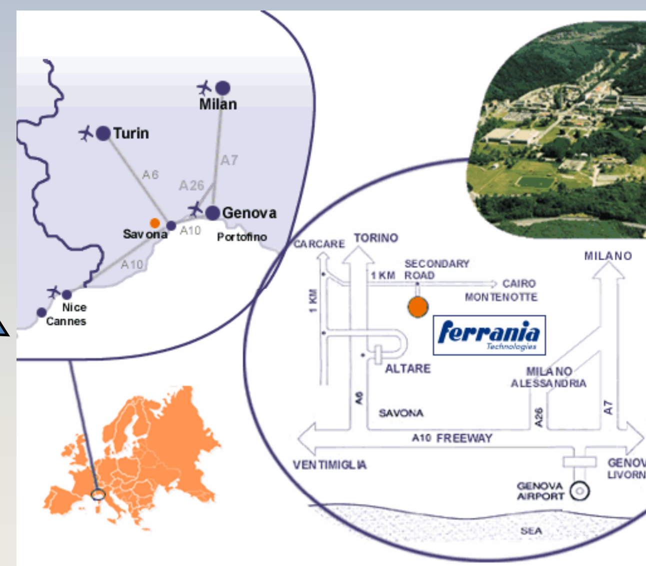
About our today's structure

7 engineers
7 workers
2 consultants
Indirect activities to ASG

R&D

2 professors
3 senior researchers
4 Postdocs
2 PhD students

Powder production



3 employees

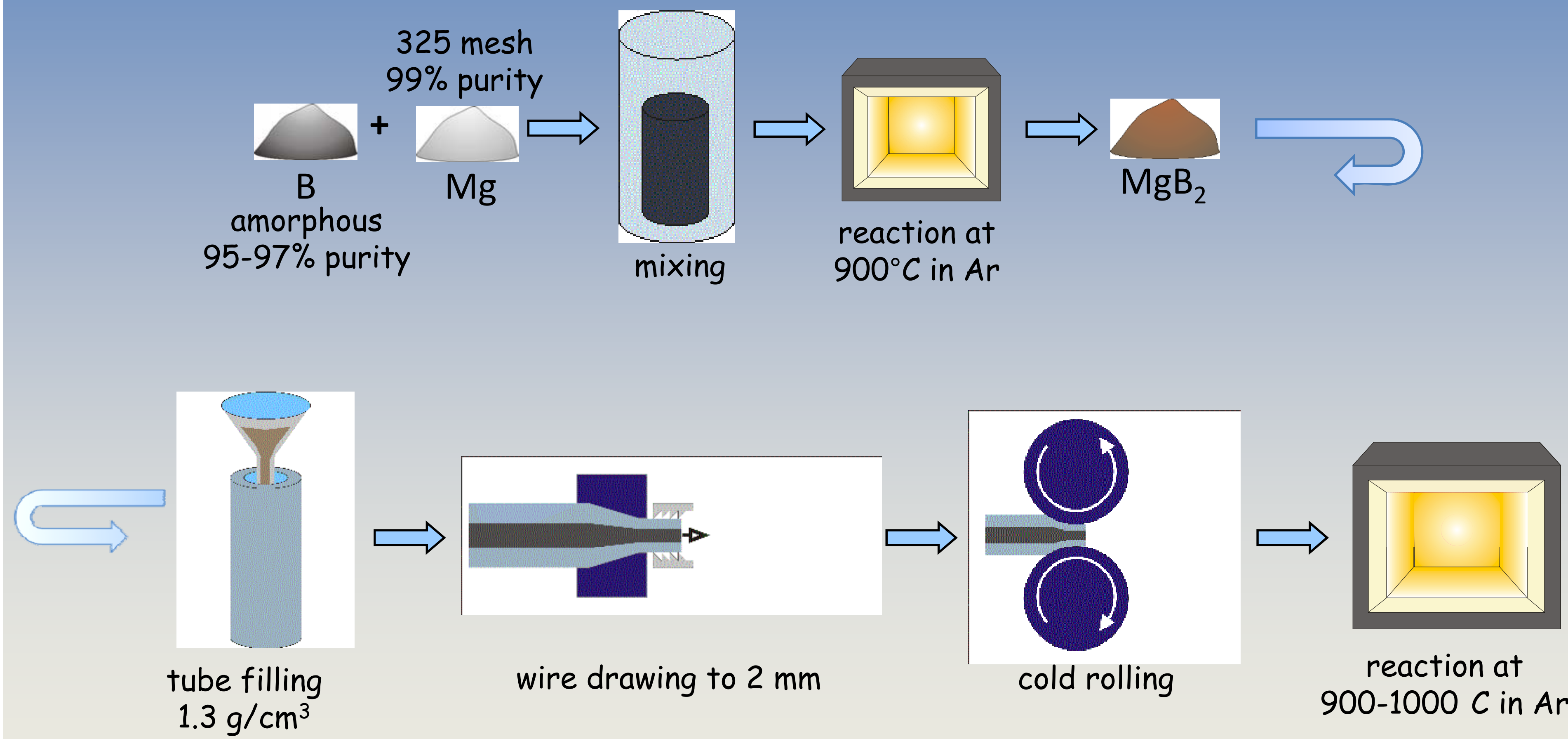
The new plant is ready and operational for a wire production scalable up to 3'000 Km/year

Wire unit length up to 5 Km single pieces

Total plant area 3'400 m^2 – 50% only used today

Columbus Superconductors activities involve about 30 people

Fabrication of MgB_2 wires by the ex-situ P.I.T. method used



Fabrication of MgB_2 wires by the ex-situ P.I.T. method

advantages

- *Straightforward multifilament processing*
- *Significant homogeneity over long lengths*
- *Allows careful control of the MgB_2 particle size and purity*

disadvantages

- *Need of hard sheath materials and strong cold working*
- *J_c is very sensitive to the processing route*
- *More tricky to add doping and nanoparticles effectively*

⬇

Reliable method for exploring long lengths manufacturing

Microstructure

Composite wire:

99.5% pure Nickel matrix

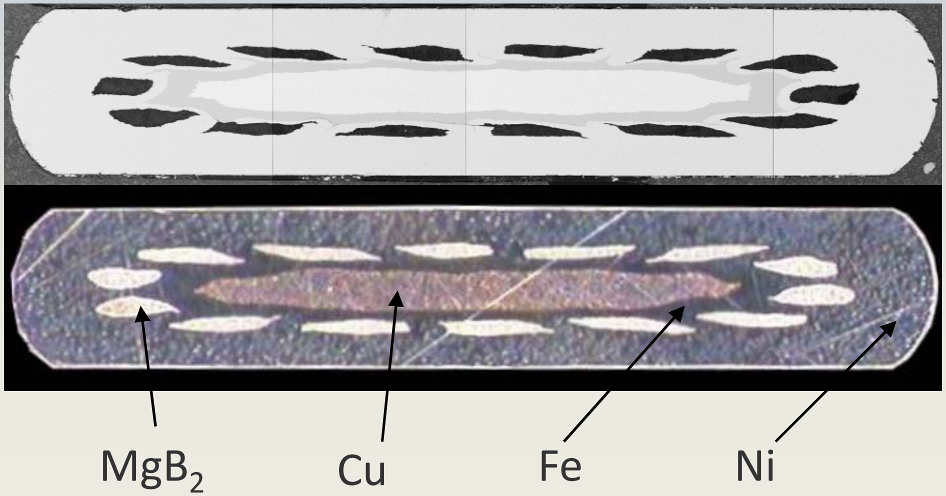
14 MgB_2 filaments

OFHC 10100 Copper core

99.5% pure Iron barrier

Dimension 3.6 mm x 0.65 mm (w x t)

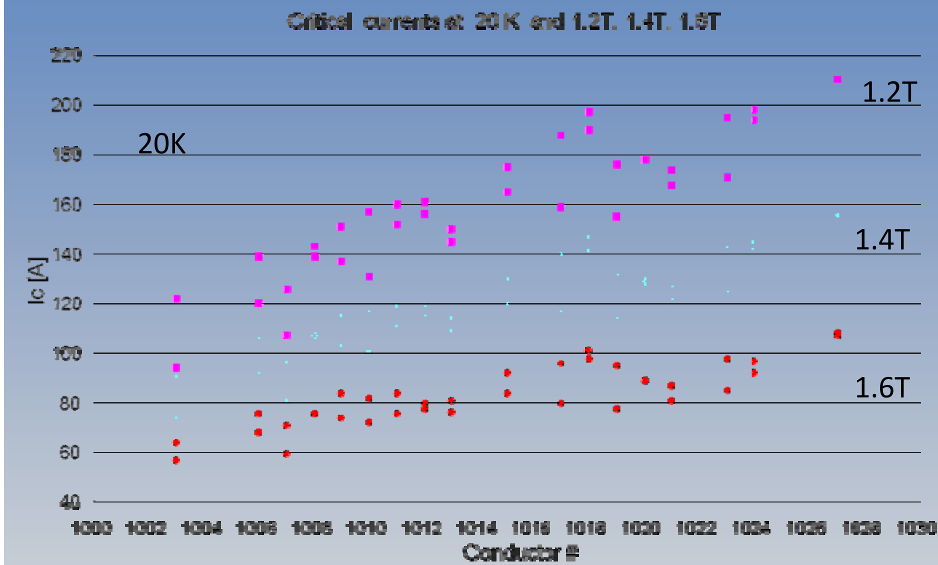
Standard batch length: > 1700 m



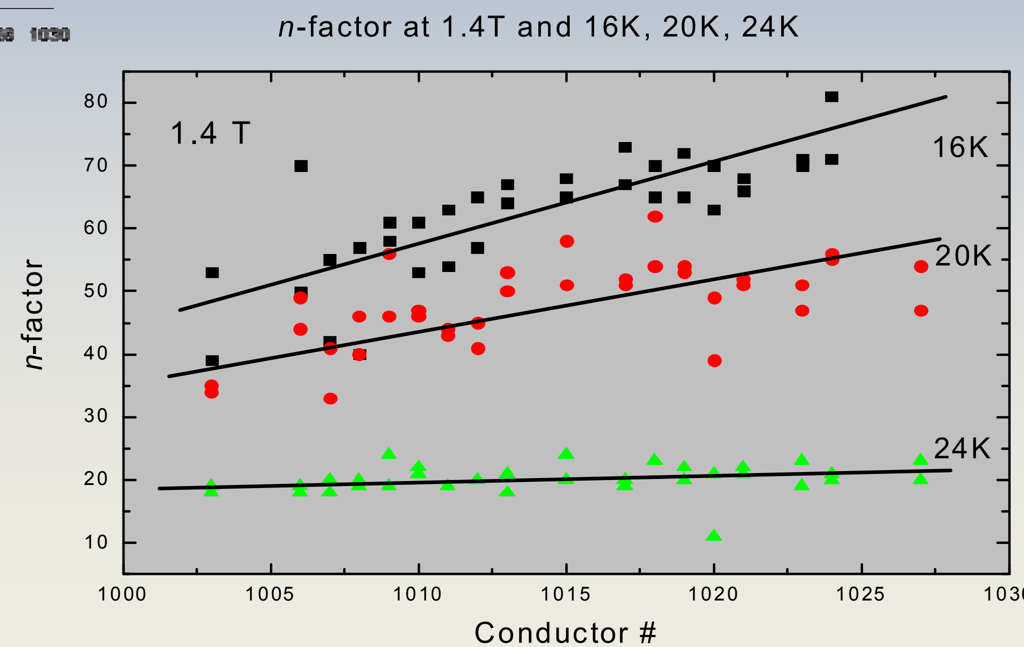
Transverse cross section area:

- MgB_2 0.21 mm^2 (total area)
- Cu 0.35 mm^2
- Fe 0.19 mm^2
- Ni 1.54 mm^2

Constant improvement of conductors from production: I_c at 20K of 1.7 Km tapes



I_c at 20K, 1 T always >> 90 A
n-factor at 20K, 1 Tesla >> 30
Minimum bending diameter: 65 mm
Maximum tensile strain: 150 MPa

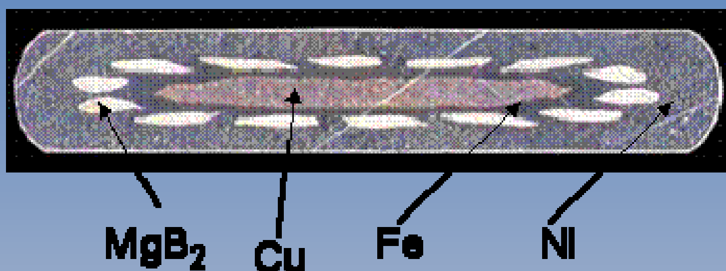


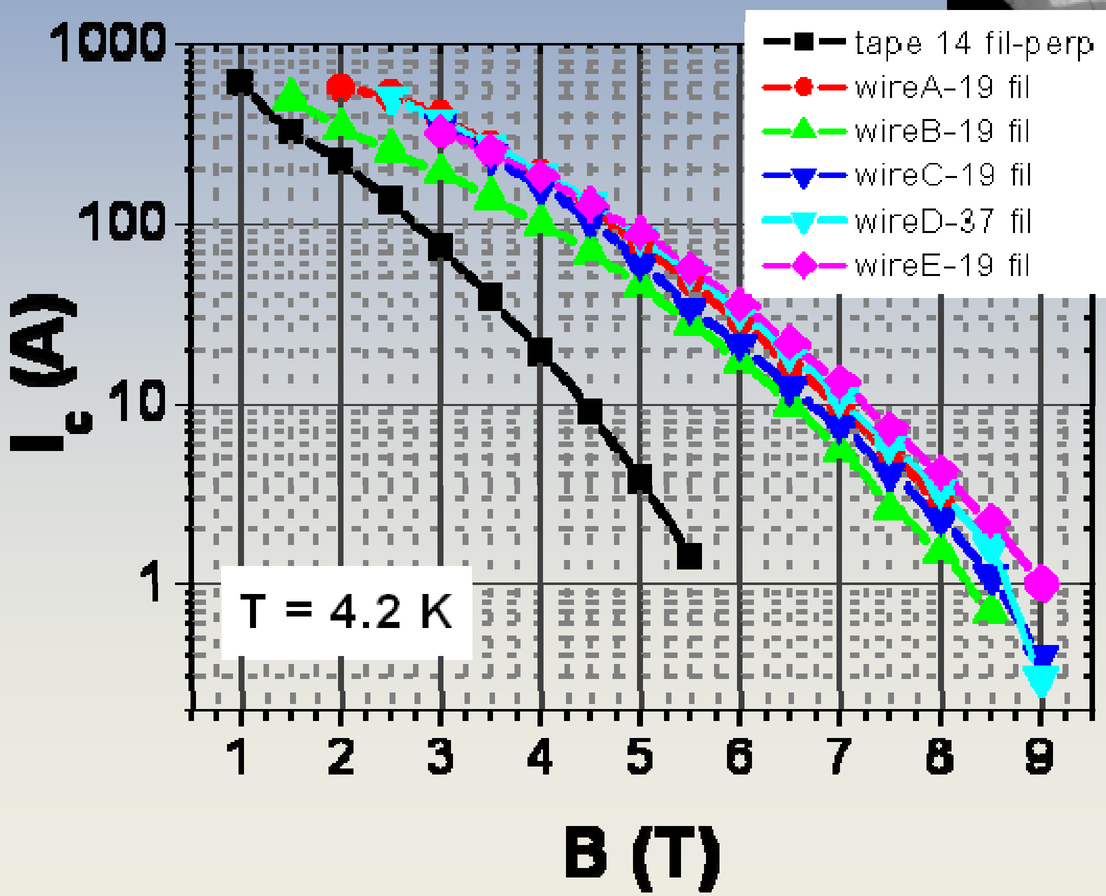
A total of 50 lengths of 1.7 Km each have been successfully produced and tested until Nov. 2006

They have been used for two Open MRI systems

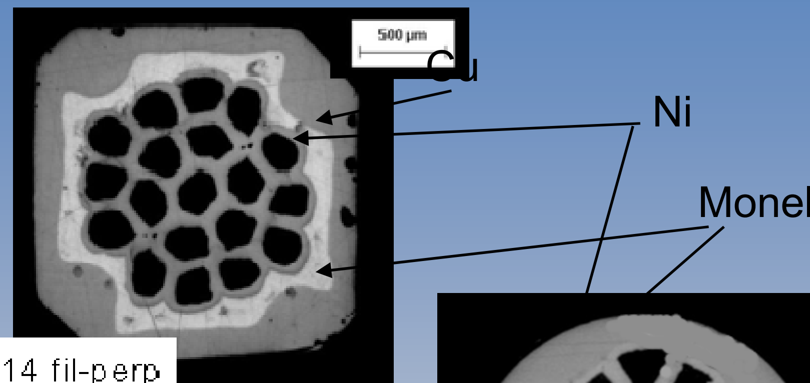
Optimisation of the wires fabrication by varying sheaths, geometry of the conductor,…

'Standard'Tape-14 filam-Cu stab

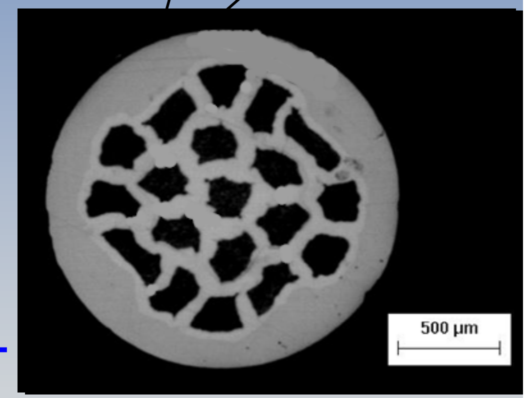




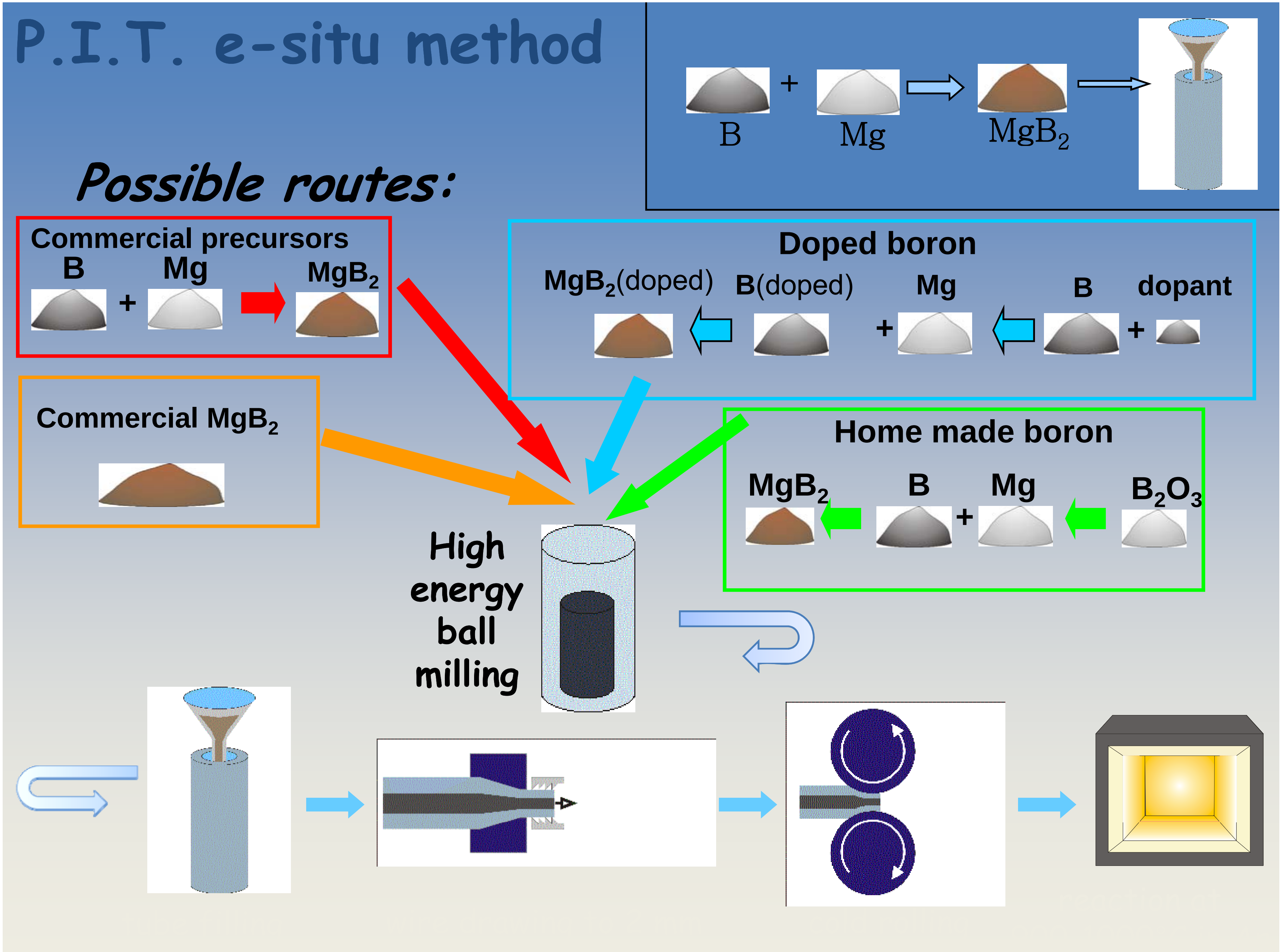
Wire B
37 filam
Cu stab



Wire C
19 filam
no Cu
up to 61



Going from flat tape to round-square wires cleans up conductor anisotropy, and the field dependence of I_c improves accordingly

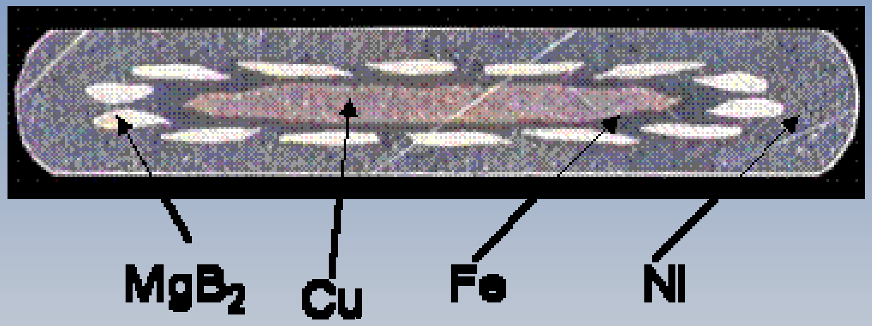

P.I.T. e-situ method
B
+
Mg
MgB$_2$
Possible routes:
Commercial precursors
B
Mg
MgB$_2$
+
Doped boron
MgB$_2$(doped)
B(doped)
Mg
B
dopant
+
+
Commercial MgB$_2$
Home made boron
MgB$_2$
B
Mg
B$_2$O$_3$
+
High energy ball milling

Progress in the I_c of the flat tape conductor in multi Km-length

'Standard'Tape-14 filam-Cu stab

3.6 x 0,65 mm

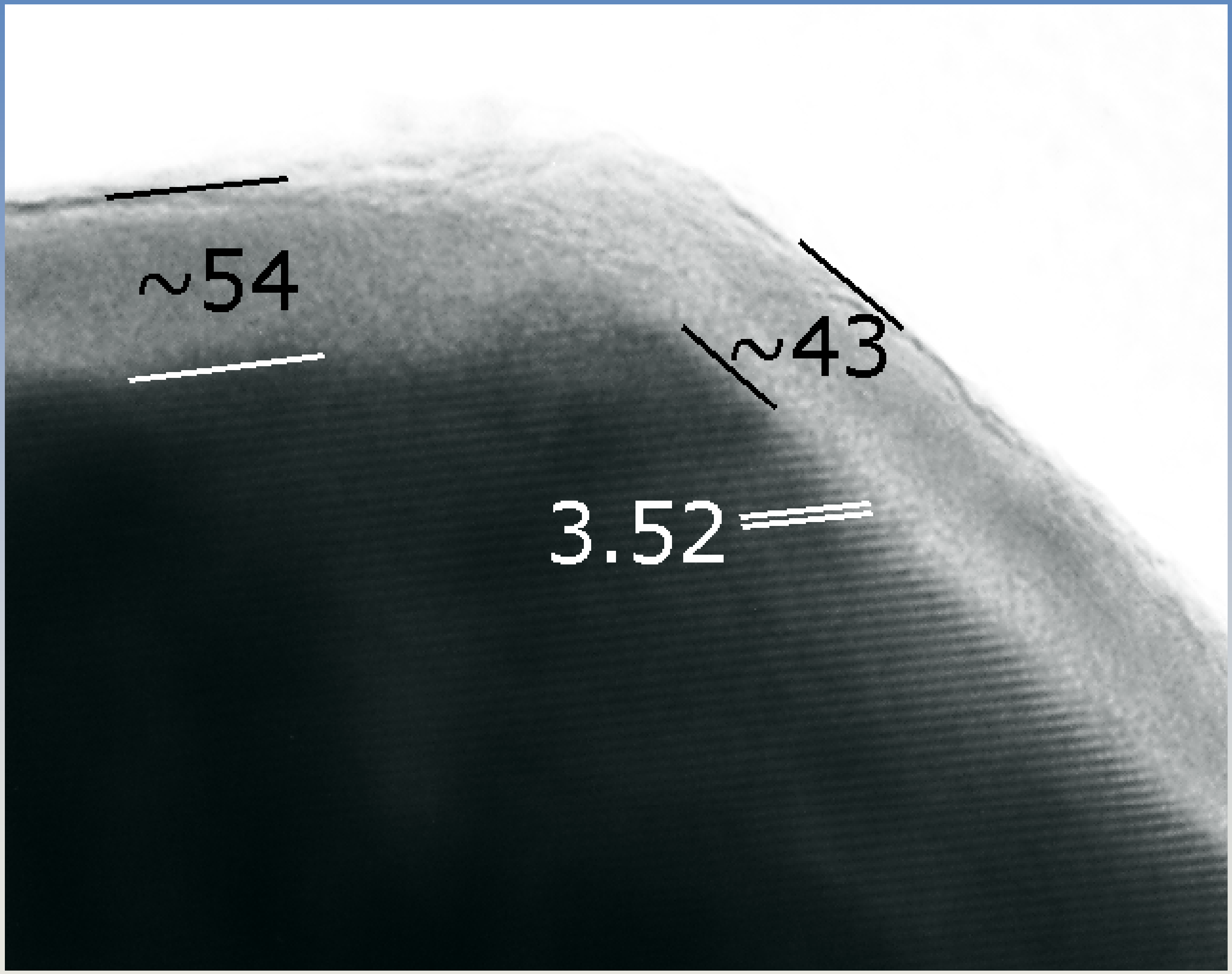
2.3 mm2



With Monel sheath minimum bending radius 30 mm

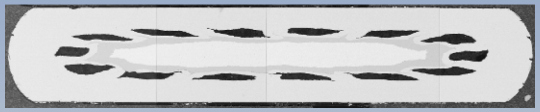
Time	Process	20K, 1 Tesla	20K, 2 Tesla
2006	Standard, 8.5 % filling factor	200	65
Beginning 2007	Improved cold working	250	75
End 2007	Controlled atmosphere	330	80
Today	Increased filling factor to 10.5%	390	95
Mid 2008	Improved MgB2 reaction path	500	150
End 2008	MgB2 ball milling and doping	>> 500	>250

MgB_2 grains are covered by 5 nm of MgO layer within 2 hours of exposition of powders to air (this layer has a thickness ~ ξ)

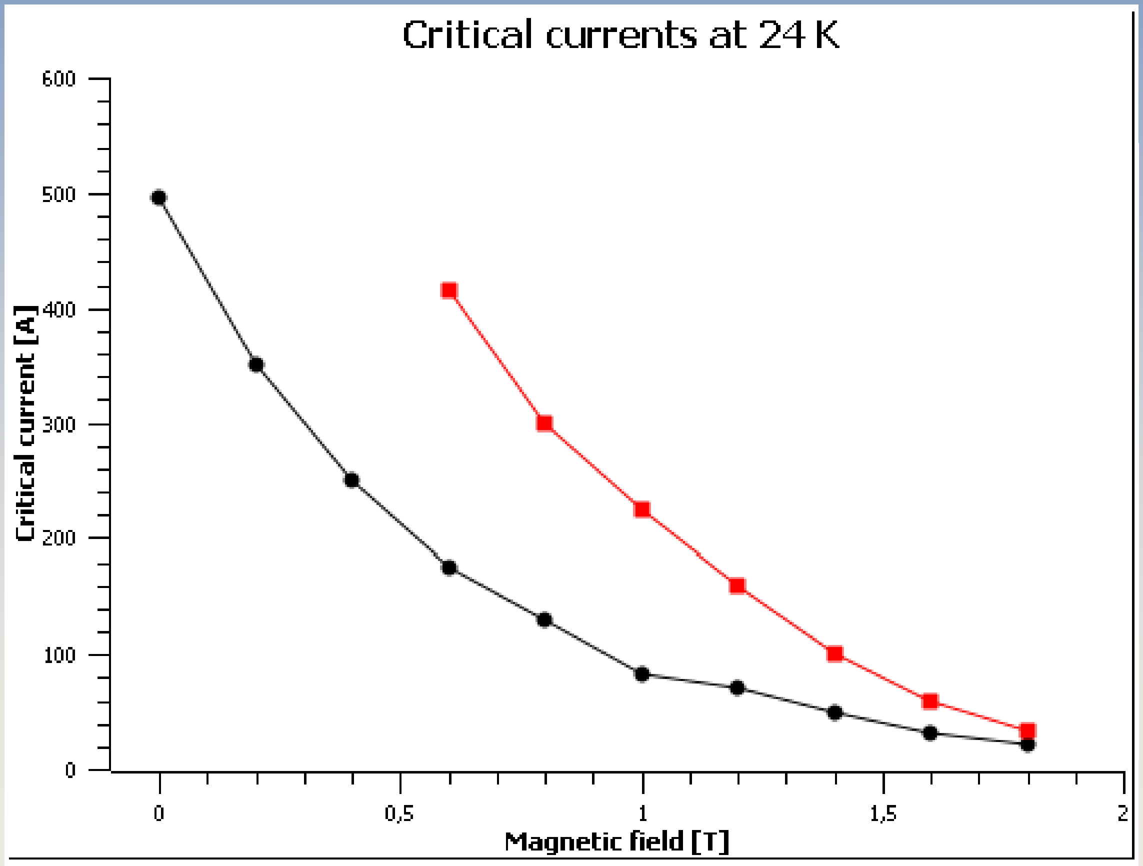


Working in Oxygen-cleaner conditions is mandatory!

Critical current improvement followed by inert-atmosphere handling

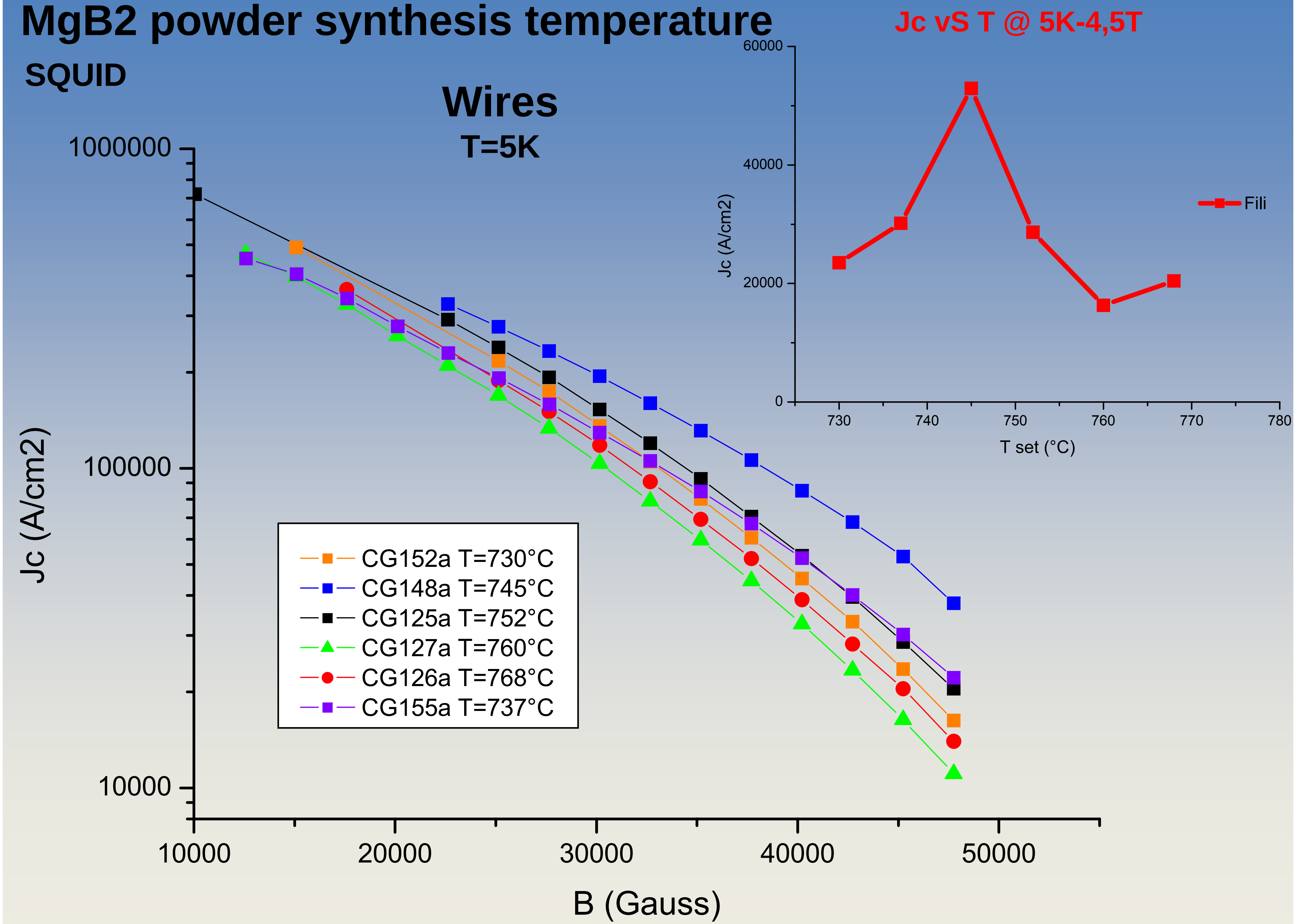


I_c is improved by a factor larger than 2 at virtually all fields just by inert atmosphere powder handling during the entire process



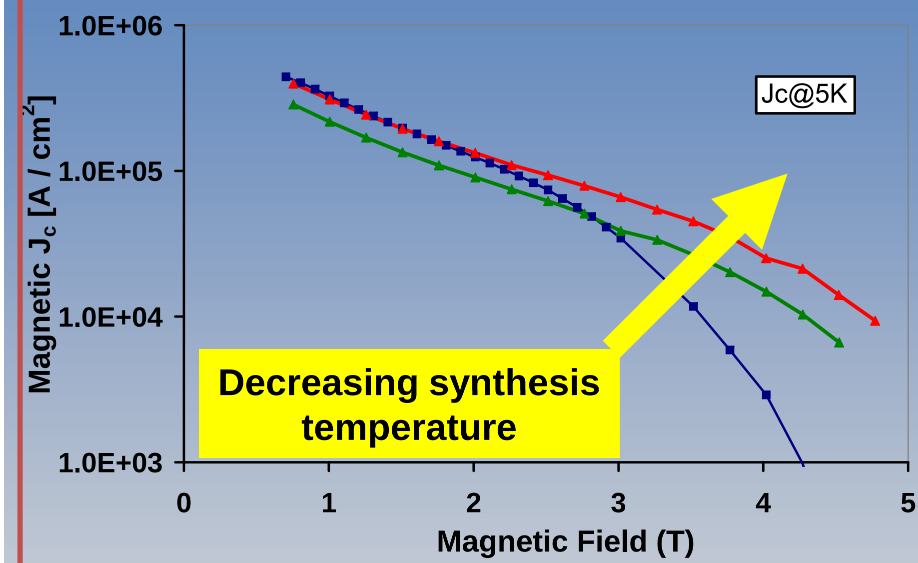
MgB2 powder synthesis temperature

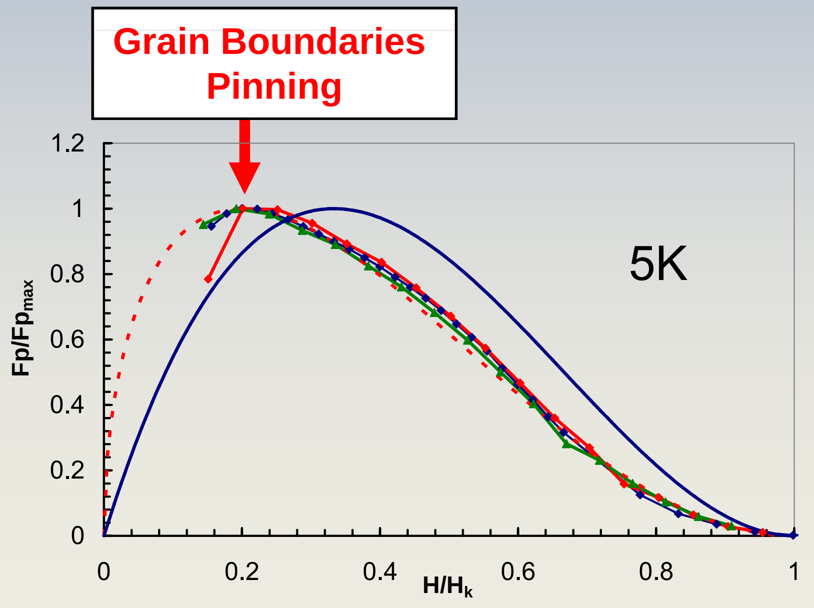
SQUID



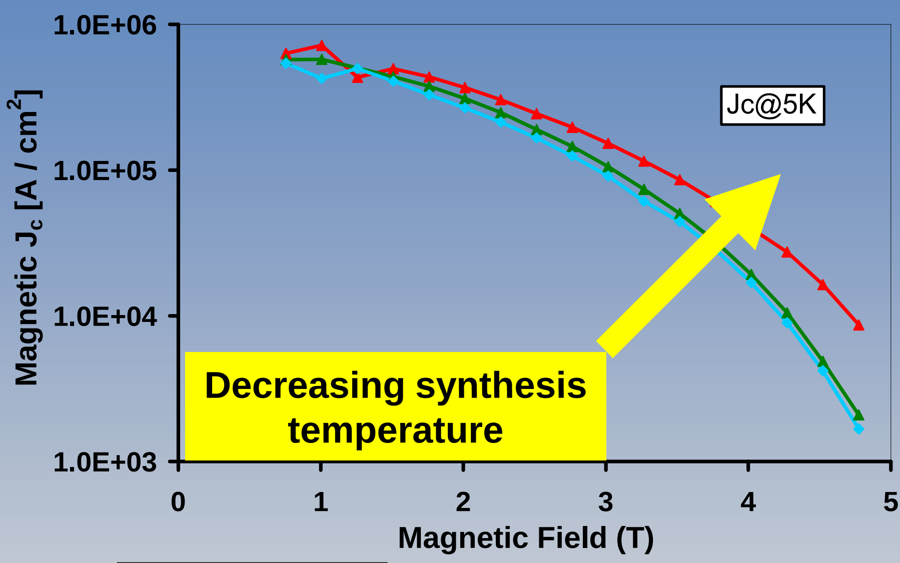
Effect of synthesis temperature

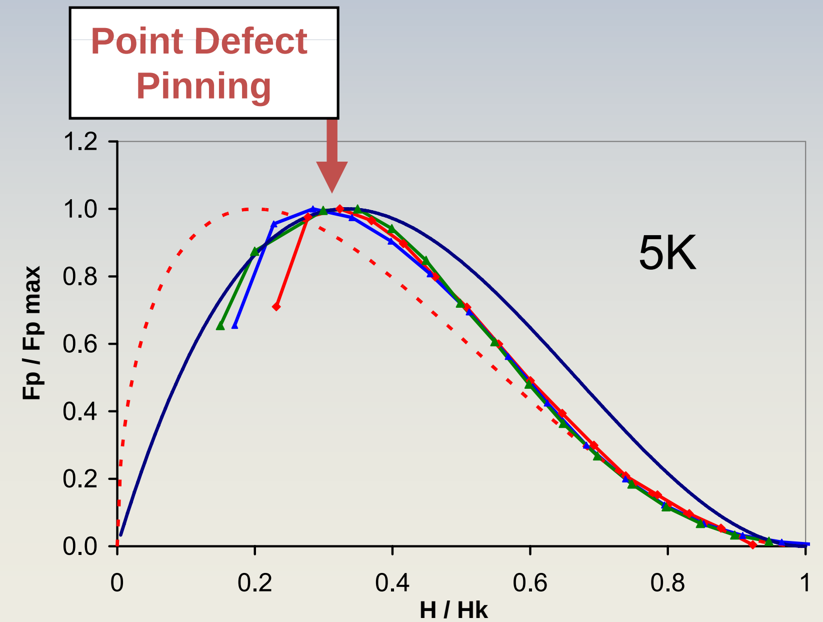
Not controlled atmosphere





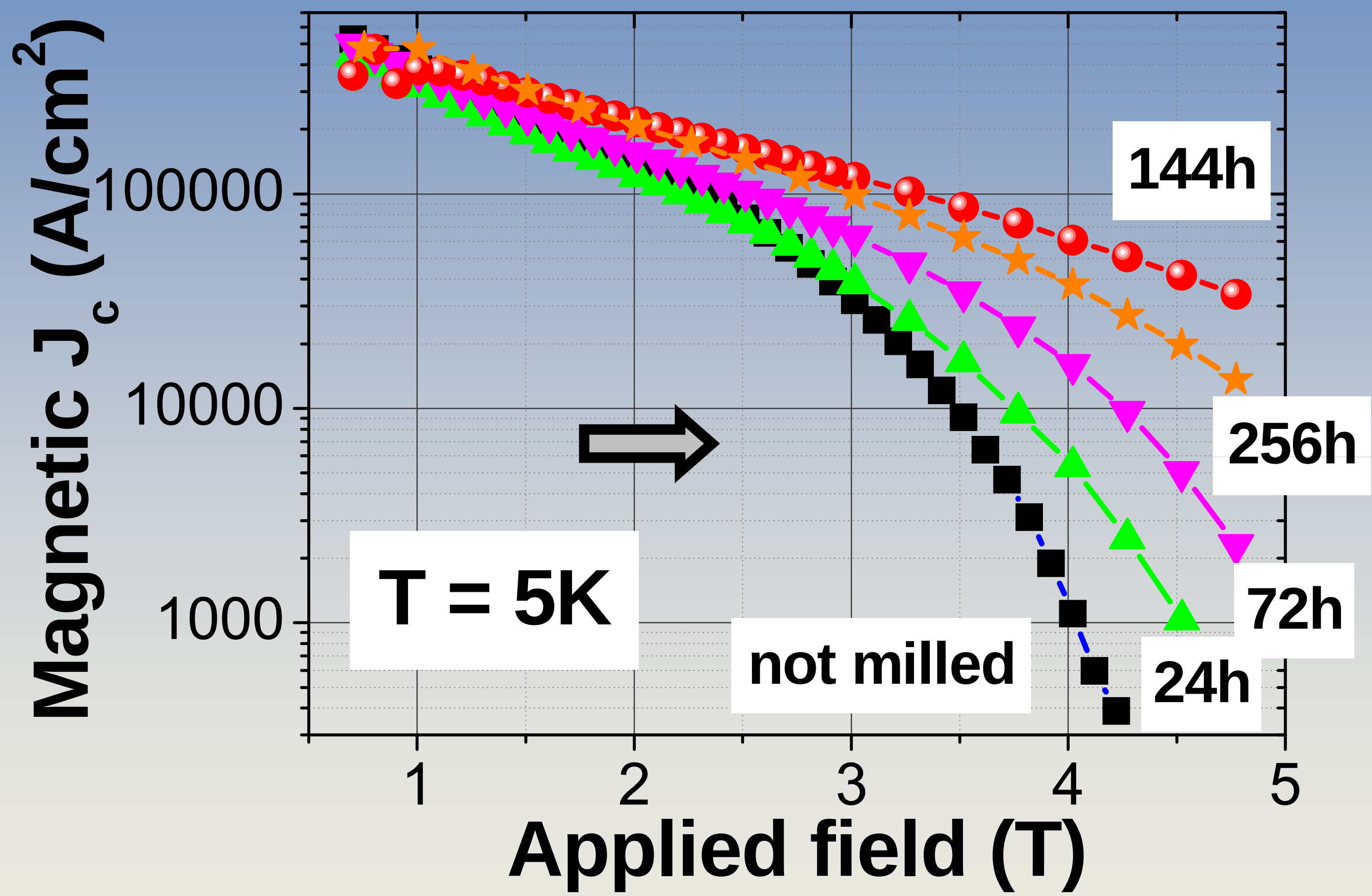
Glove box

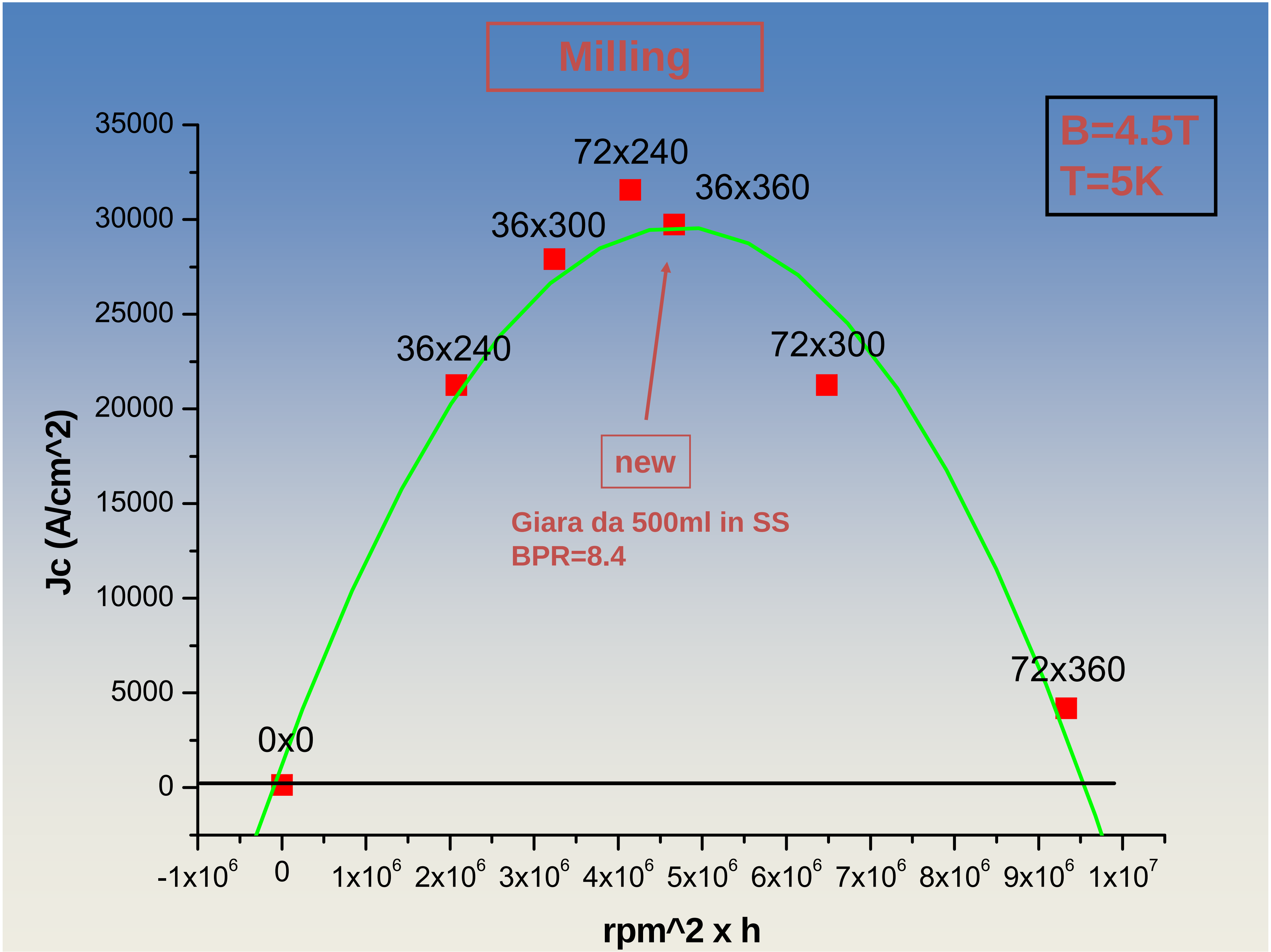




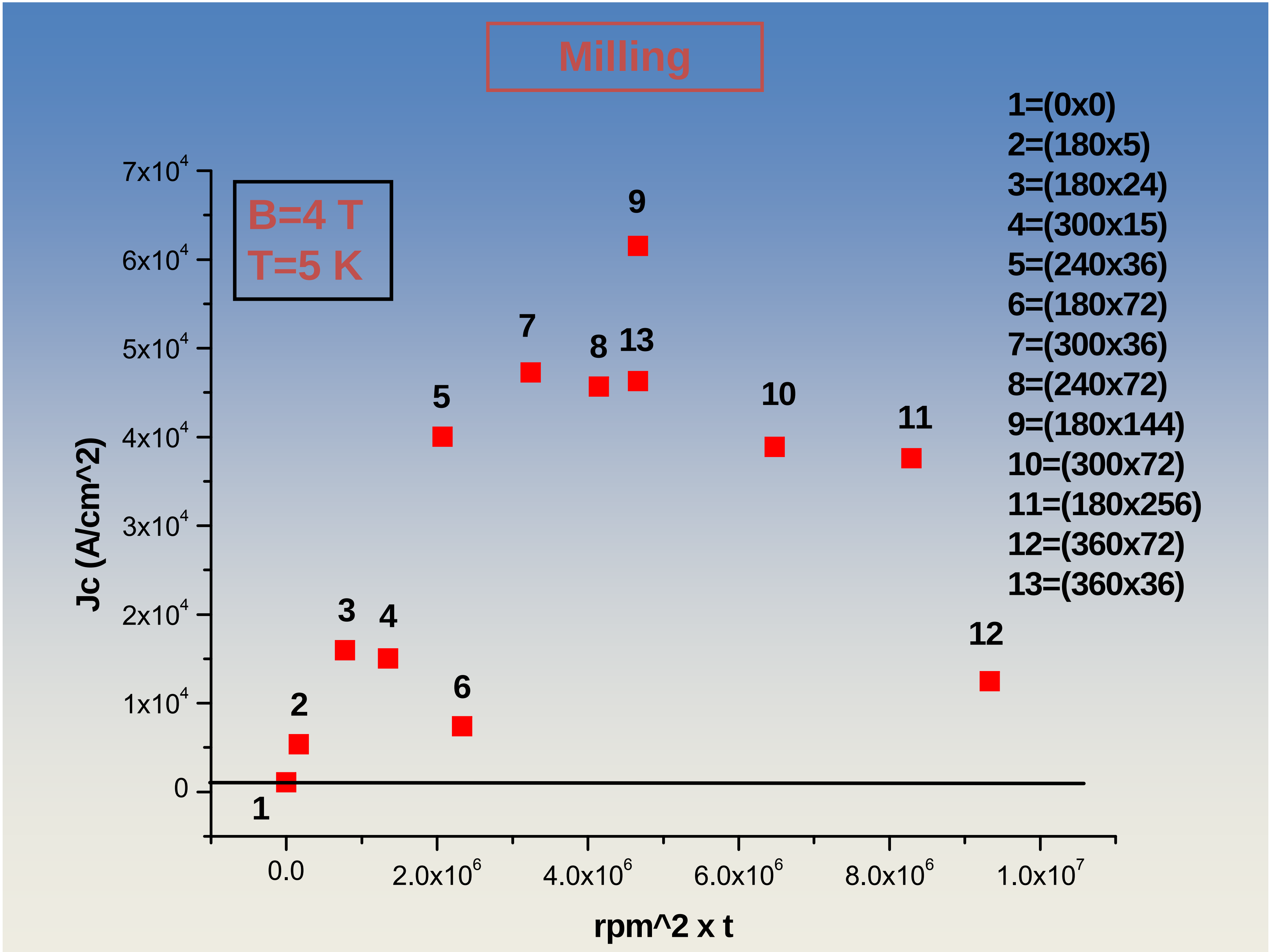
The effect of high energy ball milling is evident

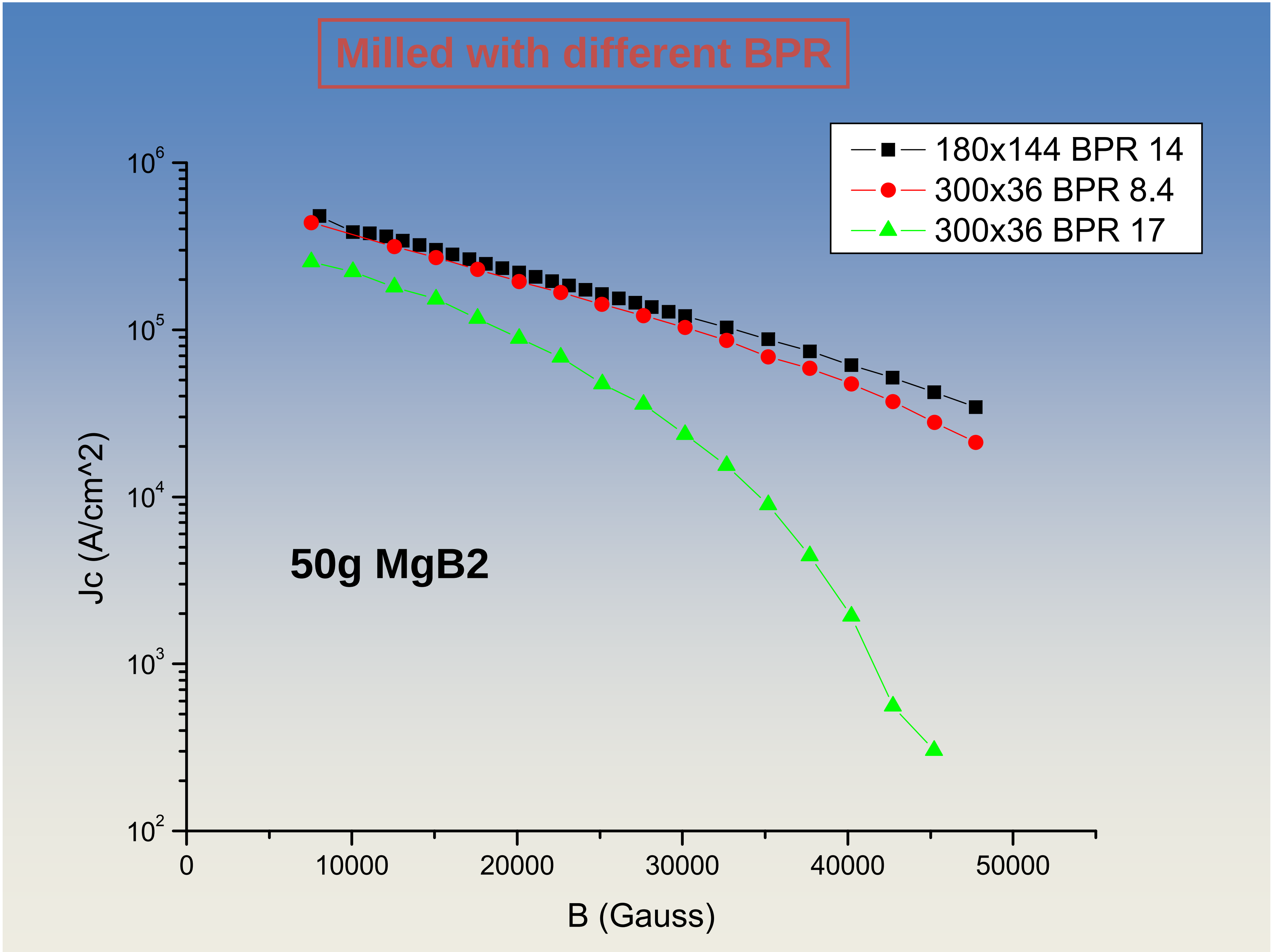
To increase the milling time (up to a certain value) – the tightness of the jars needs to be improved on longer times





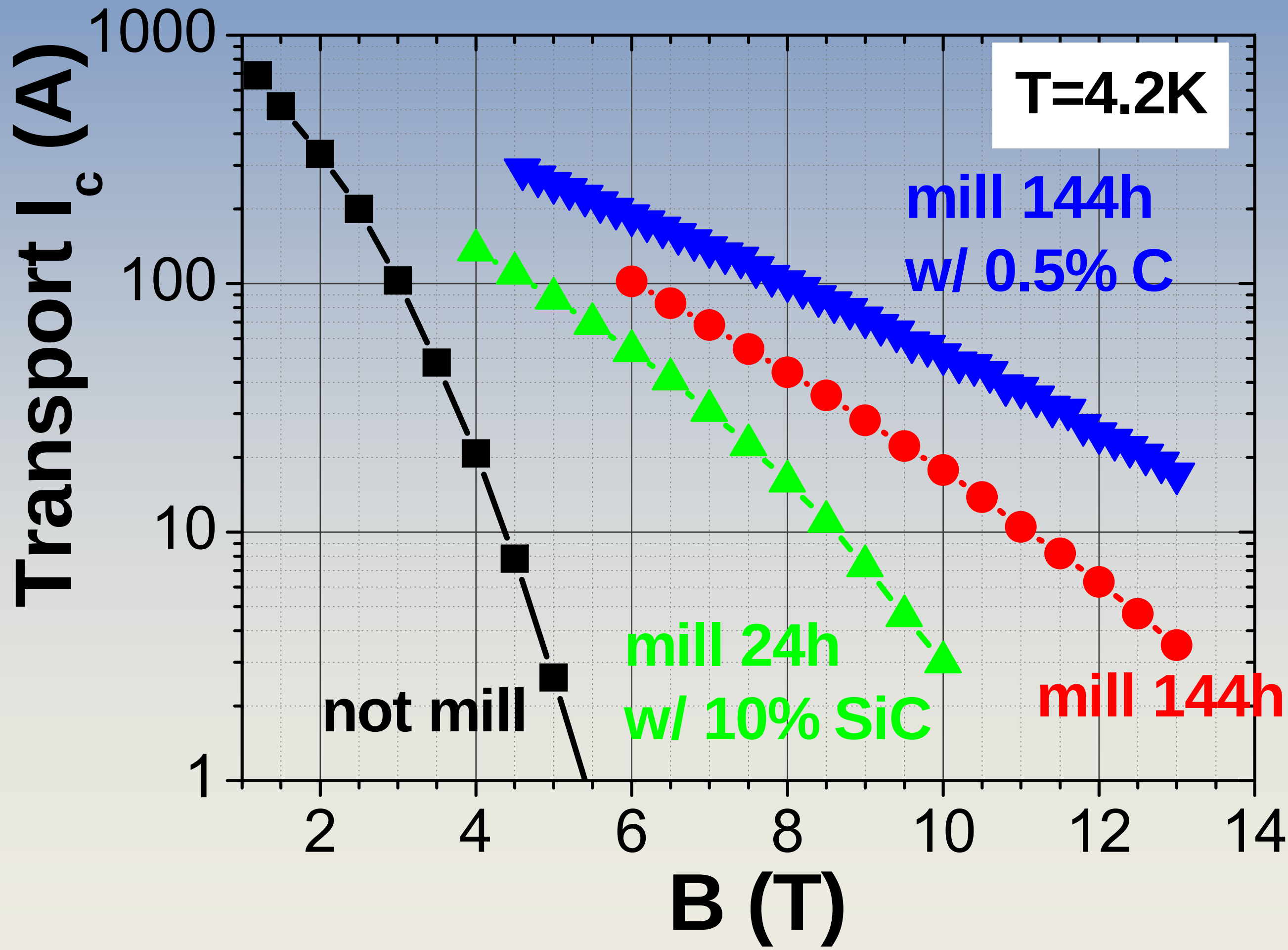
Milling
B=4.5T
T=5K
Jc (A/cm^2)
rpm^2 x h
72x240
36x360
36x300
36x240
72x300
72x360
0x0
new
Giara da 500ml in SS
BPR=8.4
35000
30000
25000
20000
15000
10000
5000
0
-1x10^6
0
1x10^6
2x10^6
3x10^6
4x10^6
5x10^6
6x10^6
7x10^6
8x10^6
9x10^6
1x10^7


Milling
B=4 T
T=5 K
1=(0x0)
2=(180x5)
3=(180x24)
4=(300x15)
5=(240x36)
6=(180x72)
7=(300x36)
8=(240x72)
9=(180x144)
10=(300x72)
11=(180x256)
12=(360x72)
13=(360x36)
Jc (A/cm^2)
rpm^2 x t
0
1x10^4
2x10^4
3x10^4
4x10^4
5x10^4
6x10^4
7x10^4
0.0
2.0x10^6
4.0x10^6
6.0x10^6
8.0x10^6
1.0x10^7

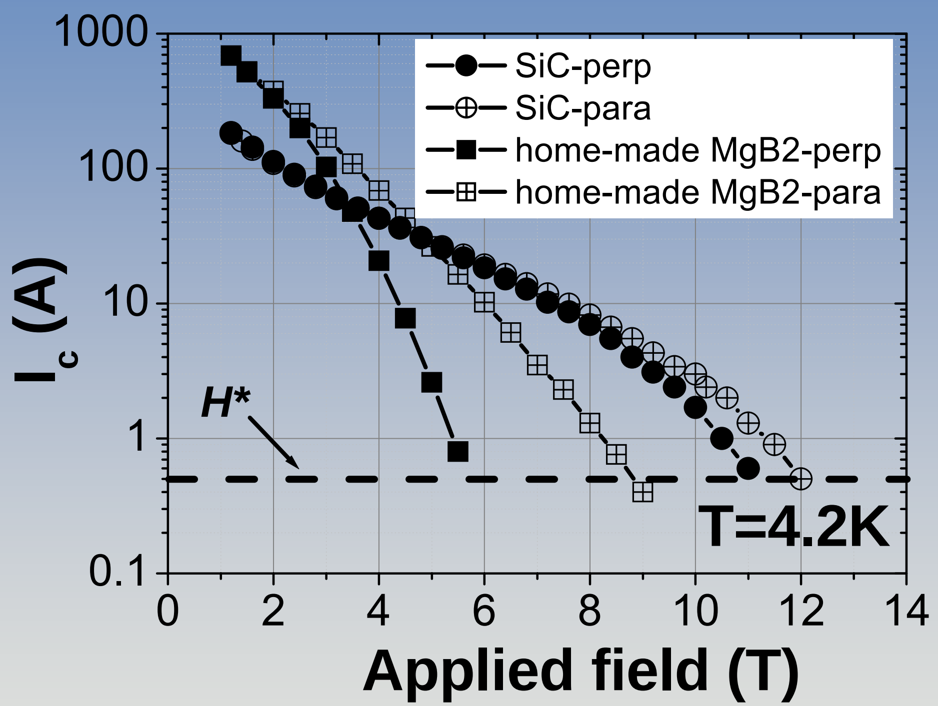


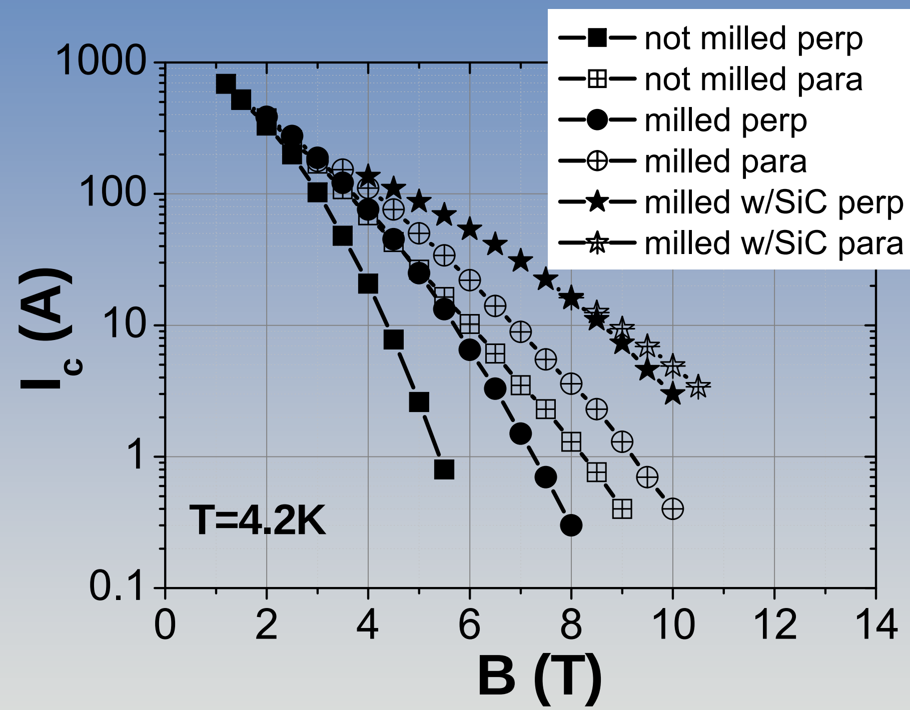
Milled with different BPR
180x144 BPR 14
300x36 BPR 8.4
300x36 BPR 17
50g MgB2
Jc (A/cm^2)
B (Gauss)
10^6
10^5
10^4
10^3
10^2
0
10000
20000
30000
40000
50000

Carbon additions can be also introduced during ball milling. Because it does not enter MgB_2 in a very uniform way by such a process, it is benificial if it is added to a very low levels.



Doping with ex-situ is underway



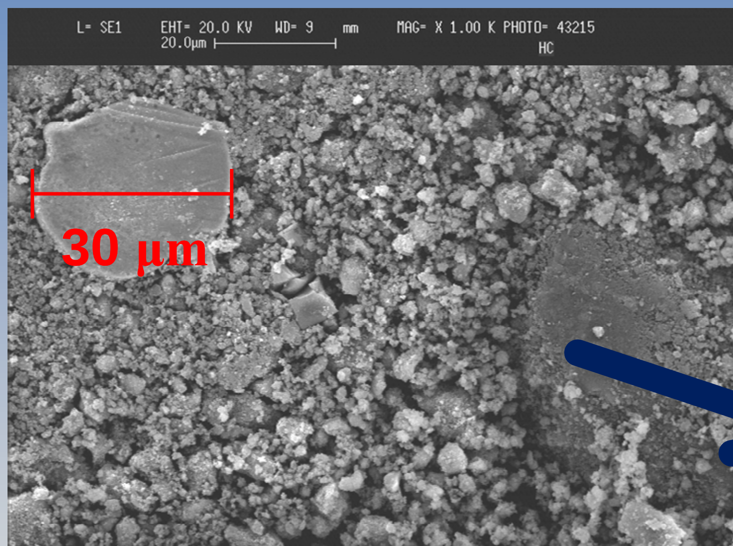


Doping with nanosized SiC is effective provided that it is added to the Boron powders prior to MgB_2 synthesis

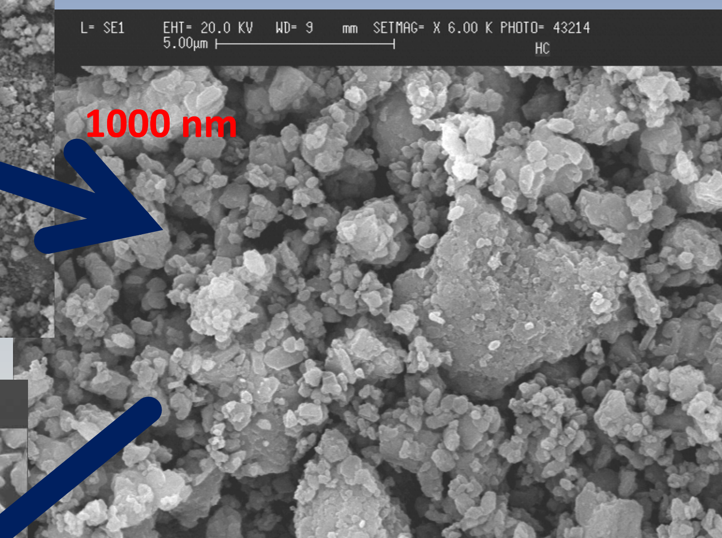
Further improvement is expected while SiC is added to optimized milling process

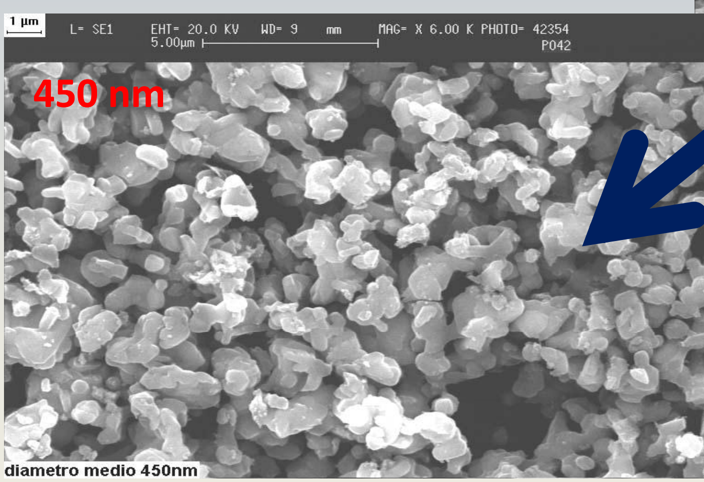
Control of powder production process is crucial to achieve optimal particle size

Commercial MgB_2



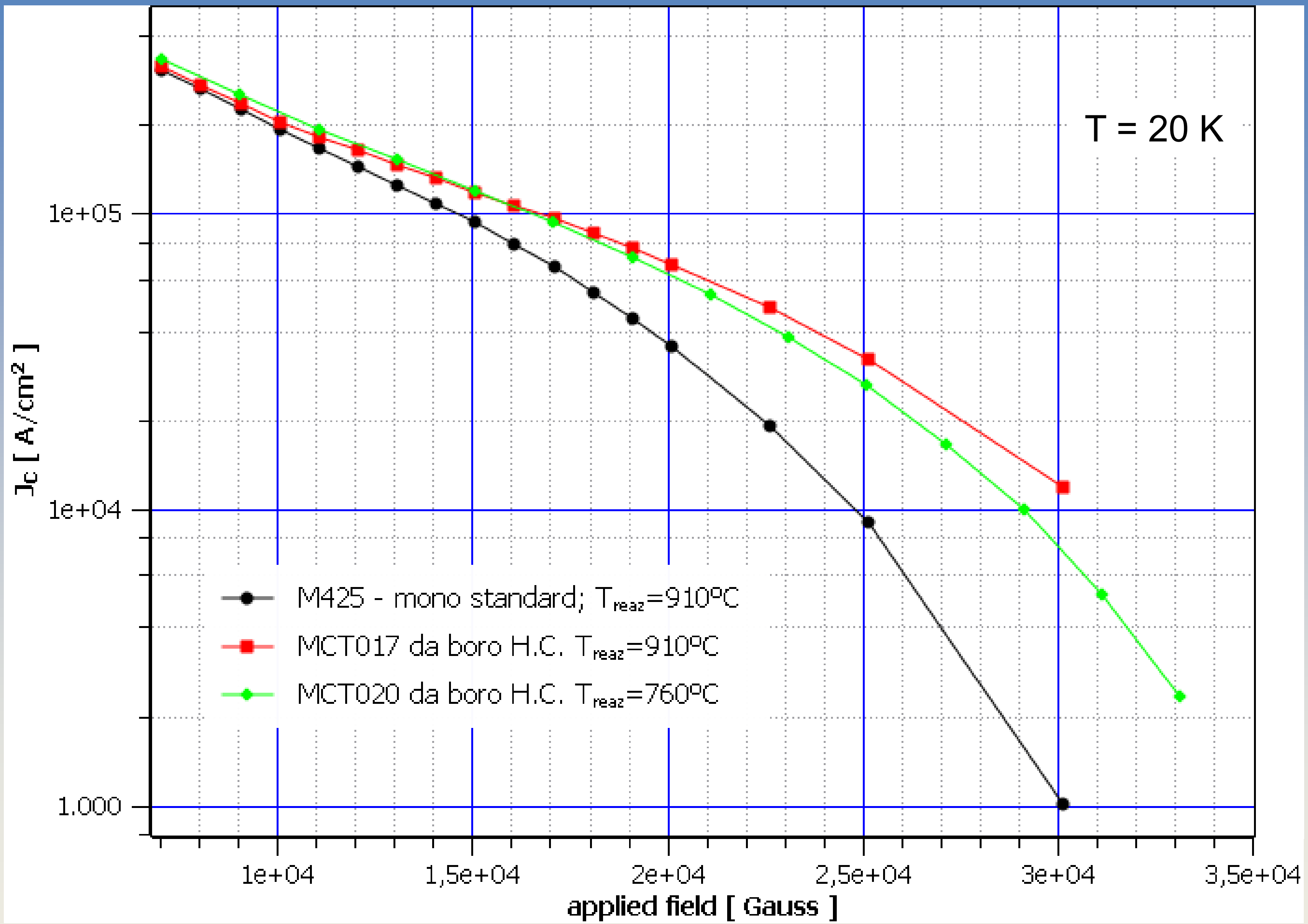
MgB_2 from commercial Boron





MgB_2 from own Boron

SQUID measurements



What is necessary to do to meet current wire demands?

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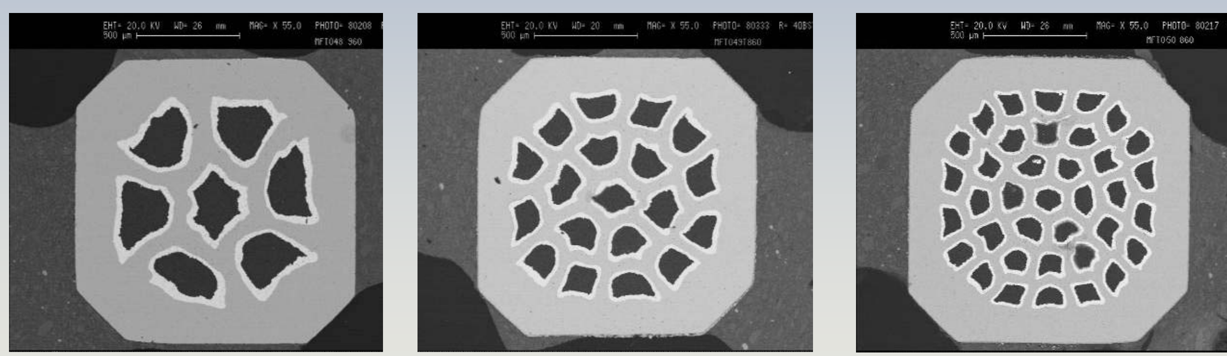
Some applications do not need better powders than today's production (dedicated low-field MRI, FCL, CERN), only more engineered conductors are preferrable – strong activity is ongoing to reach targets over long lengths



Fully non-magnetic, high resistive matrix, twisted, for low-AC loss applications

What is necessary to do to meet current wire demands?

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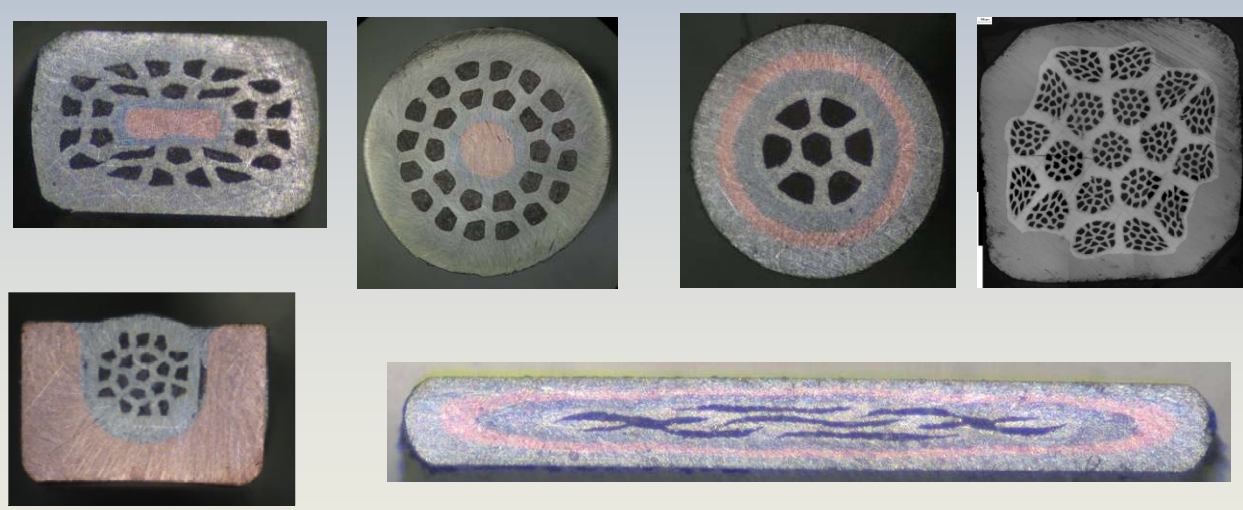
Most of the applications do need better powders than today's production in very large quantities, as well as more engineered conductors are preferrable – the last point has been already addressed – wires are twisted with no degradation, and electrically insulated with different techniques as braiding, wrapping, etc.



All wires produced in Km-class length with no degradation

Materials cost estimate

- Boron
- Magnesium
- Other metals and alloys constituents of the wire

Compound	Typical batch of today (x Kg)
Amorphous Boron (97%)	250 €
Magnesium source (-325 mesh)	100 €
Pure Nickel	80 €
Pure Iron	1 €
Cu OFHC	10 €
SS 304	4 €

In a wire we have:

60% Ni

15% Cu

15% MgB_2

10% Fe

Materials cost target for large production volumes:

below **1 €/m**

MgB_2 wire technologies

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- The production of long length of MgB_2 wires has been demonstrated in the past years, with supply to ASG and other customers of about 150 Km of conductor

- In 2008 the wire production will be of about 200-300 Km, although our production capability, considering some additional limited investment, can be raised to >1'000 Km/year in 3-6 months time in the present production plant

- Survey of different technologies to produce wires (in-situ, ex-situ), and different ways to produce and improve B and MgB_2 powders is always active

- Most of today's effort is concentrated on reliability demonstration and on scaling-up technologies as much as possible in-house in order to produce enhanced MgB_2 in relevant quantities (> 10 Kg/day) using cost-effective technologies