The reactive Mg-Liquid infiltration to obtain long superconducting MgB_2 cables

G. Giunchi

EDISON SpA, R&D , Foro Buonaparte 31, 20121 Milano (Italy)

giovanni.giunchi@edison.it

Outline

- Wires by Reactive Mg-Liquid Infiltration
- Superconducting properties
- Long cables issues and options
- Conclusions

Reactive Liquid Infiltration (RLI): sample preparation

(EDISON Spa,Milano(I): EP 1390992, USP 6957480)

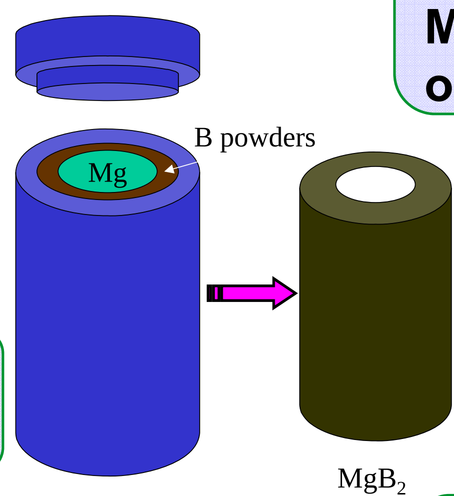
"In situ" process :

<u>NO external pressure</u>

Mg metal, in block form, and B powders (either crystal. or amorphous) are inserted in a SS container and sealed

Moderate thermal treatments: (700÷900 °C x 0.5÷3 h)

The liquid infiltration proceeds several cm in deepness and is almost gravity independent



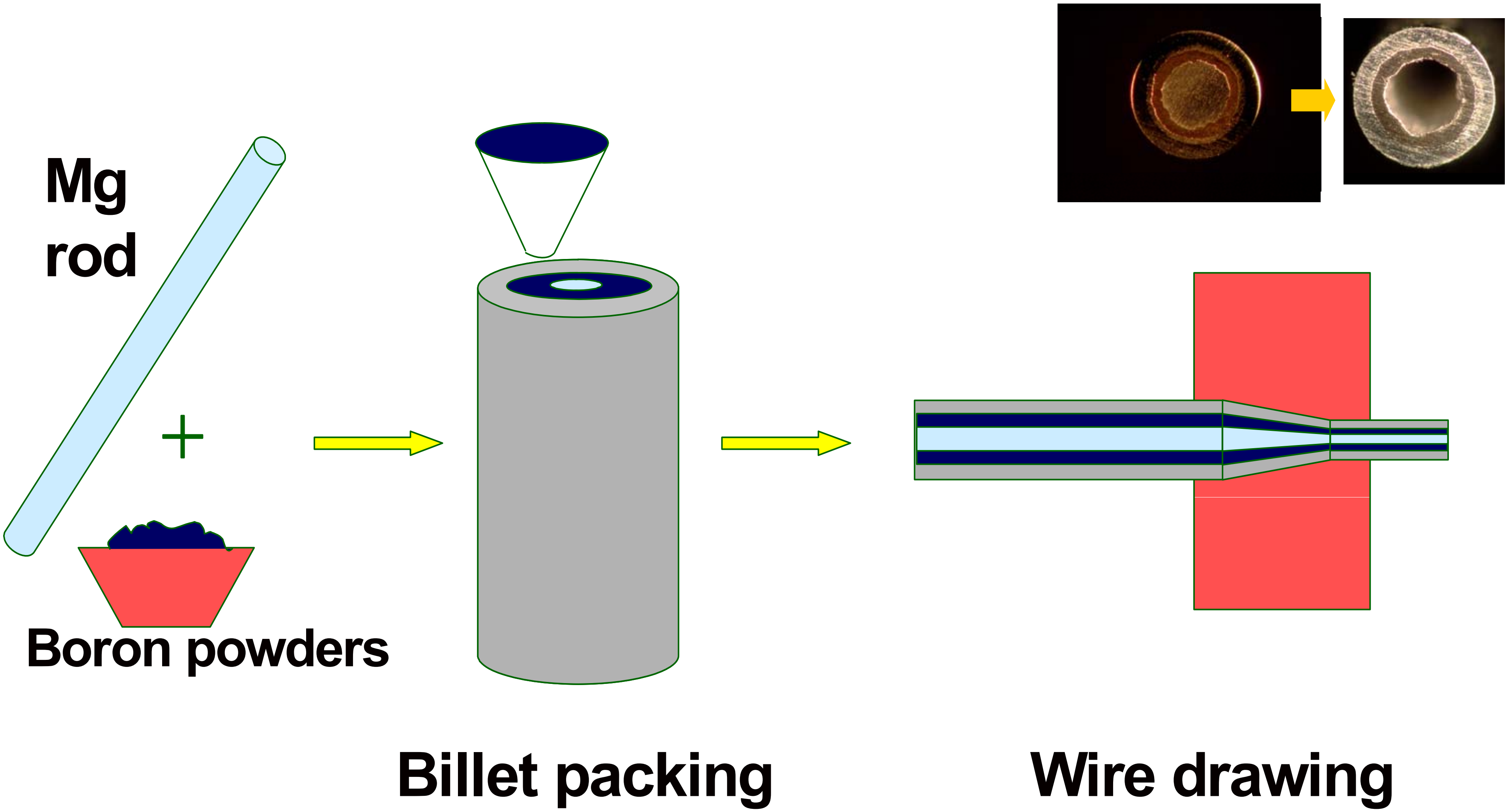
After reaction :

The B space results completely occupied by the MgB_2 and the Mg space remains almost free of products

High density (~2.4 g/cm^3) MgB_2 and near net shape manufacts

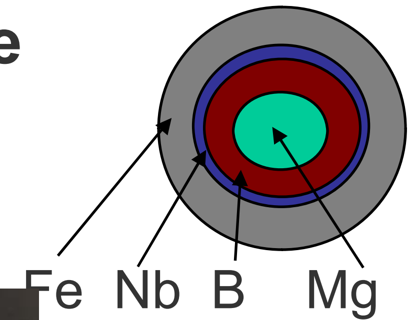
The morphology of the product is related to the grain size of the B powders

Precursor wire preparation



The hollow wire manufacturing by Mg-RLI

- Cold working of a composite billet , typically made as in Figure
- Possibility to assemble many billets for multiwire manufacturing and further cold working
- Thermal treatment



(a) (b)

Cross section optical images :
a) Precursor multifilament wire,
b) Superconducting hollow wire

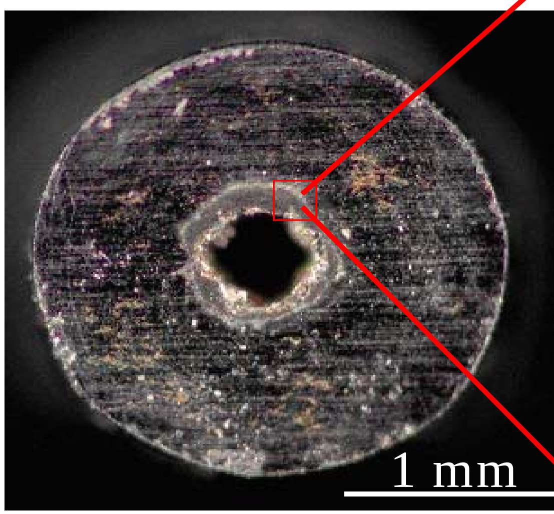
Monofilamentary hollow wire(2003), by Mg-RLI

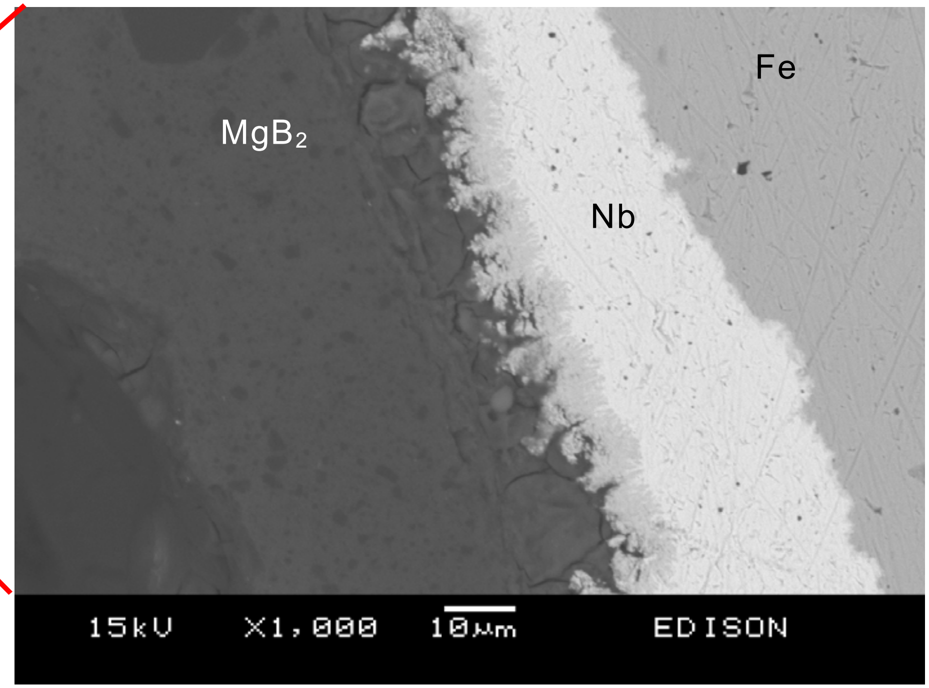
A precursor wire was prepared by insertion of a Mg rod, surrounded by microcrystalline B powders, in a Fe tube, internally lined with Nb foil. Thermal treatment at 900°C x 3 h

High J_c!

Low J_e !

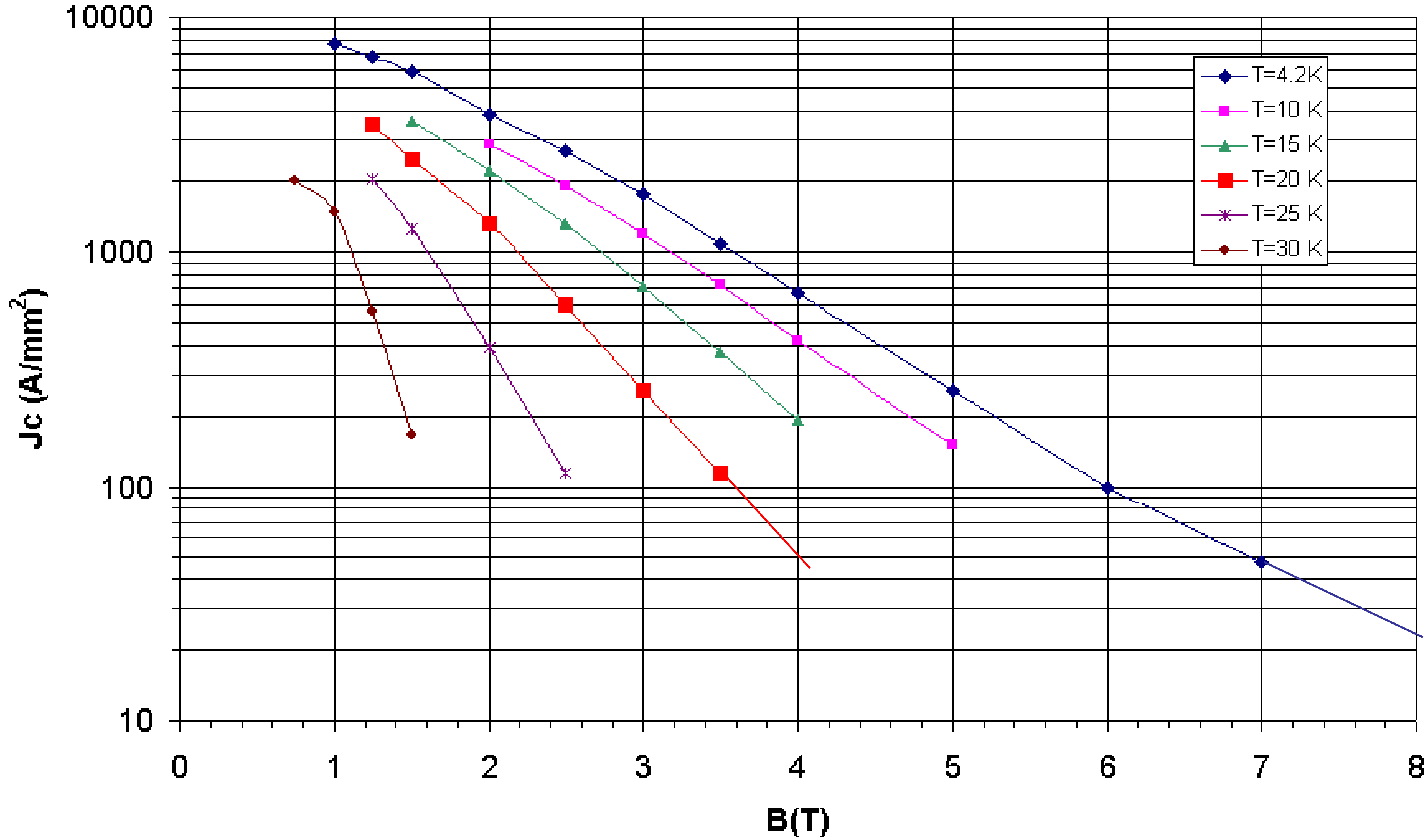
(Cross area: SC/tot≈0.026)





Cross section optical image   Backscattered electrons SEM image

Monofilamentary wire : Jc by transport measurements



G. Giunchi et al. *SuST, 16 (2003) 285–291*

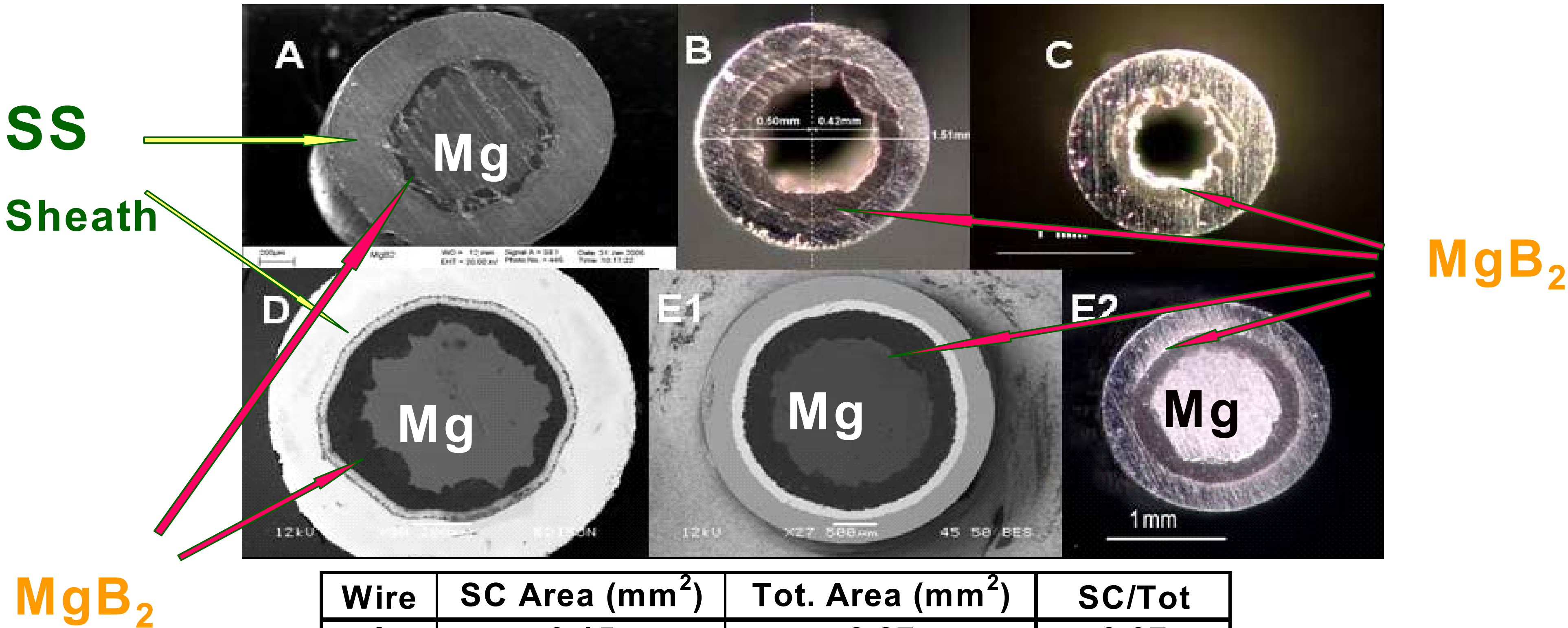
Wire preparation: actual variables

- Mg/B content (wt): 1.25 ÷ 1.59
- boron powders quality :
  amorphous /microcrystalline and purity degree
- C doping : **yes - not**
- Mg hole filling : **yes - not**
- Nb sheath interface : **yes - not**

Precursor wires characteristics

Wire	Mg/B (wt)	Diam. (mm)	B	C dop (6wt%)	Hole Filled	Nb
A	1.59	1.70	μCr	N	Y	N
B	1.36	1.51	Am	N	N	Y
C	1.25	1.51	μCr	N	N	N
D	1.25	1.30	μCr	N	Y	N
E1	1.33	3.20	Am	Y	Y	Y
E2	1.33	1.93	Am	Y	Y	Y

Cross sections of the SC MgB_2 wires



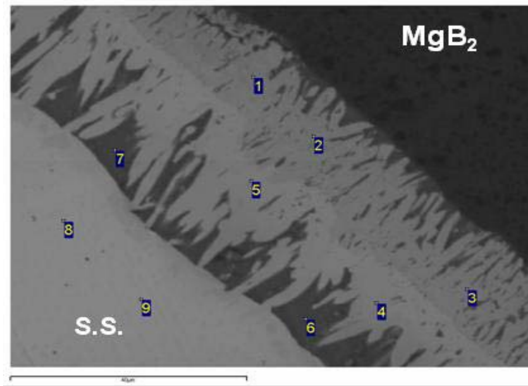
Wire	SC Area (mm^2)	Tot. Area (mm^2)	SC/Tot
A	0.15	2.27	0.07
B	0.23	1.80	0.13
C	0.40	1.80	0.22
D	0.37	1.31	0.28
E1	1.92	8.04	0.24
E2	0.75	2.93	0.26

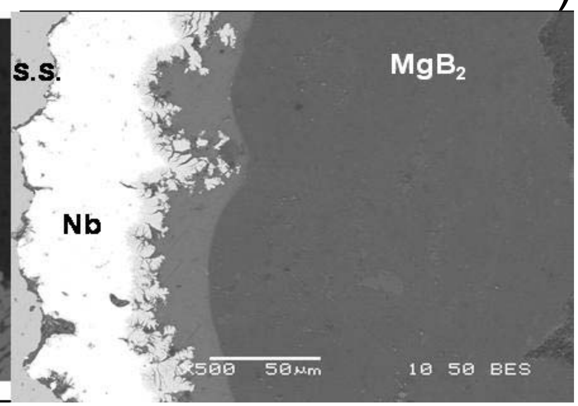
Micromorphology of the phases of MgB_2 wires by RLI

The interfaces between MgB_2 and the metallic sheaths

(Samples with the same thermal treatment: 900°C x 1 h)

Wire D :
(SS / Boron)



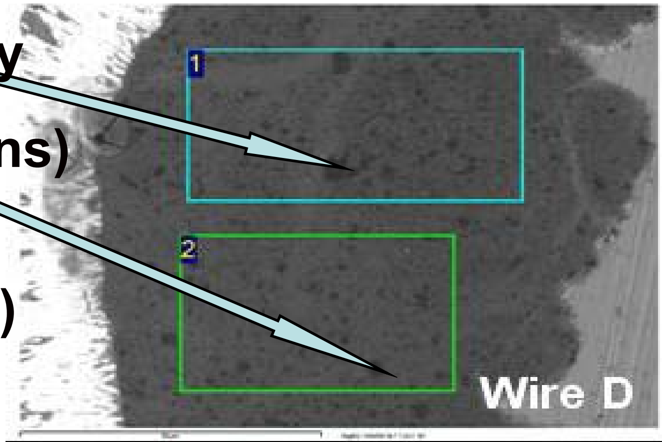


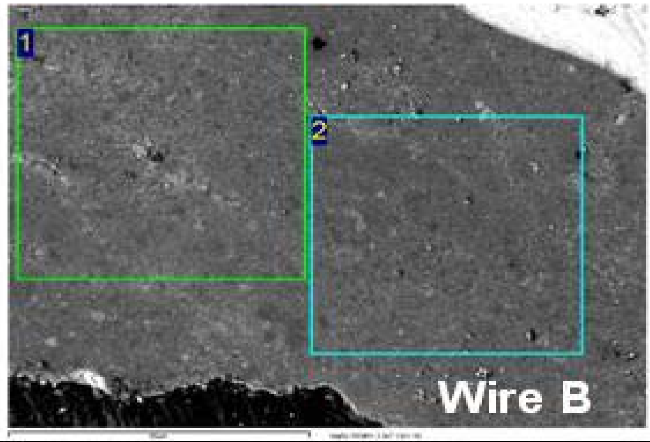
Wire B :
(SS / Nb /Boron)

The MgB_2 micromorphology and impurity phase Mg_2B_{25}

Mg_2B_{25} (impurity phase rich grains)

(averaged i.p. comp. ≈ 7mol%)

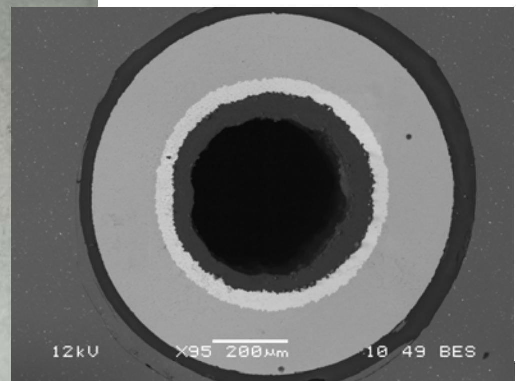




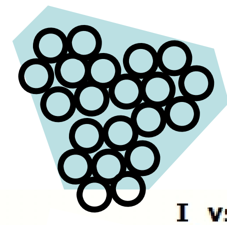
No i.p.

(averaged i.p. comp. ≈0.3mol%)

Mg- RLI Stranded Wires : Inductive method to measure Ic(B,T)

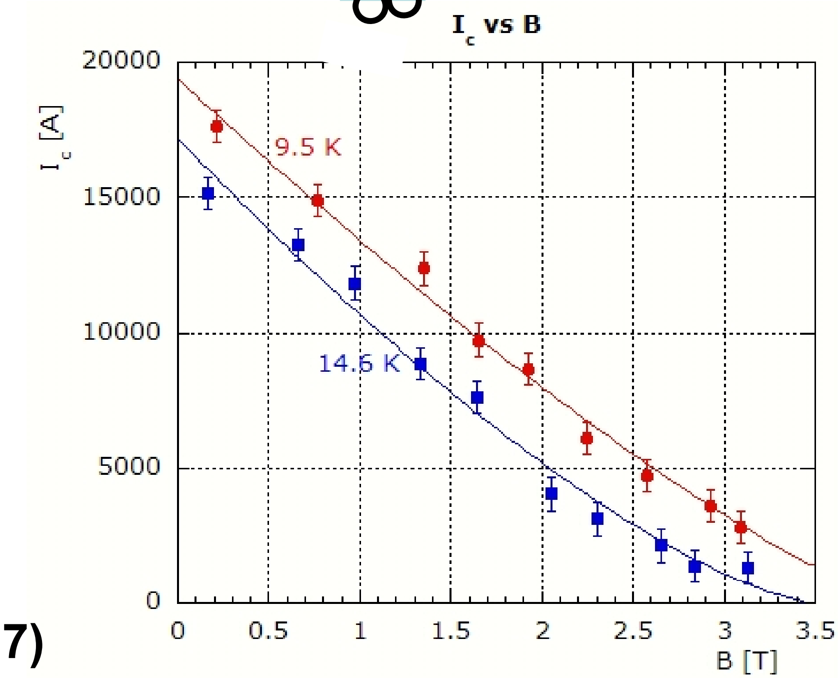


21 Wires (#T125) ; L=2 m
Stranded (3x7)
Twist pitch ≈50mm



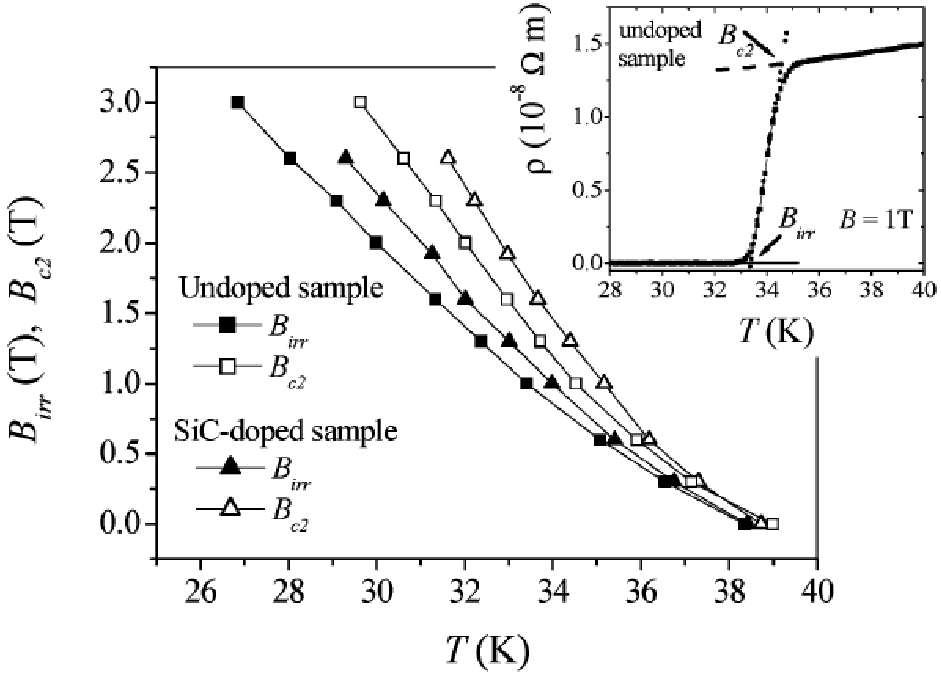
Tot area≈ 40 mm^2

SC area ≈ 2 mm^2



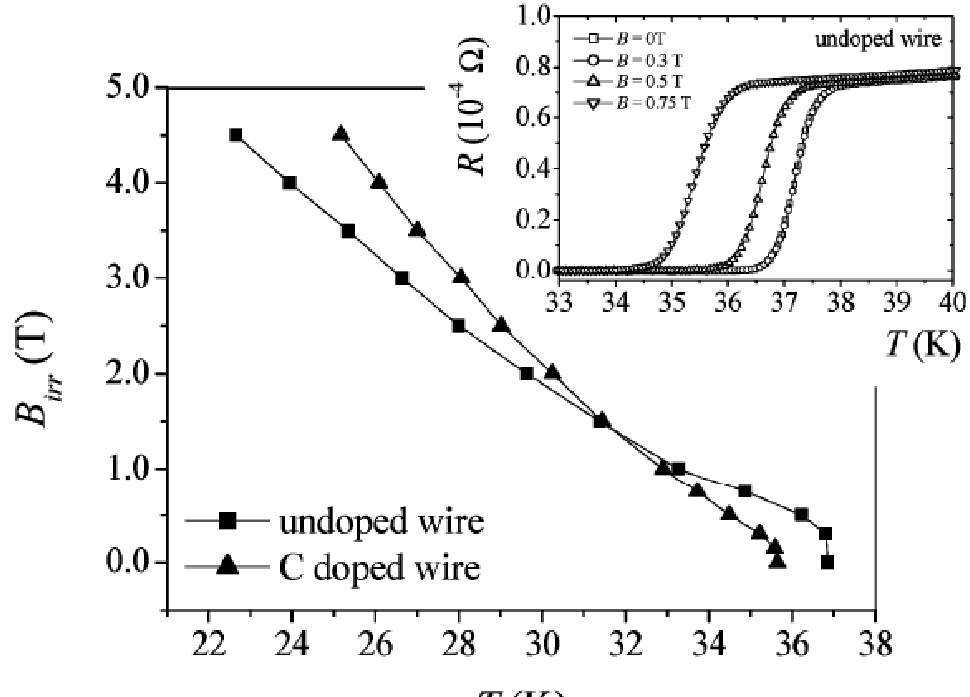
(R.Musenich,INFN,priv. comm.2007)

Doping MgB_2 by the RLI process



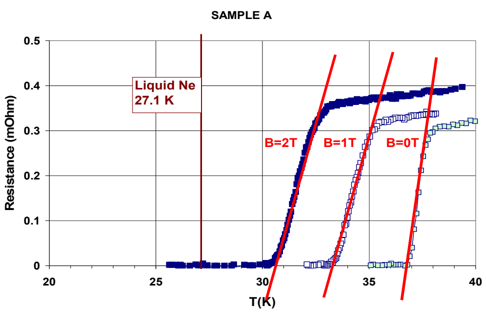
Bulk sample doped by 10% SiC nano powders

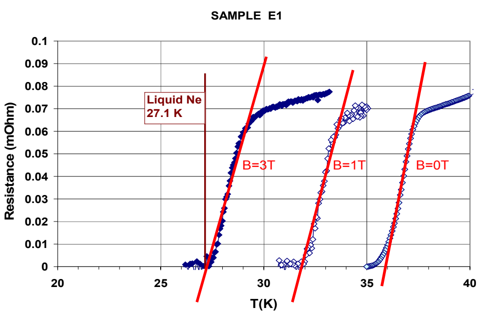
Wire doped by 6% C nano powders

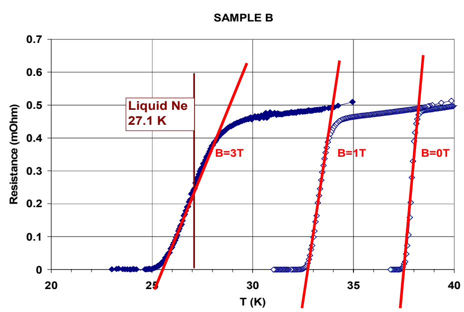


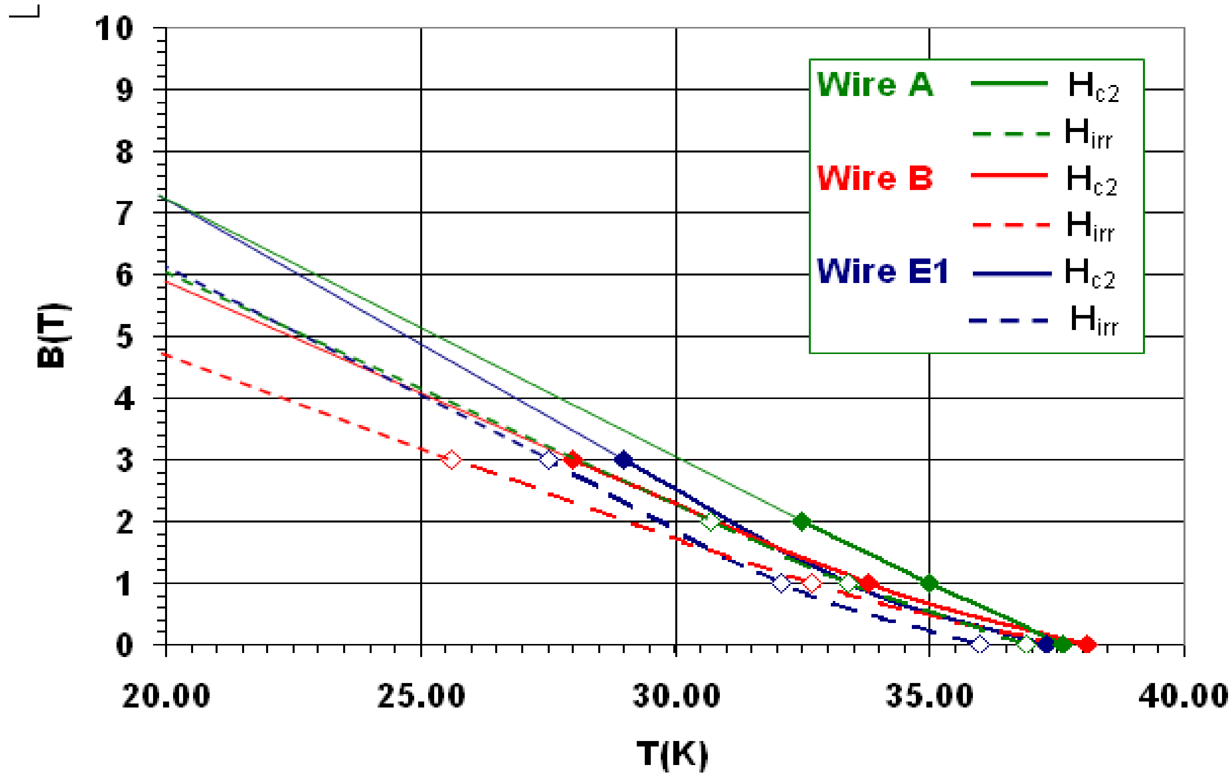
Gozzelino et al. IEEE Trans. on Appl. Supercond. 17, 2726-272(2007)

H_{irr},H_{c2} evaluation from resistivity measurements





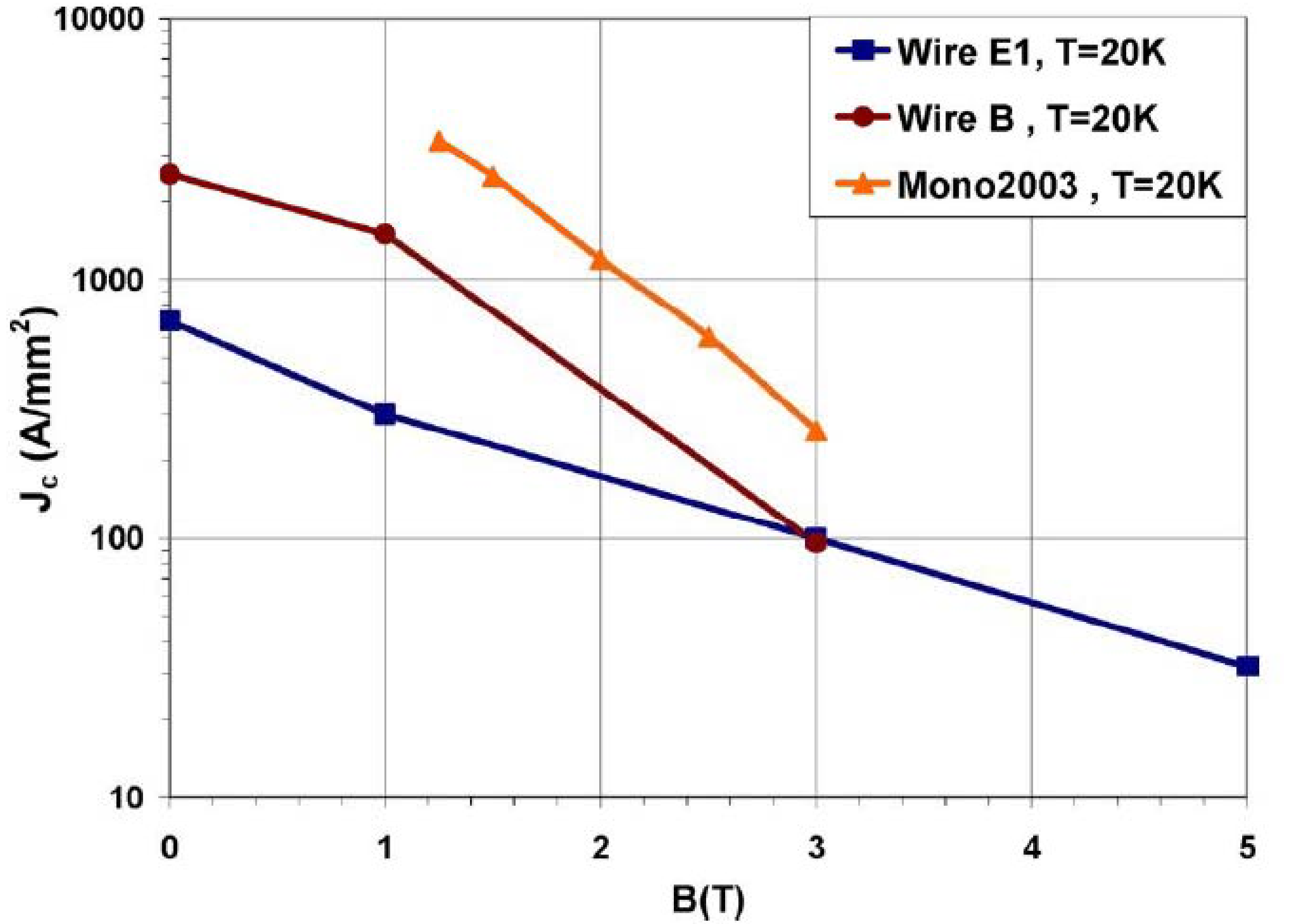




The in-field behavior goes in the order:

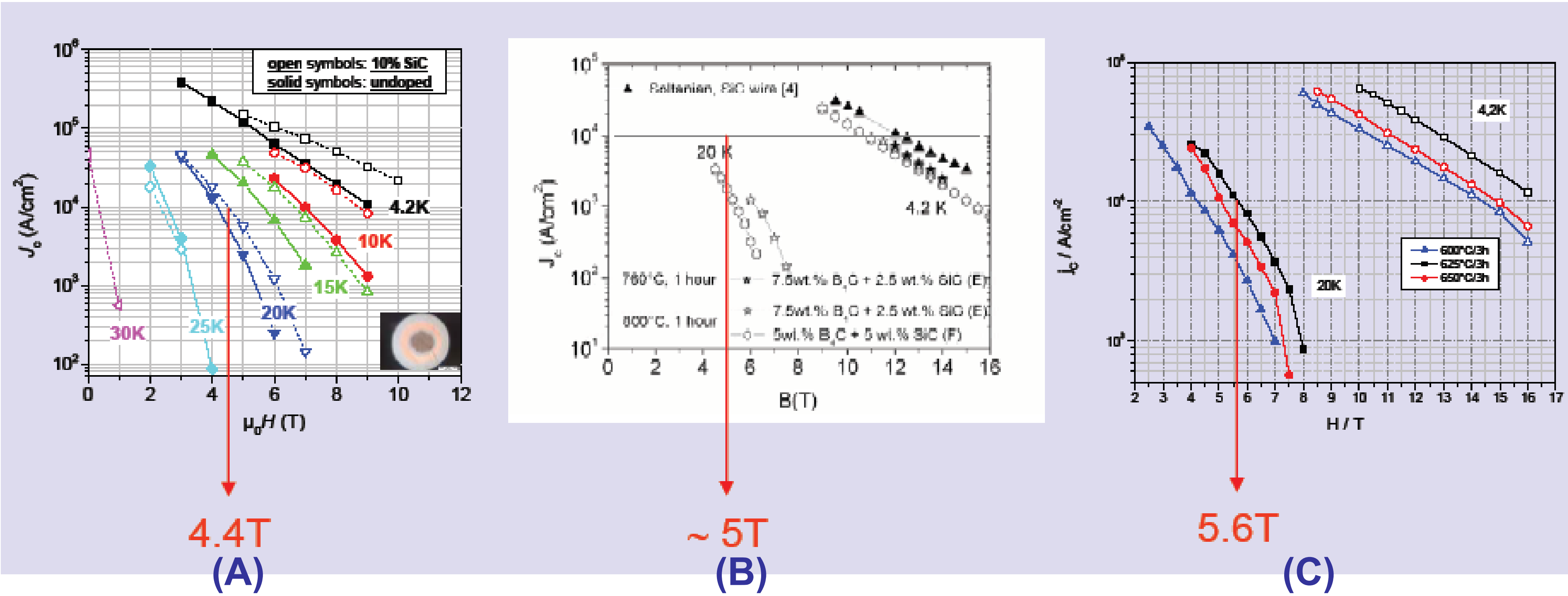
Wire E1(C dop.) > Wire A(i.p. dop.) > Wire B(w/o i.p.)

Mg-RLI wires: critical current density at 20K



E1 → B $_{am}$ + 6at%C ; **B** → B $_{am}$; **Mono2003** → B $_{\mu cr}$

MgB_2 wires : recent Jc comparison



A) SiC doped MgB_2-FZK Karlsruhe: Jc (20K,4T) = 20 kA/cm² ; Jc(4.2K,10T) = 20 kA/cm²

B) B_4C+SiC doped, Un. Geneva: Jc (20K,4T) = 7.5 kA/cm² ; Jc(4.2K,10T) = 15 kA/cm²

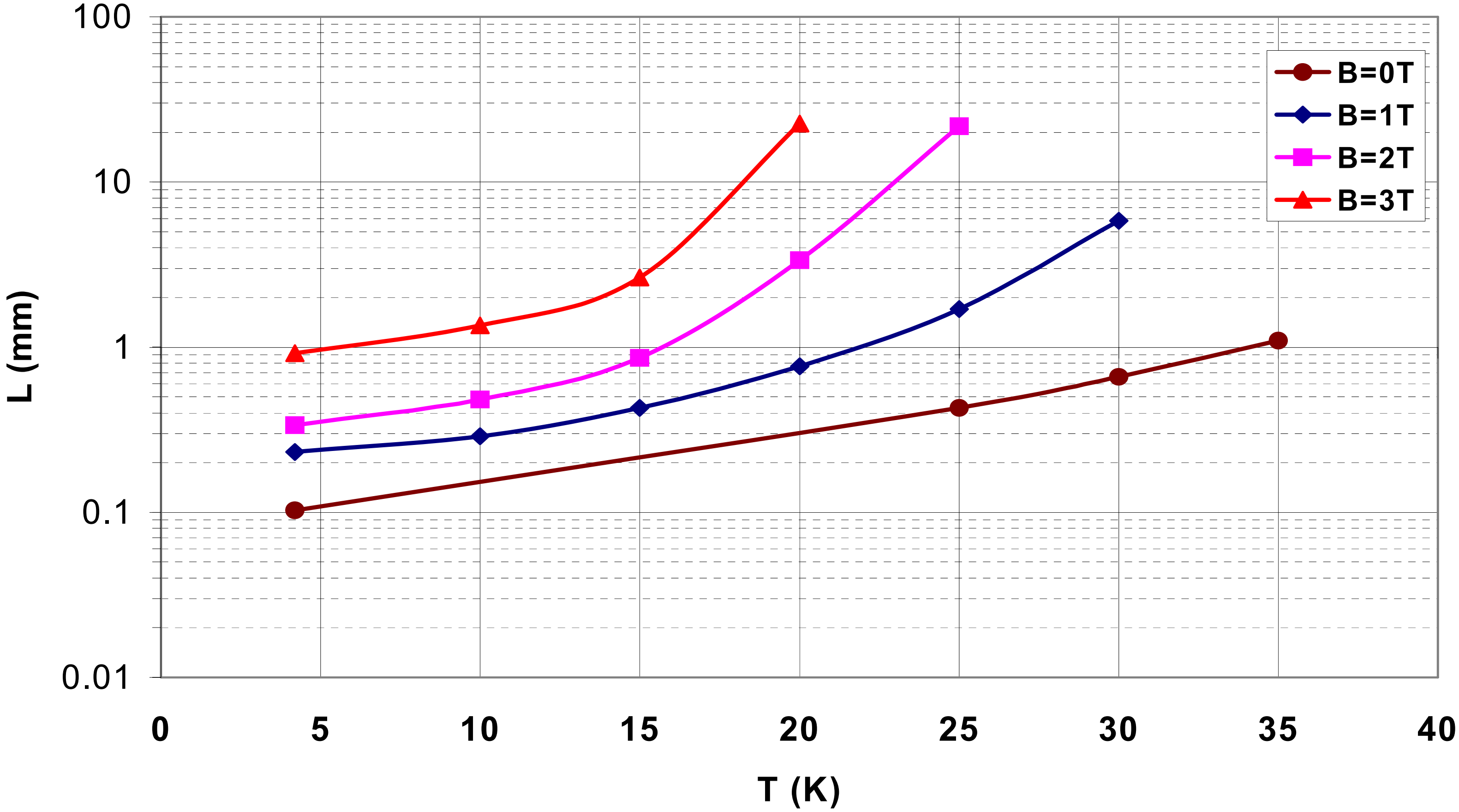
C) HE mill+nanoC doped, IFW Dresden: Jc (20K,4T) =24 kA/cm²;Jc(4.2K,10T) = 40 kA/cm²

EDISON Mg-RLI +6% C doped : Jc(20K,4T) ≈ 6 kA/cm² ; Jc(4.2K,10T) ≈ 8 kA/cm²

Thermal stability of the MgB_2

Limitation on the thickness

$$\mu_0 J_c^2 L^2 < 12 \gamma C (T_c - T)$$

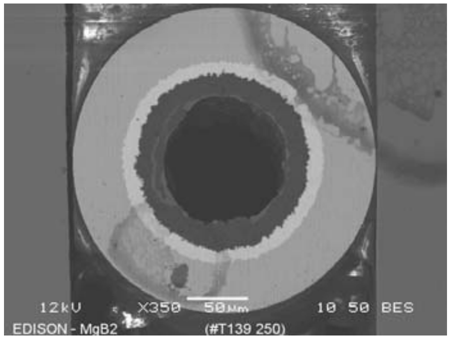


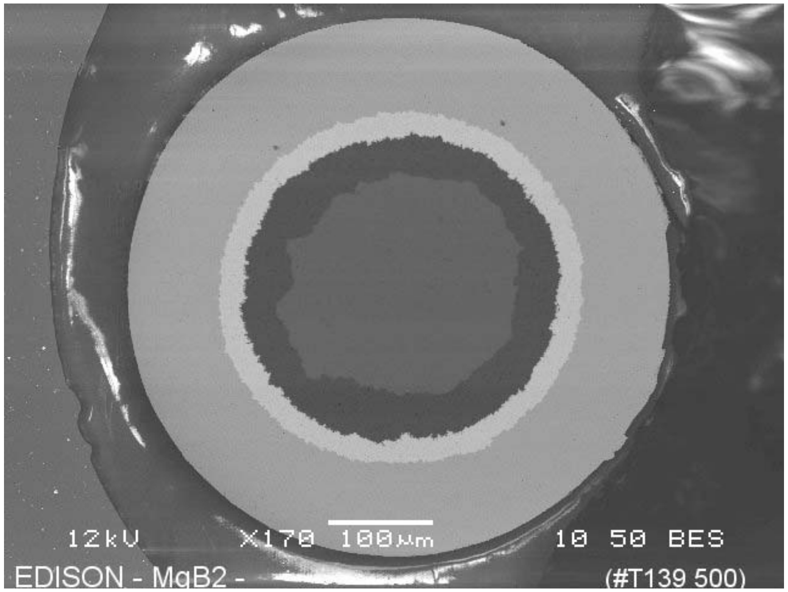
G.Giunchi, *Adv. Cryo. Eng.Trans. of ICMC, vol 52 813-819 (2006)*

Recent attempts to thin the precursor Mg-RLI wires

- **#T139 precursor wire (Monel/Nb/B/Mg) where successfully drawn to long length (6m) and 0.25 mm diameter (*)**
- **ITER Barrel test on 0.52 mm intermediate MgB_2 wire, W&R, confirms the Jc (B) at 4.2K obtained for larger diameter (1 mm)**

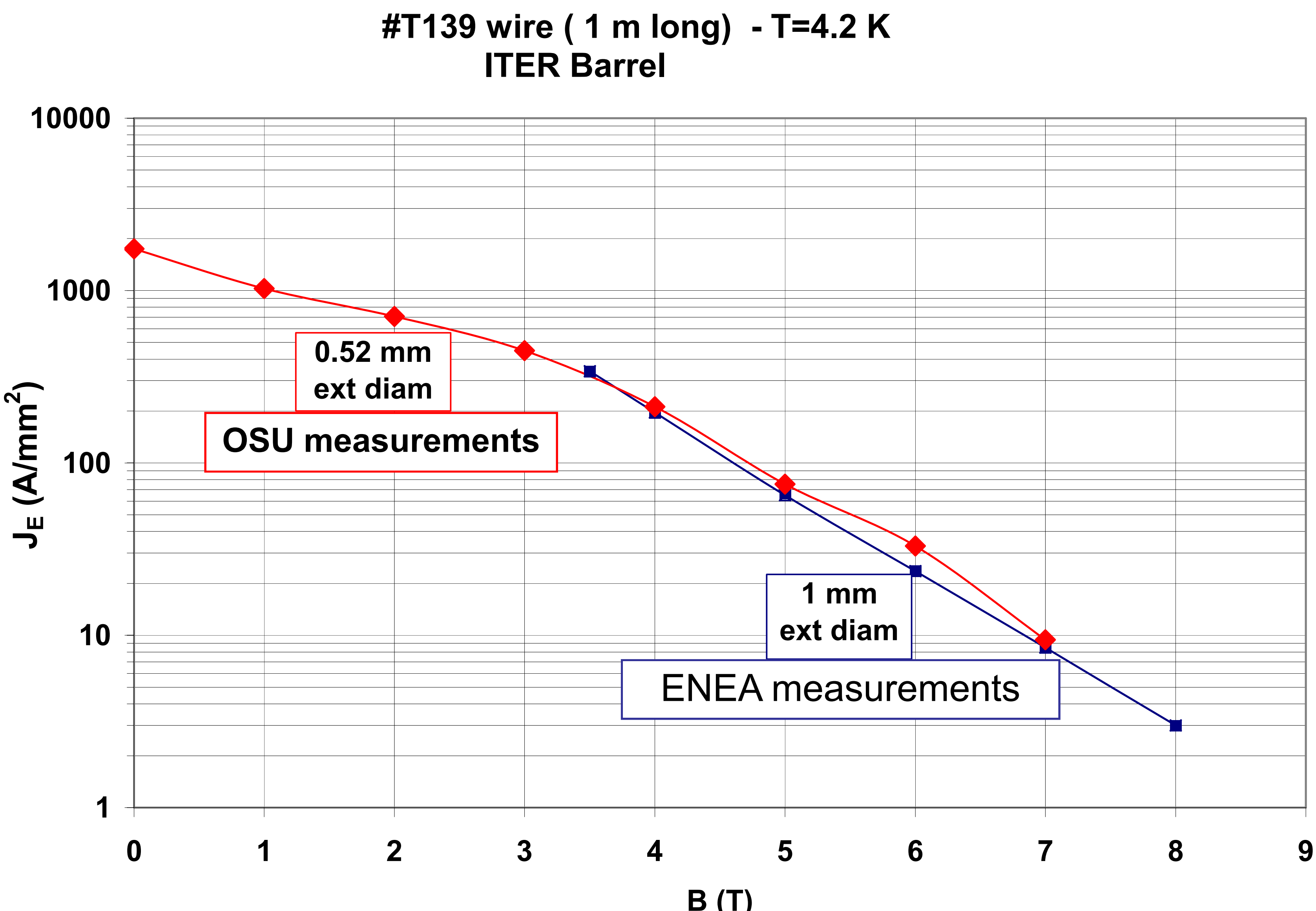
These wires have a SC fill factor = 0.16



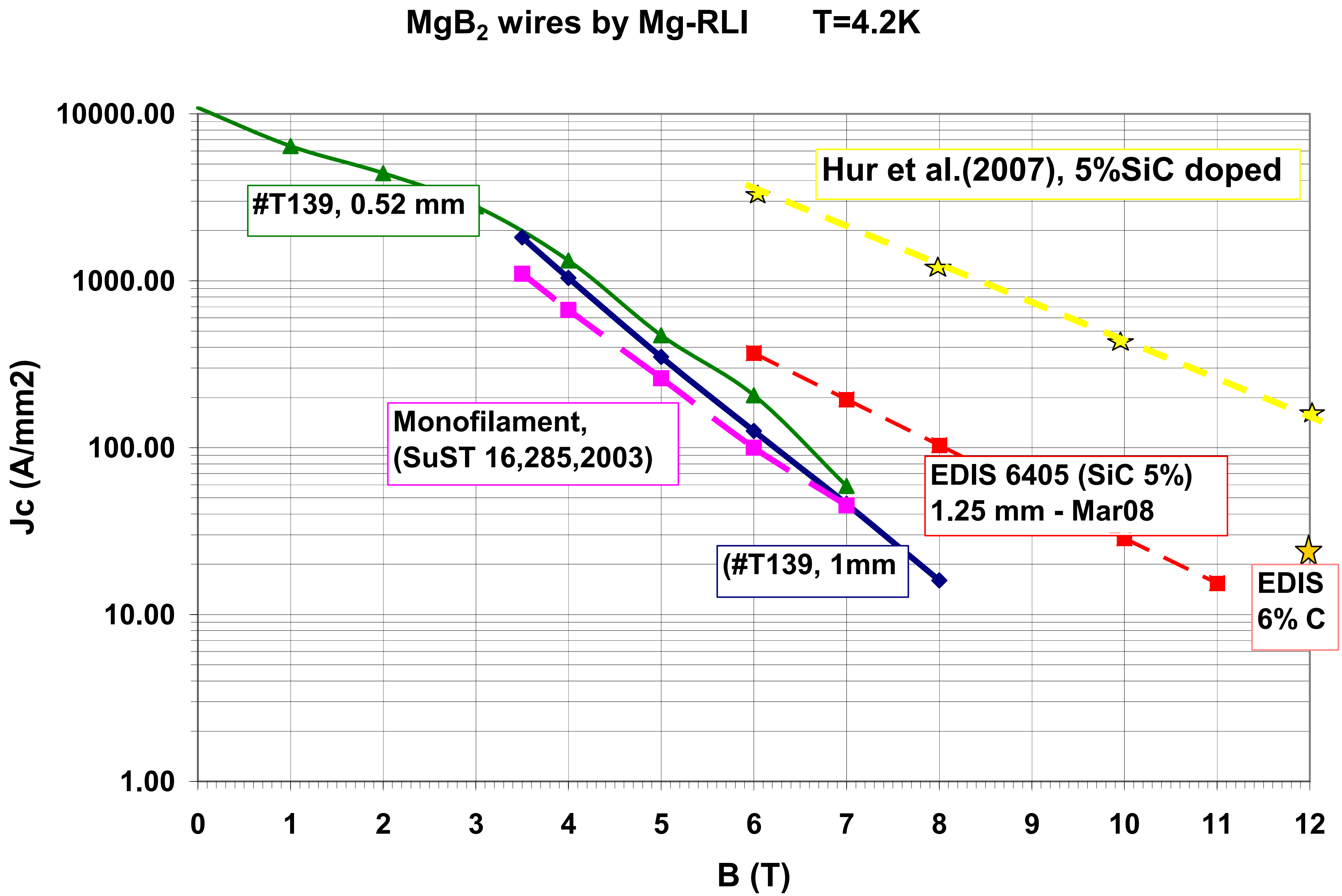


(*) performed by Matt Rindfleisch (Hypertech,OH)

Engineering current density of MgB_2 wire by Mg-RLI



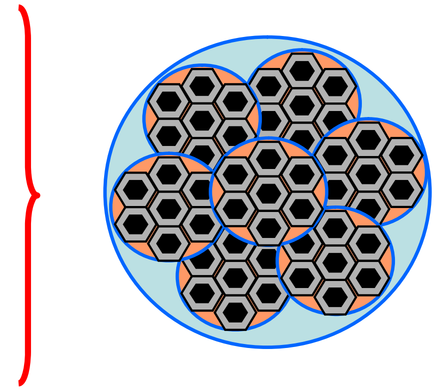
Mg-RLI wires : Jc comparison



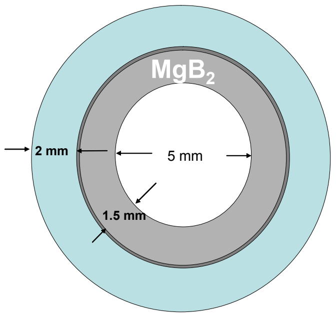
The MgB_2 cables perspectives by the Mg-RLI technology

A1) Thin hollow multiwires (0.25 mm) to perform stranded cables. Typical diameter =3 mm

A2) Multiwires by hollow monofilament of 1 mm. Typical diameter 12 mm



B) Thick monofilament hollow cable.
Typical diameters from 10 to 15 mm

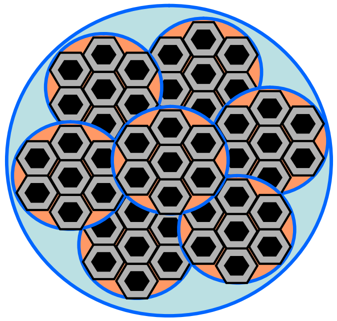


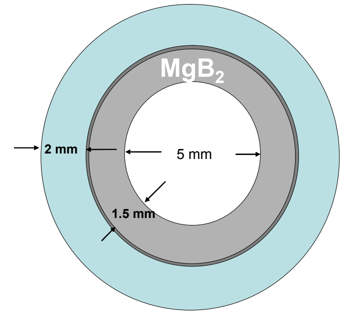
C) Thick massive cable. Typical dimensions will be (10÷20) x (50÷100) mm^2

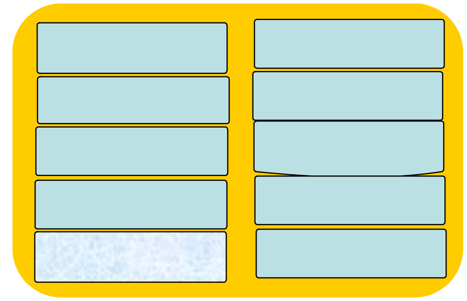
Large magnets: Superconducting cables vs Copper

Reference winding:

I_{total} = 870 kA (@20K,4T)
Area = (10x20) cm^2
Diameter = 500 cm







Cable	Lenght (m)	Turn number	I(20K,4T) (kA)	diameter (mm)	Fill factor (%)	Current Density (A/mm^2)	Winding weight (kg)
multiwire 49	1809	120	7.2	12	15	420	1750
monowire	1809	120	7.2	12	30	210	1100
Massive	150	10	87	90x19	60	85	830
Copper	1809	120	7.2	12	100	60	2700

Summary

- The Mg-RLI technique allows to obtain MgB_2 round wires ,thin and long.
- The actual performances depend on the quality of the B powders and on the thermal treatment optimization.
- A substantial improvement in magnetic field is expected from the doping.
- The distinguished characteristics are lower weight ,a more easy cooling and high mechanical strength
- The cost of the cable manufacturing should be very low
- The magnet manufacturing will use mainly W&R , but also R&W will be accessible to the thinner wires.