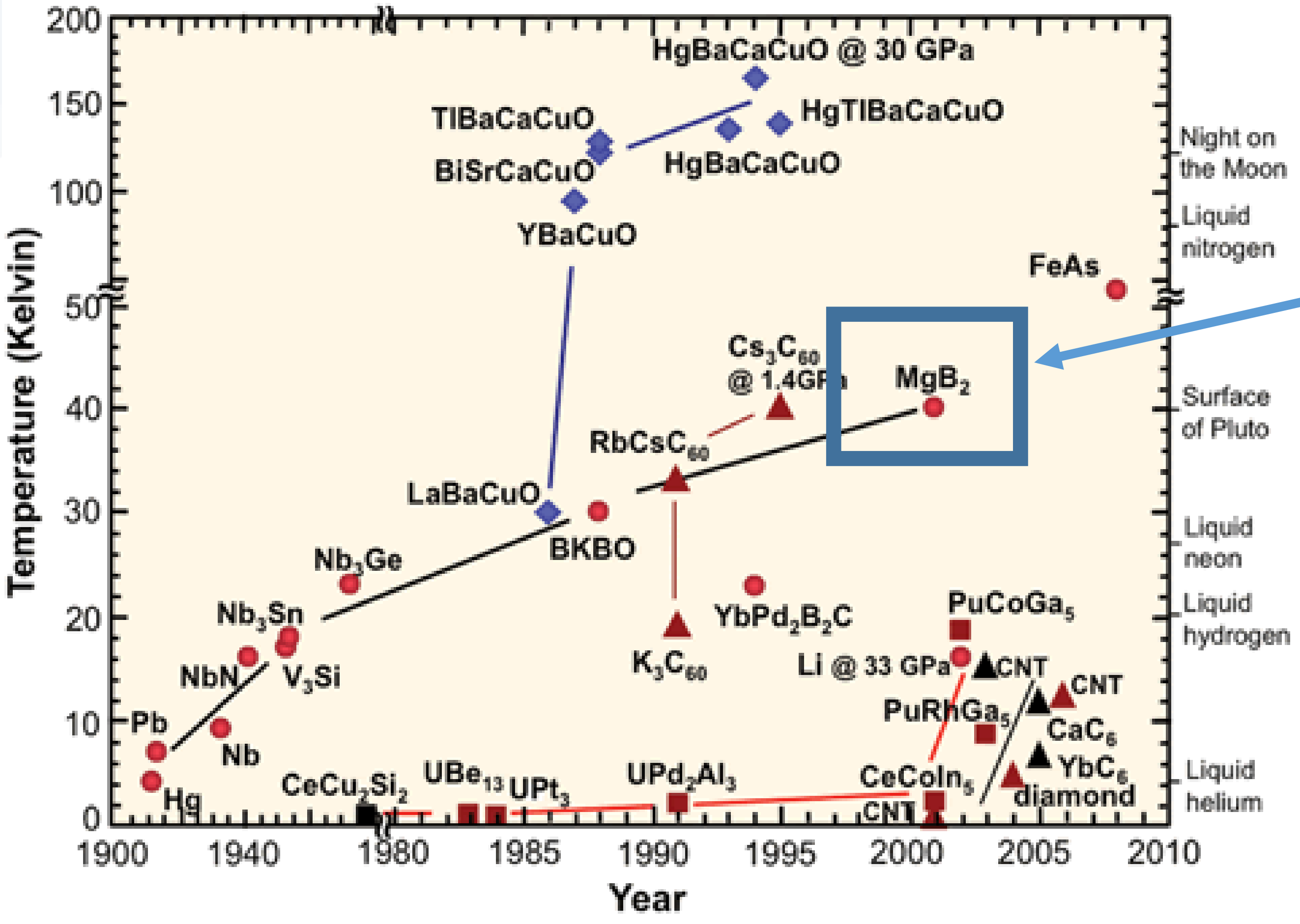
Columbus Superconductors

ESR7
Development of MgB_2 wires for high field magnet application

Matteo Tropeano

www.columbussuperconductors.com

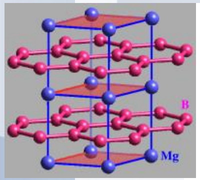
Critical temperature plot

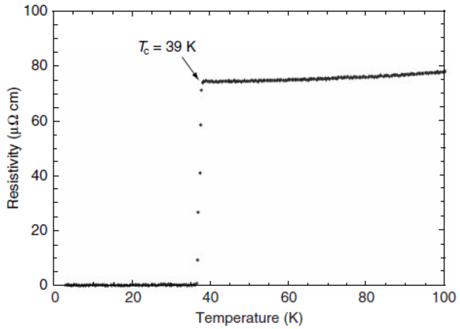


Highest T_c material of the LTS family

MgB_2 properties

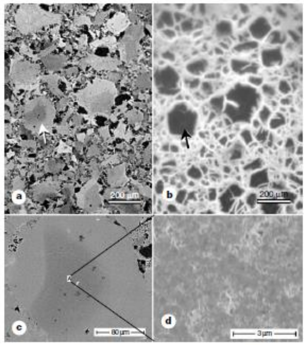
Relatively high Tc, simple structure and common materials





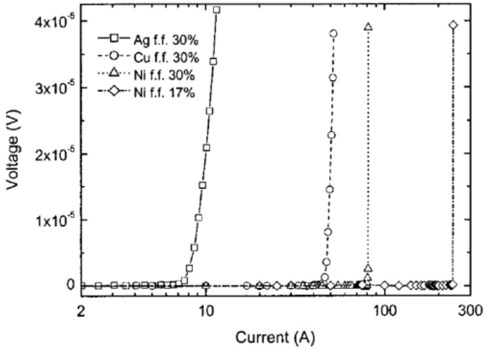
Nagamatsu et al. 2001
Superconductivity at 39K in magnesium diboride
Nature 410 63-4

No evidence of "weak link", no need of high degree of texturing



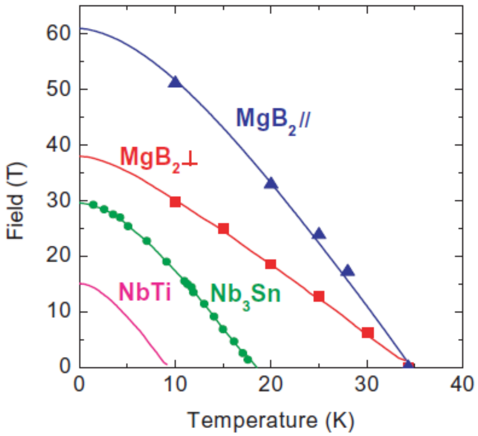
D.C Larbalestrier et al. 2001
Strongly linked current flow in polycrystaline form of the superconductor MgB_2
Nature 410

PIT process for the fabrication of wire



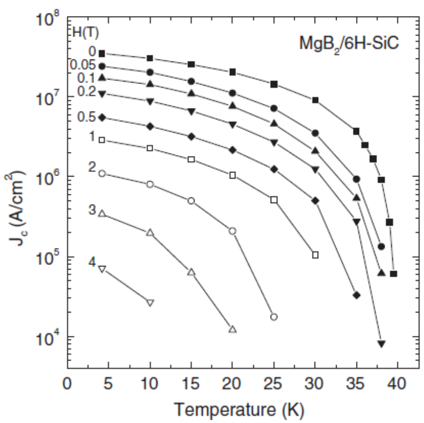
G.Grasso et .al. 2001
Large transport current in unsintered MgB_2 SC tapes
APL Volume 72, number 9

High critical field



Iwasa Y et al. 2006
A round table discussion on MgB_2: towards a wide market or a niche production?
IEEE Trans. Appl. Supercond 16 1457-64

Large critical current density



Zeng et al. 2003
Superconducting MgB_2 thin film on silicon carbide substrate by HPCVD
APL 82 2097-9

MgB_2 wire manufacturing companies

Hyper Tech Research, Inc.

Columbus Superconductors

Ready for industrial production
2 different manufacturing process
ex-situ and in-situ technique

EPOCH WIRES
infinite superconductivity

Early stage company, 2013,
Based in Cambridge UK
granted by UK SMART
for R&D activities on MgB_2

Cutting Edge Superconductors Inc.

Located in Portorico
MgB_2 wires for Cryo-free MRI
MRI magnet, open 1.5T, 3T

Interested in industriall production
of wires or wires+magnet

Interested in the MgB_2 technology

SUPERCON INC

Western Superconducting Technologies Co., Ltd.

BRUKER
Bruker BEST

1000 m of MgB2 wire
already demonstrated
in collaboration with IFW Dresden

GE Global Research
HITACHI
SIEMENS

Patents on MgB2 wires
Several R&D activities
Published paper

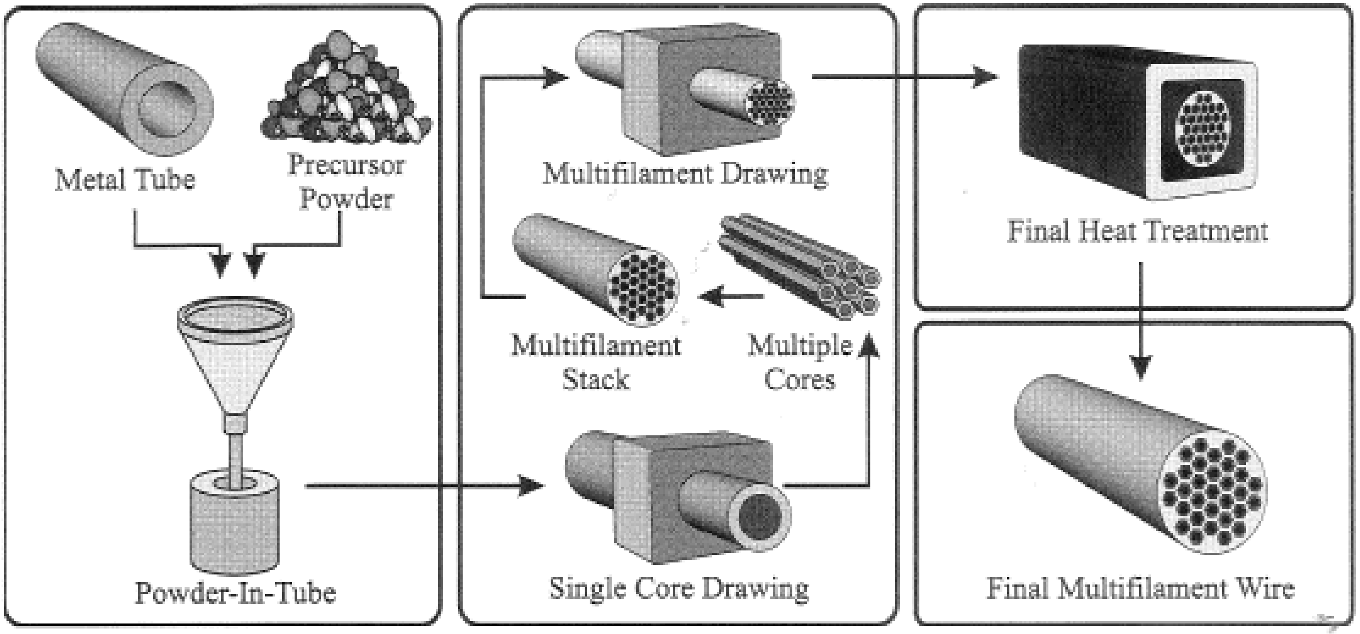
Columbus Superconductors

2003	2005	2006
Columbus Superconductors srl	R&D target →	**Columbus Superconductors SpA**
75% CNR+Researchers 25% ASG	First 1.6 km MgB_2 long wire in a single unit length	ASG became the main shareholder to sustain industrial investment and to start the business plan

Superconducting wire	Superconducting magnet	MRI
Columbus Superconductors	ASG Superconductors	PARAmed MEDICAL SYSTEMS

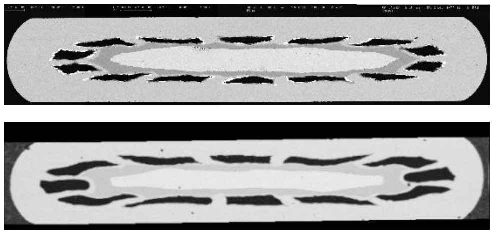
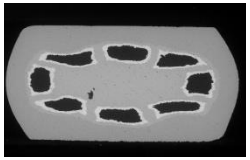
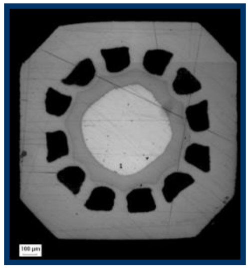
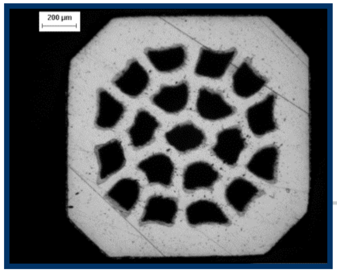
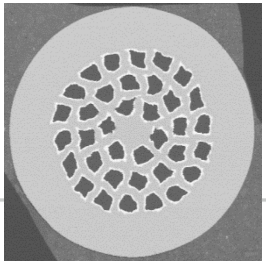
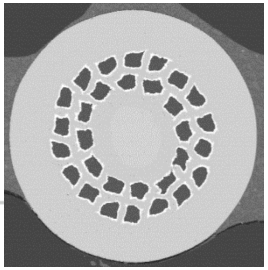
- The actual plant is fully operational for **MgB_2 wire production** with about 35 employees
- **MgB_2 chemical synthesis** also fully implemented
- Wire unit length today up to **2- 4 Km in a single piece –length**
- It will be possible up to **10 Km** with the full scale up of the process
- Columbus **MgB_2 tape production for MRI** has exceeded **500 Km** of fully tested and qualified wires
- Columbus **MgB_2 round wires production for cable** has exceeded **200 Km** of fully tested and qualified wires (end 2015-2016)

Ex-situ process



Conductors configuration:
different shape, aspect ratio,
number of filaments,
materials

Home made MgB_2 powders
Precursor quality, doping
synthesis temperature,
granulometry

Powder optimization

- Purity and granulometry control
- Grain connectivity
- MgO at grain boundaries
- Pinning and/or doping control

Sheath materials

- Mechanical properties of the raw metals
- MgB_2 / sheath reaction

Deformation process

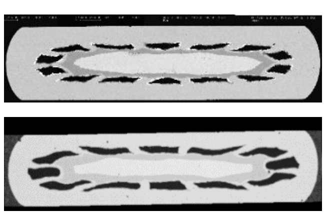
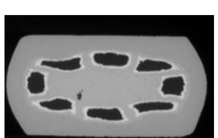
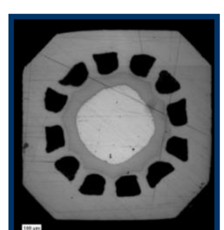
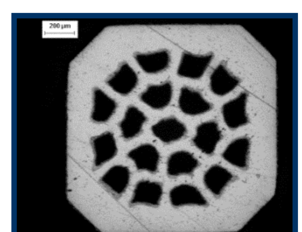
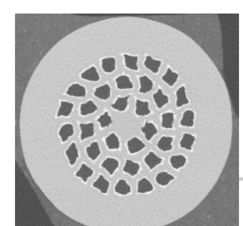
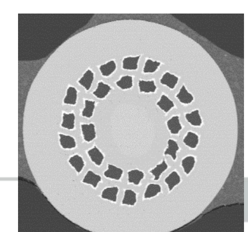
- Drawing-rolling-swaging

Optimization of intermediate (500-800°C) and final thermal treatment (900°C)

Application voted design

Layout of the conductor: shape, dimensions, number of filament

Magnetic, electrical, thermal and mechanical properties

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Clean synthesis of powders

Multistep rolling machine

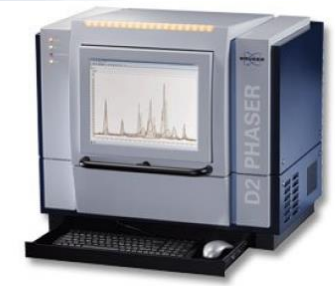
High power straigth drawing machine

- 39 new machines
- 15 existing machines will be still used over 21,
- 10 main upgrades to the technical infrastructures
- 1 new 2 floors buildiing
- 2.280m² of covered workshop area
- 20 direct production units

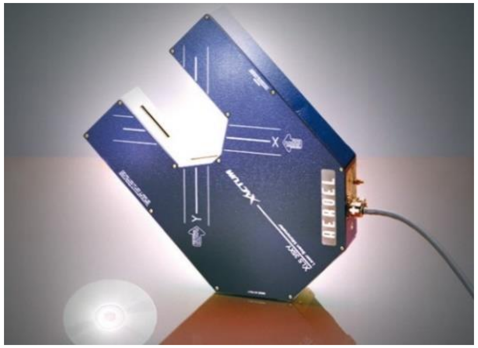
20 meter long in-line furnace

Multistep drawing machine

4 meter furnace for annealing HT

- SEM with EDS
- Optical stereomicroscopes
- XRD
- DLS-Particle size analyzer
- **XRF**
- Industrial video cameras for **surface defect detecti**
- **Eddy currents defect detector**
- Critical current evaluation (10K-30K, field up to 1.8 . ,

Quality management system is in compliance with the standard ISO 9001:2008

- ➢ Quality Control is done through all the process area from **incoming raw material** to the **final product**
- ➢ Defined responsibility in the control process
- ➢ Dedicated operative instructions and procedure
- ➢ Real time data collections of production and quality records
- ➢ Materials traceability

Wire solution for MRI

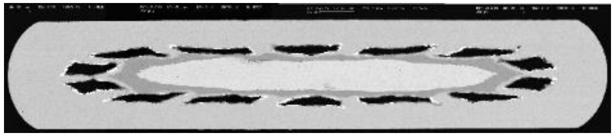
Wire solution for MRI

Original MR-Open conductor

- Wire product we used to validate our MgB_2 technology
- It showed us that MgB_2 can be produced with high yield and low cost – still in production today
- Two-fold improvement in performance – 50% less wire needed

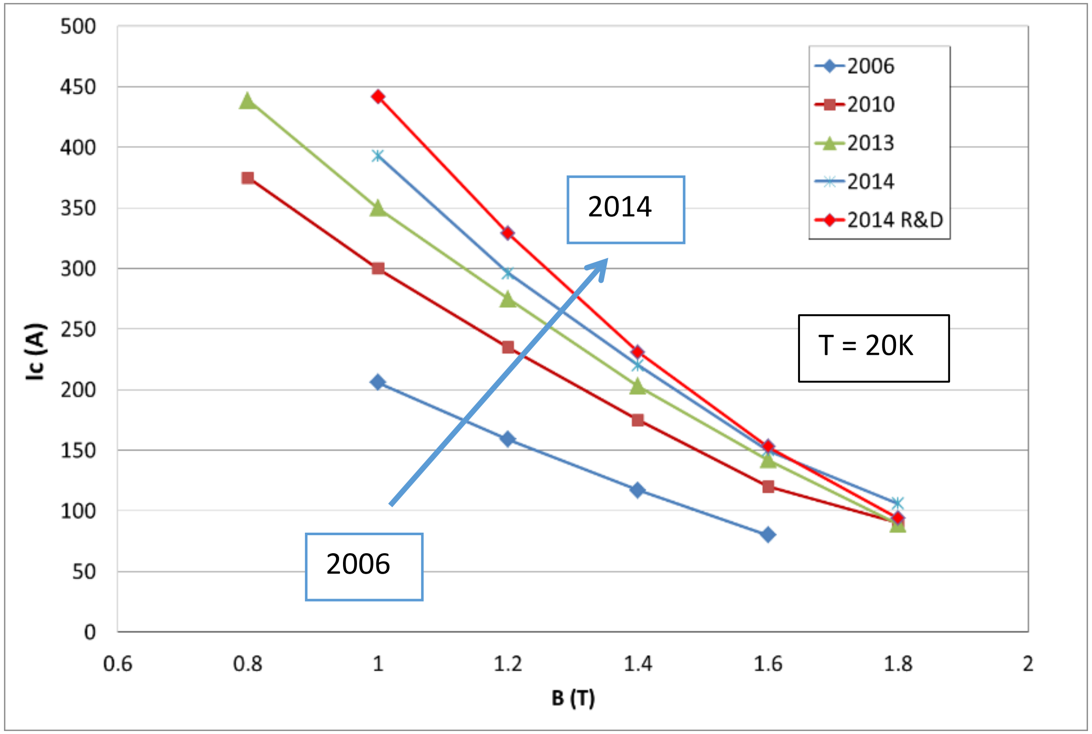
Wire layout in 2006:

- 14 filaments
- Unit piece length 1.6 Km

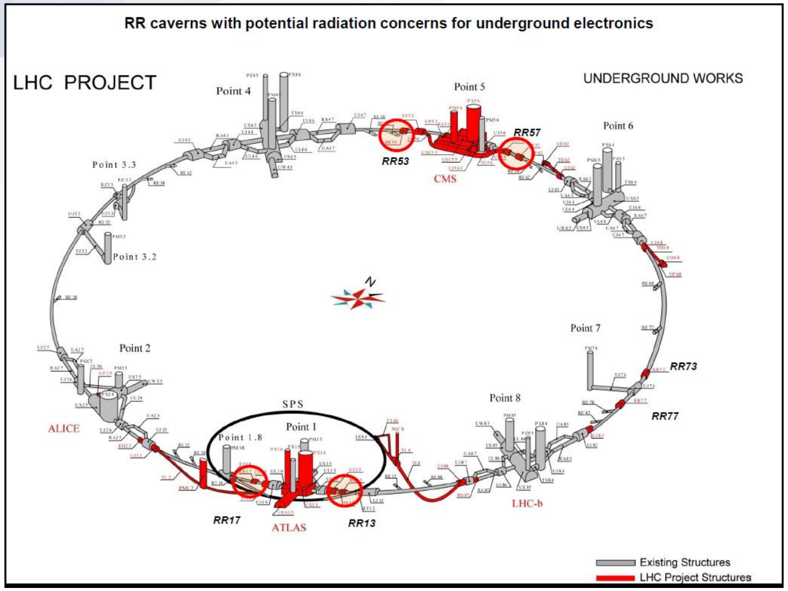


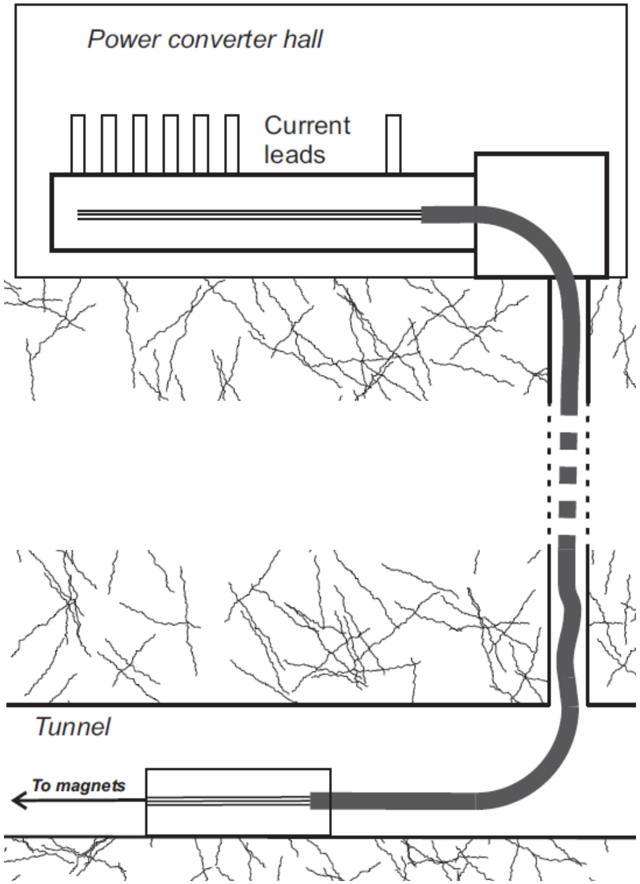
Since 2010:

- 12 filaments
- Improved fabrication process
- Unit piece length 4.0 Km
- Synthesis in controlled atmosphere



Hi-Lumi LHC upgrade
SC link project





Development of long superconducting lines for the powering of the LHC magnets via remote power converters

Total currents to be transferred: up to ~ 190 kA per line

Length: from a minimum of 150 m to a maximum of about 600 m with a significant vertical transfer for the locations where the power converters are to be located at the surface

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IOP Publishing — Superconductor Science and Technology
Supercond. Sci. Technol. 27 (2014) 044024 (7pp) — doi:10.1088/0953-2048/27/4/044024

Development of superconducting links for the Large Hadron Collider machine

Amalia Ballarino

CERN, European Organization for Nuclear Research, 1211 Geneva 23, Switzerland

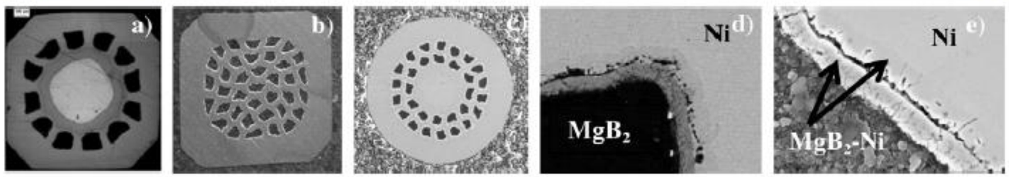
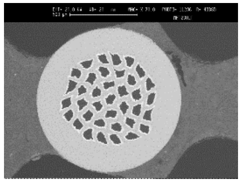
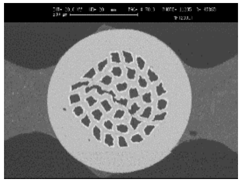
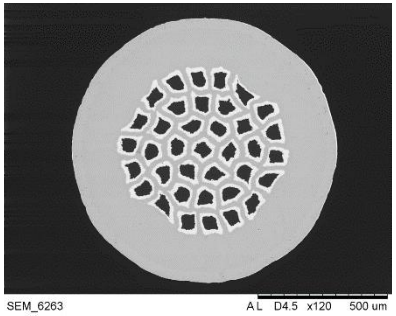


Figure 3. Different generations of MgB_2 Columbus round wires. From left: (a) S1 octagonal wire with nickel matrix and central copper stabilizer surrounded by iron barrier; (b) S2 quasi-square wire with Monel matrix and nickel barrier around the filaments; (c) S3 round wire with Monel matrix and niobium barrier around the filaments; (d) and (e) SEM cross section imaging of wire S2 [8]: porosity and detachment in between the two MgB_2–Ni reaction layers.





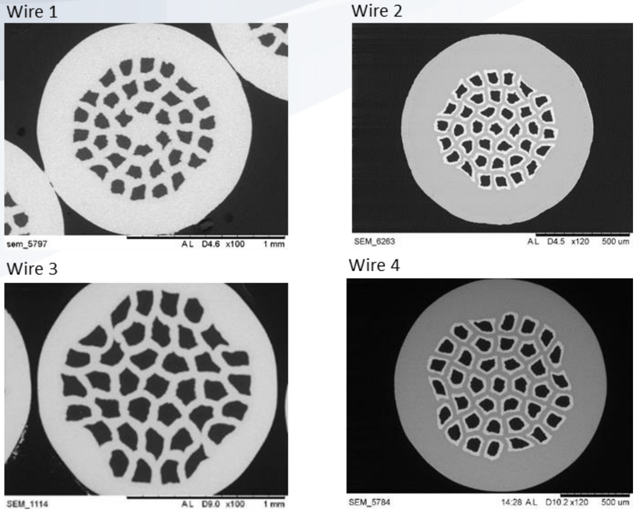


Final configuration diameter: 0.93mm
37 filaments
Materials: Monel, Ni, Nb
FF: 11.5%
Copper-Tin electrodeposition

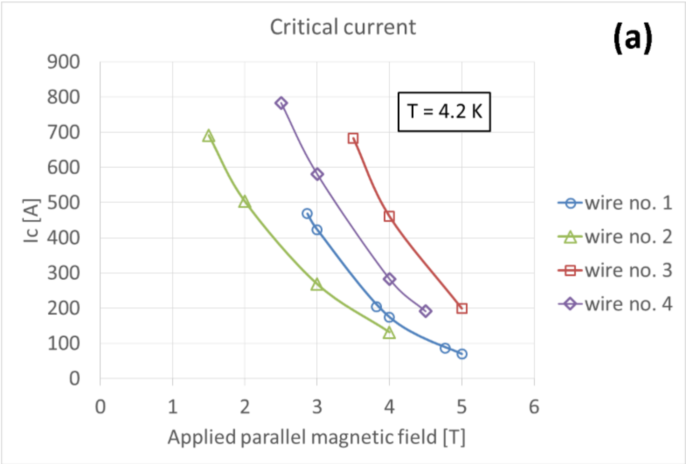
Diameter of MgB_2 wire, Φ	$0.8\ mm \leq \Phi < 1\ mm$
Diameter of superconducting filaments	$\leq 60\ \mu m$
Filaments twist pitch	≤ 100 mm
Filaments twist direction	Right-handed screw
Critical current at 25 K and 0.9 T	≥ 186 A
Critical current at 25 K and 0.5 T	≥ 320 A
Critical current at 20 K and 0.5 T	≥ 480 A
Bending radius (after final heat treatment)*	≤ 100 mm
Tensile strain at room temperature*	$\geq 0.28\%$
Copper fraction of the wire total cross section	$\geq 12\%$
RRR of copper stabilizer	> 100
*n-value*** @ 25 K and 0.9 T	> 20

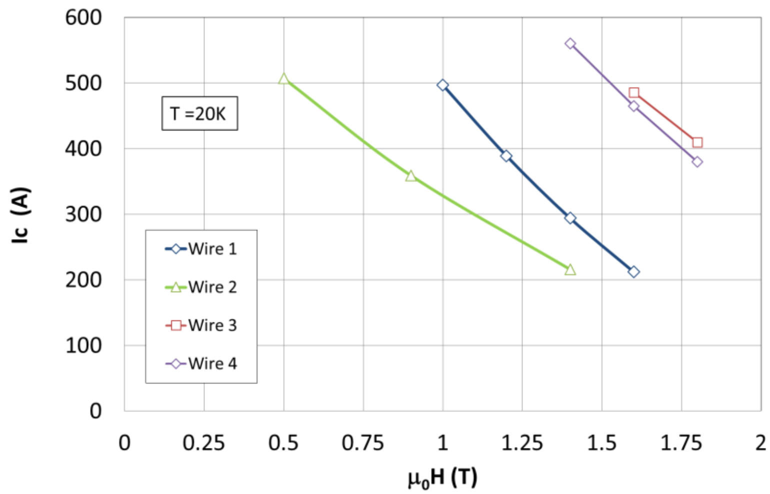
More than 200km already deliverd and qualified

Round wires configuration



PROPERTIES	Wire 1	Wire 2	Wire 3	Wire 4
Diameter (mm)	1.3	1	1.5	1.5
Materials	Monel Nickel	Monel Nickel Nb	Monel Nickel	Monel Nickel Nb
MgB2 fraction	17%	12%	30%	12%
Critical current at 20K, 1T	500A	300A	>650A	>650A
Critical current at 4.2K, 3T	280	400	>700	600
Critcal bending radius	125	100	200	150





Fellow	Host institution (Supervisor)	WP	PhD enrolment	Start date	Duration	Deliverables
ESR7	**Columbus** (G. Grasso)	**3**	Y (UGENOA)	M6	36M	D2.1, D3.4, D5.1, D5.2, D5.3
Development of MgB_2 wire for high-field magnet applications						
Objectives: Develop a novel MgB_2 wire, which is suitable for use in high field magnets at required current densities in fields above 10 Tesla, operated at liquid helium temperature (~ 4 K), extending today's state-of-the-art conductor only suitable for use in fields below 5 T. Assess the likelihood to extend operation up to 16 Tesla. Work in cooperation with TUW (**ESR12, ESR13**) to understand the key performance indicators determining the wire performances and optimise the production process.						
Expected Results: Identify viable strategies for production of MgB_2 wire for high-field applications and obtain a suitable wire layout for industrial production (**D3.4**). Obtain a detailed characterisation of the wire and its performances (**D2.1**). Produce 5-10 km of MgB_2 wire for CERN suitable for the construction of a magnet coil (**D5.1**) and document the impact on future accelerator designs. Identify MgB_2 field reach and use-cases in industry and healthcare (**D5.3**). Develop training contents on MgB_2 wire design and production (**D5.2**).						
Secondment(s): CERN (M6, A. Ballarino, 8 weeks, understand magnet and coil production requirements, wire and coil measurement techniques), **TUW** (M13, M. Eisterer, 8 weeks, understand wire characterisation methods and impacts of the wire design and the production process on its performance), **TUW** (M24, M. Eisterer, 8 weeks each, common work on assessment of wire performance for high-field coils and magnets).						

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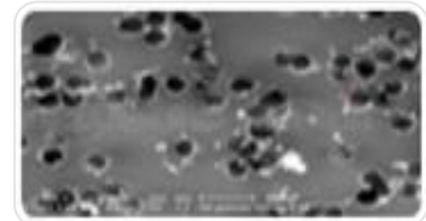
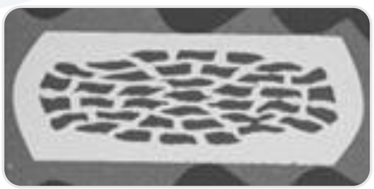
Conductor development x HF application

- B-purity
- Granulometry



- C-doping
- C-encapsulated B
- Pinning



- FF up to 30-33%

Boron

Filling factor

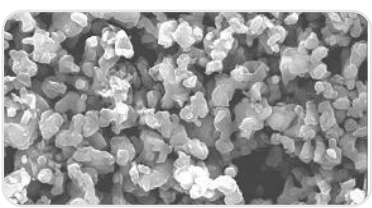
Doping and pinning

Jc enhancement

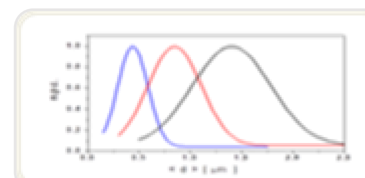
MgB2 wires

Connectivity

Particle size



- Grain boundaries
- Wire design
- Deformation process



- Number of filaments
- Filaments size
- MgB_2 density
- In field behaviour