THE INFN RESEARCH PROGRAM ON MGB2 APPLICATION OF MAGNESIUM DIBORIDE TO PARTICLE PHYSICS

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Abstract

As soon as the discovery of the superconducting properties of magnesium diboride (MgB2) has been known, several research activities started in the italian universities, research centers and industries. The INFN project, Ma-Bo, aims to understand if magnesium diboride could be used for particle physics applications: magnets, thin films for accelerating cavities, thin films for detectors and other devices. Some of the results obtained in the first two years are given in the paper.

1 INTRODUCTION

The discovery of the superconducting properties of magnesium diboride (MgB_2) [1], an already known binary compound, has renewed the interest of many researchers towards applied superconductivity. This interest is based on the material characteristics that appear favourable to technological applications: high critical temperature (39 K), upper critical field higher than 18 T, lack of weak links, low anisotropy and high critical current density (several GA/m^2 at 20 K and 0 T). Last but not least, the cost of the material is low.

Although the discovery was recent, the techniques developed to fabricate HTS conductors were promptly applied to the new material and, at present, MgB_2 wires and tapes are available in several hundreds meters lengths. The conductor manufacturing process is rather simple and consequently, the conductor cost is comparable with that of low T_c superconducting wires. Two routes can be followed to fabricate MgB_2 conductors using the powder-in-tube (PIT) technique: the in-situ (the tube is filled with the precursor powders) and the ex-situ (the tube is filled with MgB_2 powders) methods.

The main drawback of magnesium diboride is the low irreversibility field that can limit the application of the material to low field magnets. However, there are many signals of a possible enhancement of the irreversibility line by acting on the structure and on the morphology of the material [2].

To nowadays knowledge, the use of magnesium diboride can be imagined in large scale applications as material for conductors either to wind superconducting devices generating field lower than 4 T and operating at about 20 K or to fabricate energy transport lines.

As regards particle physics devices, the possible applications of magnesium diboride are magnets, rf cavities and particle detectors.

2 MGB_2 RESEARCH PROGRAMS IN ITALY

As soon as the discovery of the superconducting properties of MgB_2 has been known, several research activities (mainly fundamental) started in Italy by research institutions (CNR, INFM, universities) with ordinary funds. Few months later, the

Italian industries operating in the manufacture of superconductor devices (Ansaldo Superconduttori, Columbus Superconductors, Edison, Europa Metalli, Pirelli) started R&D activities. It is of particular interest the birth of Columbus Superconductors, a new company devoted to the development and fabrication of diboride conductors.
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Ma-Bo, the INFN program on magnesium diboride applications to nuclear and particle physics, started at the beginning 2002. Six INFN sections and laboratories, with 30 people involved (about 10 FTE), have joined this project: Genova, Frascati National Laboratories, Legnaro National Laboratories, Milano, Napoli, Torino. Ma-Bo is in collaboration with ENEA, INFM (LAMIA laboratory in Genova), Ansaldo Superconduttori and Columbus Superconductors.

3 THE INFN RESEARCH PROGRAM ON MgB_2

The research project Ma-Bo aims to understand if magnesium diboride could be used for particle physics applications. The research activities are related to: magnets, thin films for cavities, thin films for detectors and other devices.

3.3 Accelerating cavities

The application of superconducting materials to accelerating cavities requires low rf dissipations that means not only good characteristics of the superconductor itself (high T_c, low normal state resistivity, large gap, absence of weak links) but also a homogeneous, clean and pure surface. Several techniques can be used to deposit MgB_2: laser ablation, evaporation, sputtering. In order to obtain films suitable for accelerating cavities only magnetron sputtering in several conditions has been used.

Although good quality films were obtained onto small substrates, several problems in using MgB_2 for rf resonant cavities have been found:

- MgB_2 is a double gap superconductor: the lower gap (Δ_π=2.8 meV) limits the behavior of the material exposed to the rf field. The value of $2\Delta/kT_c$=1.7 is close to the Nb_3Sn one.
- A homogeneous, pure (i.e. single phase) film must be deposited onto large area substrates but the presence of magnesium and boron oxides cannot be completely avoided.
- The material is chemically instable if exposed to atmospheric humidity.

The above-mentioned problems leaded us to abandon the study of the application of MgB_2 to rf cavities.

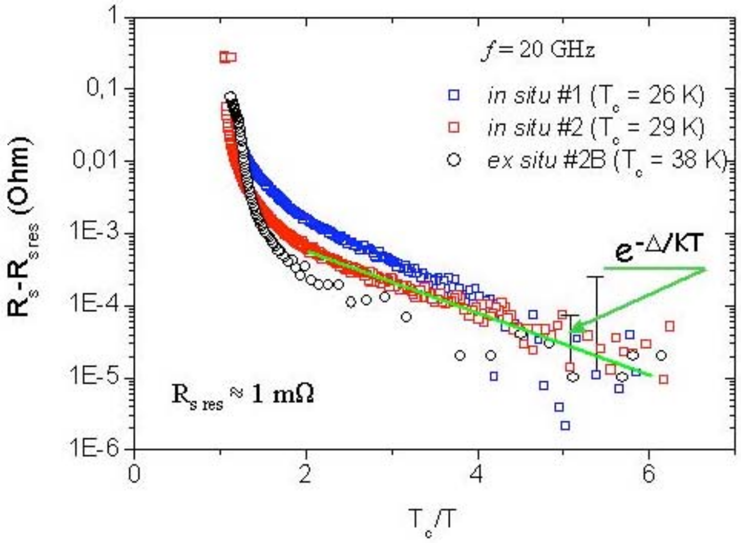

Fig.1. Rf resistance of a MgB_2 sample (R.Vaglio, University of Napoli and INFN)

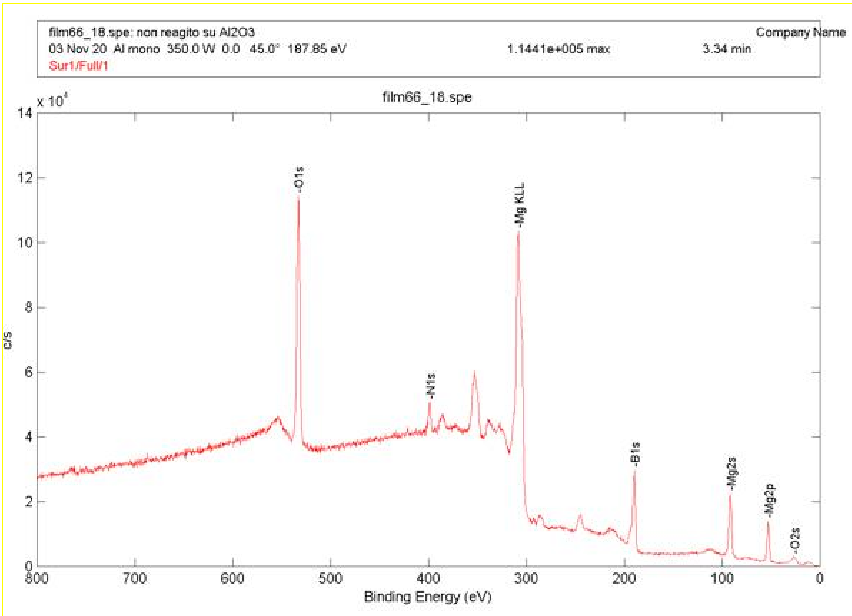

Fig.2. The XPS spectra of MgB_2 films show the presence of MgO, B_2O_3 and BN.

3.4. Detectors

Some MgB_2 properties make it a possible material for radiation:

- Low activation energy;
- Good radiation hardness;
- High thermal conductivity;
- Short recovery time.

Recently, the use of MgB_2 films as neutron detector has been proposed [4]: the energy released by the neutron reaction with ^{10}B partially destroys the superconductivity of a MgB_2 film.

Part of the INFN activity is devoted to the study of microstrip detectors based on magnesium diboride.

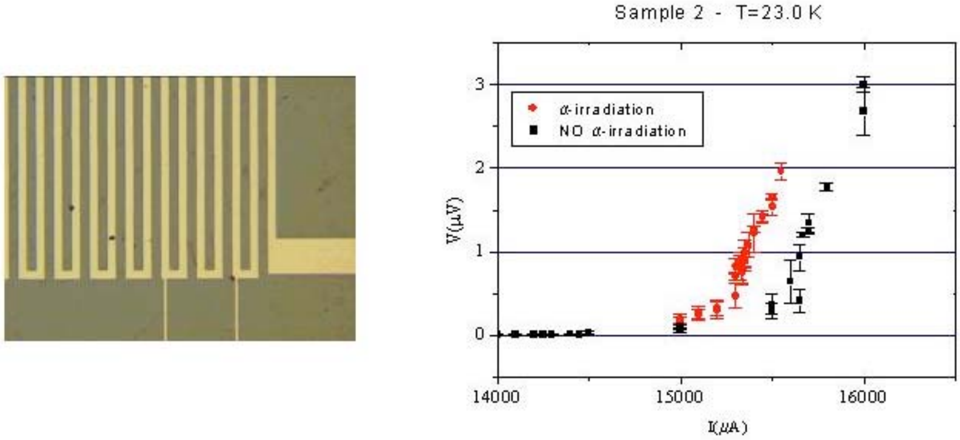

Fig.3. Effect of α irradiation on a 20 μm MgB_2 microstrip
(E.Monticone, IEN Torino, and M.Truccato, University of Torino and INFN).

3.5 Magnets

The most promising application of MgB_2 is the fabrication of conductors. The interest of INFN in this field has joined the one of other research groups and industries in Italy leading to a common program devoted to the development of magnet. One of the goals of the research program was to demonstrate the feasibility of react & wind MgB_2 coils.

Magnesium diboride-based conductors are prepared by INFM-LAMIA laboratory and by Columbus Superconductors using the powder-in-tube (PIT) method and following the ex-situ route [3]. Pure nickel tubes are filled with commercial MgB_2 powders (the powder density inside the tube is 1.3 g/cm^3) and cold worked in several steps without intermediate annealing. Both monocore and multifilamentary tapes are obtained using the described method. The conductor has a critical current in the order of 10^9 A/m^2 at 4.2 K and zero applied field. Fig.4 shows a monocore tape whose typical dimensions are 4 mm × 0.35 mm, with a metal/superconductor ratio about 5, i.e. a superconductor cross section area of 0.24 mm^2. As a final step, the tape is heat treated at about 900°C in argon atmosphere, using an in-line oven, in order to enhance its transport properties. The critical current of the tape, after the heat treatment, is shown in fig.5. The critical current density at 4.2 K, measured in liquid helium bath, between 3.5 and 12 T is shown in fig.6.

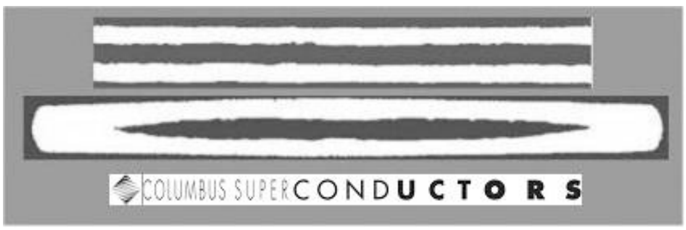

Fig.4. Cross and longitudinal section of a monocore tape produced by Columbus Superconductors

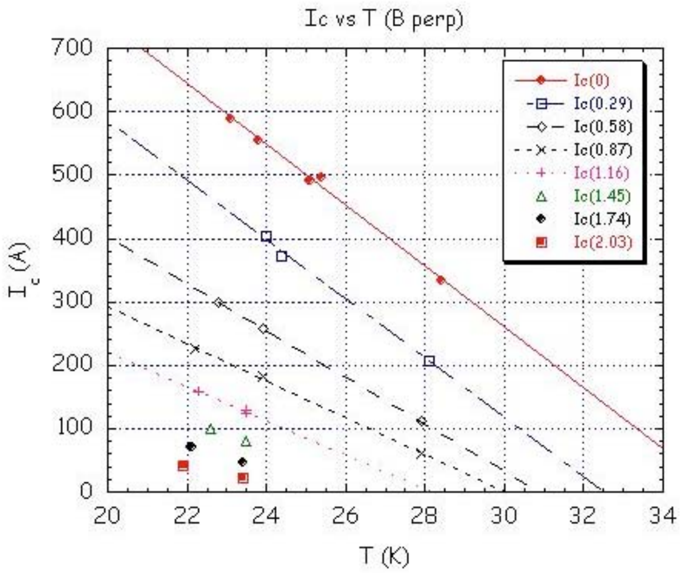

Fig.5. Critical current of the monocore tape between 0 and 2T (INFN-Genova)

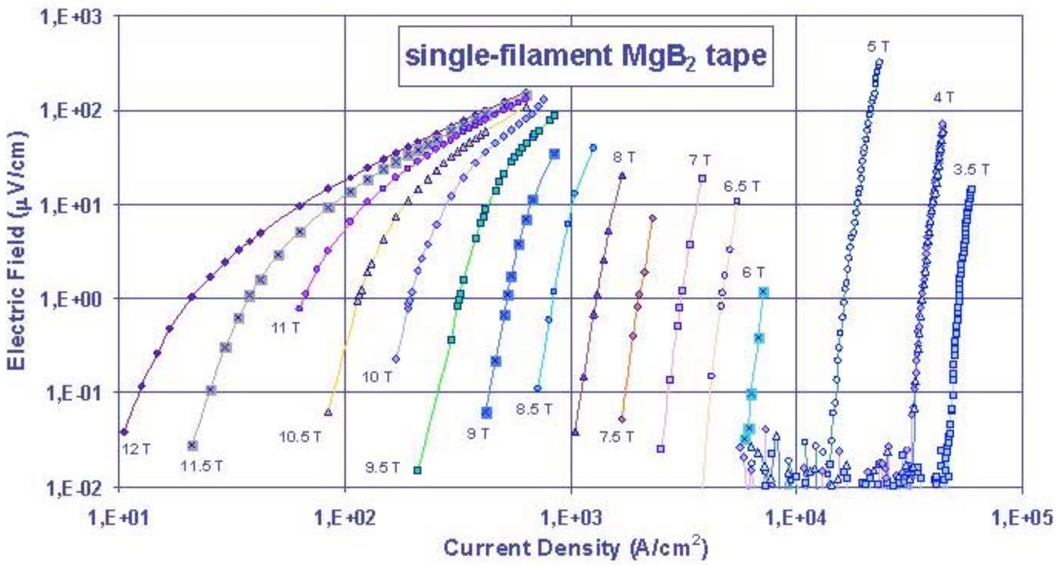

Fig.6. Critical current density at T = 4.2 K (INFN-LASA, Milano)

The tapes are used to wind solenoids and pancake coils using the react & wind technique (the tapes already undergo the heat treatment). A 6 layers solenoid, 15 cm diameter, was wound with 80 m of MgB_2 tape. The pancake coils were wound with 40 m tape (the external diameter is 20 cm).

The solenoid was tested in liquid helium: despite local dissipation at one of the exits, it reached 53 A before quenching [5]. It is worth noting that no resistance was detected at the layer transitions.

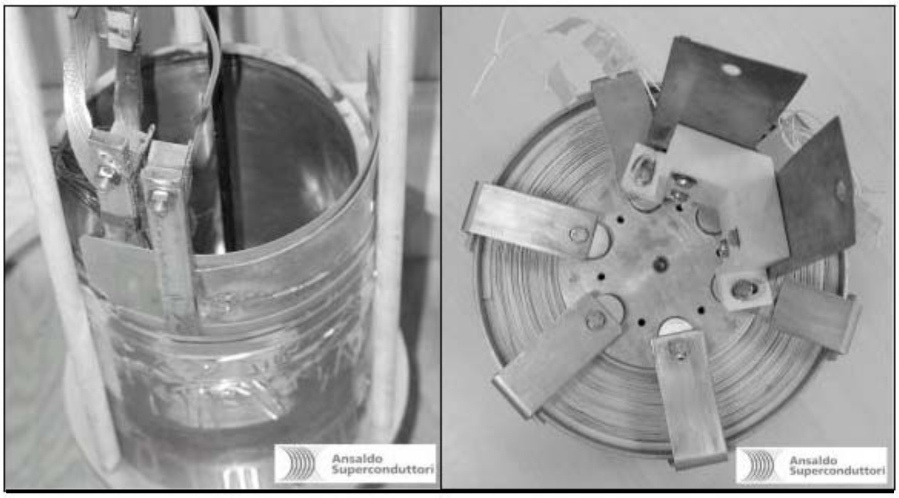

Fig.7. Solenoid and pancake coil (Ansaldo Superconduttori, Genova)

The pancake coils gave better results: the maximum quench current reached by a pancake coil in liquid helium was 343 A corresponding to a field of 0.76 T at the conductor, and 0.21 T at the coil center.

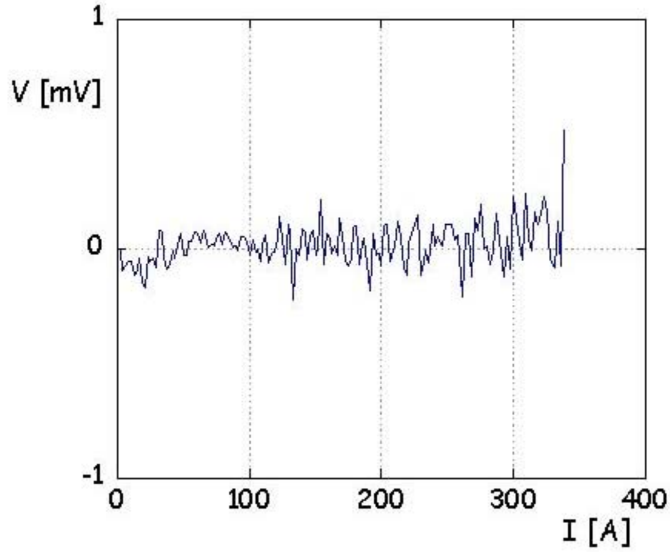

Fig.8. V-I curve of the pancake #8 tested in liquid helium bath

MgB_2 pancake coils were also tested at variable temperature between 15 K and 38 K. The coils are connected to a cryocooler and supplied via a couple of cryogen free current leads with HTCS bars. The result of the tests of the Ansaldo Superconduttori coil #10 is shown in fig.9.

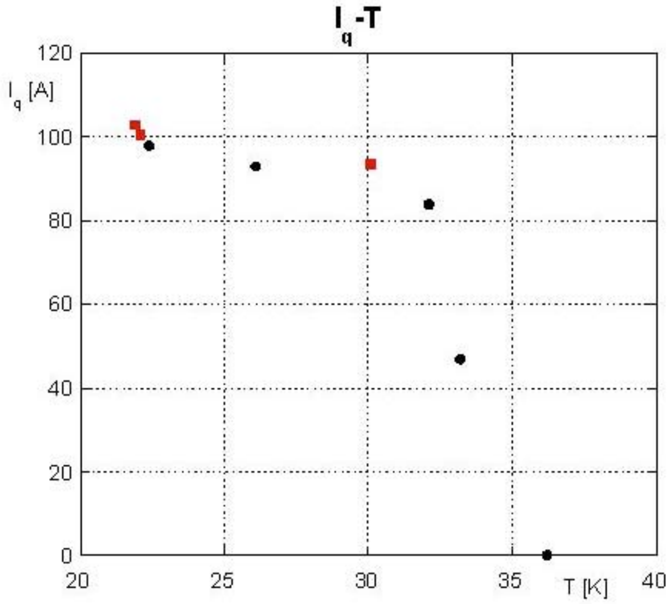

Fig.9. Quench current of the pancake coil #10 (Red squares: values obtained increasing the temperature at constant current. Black circles: values obtained increasing the current at constant temperature.)

4 CONCLUSIONS

Magnesium diboride is a low cost material with high critical current density and without weak link problems. Moreover cable and tapes can be easily produced using techniques already developed.

Looking at the applications of MgB_2 to nuclear and subnuclear physics, the perspective can be schematized as follows:

- Till now, neither MgB_2 nor other superconducting materials can compete with niobium for application in accelerating cavities.
- Magnesium diboride seems a possible candidate as material for radiation microstrip detectors.
- The feasibility of magnets has been clearly demonstrated. Magnesium diboride can be considered a promising material for the construction of magnets for accelerators (dipoles for syncrotrons or beam lines, cyclotrons) and detectors. Low field (less than 3 T) magnets will be probably the first step but there are several indications about the possibility of a field improvement.

Due to the excellent results, particularly as regards magnets, a new research program concerning the application of MgB_2 will be presented to INFN.

ACKNOWLEDGEMENTS

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