

# Superconducting properties of MgB<sub>2</sub> materials

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MgB<sub>2</sub> becomes superconducting just below 40 K. Superconducting transition with the onset temperature of 39K was confirmed by both magnetic and scanning electronic microscopy measurements. Magnetization versus field (M-H) curve shows the behavior of a typical Type II superconductor. The bulk sample shows good connection between grains. SEM studies of bulk samples of MgB<sub>2</sub> revealed details of the grain boundary structure. Also, the powder X-ray diffraction pattern of the MgB<sub>2</sub> powder is presented.

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## 1. Introduction

Superconductivity occurs when electrons in a material bind together to form Cooper pairs that can travel through the sample without resistance. At low temperature, the electrons overcome their mutual repulsion by interacting with lattice vibrations called phonons. The energy gap of a superconductor is the energy needed to break the electron pair apart.

In March 2001, Jun Akimitsu and colleagues at Aoyama-Gakuin University in Tokyo, Japan reported a superconducting transition temperature of 39 Kelvin for magnesium diboride, [1]. This has generated a great deal of excitement not only because this is the highest transition temperature yet observed for a type-II superconductor, but also because the materials used are quite common.

It caused excitement in the solid state physics community because it introduced a new, simple (three atoms per unit cell) binary intermetallic superconductor with a record high (by nearly a factor of 2) superconducting transition temperature for a monoxide and non-C60- based compound. The reported value of T<sub>c</sub> seems to be either above or at the limit suggested theoretically several decades ago for BSC, phonon-mediated superconductivity. An immediate question raised by this discovery is whether this remarkably high T<sub>c</sub> is due to some form of exotic coupling.

## 2. Results and discussion

MgB<sub>2</sub> crystallizes in the hexagonal AlB<sub>2</sub> type structure, which consists of alternating hexagonal layers of Mg atoms and graphite like honeycomb layers of B atoms, [1, 2]. This material, along with other 3d-5d transition metal diborides, has been studied for several decades, mainly as a promising technological material.

Magnesium diboride consists of hexagonal planes of boron atoms separated by planes of magnesium atoms,

with the magnesium centered above and below the boron hexagons, Fig. 1.

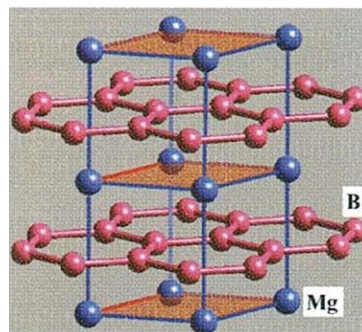


Fig. 1 The structure of MgB<sub>2</sub> compound.

This structure is very similar to that of graphite: each carbon atom – which has four valence electrons – is bonded to three others and occupies all planar bonding states (the sigma bands). The remaining electron moves in orbitals above and below the plane to form pi bands. Boron atoms have fewer valence electrons than carbon so not all of the sigma bands are occupied. This means that lattice vibrations in the planes are much larger, which results in the formation of strong electron pairs.

The MgB<sub>2</sub> superconductivity is based on Borden – Cooper – Schrieffer (BCS) theory. High transition temperature is due to the high vibration frequencies of easy boron atoms and to strong interactions between electrons and lattice vibrations.

The material used for research is commercial powder of MgB<sub>2</sub> (Alfa Aesar). The analyzing certificate of the powder mentions the following elements: 44.1% boron, 51.6% magnesium, 0.3% carbon, iron less than 0.1% with a medium size of particles of 4.0 μm.

The powder was pressed in pellets under argon flow and sinterized in the same atmosphere for 1 hour at 750°C. The cooling was made also in argon, with a cooling speed of 5°C/min. There were not measurable losses of weight.

Cylindrical pellets with a diameter/height ratio of about one and mass of 1.5 g were pressed with a power press of 12 tf. Other pellets were pressed with the same power press, having a diameter/height ratio of 2/1. The diagram of the sintering process is presented in Fig. 2.

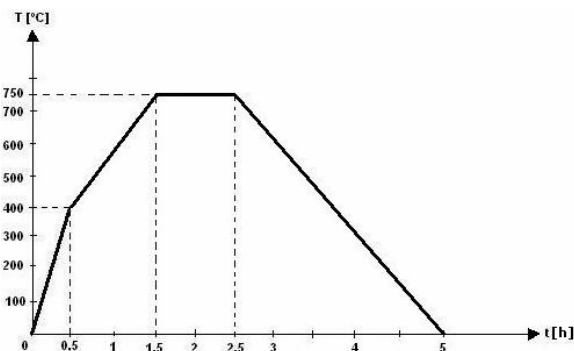


Fig. 2. The diagram of the sintering process for obtaining of  $MgB_2$  material.

Electron microscopy was realized with an electronic microscope, type scavenging CAMSCAN 3 (Cambridge Instruments/1981) with maximum extension:  $20000\times$  ( $200000\times$  theoretical) and microprobe type EDS + soft for quantitative analyze of elements in Na-U domain.

The micrography obtained by electronic scanning for the treated  $MgB_2$  sample is presented in Fig. 3. It remarks that the particles have an irregular shape both for the annealed and for not annealed sample.

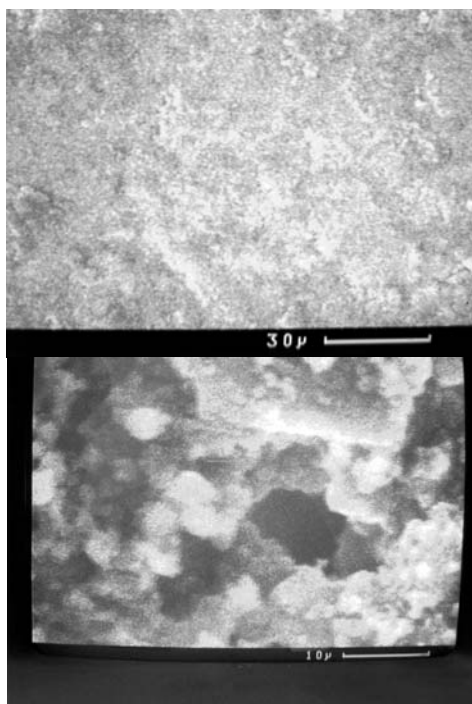


Fig. 3 The microstructure of  $MgB_2$  powder annealed at  $750^\circ C$ , for one hour in argon.

The transversal sections of the samples were observed by electronic microscopy SEM. It is not observed either a porosity, which indicates the fact that the samples have a high density, Fig. 4.

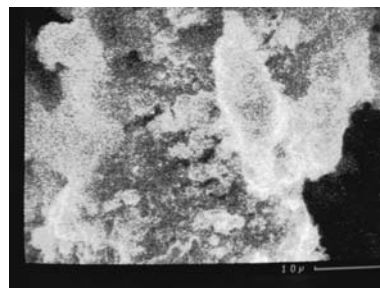


Fig. 4. The microstructure of  $MgB_2$  sample treated at  $750^\circ C$ , for one hour, in argon.

For more structural information, there were carried out analyzes by X-ray diffraction. These were effectuated with an X-ray diffractometer by type D8 Advance (Bruker – AXS/2000), using the data bank PDF-ICDD 1999, dotted with an vertical goniometer, scanning  $\theta$ - $2\theta$ ,  $\theta$ , or  $2\theta$  [incidence angle ( $\theta_{\min} = 1^\circ$ )].

The X-ray diffraction pattern of the powder treated at  $750^\circ C$  is almost the same as that of  $MgB_2$  starting powder, Fig. 5.

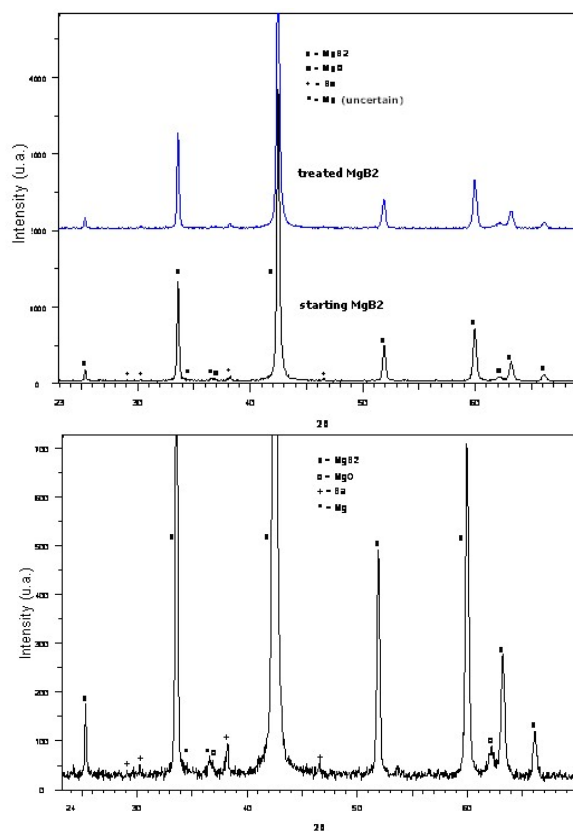


Fig. 5. X-ray diffraction pattern of  $MgB_2$  in raw state (untreated) and treated at  $750^\circ C$ , for one hour, in argon.

The phases analyzing by XRD relieves the fact that MgB<sub>2</sub> is the major phase. All peaks of impurities are noted o for MgO and + for Ba, and other phases like ^ Mg are under the detection limit. When the reaction temperature is relative low, there is unreacted Mg in samples; when the reaction temperature is relative high, it appears the MgB<sub>4</sub> phase [3]. The forming of MgB<sub>2</sub> from powders of Mg and B is exothermic. The sintering temperature of 750 °C is too low to improve the crystallinity.

The lattice parameters determined for MgB<sub>2</sub>, are:  $a = 3.0827 \text{ \AA}$  and  $c = 3.5245 \text{ \AA}$ .

The measured density was  $1.27 \text{ g/cm}^3$ , which is about two times smaller than the calculated value of  $2.63 \text{ g/cm}^3$ .

Fig. 6 presents the temperature dependency of electrical resistivity in zero magnetic field of MgB<sub>2</sub> material. The transition temperatures for initial and ending points are 39 K and respectively 38 K, indicating thus that the superconductivity is indeed realized in this system, [1].

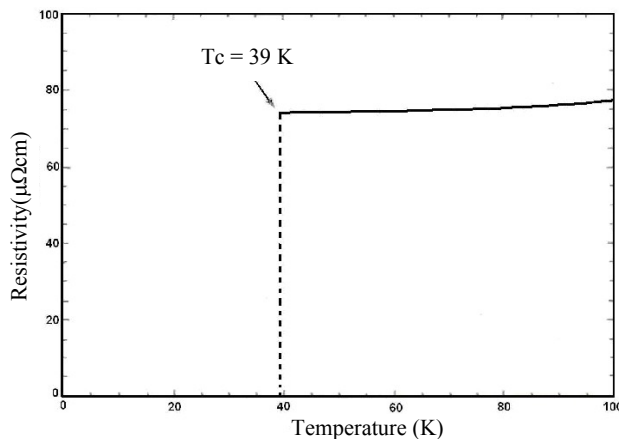


Fig. 6. The temperature dependency of electrical resistivity in zero magnetic field of MgB<sub>2</sub> material.

Measurements of the upper critical field in temperature show a wide range of values for  $H_{c2}(0)$ , from 13 T up to 20 T, Fig. 7. These measurements were obtained for bulk MgB<sub>2</sub> [4].

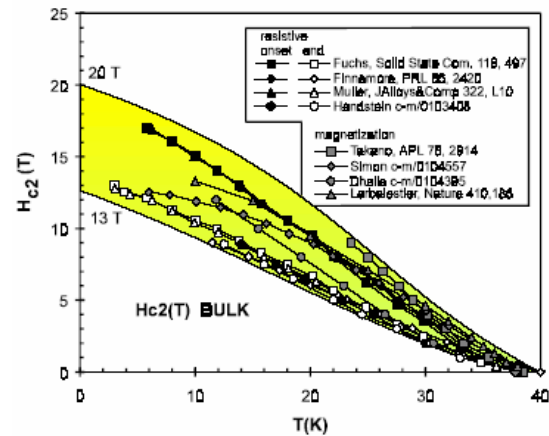


Fig. 7. Upper critical field versus temperature for MgB<sub>2</sub> bulk.

### 3. Conclusions

It was revealed, by microscopic analyzes the formation of specific crystals from MgB<sub>2</sub> system.

From the analyzes got by X-ray diffraction, we demonstrated that hexagonal AlB<sub>2</sub> type structure has been obtained, specific for the studied superconductor. SEM studies of bulk samples of MgB<sub>2</sub> revealed details of the grain boundary structure.

### References

- [1] Jun Nagamatsu, Norimasa Nakagawa, Takahiro Muranaka, Yuji Zenitani, Jun Akimitsu, Nature **410**, March 2001.
- [2] <http://arxiv.org/ftp/cond-mat/papers/0105/0105545.pdf>
- [3] C. Dong, J. Guo, G.C. Fu, L.H. Yang, H. Chen, Superconductor Science and Technology **17**, L55-L57 (2004).
- [4] C. Buzea, T. Yamashita, Superconductors, Science&Technology, August 2001.

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