SUPERCONDUCTIVITY IN MgB2

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Abstract **- The phenomenon of suddenly decrease of electrical resistance at negligible values was emphasized for a lot of metals and alloys in low temperature conditions and was named superconductivity.**
The paper presents an overview regarding the evolution of the superconductor materials and the actual stage of these materials used in electrotechnics and in other different domains, being presented the methods through which the superconductors were obtained and the properties achieved for each one.
The paper refers to obtaining MgB_2 superconducting material. The evolution of formation superconducting phases was monitored by mean of X-ray diffraction and scanning electron microscopy respectively.

Keywords: *superconductivity, superconducting materials, MgB_2, X-ray diffraction, critical temperature*

1. INTRODUCTION

Superconducting materials are used in some applications known at the first sight, but incompatible parameters with classical materials, for example, wires and cables for electrical energy transportation (without losses in DC and with very low losses in AC), electromagnets with very high magnetic field, magnetic susceptibility of some means of transportation. Generally, the applications in the field called "hard currents" belong to this category, [1].
A second category of applications of the field of "hard currents" contain the applications of Josephson effect in principal; for example, SQUID (Superconducting Quantum Interference Device), used as transducer, allows magnetic carding of human body and of all its organ separately (brain, heart, eye, muscle etc.), and as circuit element have the switching time of order of some picoseconds.
The revealing of high temperature superconducting will allow the using on a large scale of the superconducting materials in industry in the scope of reducing the energy losses and of miniaturization the electronics and electrical devices, in medicine for diagnostic and treatment, in research in physics and techniques.
The field of high critic temperature superconducting applications is very large, from the capable lines to transport currents more than 10^6 A, magnets which have fields more than 10^5 Gs, storage of some energies more than 10^7 Joule, up to devices with sizes of some microns, sensors capable to measure 10^{-11} Gs or 10^{-17} V, shields that could make a zero magnetic field. Very low electrical resistance, zero practically in DC of superconducting materials and elimination of Joule losses could represent arguments in introduction of superconductibility in electrical energy distribution. However, economical studies had demonstrated that the superconducting electrical lines are not competitive with classical high voltage cables, the problem of cooling of these cables presenting specially difficulties. The passing from the He liquid for metallic superconductors to H_2 liquid for HTSC, is not leading at economical efficiency rising of cryogenics electrical lines.
Superconducting solenoids or superconducting magnets are the first type of applications made on large scale because superconducting alloys with low critical temperature presents very high critical currents. Superconducting magnets are used already on large scale in industry and laboratories, wherever is necessary o high intensity and an especially stability in time of magnetic field, which is obtain by operation in short-circuit regime of solenoid. Superconducting magnets are used in chemical industry for synthesis of special materials, obtained only in magnetic fields.
Magnetic separators used in mining industry are another application of superconducting magnets.
The manufacture of monofilament conductors and later multifilament was enlarged the application field of HTSC.
In the past this type of application had believed to remain long time the advantage of conventional superconducting materials because the HTSC materials present critical density of too low currents. However, in present, is making electrical motors, electric generator from HTSC multifilament conductors.
HTSC materials can be used in the field of electronics and electrical engineering, too.
The field of electronics with superconductors is making from digital integrated circuits with large integrated scale (LSI), because no semiconducting devices have not simultaneously delay times of 10 ps order and consumption powers of 10^{-7} – 10^{-6} W. The most used circuit element is three junctions interferon.
The using of superconducting materials in applications of electrical field is limited in present by low values of the critical currents and by high instabilities which are presenting the electrical conductors from these

materials.
It was made researches in the field of superconducting limiting device of current, also.

2. RESULTS AND DISCUSSION

After the first discovery of the superconducting ceramic system La-Ba-Cu-O with critical transition temperature between 30 – 40 K, other families of copper-oxide based ceramics have been synthesized with higher critical temperatures. These oxides include the Y-Ba-Cu-O series (Tc ≈ 90K), the Bi-Sr-Ca-Cu-O series (Tc ≈ 80-115K), the Tl-Ba-Ca-Cu-O group (Tc ≈ 85-125K), and some others which do not form obvious classes (e.g., $Ba_{0,6}K_{0,4}BiO_3$), [2].
YBCO remains the best studied ceramic superconductor, although other ceramic oxide systems based on Bi/Sr/Ca/Cu/O or Tl/Ba/Ca/Cu/O have been prepared and found to have somewhat higher Tc's than YBCO.
The discovery of superconductivity with Tc ≈ 39K in magnesium diboride (MgB_2) was announced in January 2001, [3]. 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 nonoxide and non-C60- based compound. The reported value of T_c 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_c is due to some form of exotic coupling.
Precise knowledge of the powders is very important both from the point of view of manufacturing technology, and for assurance of quality and properties required to the products obtained from these powders.
From the physical properties of the powders, the granules size and granulometric repartition have a conclusive influence upon the technological properties of the powders, upon the properties of pressed semi-products and of finite sintered products.
The powders used for the obtaining of superconducting materials which appertain to the YBCO and BSCCO systems are mixture of oxides and carbonates for example Y_2O_3, Bi_2O_3, CuO and $BaCO_3$, $SrCO_3$, $CaCO_3$, respectively. These powders are characterized by a high purity and by very good properties of pressing and sintering.
Examination of grain size constitutes an important factor in the determination of $YBa_2Cu_3O_{7-\delta}$ properties. Twinning and micro fissures to the ceramic materials $YBa_2Cu_3O_{7-\delta}$ in time of tetragonal/orthorhombic transformation are related to the grain size.
The granules shape, determined by the methods of obtaining of the powders mixtures, is polyhedral for the YBCO system and lamellar for the BSCCO system.
Internal structure of the granules may be compacted or porous, spongious. For determination of the internal structure, powder granules are immersed in a plastic mass or in bakelite and then the metallographic samples obtained like this, are prepared by known methods of abrasion, polishing and etching. For both systems YBCO and BSCCO, the internal structure of the granules is compacted.
For achievement of prescribed chemical composition to the finite product, to these manufacturing, mostly it using powders mixtures, which contain the necessary quantity of lubricants for pressing facilitation and density uniformity in the inner of pressed semi-products. The mixture components graduation it makes by weighing, in conformity with prescribed prescription, from much more powders types, mostly it add the small quantities of lubricant materials which favor the forming operation.
One of the advantages of MgB_2 fabrication is that magnesium diboride is already available from chemical suppliers, as it is synthesised since early 1950's. However, sometimes the quality of MgB_2 powder commercially available is not as high as desirable. For example, MgB_2 commercial powders have wider transition in superconductive state and slightly lower Tc than the materials prepared in laboratory from stoichiometric Mg and B powders.
In the figure 1 is a schematic picture of the fabrication methods used up to date for MgB_2 thin films, powders, single crystals, wires and tapes, [4].

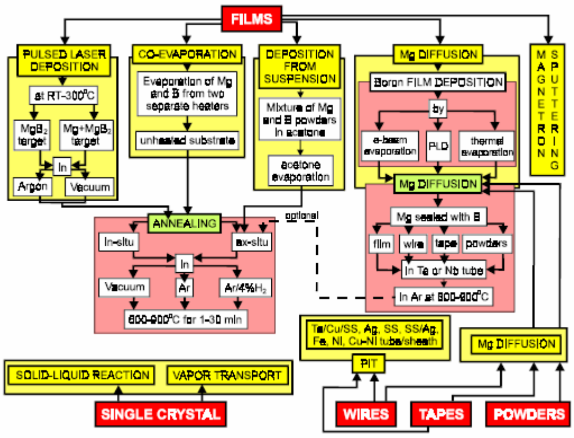

Figure 1: Schematics of the methods of preparation used for magnesium diboride, [4]

MgB_2 crystallizes in the hexagonal AlB_2 type structure, which consists of alternating hexagonal layers of Mg atoms and graphite like honeycomb layers of B atoms, [5, 6]. 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, figure 2.

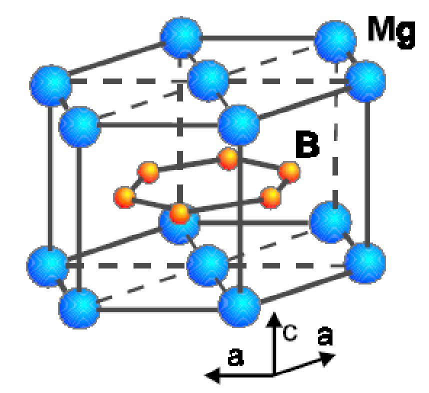

Figure 2 : The structure of MgB_2 containing graphite-type B layers separated by hexagonal close-packed layers of Mg, [5, 6]

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_2 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_2 (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.

Electron microscopy was realized with an electronic microscope, type scavenging CAMSCAN 3 (Cambridge Instruments/1981) with maximum extension: 20000x (200000x theoretic) 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 figure 3. It remarks that the particles have an irregular shape both for the treated sample and for that untreated. It is not observed either a porosity, which indicates the fact that the samples have a high density.

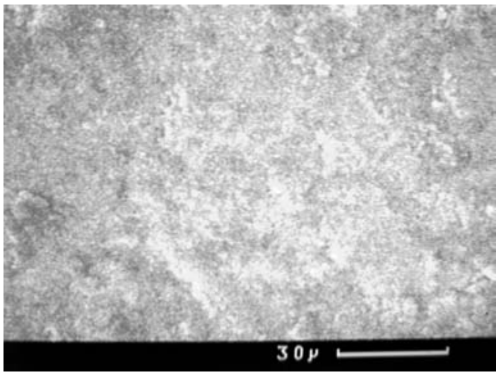

Figure 3 : The microstructure of MgB_2 powder treated at 750˚C, for one hour in argon

For more structural information, were effectuated analyzes by X-ray diffraction. These were effectuated with an X-ray diffractmeter by type D8 Advance (Bruker – AXS/2000), using the data bank PDF-ICDD 1999, dotted with an vertical goniometer, scanning θ-2θ, θ, or 2θ [ray incidence (θ_{min} = 1°)].

The X-ray diffraction pattern of the powder treated at 750°C is almost the same as that of MgB_2 starting powder, figure 4.

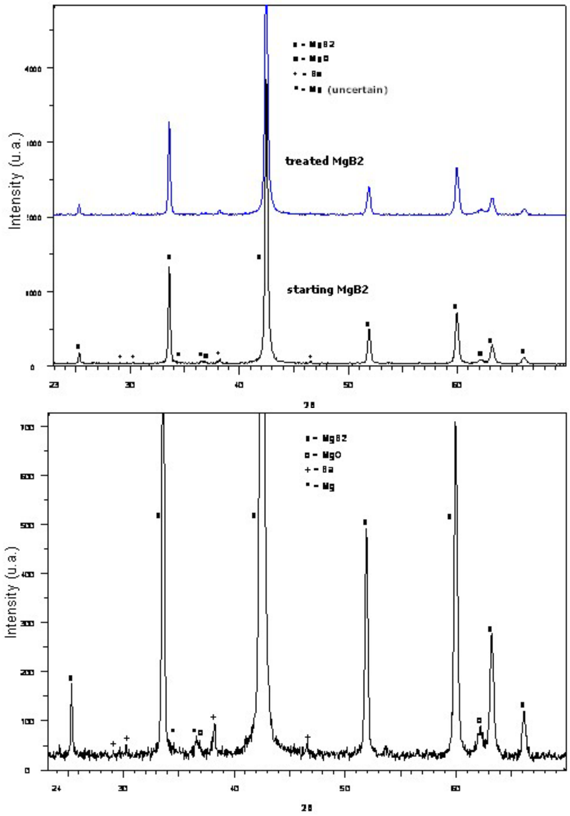

Figure 4 : X-ray diffraction pattern in raw state (untreated) and treated at 750°C, for one hour, in argon

The phases analyzing by XRD relieves the fact that MgB_2 is the majority 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, appears the MgB_4 phase [7, 8]. The forming of MgB_2 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_2, are: a = 3.0827 Å and c= 3.5245 Å.

3. CONCLUSIONS

It was relieved, through microscopic analyzes, formation of specific crystals from MgB_2 system.
From the effectuated analyzes through X-ray diffraction, results that was obtained hexagonal AlB_2 type structure, specific for the studied superconductor. SEM studies of bulk samples of MgB_2 revealed details of the grain boundary structure. Also, the powder X-ray diffraction pattern of the MgB_2 powder is presented.

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