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Physical Properties of Magnesium Diboride Superconductor and its Role in Hybrid Energy Transfer

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Abstract: This article discusses the properties of magnesium diboride material and superconductors made of magnesium diboride. Magnesium diboride superconductors can be used more efficiently than other superconductors. For this reason, in recent experiments in various fields of physics, it is necessary to use superconductors, while superconductors made of magnesium diobride are used. The article notes the use of magnesium diboride in a hybrid power transmission system that transmits hydrogen energy and electricity in parallel. At the end, important issues for discussion and necessary conclusions were given.

Keywords: magnesium diboride superconductor, hexagonal structure, superconducting transition temperature, oxygen free high conductivity, magnetic resonance imaging superconductor, hybrid energy, hot isostatic pressing, resistive sintering, paint coating.

Introduction. Superconductivity har separately importance in physics world. Since superconductivity was discovered, it has been one of the most useful process in science. Super conductor reused in many devices. Spealists fix them to be used in from small nanotechnology devices to huge magnet and electromagnet devices. In last years, science is rapidly developing and types of superconductors are also increasing fast. Superconductors made from magnesium diboride (MgB_2) are mentioned as successful super conductors by scientists at the moment. In this article, we observe such superconductors and their role in hybrid energy.

Firstly, we meet information about MgB_2. Magnesium diboride is the inorganic compound with the formula MgB_2. Having a dark gray and water-insoluble solid make magnesium diboride be more essential compound.MgB_2has attracted attention because of its superconducting at 39 K (−234 °C). MgB_2 differs strikingly from most low-temperature superconductors, which feature mainly transition metals in terms of its composition. Superconducting mechanism of $MgB_2$is primarily described by BCS theory.

Chemical formula	MgB_2
Molar mass	45,93 g/mol
Density	2,57 g/cm^3
Melting point	830^0C (1530^0F, 1100 K)
Structure	Crystal structure (Hexagonal, hP3)
Space group	P6/mmm, No 191

Table-1.Basic properties of magnesium diboride [13].

Methods. In 1953 synthsis and structure of magnesium diboridewas were identified. The reaction between boron and magnesium powders in high tempurature makethe simplest synthesis. This reaction formally begins at 650 °C, because of melting of magnesium metal at 652 °C, the reaction may involve diffusion of magnesium vapor across boron grain boundaries. At conventional reaction temperatures, sintering is minimal, although grain recrystallization is sufficient for Josephson quantum tunnelling between grains.

Structure of magnesium diboride is hexagonal type [1].Its unit structure consists of alternating hexagonal layers of magnesium atoms and graphite-like honeycomb layers of boron atoms. The boron planes are separated by the layers of magnesium, and magnesium atoms are closely packed with each magnesium atom situated in between the centers of the hexagons forming each of the boron lattice planes.

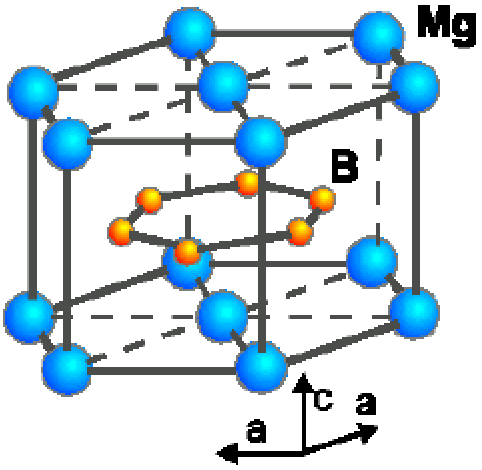


Figure-1.Hexagonal crystal structure of MgB_2 [3].

In 2001 it was regarded as behaving more like a metallic than a cuprate superconductor. The superconductivity of MgB_2 was discovered by Akimitsu Jun and his team in 2001 although MgB_2 was known since 1950. MgB2 superconductor is the simple metallic binary compound which has the highest critical temperature. The critical temperature of around 39 K is nearly twice the temperature of the intermetallic superconductors at that time. Of course, this announcement had excited the tremendous research passion from fundamental physics properties to practical application research around the world. MgB_2 superconductor would be a high quality material for both large scale applications and electronic devices due to its high critical temperature T_c large coherence lengths ξ, high critical current densities J_c large coherence lengths ξ, high critical current densities J_c, simple crystal stru, simple crystal structure, and high upper critical fields H, as well as the transparency of its grain boundaries to current . MgB_2has been fabricated into various shapes such as bulks single crystals, thin films, wires and tapes *etc.* An abundant published research results revealed the great interest community in this materials.

Many properties are anisotropic due to the layered structure. It has the highest superconducting transition temperature T_c is 39 K.MgB_2 is a type-II superconductor. There is connection between magnesium diboride’s magnetic field induction and critical current.

Magnetic field induction (T)	Maxsimum critical current, J_c (A/m^2)
5	10^9
10	10^8
15	10^7

18	10^6
20	10^5

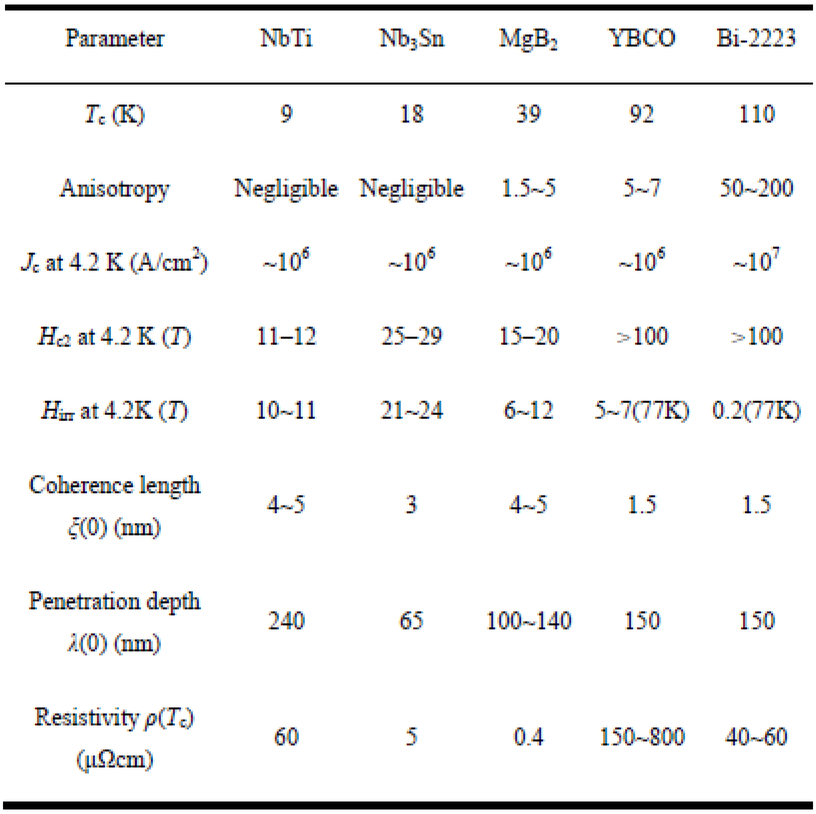
Table-2.Connection between magnetic field induction and maxsimum critical current of magnesium diboride [13].

There are several companies which can fabricate MgB_2 wires and tapes presently. Columbus Superconductors has fabricated the first kilometer level long length MgB_2tapes up to 1.6 km in 2006. The tapes had been fabricated with ex sit powder-in-tube method. In such a process, fully reacted MgB_2 powders were packed into pure nickel tubes, which were cold worked in order to manufacture a long wire. Such a monofilament wire was cut into several pieces and stacked again inside the second nickel tube, which also included an inner oxygen free high conductivity copper core (OFHC) and an iron diffusion barrier in order to prevent diffusion of copper to nickel and MgB_2 during heat treatment. The composite was cold worked again by drawing and rolling to achieve the final rectangular shape of the tape. The typical thickness and width of the manufactured tapes were 0.65 mm and 3.65 mm, respectively. The final heat treatment at high temperature (900 °C) was applied to sinter the MgB_2 grains and achieve the high critical current density.

In 2006 a 0.5 tesla open MRI(Magnetic resonance imaging) superconducting magnet system was built using 18 km of MgB_2 wires. This MRI used a closed-loop cry cooler, without requiring externally supplied cryogenic liquids for cooling. The next generation MRI instruments must be made of MgB_2 coils instead of NbTi coils, operating in the 20–25 K range without liquid helium for cooling. Besides the magnet applications MgB_2 conductors have potential uses in superconducting transformers, rotors and transmission cables at temperatures of around 25 K, at fields of 1 T. A project at CERN to make MgB_2 cables has resulted in superconducting test cables able to carry 20,000 amperes for extremely high current distribution applications, such as the high luminosity upgrade of the Large Hadron Collider. The IGNITOR tokamak design was based on MgB_2 for its poloidal coils. Thin coatings can be used in superconducting radio frequency cavities to minimize energy loss and reduce the inefficiency of liquid helium cooled niobium cavities. Because of the low cost of its constituent elements, MgB_2 has promise for use in superconducting low to medium field magnets, electric motors and generators, fault current limiters and current leads. Unlike elemental boron whose combustion is incomplete through the glassy oxide layered impeding oxygen diffusion, magnesium diboride burns completely when ignited in oxygen or in mixtures with oxidizers. Thus magnesium boride has been proposed as fuel in ram jets. In addition the use of MgB_2 in blast-enhanced explosives and propellants has been proposed for the same reasons.

Since 2001, conductor development has progressed to where MgB_2 superconductor wires in kilometer long lengths have been demonstrated in magnets and coils. Currently, works have been started and are in-progress on demonstrating MgB_2 wire in superconducting devices for which the wires are also available commercially.

Magnesium diobride is widely used because superconductors are convenient for all-round production. In the table-3, we see that magnesium diobride superconductors differ from others by the satisfaction of several physical parameters. Nowadays, science is closely related to economics. For this reason, production requires economic savings. It is the experiments performed with magnesium diboride superconductors that increase the scientific and economic efficiency of the practice [2].



Parameter	NbTi	Nb_3Sn	MgB_2	YBCO	Bi-2223
T_c (K)	9	18	39	92	110
Anisotropy	Negligible	Negligible	1.5~5	5~7	50~200
J_c at 4.2 K (A/cm^2)	$\sim 10^6$	$\sim 10^6$	$\sim 10^6$	$\sim 10^6$	$\sim 10^7$
H_{c2} at 4.2 K (T)	11–12	25–29	15–20	>100	>100
H_{irr} at 4.2K (T)	10~11	21~24	6~12	5~7(77K)	0.2(77K)
Coherence length $\xi(0)$ (nm)	4~5	3	4~5	1.5	1.5
Penetration depth $\lambda(0)$ (nm)	240	65	100~140	150	150
Resistivity $\rho(T_c)$ (μΩcm)	60	5	0.4	150~800	40~60

Table-3. Fundamental superconducting properties of the practical Superconductors [4].

Results. The transfer of massive amounts of both electrical and chemical power over long distances will present a major challenge for the global energy enterprise in the future. Attraction of hydrogen is apparent as a chemical energy agent, possessing among the highest energy density content of various common fuels, whose combustive “waste” is simply water. It could be transferredvia cryogenic tubes being liquid at temperatures ~18–26 K. Superconductors are used to store and transport liquid hydrogen. This is considered beneficial to the economy. The transportation and delivery of hydrogen in superconducting pipes has been introduced into practice. It is known that the problem of energy transmission is a topical problem of its production. Methods of using superconductors have been studied to solve this problem. Some of the successes achieved in high-capacity liquid helium superconducting cables in the late 1970s made it impossible to take advantage of the high cost of helium cooling. With the discovery of high-temperature superconductors, new research in this area was opened. One of the ideas that has been put forward for a long time as a hypothesis is that cryogenic for a liquid hydrogen superconducting cable and a very high energy fluxis used as an additional fuel to provide. This is called as hybrid transfer line or super-grid. The idea has become even more attractive due to the growing need to use hydrogen energy in the energy sector and for other purposes. This is also determined by the effective physical parameters of hydrogen use. For example, hydrogen has the highest fuel efficiency among other chemical elements - 120 MJ / kg. Hydrogen is the best refrigerant, i.e. the best cryogen. For example, if the cooling capacity of liquid nitrate $(LN_2)$is 199 kJ / kg, the cooling capacity of hydrogen is about 2.3 times greater than that of 446 kJ / kg. Parallel connection of the conductor to the cable was accepted as a feasible project. Of course, this idea had to be tested in practice.

Two experiments in the world test of the hybrid energy transfer line has been performed by Russian scinetists at the KB “Khimavtomatika” (Voronezh City) in 2011 and 2013. In these experiments, both electrical and chemical power over are transferred by two parallel cables. The team of experementers with using Italian-produced superconductor (MgB_2) wire has made and successfully tested two hybrid energy transfer lines with liquid hydrogen as a chemical source of power and superconducting cable as a source of electricity(Figure-2). Researchers performed successful tests of two prototypes of hybrid energy transfers lines: 10 m in 2011 and 30 m in 2013.

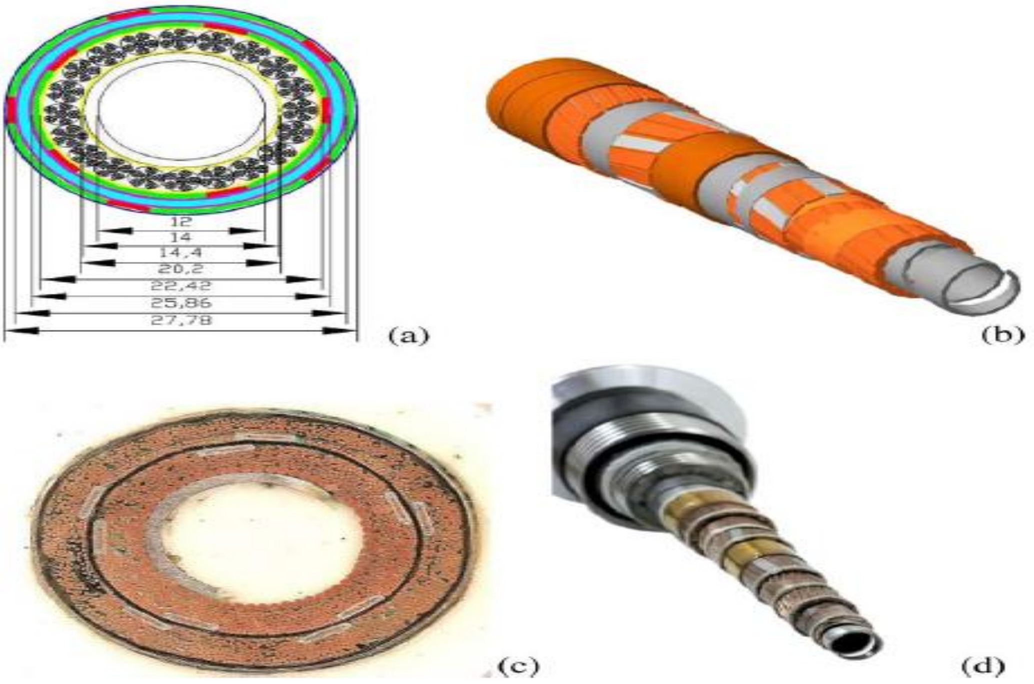


Figure-2.MgB_2cable design: (a) sketch of cross-section with sizes shown;

(b) 3D view of cable; (c) cross-section of a cable; and (d) photo of the cable Model [7,8].

The design of a prototype of a superconducting MgB_2 cable consists of three elements: a former, current carrying layers and insulation (Figure-2(a)). The former is a central element that performed the supporting function. It consists of:

- the main supporting stainless steel spiral that formed a ∼12 mm diameter internal channel for the flow of liquid hydrogen;
- twisted winding of copper wires with a total cross section sufficient to ensure reliable protection of the superconducting current carrying layer in case of short circuit fault;
- copper tapes winding providing a smooth outer surface of the former for assembling the superconducting MgB_2 tapes which are the main current carrying layer.

Magnesium diobride was used in those experiments as it is the preferable choice for a system with liquid hydrogen. Dependence of critical current on magnetic field at different temperatures is shown in Figure-3 for the flat MgB_2 wire used in the experiment.

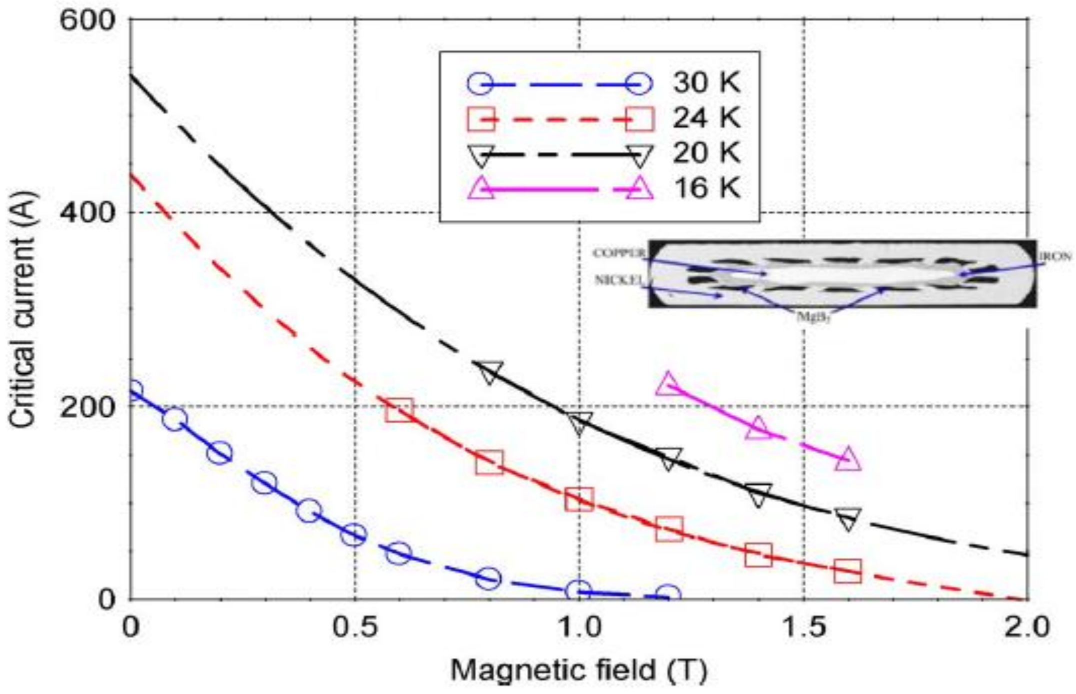
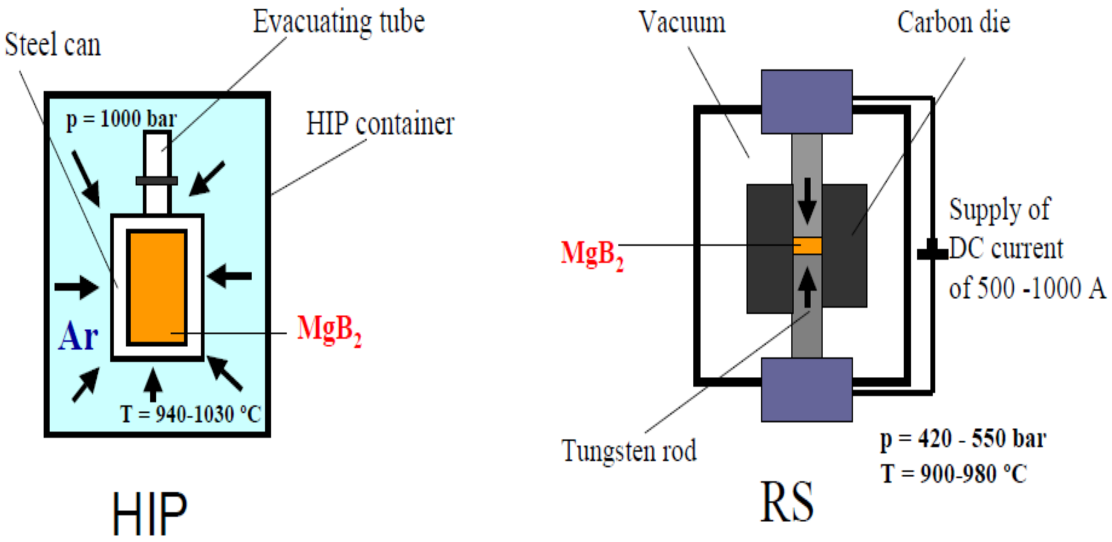


Figure-3. Dependence of critical current on magnetic field at different temperatures in the experiment [7,8].

Discussion. From some experimental works we also get information about magnesium diboride’s applies. For example, three experimental techniques for the preparation of MgB_2 are used in this work; they are hot isostatic pressing (HIP), resistive sintering (RS) and paint coating (PAC) [11]. HIP is a standard technique that was very successful in application to MgB_2. RS is an original technique. Its closest analogue is spark plasma sintering (SPS). HIP allows producing dense samples with lower porosity (5-7%), bigger volume and better superconducting properties than in RS samples. However, it is a slow process involving long preparation procedures.MgB_2 samples prepared by HIP or RS are cut on a wire spark erosion unit into small, about 0.2×0.2×3-4 mm^3, bars and their magnetic moment (m) is measured on a Quantum Design Magnetic Properties Measurement System MPMS-XL in DC field μ_0H up to 7 T. The critical density is derived from m using equation:

$$J_c = \frac{4m}{a^2bc(1-\frac{a}{3b})}$$

wherea,b and c are dimension of the bar (c>b>a) and magnetic field is applied along the longest c-axis. The small size of samples is necessary because a vry high J_c in MgB_2generates large magnetic moment exceeding the limit of m measurable in MPMS.



Picture-4. Schemes of HIP and RS [9].

The improvement is attributed to a high density of structural defects, which are the likely source of vortex pinning. These defects, observed by transmission electron microscopy, include small angle twisting, tilting, and bending boundaries, resulting in the formation of sub grains within MgB2 crystallites [10].

Conclusion. The disappearance of fossil fuels, global warming and transition to renewable energy resources lead to synergy of superconductivity. The superconductivity offers compactness, efficiency, energy savings and wide range of applications that are not possible without using this macroscopic-scale quantum phenomenon. It gives hope to cope with threatening energy crisis and may addresses global problems on the planetary scale. Magnesium diobride superconductor is important to solving many problems. In the future, many devices may be based on using magnesium diobride superconductors.

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