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Review Article

Superconducting Properties and Applications of MgB_2

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ABSTRACT

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, electromagnets with very high magnetic field and magnetic susceptibility of some means of transportation. Generally, the applications in the field called hard currents belong to this category. A second category of applications of the field of hard currents contain the applications of Josephson effect in principal; for example, Superconducting Quantum Interference Device, used as transducer, allows magnetic carding of human body and of all its organ separately and as circuit element have the switching time of order of some picoseconds. The search of new superconducting materials with increasingly high critical temperature is a very active field of outmost importance. The recent discovery of phonon mediated superconductivity at 39.5 K in MgB_2 has renewed the interest in the phonon driven mechanism alive. While in fact the mechanism of superconductivity in cuprates is still under debate, there are many materials in which the electron - phonon interaction is certainly the mechanism responsible for superconductivity. MgB_2, in particular, has many important aspects which make it interesting from the point of view of applications.

Keywords: Superconductors, Critical Temperature, MgB_2, Properties and Applications.

1. INTRODUCTION

The phenomenon of superconductivity has not lost its fascination ever since its discovery in 1911. The flow of electric current without friction amounts to the realization of the old human dream of a perpetuum mobile. The ratio of resistance between the normal-conducting and the superconducting state has been tested to exceed 10^{14}, i. e. it is at least as large as between a usual insulator and copper as the best normal-conducting material. But superconductivity is more than just the disappearance of resistance: The Meissner effect, the expulsion of magnetic fields from a superconductor, discovered in 1933, shows that superconductivity is a true thermodynamical state of matter since, in contrast to the situation for a merely perfect conductor; the expulsion is independent of the experimental history[1]. As the progress of cooling technique gave access to lower and lower temperatures, superconductivity established as common low-temperature instability of most, possibly all metallic systems. As the apparent $T \rightarrow 0$ K state of metals, the zero entropy postulate of thermodynamics for this limit points to its nature as a macroscopic quantum state.

In spite of the great impact of BCS theory, the discovery of oxide high-temperature superconductors (HTSC) in 1986 made it very clear that new theoretical concepts will be required here. The problem is not the high Tc of up to 138 K under normal pressure, far above the pre-HTSC record of 23 K. Fermi sea of quasi-free electrons in the case of classical metals where the Cooper-pair condensed electrons amount only to a small part of the valence electron system ($k_BT_c << E_{Fermi}$), in these layered cuprate compounds there is only a shallow reservoir of charge carriers ($k_BT_c \sim E_{Fermi}$) which have to be introduced in the insulating antiferromagnetic stoichiometric parent compound by appropriate doping. The thus generated normal state corresponds to a bad metal in which Coulomb correlations strongly link the charge and spin degrees of freedom. This intrinsic proximity of metal-insulator, magnetic and SC transitions continues to present a great challenge to theory, which is sensibly more complicated than the classical Superconductivity problem. The SC instability in cuprate HTSC, as well as in the structurally and chemically related layered cobaltate and ruthenate compounds, is hence believed to stem predominantly from a magnetic and not from a phononic interaction as in the case of the classical metallic superconductors where magnetism plays only the role of alternative, intrinsically antagonistic long range order instability[2].

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. 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 limitated 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[3].

Magnesium diboride (MgB_2)is an old material, known since early 1950's, but only recently discovered to be superconductor at a remarkably high critical temperature about 40K for its simple hexagonal structure. Fig. 1 shows the structure of MgB_2 containing graphite-type B layers separated by hexagonal close packed layers of Mg. Since 1994 there has been a renewed interest in intermetallic superconductors which incorporate light elements, such as boron, due to the discovery of the new class of borocarbides RE-TM_2B_2C, where RE = Y, Lu, Er, Dy or other rare earths and TM = Ni or Pd. The main characteristics of these compounds are very high Tc among inter metallics, the anisotropic layered structure and a strong interplay between magnetism and superconductivity. The discovery of superconductivity in MgB_2 certainly revived the interest in the field of superconductivity, especially non-oxides and initiated a search for superconductivity in related boron compounds. Its high critical temperature gives hopes for obtaining even higher critical temperature (T_c's) for simple compounds[4].

2. PROPERTIES

The study of MgB_2 energy gap showed its two gap nature. The values of gaps energy allow the conclusion that MgB_2 combines features of I and II type's superconductors and thus, are belong the so called 1.5-type superconductors. The fact that both gaps close at the same transition temperature can be the evidence that the first low-temperature gap is induced by the second one and in the moderate or high magnetic fields it behaves as II type superconductor[5].

The discovery of superconductivity at 39 K in MgB_2 has caused great interest among the many researchers in applied superconductivity. In experiments on MgB_2 bulks and tapes, the MgB_2 system shows no weak coupling of grains, which is advantageous to obtain a large current transfer across the grains. The relatively high transition temperature, weak link free grain boundaries, and low cost of materials make this a promising material for various applications[6]. One of the most important features of MgB_2 is that it does not exhibit weak link electromagnetic behavior at grain boundaries or fast flux creep, which limits the performances of YBCO cuprates, oxidized Nb, Nb_3Sn and Nb films.

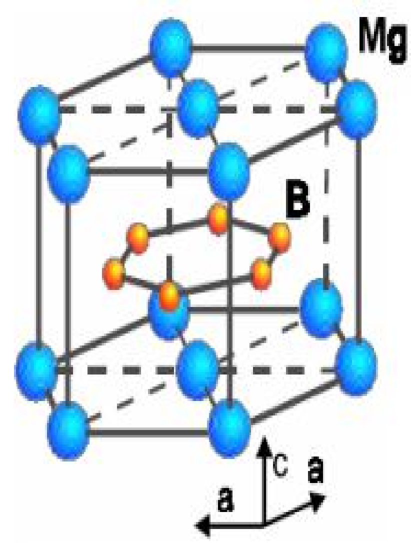

Fig. 1: The structure of MgB_2 containing graphite type B layers separated by hexagonal close packed layers of Mg

3. APPLICATIONS

The discovery of superconductivity at 39 K in MgB_2 has attracted great interest because it introduces a new, simple binary intermetallic superconductor with record high superconducting T_c for a non-oxide and non-C_{60}-based compounds[7]. The reported value of Tc seems to be either above or at the limit suggested by BCS theory. This raises the question whether this remarkable high Tc is due to some exotic form of electron pairing. Therefore, any experimental data that can shed light on the mechanism of superconductivity in this material is of great interest and for this, availability of high quality samples is necessary. Material stability is another issue of great concern for device applications of superconductors. Clearly material should preferably be stable against prolonged atmospheric exposures as well as during fabrication processes, such as photolithography where superconductor could be exposed to water or various solvents. The newly discovered MgB_2 superconductor is expected to be useful for various electric power applications as well as electronic device applications because its transition temperature is much higher than those of conventional metallic superconductors such as Nb-Ti and Nb_3Sn. In order to evaluate the potentiality for power applications, the development of wire processing techniques is essential[8].

4. CONCLUSIONS

MgB_2 is an old material, known since early 1950's, but only recently discovered to be superconductor at a remarkably high critical temperature about 40K for its simple hexagonal structure. Material stability is another issue of great concern for device applications of superconductors. Clearly material should preferably be stable against prolonged atmospheric exposures as well as during fabrication processes, such as photolithography where superconductor could be exposed to water or various solvents. MgB_2 system shows no weak coupling of grains, which is advantageous to obtain a large current transfer across the grains. One of the most important features of MgB_2 is that it does not exhibit weak link electromagnetic behavior at grain boundaries or fast flux creep.

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