Fabrication of Superconducting Materials based on Magnesium diboride by SHS Technique in Centrifuge

Sanat Tolendiuly[1, a], Sergey Fomenko[2, b], Anna Baideldinova[2, c], Zulkhair Mansurov[2, d], Karen Martirosyan[3, e]

[1]Al-Farabi Kazakh National University, 050040, Almaty, Kazakhstan

[2]Institute of Combustion Problems, 050012, Almaty, Kazakhstan

3University of Texas Rio Grande Valley, 78520, Brownsville, the USA

sanat_tolendiuly@mail.ru; exotherm@yandex.ru; abaid@inbox.ru; zmansurov@kaznu.kz; karen.martirosyan@utrgv.edu

Keywords: magnesium diboride, superconductor, centrifuge, transition temperature, current density.

Abstract. The superconducting nanocomposites based on magnesium diboride were produced by self-propagating high-temperature synthesis (SHS) under the effect of centrifugal force in high-temperature centrifuge. The centrifugal rotational speed shaft was within the limits of 2000 rpm. The critical transition temperature (T_c) and current density were determined by magnetometric measurements by the Physical Property Measurement System (PPMS, Ever Cool-II) Quantum Design. It was found that the critical transition temperature (Tc) of sample is in the range of 37.5K and the critical current density (J_c) is in the range of about $0.8x10^8$A/см^2.

Introduction

The discovery of superconductivity in magnesium diboride MgB_2, renewed abundantinte rest in non-oxides materials for superconductivity and relativity high critical temperature (at about 40 K), which offers expectations to obtaining even higher Tc's for simple compounds [1]. The application of superconductivity can lead to formation of novel efficient energy delivery systems and devices and ultrafast electronic computers [2-3].There are several conceptual different methods to synthesis of superconducting magnesium diboride, such as high temperature solid state formation, chemical vapor deposition, arc casting and melting in the vacuum, etc [4].One of the prospective methods of synthesis of magnesium diboride is a self-propagating high-temperature synthesis [5].In the present paper, the laboratory samples based on magnesium diboride were synthesized by combustion synthesis under the effect of centrifugal force in high-temperature centrifuge [6]. Duo to this setup is possible to create the following conditions: the temperature of chemical reaction up to 3000 K, and centrifugal acceleration up to 2000g.High-temperature centrifuge shown in Figure 1,a consists three main parts: the engine, shaft with three reactors, the ignition system of combustion during the rotation. The reactor is consists a quartz tube with 35 mm diameter and 130 mm in length, which placed in a metal sleeve closed at both sides of the lids. The covers have several small holes used for eliminate the outlet gases from the combustion process and to ignite composition by electrically heated coil.

Experimental Part

The initial regents were amorphous boron powder (20 microns), magnesium powder (250 microns) for synthesis superconductingmagnesium diboride. The initial powdersof Mg (55.3%) and B (44.7%) were mixided well in the ball milimh machine and was compacted into discs by a steel cylindrical press – for munder pressure 0.4 GPa.Nonstoichiometric mixture (excess of magnesium) was prepared in order to decrease the loss of magnesium during the synthesis due to its high volatility at high temperature.Because the system magnesium and boron weakly exothermic, and for excitation of combustion processwas used the mixture (55% CuO + 12% Al + 33% Al2O3) to ignite the samples. Schematic diagram of loading the initial mixture in the centrifuge was shown in Figure 1 b.

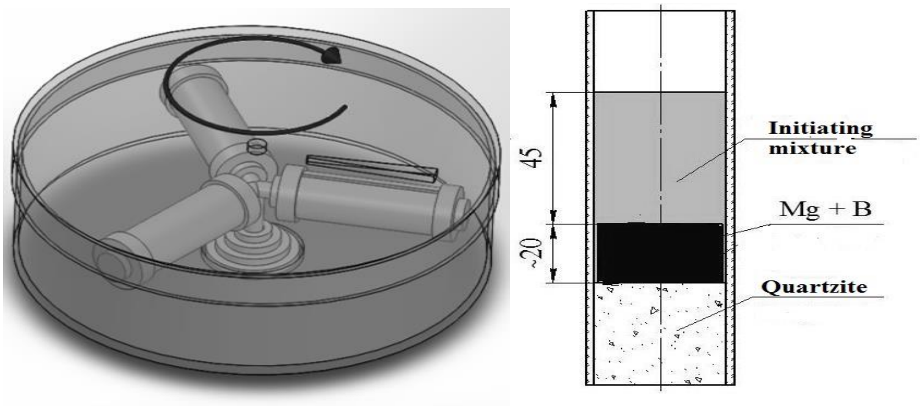

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Figure 1. (a) – High temperature centrifugereactor;(b) - Schematic diagram of loading of the initial mixture.

According to the layer-by layer XRD analyses of products the formation of magnesium diboride appires during 0.8 s after the ignition of combustion. The synthesized product exhibited about70% of MgB_2phase by weight. Besides MgB_2phase was formed following phases in this system: magnesium oxide (22% by mass), and have been identified a small amount of Mg, MgB_4, SiO_2 and intermetallic phases $CuMg_2$, AlB_2.Figure 2 shows morphology of a sample after the combustion process in the centrifuge. The average particle size is in the range of 250-300 nm.

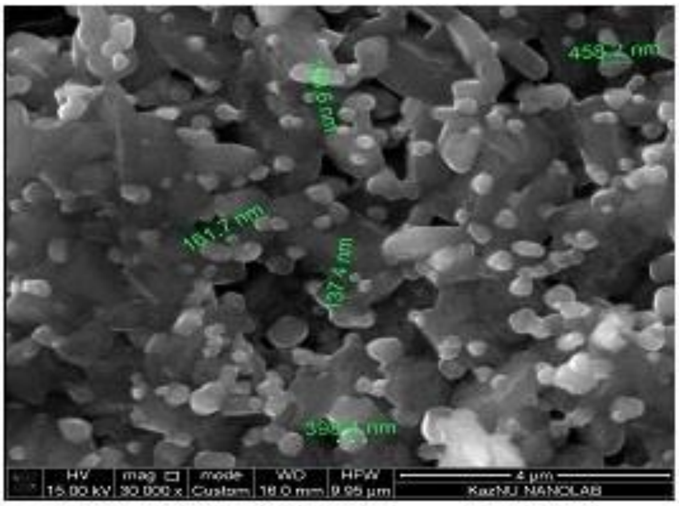

Figure 2. The SEM image of the magnesium diboride obtained in a centrifuge reactor by combustion process

It is evident that the sample has kept its original shape. SEM layer-by layer analysis revealed that the film cover of brown color was identified as the intermetallic phases of $CuMg_2$and AlB_2 formed on the sample surface. Relying on this result, we can be assumed that the initiating mixture during combustion process not only transferred its heat energy, but also partially interacted with the surface layer of the sample. The superconducting characteristics of samples were measured by magnetic measurement method (Quantum Design PPMS Ever Cool-II) under temperature range of 1.9-100 K and magnetic field of 10 Oe in both zero-filed-cooled (ZFC) and in field-cooled (FC) states. It was found to decrease in the magnetic moment of the samples at temperatures $37 < T < 38$K, proceeded by a sharp response of the magnetic moment of the transition material in the diamagnetic state at T = 37.5K in the measurement of temperature dependences of the magnetization of the sample (Figure 3).The lower T_c in the present sample could be possibly due to the presence of small amount of MgO phase and the resulting off stoichiometry of the desired superconducting phase of MgB_2.

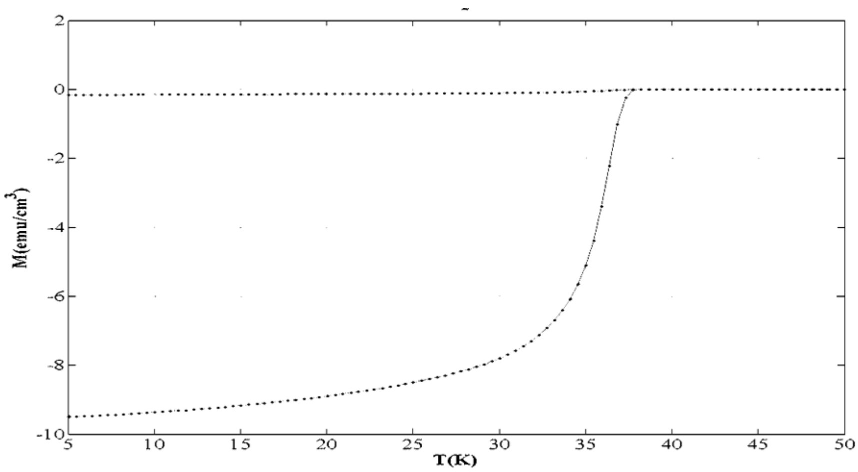

Figure 3. Field-cooled and zero-field-cooled magnetization of MgB_2 (produced in a centrifuge at 2000 rpm) as a function of temperature in an applied field of 10 Oe showing the superconducting transition temperature.

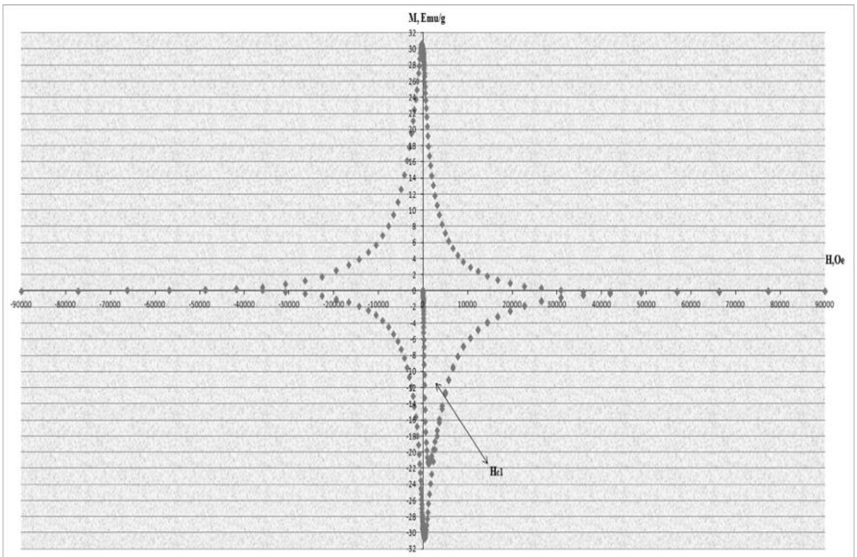

Figure 4.The curves of hysteresis loop for the sample produced in a centrifuge at 2000 rpm.

This temperature is characterizing the transition temperature from the normal to the superconducting state, indicating the nucleation of the superconducting phase in the samples at these cryogenic temperatures. One of the basic characteristics of superconductivity "the critical current density" was calculated and analyzed. The value of the critical current density of the samples was calculated by the Bean's formula [7]:

$$J_c=30*\Delta M/d,$$

Where, J_c – critical current density, d – average size of particle ~250 nm,ΔM - the difference in the decreasing and increasing of the magnetization curve defined by the magnetic hysteresis obtained from Figure 4. The value of the critical current density of MgB_2 powders were found that is equal to $0.8x10^8 A/cm^2$.

Summary

The superconducting material based on magnesium diboride wassynthesizedby the centrifuge technique by using combustion synthesis.It was found that the centrifugal force contributes to the intensification of the process and reduce the period of formation of the superconductor structure. At the same time the injection of impurities into the surface layers of the synthesized materials has no significant effect on the critical transition temperature of samples. In this regard, further investigation of the influence of the centrifugal acceleration on the combustion processes of magnesium diboride and on its superconducting properties is appeared more promising.

Acknowledgments

This work was supported by the Foundation of the First President of the Republic of Kazakhstan – the Leader of the Nation.

References

[1] Nagamatsu J., Nakagawa N., Muranaka T., Zenitani Y. and Akimitsu J. Superconductivity at 39 K in magnesium diboride, Nature, Vol. 410 (2001), p. 4.

[2] [2] Phillips J.C. Physics of High-Tc Superconductors, J.C. Phillips. - Boston: Academic Press, Vol. 5 (1989), p. 393.

[3] Shackelford J.F. Introduction to Material Science for Engineers, J.F. Shackelford. - Upper Saddle River, New Jersey: Prentice Hall, Vol.4 (2000), p. 877.

[4] Buzea C, and Yamashita T., Review of the superconducting propertiesof MgB2, Supercond. Sci. Technol., 14, (2001) R115–R146.

[5] Przybylski, K, Stobierski, L., Chmist, J., and Kołodziejczyk, A., Synthesis and properties of MgB2obtained by SHS method, Physica C, (2003), Vol. 387,no. 2, pp. 148–152.

[6] Ksandopulo G.I. Non – chain autoacceleration of the self – propagating high temperature synthesis (SHS) wave at rotation conditions, International Journal of Self Propagating High Temperature Synthesis, Vol. 24, (2015), p. 8-13.

[7] Bean C.P. Magnetization of High-Field Superconductors // Rev.Mod.Phys., Vol. 36 (1964), p. 31-39.

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