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Superconducting Regions and Kondo Effect of MgB_2 Formed by Implantation of Magnesium Ions into Boron Substrate

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The results of investigation of the polycrystalline boron implanted by magnesium and argon plasma pulse treatment are presented. The four-probe electric conductivity measurements and magnetically modulated microwave absorption showed the presence of superconducting islands below the temperature of 25 K. Below $T = 23$ K we detected the Kondo effect, a logarithmic increase in the resistivity as the temperature is lowered, due to iron impurity.

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1. Introduction

Since the discovery of superconductivity in an intermetallic compound MgB_2 [1] with transition temperature as high as 39 K, considerable progress has been made in the understanding of the properties of this material. The purity of the boron used to make the compound of MgB_2 and the effects of magnesium stoichiometry are dominant factors to physical properties. Due to the carbon [2, 3] or impurity phases: MgO, MgB_4, and B_2O_3 [4] the T_c is shifted to lower temperatures.

For applications, the use of bulk boron is limited by its poor mechanical properties and rather thin films or/and boron fibers can be considered as candidates for practical purposes. Several successful attempts have been made to fabricate the superconducting thin films of this material. The main reasons for this interest are the low price of the component elements, relatively high values of T_c and critical current density J_c, ease of synthesis, broad perspectives of application in various industries including the power generation industry and microelectronic applications. The synthesis of films occurs in a solid phase of the Mg–B system [5–9]. The values of T_c reported in the [5–9] papers are in the 22–35 K range, and the critical current density J_c in the $3 \times 10^4 - 2 \times 10^6$ A/cm^2 range. The highest T_c value 41.7 K was obtained on a single crystal boron substrate [10].

Recently we have undertaken an attempt to synthesize superconducting phase of MgB_2 from the liquid state using a transient melting process without necessity of annealing in Mg vapor. In our preliminary experiments [11, 12] we obtained encouraging results using boron implanted magnesium substrates. In the present work we show results of the samples of MgB_2 in which the magnesium is implanted into boron substrates.

2. Experimental

The substrates of boron were cut out from commercial (Goodfelow) cast boron ingot of 99.6wt% purity in the form of highly polished disc of 3.8 mm in diameter and 2 mm thick. In the first step they were implanted with Mg ions implanter with direct beam, described in detail elsewhere [13]. Ions were implanted at acceleration voltages 33 kV which correspond to an energy of 50 keV. The implanted ion dose was 1×10^{18} Mg/cm^2. In the second step, the three argon pulses were applied to melt the top layer of the Mg–B system. The energy density of plasma were: 2.4 J/cm^2, 2.7 J/cm^2, and 2.6 J/cm^2. Pulse duration in the μs range corresponds to irradiance in the MW/cm^2 range.

Three experimental methods were used to study superconducting behavior of thin film discs of magnesium-diborate: magnetically modulated microwave absorption (MMMA) and four-probe electric conductivity measurements using Picowatt RV-Elektronikka OY AVS-47 resistance bridge equipped with helium-flow cryostat, in the temperature range from 3.6 K to 300 K.

3. Results and discussion

Figure 1 shows MMMA signals versus temperature. Below 26 K the MMMA signal increases. The superconducting transition with onset of T_c below 25 K is well defined. The Josephson hysteresis loop (JHL) presented in Fig. 2 is the confirmation that the zero field MMMA line is related to the superconducting state. These results suggested that the studied sample could show superconduc-

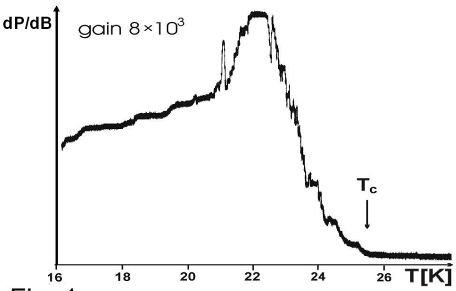

Fig. 1

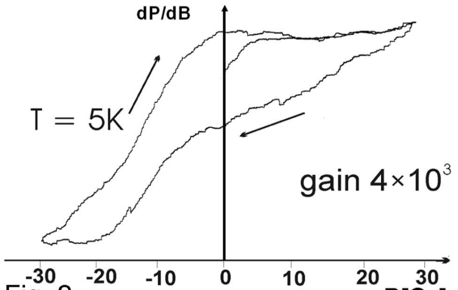

Fig. 2

Fig. 1. The temperature dependence of the MMMA signals for the polycrystalline boron implanted by magnesium.

Fig. 2. Josephson hysteresis loop at $T = 5$ K for the polycrystalline boron implanted by magnesium.

tivity above the percolation threshold. To check this property we performed the in-plane four-probe electric resistivity and magnetic measurements. The resistivity drops sharply at a temperature which is in good agreement with T_c obtained in MMMA experiment. In Fig. 3 one can see that changes are very strong — resistivity decreases by about 500%. However, R_{min} from Fig. 3 does not reach the zero value of resistance. It is probably due to the microcracks generated by stresses occurring as a result of rapid resolidification at the surface. The $T_c = 25$ K is lower compared with $T_c = 39$ K [1], due to the impurity phases: MgO, MgB_4, and B_2O_3.

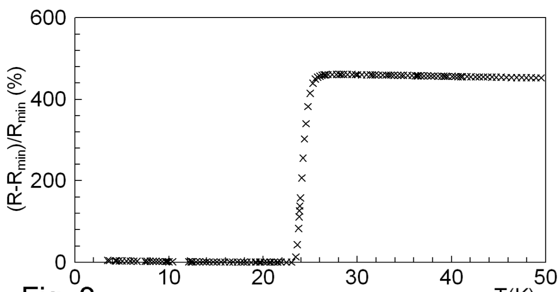

Fig. 3

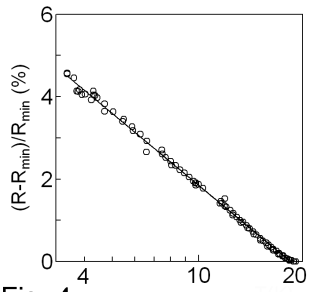

Fig. 4

Fig. 3. Temperature dependence of the normalized resistance for the polycrystalline boron implanted by magnesium.

Fig. 4. The Kondo effect for the polycrystalline boron implanted by magnesium. The solid line is the fit according to $R(T) = R_0 - R_K \ln T$.

Figure 4 shows the low temperature resistivity of measured sample. Below 23 K a logarithmic increase in the resistivity as the temperature is lowered was detected. This is the Kondo effect. Analysis of the sample shows the iron impurity, then this effect is possible.

4. Conclusions

The above results of investigation of the polycrystalline boron implanted by magnesium and argon plasma pulse treatment leads to formation of layers showing the presence of superconductivity regions. Lack of a macroscopic percolation of superconducting regions, which should be manifested by an evident drop of resistance to zero value, is most likely due to microcracks in the layer caused by rapid solidification and excessive amount of oxygen in the system which may form the insulating MgO films.

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