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Effect of PVA doping on flux pinning in bulk MgB_2

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Abstract

The synthesis and characterization of PVA (Poly Vinyl Acetate) doped bulk MgB_2 superconductor is reported here. PVA is used as a carbon source. PVA doping effects made two distinguishable contributions: first enhancement of J_c field performance and second an increase in H_{c2} value, both because of carbon incorporation into MgB_2 crystal lattice. The susceptibility measurement reveals that T_c decreased from 37 to 36 K. Lattice parameter '*a*' decreased from 3.085 Å to 3.081 Å due to the partial substitution of carbon at boron site. PVA doped sample exhibited the J_c values greater than 10^5 A/cm^2 at 5 and 10 K at low fields; which is almost 3 times higher than the pure one, while at high fields the J_c is increased by an order of magnitude in comparison to pure MgB_2. From $\rho(T)H$ measurements we found higher T_c values under magnetic field for doped sample; indicating an increase in H_{c2}. Also the magnetization measurements exhibited a significant enhancement in H_{irr} value. The improved performance of PVA doped MgB_2 can be attributed to the substitution of carbon at boron site in parent MgB_2 and the resulting impact on the carrier density and impurity scattering. The improved flux pinning behavior could easily be seen from reduced flux pinning force plots.

Keywords: MgB_2 superconductor; Magnetization and flux pinning

1. Introduction

After the discovery of superconductivity [1] in MgB_2, enormous efforts had been directed towards making this material technologically important for applications [2–7]. For practical applications of a superconductors, besides its superconducting transition temperature (T_c), further crucially important parameters are critical current density at higher fields $J_c(H)$ and irreversibility field H_{irr}. The J_c of pristine MgB_2 drops rapidly in high magnetic fields due to weak pinning centers and low upper critical field H_{c2}. Chemical doping is generally thought of as an effective approach to improve the superconducting performance of MgB_2. Many of the groups have doped several elements and *nano*-particles in MgB_2 [2–7] to improve its superconducting performance via effective pinning of flux vortices. Carbon doping had given good results in this aspect [8–11]. The solubility of carbon in MgB_2 lattice varies from say 1.25% to 30% [12,13]. Mostly carbon is doped in MgB_2 by direct reaction of magnesium, boron and carbon powders [12–15]. Carbon is the only element which partially substitutes at boron sites into the MgB_2 lattice. The B-site partial substitution of C creates disorder in the lattice and hence enhances the H_{c2} and $J_c(H)$ via intrinsic pining. Carbon has one more electron than boron, so it is expected that carbon doping would modify the superconductivity in MgB_2. We explored here this role of carbon, but we did not put the carbon directly in MgB_2 and rather added the PVA solution in MgB_2 as a carbon source. This way one produces fresh carbon at the time of formation of MgB_2. In most of the reports, dopants were introduced

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through dry mixing process that might be a cause of inhomogeneous distribution of dopants with in the matrix material. To avoid this we used the carbon source in liquid form as PVA (Poly Vinyl Acetate) solution. The carbon atoms in present case may either substitute at boron site in lattice or remain as additives in host matrix. Both ways (substitution/addition) carbon in MgB_2 is supposed to enhance the $J_c(H)$ and irreversibility field H_{irr} via intrinsic/extrinsic pinning of flux lines. We report in this article the results of H_{c2}, $J_c(H)$ and H_{irr} for pristine and PVA added MgB_2, and found that all these physical parameters improve dramatically with PVA addition.

2. Experimental

The PVA doped MgB_2 sample is prepared by solid-state reaction route. The constituent powders (magnesium and boron) were well mixed in stoichiometric ratio through grinding for 1.5 h. We dissolved half gram of PVA (Poly Vinyl Acetate) powder in 5 ml of acetone. Then we added 3 ml of this PVA solution in 2 g of MgB_2 raw powder, which was followed by again grinding in order to form the homogenous mixture. The mixture was palletized using hydraulic press. The pallets were enclosed in soft iron tube and that was put in tubular furnace at 850 °C in argon atmosphere. The heating rate was about 425 °C per hour and the holding time was 2.5 h. After this annealing treatment the furnace was allowed to cool down naturally. The X-ray diffraction pattern of compound was taken using CuK_α radiation. The magnetoresistivity, $\rho(T)H$, was measured with H applied perpendicular to current direction, using four-probe technique on *Quantum Design PPMS*. The magnetization measurements were carried out using *Quantum Design MPMS-XL*.

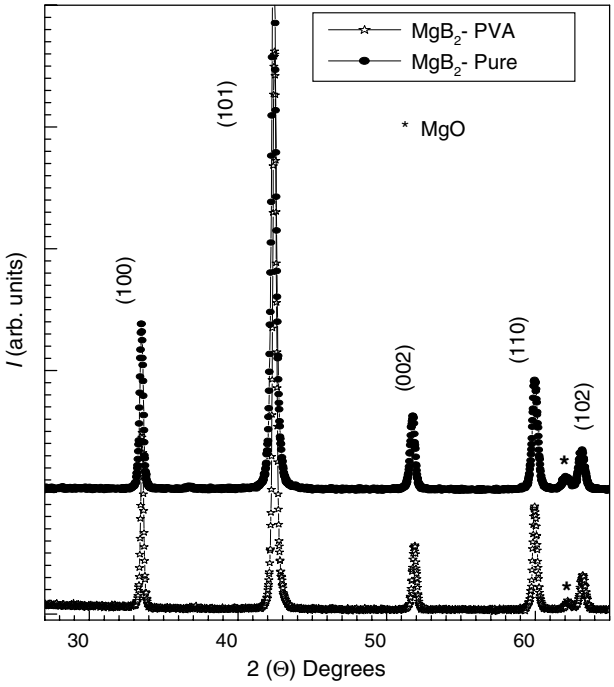

Fig. 1. The X-ray diffraction pattern for pure and doped MgB_2.

3. Results and discussion

Fig. 1 shows the XRD patterns of pure MgB_2 and PVA doped MgB_2 samples. This figure depicts that both the samples are having hexagonal pure MgB_2 phase with traces of a little amount of MgO impurity. The lattice parameters for pristine and PVA added MgB_2 compounds are $a = 3.085$ Å, $c = 3.520$ Å, and $a = 3.081$ Å, $c = 3.521$ Å, respectively. The c/a value of the pure compound is close to 1.142, which is known to be optimum for stoichiometric MgB_2. The reduction in 'a' parameter is due to the substitution of carbon for boron in the lattice of MgB_2 [14,15], which is released from the heating of added PVA during synthesis. On the other hand lattice parameter 'c' is slightly increased. The variation of lattice parameters clearly indicate that carbon is substituted at boron site in PVA added MgB_2 compound.

Resistivity vs temperature plots under various applied magnetic fields $\rho(T)H$ are shown in Fig. 2a and b for the undoped and doped sample, respectively. The residual resistivity ratio ($RRR = R_{T300\ K}/R_{Tonset}$) for pure sample and PVA added samples are 2.36 and 2.24, respectively. The higher values of room temperature resistivity for doped sample indicate that the impurity scattering is stronger due to the carbon substitution at boron sites. The superconducting transition temperature T_c ($\rho = 0$) for pure MgB_2 is ≈37 K without applying any field and is decreased to 18 K under applied field of 8 T (this is shown in inset of Fig. 2a). As we added PVA into pure MgB_2 the T_c is decreased to 36 K due to carbon doping. This was the situation at 0 T field while at higher fields the superconducting performance of doped sample is improved. For example the T_c ($\rho = 0$) is observed at 20 K under 9 T applied field for the PVA added sample (inset of Fig. 2b). This effect was attributed to the role of carbon as trapping centers in the presence of magnetic fields.

Susceptibility vs temperature $\chi(T)$ plot for doped and undoped samples in field-cooled and zero field-cooled cases is shown in Fig. 3. Both samples exhibit sharp one step superconducting transition. The superconducting transition temperature T_c decreased with PVA doping. This is because of partial substitution of carbon for boron in MgB_2, resulting in a decrease of the carrier (hole) concentration and consequently a reduction in the T_c [13,16]. The amplitude of diamagnetic signal is changed slightly by PVA doping in zero-field-cooled case. Though the pinning is more in PVA doped sample, the weak field- cooled transitions for both samples indicate strong pinning in them. The volume fraction of superconductivity is not estimated, because of weak field-cooled transitions.

Fig. 4 shows the magnetization plots for undoped and doped samples at 5 K. The magnetization loop for the undoped sample is relatively narrow and small, revealing comparatively low irreversibility field. On the other hand