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Flux pinning mechanism in codoped-MgB_2 with Al_2O_3 and SiC

Narjess Sadat Kiafiroozkoohi, Shaban Reza Ghorbani*, Hadi Arabi

Renewable Energies, Magnetism and Nanotechnology Lab., Department of Physics, Faculty of Science, Ferdowsi University of Mashhad, Mashhad, Iran

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ABSTRACT

MgB_2 superconductor samples, co-doped with 0.02 wt of Al_2O_3 and 0.02 wt SiC, have been examined by M-H loop measurements and calculation of the critical current density based on the Bean model. Normalized volume pinning force, $f = F/F_{max}$, as a function of the reduced magnetic field, $h = H/H_{max}$ has been obtained at each temperature. Hughochi flux pinning model, which was included the normal point pinning, the normal surface pinning, and the pinning based on spatial variation in the Ginzburg–Landau parameter, was used to study the flux pinning mechanisms. It was found that the $\Delta\kappa$ effect and the normal point pinning mechanisms play the main role in the flux pinning at the magnetic field lower than H_{max} and the contribution of the $\Delta\kappa$ mechanism increases with the increasing temperature, while the contribution of normal point pinning mechanism decreases. At magnetic field larger than H_{max}, the only mechanism that acts as the flux pinning was the normal surface pinning mechanism.

1. Introduction

MgB_2 superconductor has attracted a lot of attentions among various superconductors material due to its specific properties. The MgB_2 has long coherence length. Therefore it has highly isotropic features while it has a rather high critical temperature, $T_c = 39$ K. On the other hand, the simple structure and the low costs of producing caused MgB_2 as an inexpensive and a simple superconductor to synthesize.

The grain boundaries, in this compound, are transparent towards the current flow, so MgB_2 should have high critical current density. But due to the weak connections between grains [1], and therefore, lack of flux pinning centers, this metallic superconductor has low critical current density, J_c. There are different ways for improving the pinning mechanism in MgB_2, such as doping with nano-scaled particles [2,3] or irradiation by high energy ion beam [4]. In Al_2O_3 nano-particles doping, Al particles substitute for Mg [5,6]. It was found that 2% wt of Al_2O_3 -doped MgB_2 increases the irreversibility magnetic field H_{irr} and critical current density, J_c [7]. But more than 5% wt of Al_2O_3 has a destructive effect on transporting properties of MgB_2 [8,9]. For SiC doping [3,10], C substitute for B element. It was reported that up to 10% wt of SiC doping improve J_c, H_{c2} and H_{irr} [10] but further substitution has been reduced these features.

There are a few studies and reports about co-doping Al_2O_3 and SiC on MgB_2. The co-doped compounds of $Mg_{1-x}Al_x(B_{1-y}C_y)_2$ with x = 2% and y = $0-10\%$ has been investigated [11], and the consequence is that the compound with 2% wt Al and 1% wt C has the higher critical current density, J_c.

In this paper, the flux pinning mechanisms of co-doped MgB_2 with 2% wt of Al and 2% wt of C was investigated by the magnetic hysteresis loops measurements and calculation of the critical current density. The result shows that these dopants are more effective at a higher magnetic field. Co-doping of Al and C caused to the enhancement of the critical current density J_c at higher magnetic field and the irreversibility field H_{irr}.

2. Experimental procedure

The superconductor compound of $Mg_{0.98}Al_{0.02}(B_{0.99}C_{0.01})_2$ has been prepared by solid state method, which has been described elsewhere [12]. The X-ray diffraction (XRD) results revealed that the sample was crystallized in the MgB_2 structure as the major phase. The magnetic hysteresis loops were measured using a physical properties measurement system (PPMS, Quantum Design). The critical current density was calculated by using the Bean approximation.

3. Results and discussions

The critical current density J_c as a function of magnetic field in different temperatures for both doped and pure (undoped) samples has been shown in Fig. 1. In lower magnetic fields, the J_c decreases for doped MgB_2 sample in all temperatures, but it improved by field increasing, so that in magnetic field of 1.2 T and temperature of 15 K, the J_c is equal for both doped and undoped samples. For the magnetic field larger than 1.2 T, co-doped sample shows the higher critical current

* Corresponding author.
E-mail address: sh.ghorbani@um.ac.ir (S.R. Ghorbani).

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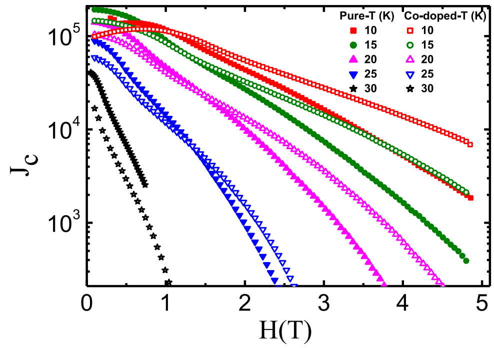

Fig. 1. The filed dependence of the J_c at different temperatures for both pure and co-doped samples.

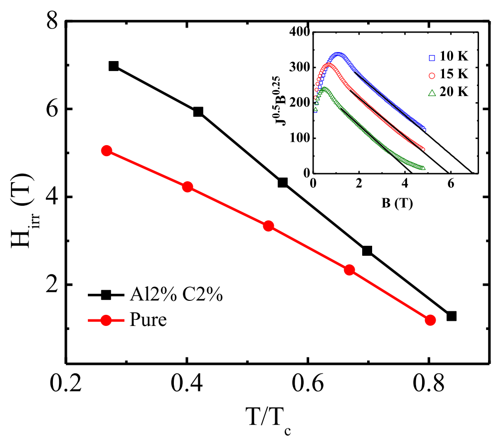

Fig. 2. Temperature dependence of H_{irr} for both MgB_2 and the codoped MgB_2 samples.

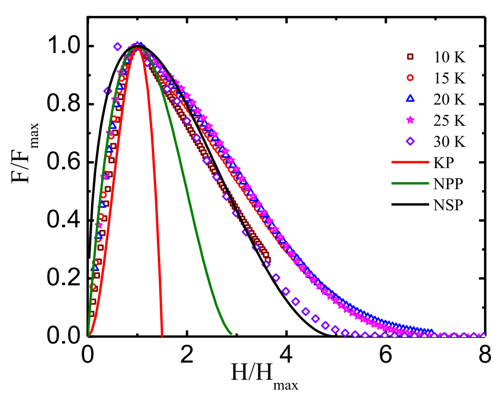

Fig. 3. $f = F/F_{max}$ as a function of $h = H/H_{max}$. Curves are shown different pinning mechanisms based on Higuchi method.

density than the pure one.

The irreversibility field H_{irr} at different temperatures for co-doped and pure samples has been obtained by Kramer method [13], which was obtained from the curve of $J_c^{0.5}B^{0.25}$ vs. magnetic field B as shown in the inset of Fig. 2. The H_{irr} results for co-doped and pure MgB_2 samples as a function of reduced temperature has been shown in Fig. 2. It can be seen in Fig. 2 that H_{irr} for the co-doped sample is improved.

Flux pinning mechanism for co-doped sample has been investigated by Higuchi method [14]. This model has included three pinning mechanisms such as the normal point pinning, NPP, the normal surface pinning, NSP, and the pinning based on spatial variation in the Ginzburg–Landau parameter, KP. According to this method, the flux pinning mechanisms in a superconductor sample are obtained based on $f_p = 3h^2(1-2h/3)$ for Δκ pinning (KP), $f_p = 9h/4(1-h/3)^2$ for normal point pinning (NPP), and $f_p = (25/16)h^{1/2}(1-h/5)^2$ for normal surface pinning (NSP). As can be seen in the Fig. 3, the real experimentally data reside in between master curves of the NPP pinning and the $\Delta\kappa$ pinning mechanism (KP) at reduced magnetic field h smaller than h_{max}. While at $H > H_{max}$, the pinning mechanisms change. One can clearly see that the main pining effect is the normal surface pinning, which originates from the grain boundaries. At low temperatures, to investigate the real pinning by assuming existence of two mechanisms, by $f = b_k f_{KP} + b_p f_{NPP}$ equation, which was fitted to the experimental data. Where b_p and b_k are fitting parameters, which indicate the KP and NPP effects, respectively, with the condition of $b_p + b_k = 1$. It shows in Fig. 3 that both the point pinning and the $\Delta\kappa$ pinning mechanism coexist in co-doped MgB_2 at $H < H_{max}$, while there is no contribution from the surface pinning, but which pinning mechanism is dominant depends on the temperature range. More importantly, the pinning mechanisms change at $H > H_{max}$. From the Fig. 3, one can clearly see that the surface pinning has become dominant, and there is no contribution from both the $\Delta\kappa$ pinning and the NPP pinning mechanism.

In conclusion, it was found that co-doping of Al and C in MgB_2 improves the irreversibility field and the J_c at high magnetic fields, which indicates that the co-doping produces stronger and more plentiful pinning centers, which induce different pinning mechanisms. Studies of the pinning mechanisms regarding the different pinning models indicate that a variety of pinning mechanisms, e.g. normal point pinning, normal surface pinning, and normal volume pinning mechanisms coexist in co-doped MgB_2. The contribution of the each pinning effects depends on the temperatures and magnetic field. We are found that the $\Delta\kappa$ effect and the normal point pinning mechanisms play the main role in the flux pinning at the magnetic field lower than H_{max}. It was found that the $\Delta\kappa$ effect increases with the increasing temperature, while the contribution of normal point pinning mechanism de-decreases. At magnetic field larger than H_{max}, the only mechanism that acts as the flux pinning was the normal surface pinning mechanism.

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