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Publication Details

Vajpayee, A, Awana, VP, Kishan, H, Narlikar, A, Bhalla, GL & Wang, P (2008), High field performance of nano-diamond doped MgB2 superconductor, In 52nd Annual Conference on Magnetism and Magnetic Materials (MMM), NOV 05-09, 2007, Tampa, FL, USA, Journal of Applied Physics, 103(7), pp. 1-12.

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High field performance of nano-diamond doped MgB2 superconductor

Abstract

The results from magnetotransport and magnetization of nanodiamond doped MgB_2-nD_x are reported. Superconducting transition temperature (T_c) is not affected significantly by x up to x =0.05 and latter decreases slightly for higher x>0.05. R(T) vs H measurements show higher T_c values under same applied magnetic fields for the nanodiamond added samples, resulting in higher estimated Hc_2 values. From the magnetization measurements, it was found that irreversibility field value H_{irr} for the pristine sample is 7.5 T at 4 K and the same is increased to 13.5 T for 3 wt % nD added sample at the same temperature. The J_c(H) plots at all temperatures show that J_c value is lowest at all applied fields for pristine MgB_2 and the sample doped with 3 wt % nD gives the best J_c values at all fields. These results are discussed in terms of extrinsic pinning due to dispersed n-diamond in the host MgB_2 matrix along with the intrinsic pinning due to possible substitution of C at boron site and increased interband scattering for highly doped samples resulting in extraordinary performance of the doped system.

Keywords

High, field, performance, nano, diamond, doped, MgB2, superconductor

Disciplines

Engineering | Physical Sciences and Mathematics

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High field performance of nanodiamond doped MgB_2 superconductor

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(Presented on 9 November 2007; received 4 September 2007; accepted 22 October 2007; published online 6 February 2008)

The results from magnetotransport and magnetization of nanodiamond doped MgB_2-nD_x are reported. Superconducting transition temperature (T_c) is not affected significantly by x up to $x=0.05$ and latter decreases slightly for higher $x>0.05$. $R(T)$ vs H measurements show higher T_c values under same applied magnetic fields for the nanodiamond added samples, resulting in higher estimated H_{c2} values. From the magnetization measurements, it was found that irreversibility field value H_{irr} for the pristine sample is 7.5 T at 4 K and the same is increased to 13.5 T for 3 wt % nD added sample at the same temperature. The $J_c(H)$ plots at all temperatures show that J_c value is lowest at all applied fields for pristine MgB_2 and the sample doped with 3 wt % nD gives the best J_c values at all fields. These results are discussed in terms of extrinsic pinning due to dispersed n-diamond in the host MgB_2 matrix along with the intrinsic pinning due to possible substitution of C at boron site and increased interband scattering for highly doped samples resulting in extraordinary performance of the doped system. © *2008 American Institute of Physics*.
[DOI: 10.1063/1.2831778]

I. INTRODUCTION

The improvement of the pinning behavior in MgB_2 is being considered as a key issue in the superconductivity field; many attempts have been made in this direction for enhancing the pinning strength of MgB_2. In the last five years, various carbon sources,[1–3] silicates,[4] single elements,[5,6] carbohydrates,[7] organic acids,[8] and other compounds[9,10] have been doped in MgB_2 and reported. It has become more clear that structural defects with dimensions at nanoscale play an important role for flux pinning, i.e., nanoparticle doping is the most effective approach to improve the superconducting performance of MgB_2 and making MgB_2 acceptable for practical applications.[11] Nanoparticle doping can modify structure and electronic properties such as T_c, upper critical field and its anisotropy, gap widths, inter- and intraband scattering, defect structure, etc.[12–14] In present paper, we are discussing the effect of nanodiamond addition on polycrystalline MgB_2, i.e., how the superconducting performance of pristine sample is modified by addition of n-diamond.

II. EXPERIMENT

The MgB_2-nanodiamond composites with composition MgB_2-nD_x (x=0%, 1%, 3%, 5%, 7%, and 10%) are synthesized by solid-state reaction route with ingredients of Mg, B, and n-diamond (see details in Ref. 15). The x-ray diffraction pattern of the compound was recorded with a diffractometer using Cu $K\alpha$ radiation. The magnetoresistivity, $\rho(T)H$, was measured with H applied perpendicular to current direction, using the four-probe technique on the Quantum Design physical property measurement system (PPMS). Magnetization measurements are carried out with a Quantum Design superconducting quantum interference device (SQUID) magnetometer MPMS-7.

III. RESULTS AND DISCUSSIONS

X-ray diffraction patterns show that all the samples of MgB_2-nD_x series are of nearly single phase with only a small quantity of unreacted MgO in them. For highest nD_x sample, i.e., x=10 wt %, the main intensity peak is broadened slightly (patterns not shown). The lattice parameters remain nearly invariant for all the samples until x=5 wt % for MgB_2-nD_x. For 10 wt % sample, slight decrease in "a" is seen. It means that, for this higher concentration, some diamond particles has got broken into carbon atoms, which substituted at boron site resulting in slight decrease in "a," but at low concentration, there is not such indication of breakage of n-diamond.

Variation of resistance with temperature under applied magnetic fields of up to 8 T $R(T)H$ is shown in Fig. 1 (only transition zone). As we can see from this figure, with increasing n-diamond concentration, the superconducting onset temperature remains unchanged and the transition width changes slightly. This indicates that no substitution has taken place in

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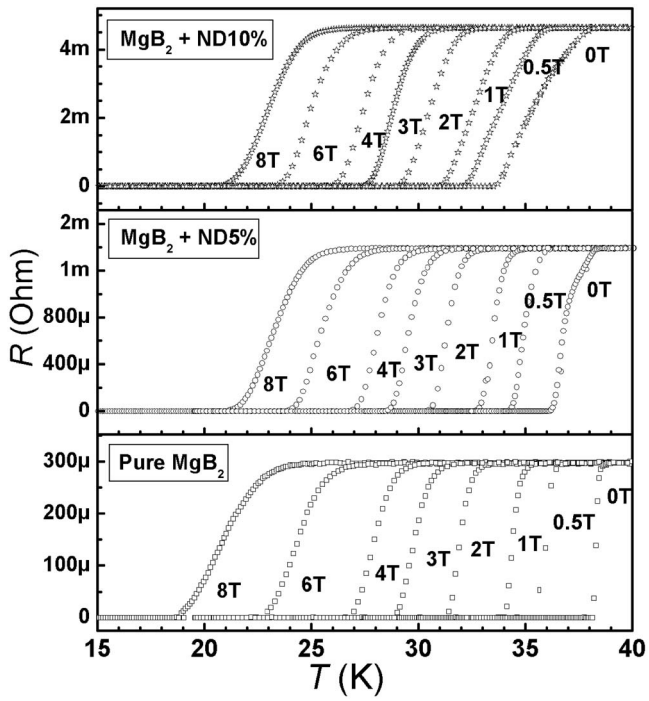

FIG. 1. Superconducting transition zone of resistance vs temperature plot under applied magnetic field $R(T)H$ up to 8 T for pure, 5 wt %, and 10 wt % nanodiamond added samples.

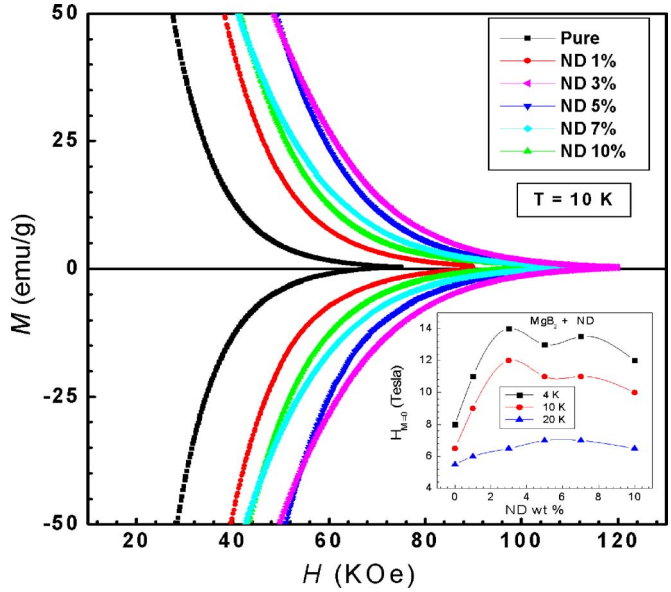

FIG. 2. (Color online) Magnetization loop $M(H)$ at 10 K for MgB_2-nD_x (x=0%, 1%, 3%, 5%, 7%, and 10%) up to 12 T field, and inset shows the behavior of irreversibility field H_{irr} with respect to n-diamond concentration at 4, 10, and 20 K.

this system. It is noted that $R(T)H$ curves for the doped samples shifted with increasing field much more slowly than the undoped one. For pure MgB_2, the $T_c(R=0)$ value is observed at 38 and 18 K in 0 and 8 T applied fields, respectively. Interestingly, the $T_c(R=0)$ for MgB_2-5 wt % nD sample in comparison to pure MgB_2 is lowered to 36 K in zero applied field, the same is increased to 22 K under 8 T field.

Now, to see the effect of n-diamond addition on the upper critical field H_{c2}, using resistivity variation under magnetic field plots, we estimated the H_{c2} values, i.e., H_{c2} obtained from the 90% values of the resistive transitions. The variation of H_{c2} with respect to temperature is not shown here (see Ref. 15), which demonstrates that, on increasing the concentration of n-diamond, a clear shift in upper direction can be achieved. The behavior of 3 and 5 wt % n-diamond added samples is quite competitive; but since the T_c of 5 %nD is lower than 3 %nD, we can say that 5 %nD sample shows better improvement in H_{c2} value. The formation of nanodomain structures is due to the presence of dispersed diamond in parent MgB_2 grains (we have reported the high resolution transmission electron microscopy (HRTEM) and energy dispersive (ED) pattern in another paper[15]) causing the disorder in lattice. These nanodomains, which are comparable in size (~8–10 nm) with the coherence length of MgB_2 could result in strong in-plane and out-of-plane scatterings and contribute to the increase of H_{c2} value in a wide temperature regime.

In Fig. 2 the magnetic hysteresis loop for all the doped samples (x=0%, 1%, 3%, 5%, 7%, and 10%) at 10 K is shown in applied field up to 13 T. This tells that the closing of hysteresis loop for pure MgB_2 is at ~6.5 T, whereas the same is opened up to ~11 T for 3 wt % doped sample. This indicates that there will be significant improvement in irreversibility field values for the doped samples. The irreversibility fields (H_{irr}) is the one at which the magnetic hysteresis loop is nearly closed with $M \approx 0$. The H_{irr} versus x (concentration on nanodiamond) plot is shown in inset of Fig. 2 at 4, 10, and 20 K. The best values of H_{irr} among these diamond added samples (MgB_2-nD_x) is found for the sample with x =3%. The H_{irr} values for the undoped samples are 7.5, 6.5, and 4.5 T at 4, 10, and 20 K, respectively; the same is increased up to 13.5, 11.3, and 5.5 T for the 3 wt % n-diamond added sample, which reveals that nanodiamond doping significantly improved the H_{irr} values. These results show that diamond doping enhances the flux pinning strength in parent MgB_2 significantly. These results are in well agreement with previously reported data.[16]

Using $M(H)$ loop we estimated the critical current density by invoking Bean's critical state formula. Figure 3 shows the magnetic critical current density (J_c) versus applied field (H) at 20 and 10 K. For all the samples (doped and undoped), J_c attains the value greater than 10^5 A/cm^2 at low fields at both the temperatures. At 20 K, J_c falls to 100 A/cm^2 at 4.5 T for pure MgB_2, whereas for rest of the samples, this J_c value is reached only at nearly 6 T. At 20 K, the J_c is improved by an order of magnitude for doped samples as compared to the pure MgB_2 at high fields, but for doped samples, all the plots are merging nearly at the same field (6 T), i.e., not much difference in $J_c(H)$ behavior is seen for doped samples at higher fields. For 10 K, the situation is quite different at higher fields, i.e., the rate of J_c drop is smaller than for all samples compared to undoped MgB_2. The J_c is 40 times higher than pure MgB_2 at 10 K at 6 T applied field in case of 3 wt % n-diamond added sample and J_c value is still of the order of 10^3 A/cm^2 at 10 T for the same sample. These results are quite comparable as reported

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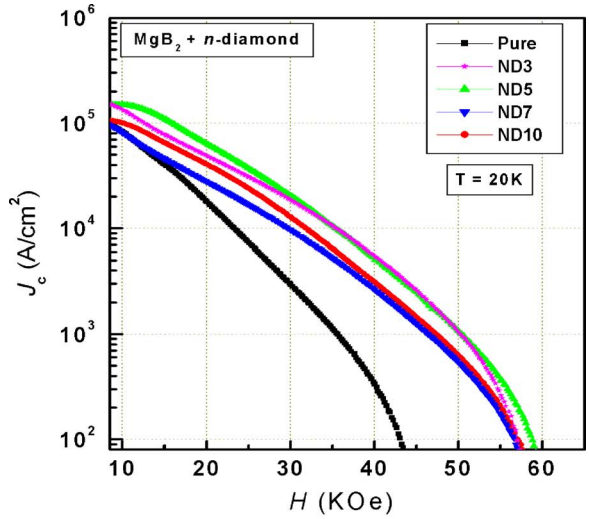
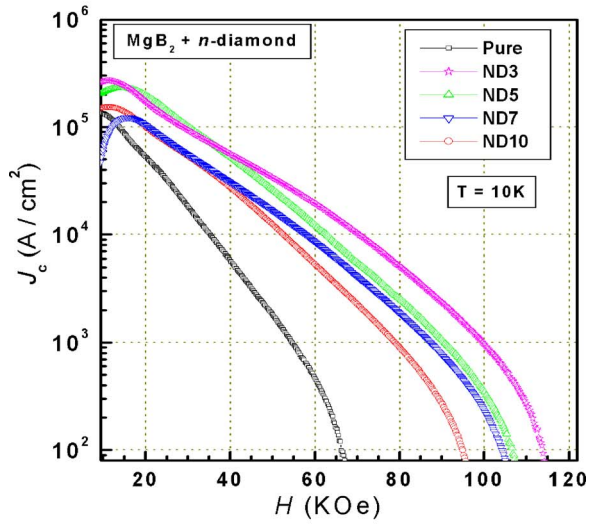


(a)



(b)

FIG. 3. (Color online) Critical current density (J_c) variation with respect to applied magnetic field (H) (a) at 20 K and (b) at 10 K.

earlier.[17] The better $J_c(H)$ performance of n-diamond added samples indicates towards that the additional impurities at nanoscale introduced by n-diamond serve as strong pinning centers to improve flux pinning in higher applied fields.

To confirm the improved flux pinning behavior through diamond doping, the field dependence of normalized flux pinning force ($F_p/F_{p,\max}$) is shown in Fig. 4 at 10 K. The relationship between flux pinning force and critical current density could be described by[18]

$$F_p = \mu_0 J_c(H) H, \tag{1}$$

where μ_0 is the magnetic permeability in vacuum. This figure depicts that the pinning forces are significantly improved than the pure MgB_2 above 2 T for n-diamond doped samples because curves for the doped samples are shifted towards the higher fields, indicating enhanced flux pinning force in high fields. As revealed by the microstructure analysis,[15] nanodiamond particles of size around ~10 nm are dispersed in

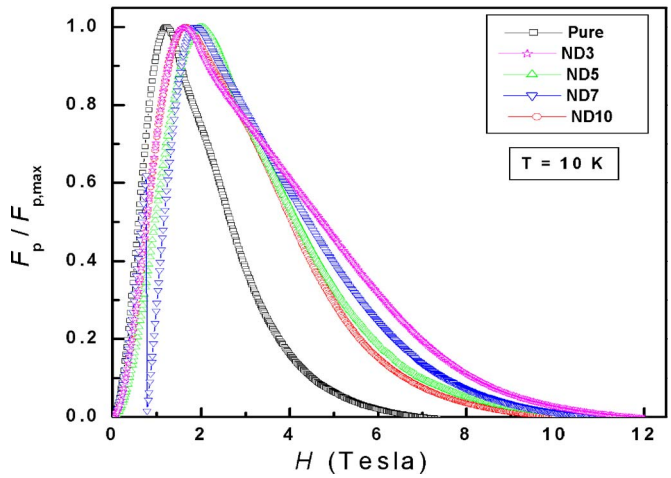


FIG. 4. (Color online) Variation of reduced flux pinning force ($F_p/F_{p,\max}$) with magnetic field for MgB_2-nD_x (x=0%, 1%, 3%, 5%, and 10%) at 10 K.

MgB_2 matrix. Because these particles have the size comparable to the coherence length of MgB_2, it is highly possible that they may work as point pinning centers, causing a shift of the curve in $F_p/F_{p,\max}$ vs H curve towards the higher field. It can be seen from Fig. 4 that the peak corresponding to 3 wt % n-diamond doped sample is much broader than those of other samples, indicating highest pinning strength in this sample at higher fields, which is consistent with the results of J_c (Fig. 3).

In summary, the present work shows that nano-diamond doping is a promising way to fabricate high performance MgB_2 bulk material with excellent values of $J_c(H)$, H_{c2}, and $H_{\mathrm{irr}}(T)$.

ACKNOWLEDGMENTS

Dr. Rajeev Rawat from CSR-Indore is acknowledged for the resistivity under magnetic field measurements. Mr. Kranti Kumar and Dr. A. Banerjee are acknowledged for the high field magnetization measurements. Further, DST, Government of India is acknowledged for funding the 14 T PPMS-VSM at CSR, Indore. The authors from NPL would like to thank Dr. Vikram Kumar (DNPL) for his constant encouragement.

[1]S. X. Dou *et al.*, Appl. Phys. Lett. **83**, 4996 (2003).
[2]R. H. T. Wilke *et al.*, Phys. Rev. Lett. **92**, 217003 (2004).
[3]S. X. Dou *et al.*, Phys. Rev. Lett. **98**, 097001 (2007).
[4]Y. Ma *et al.*, Supercond. Sci. Technol. **16**, 852 (2003).
[5]S. Y. Li *et al.*, Physica C **363**, 219 (2001).
[6]J. Y. Xiang *et al.*, Physica C **386**, 611 (2003).
[7]J. H. Kim *et al.*, Appl. Phys. Lett. **89**, 142505 (2006).
[8]J. H. Kim *et al.*, Supercond. Sci. Technol. **20**, 715 (2007).
[9]T. M. Shen *et al.*, Supercond. Sci. Technol. **18**, L49 (2005).
[10]A. Vajpayee *et al.*, Physica C **466**, 46 (2007).
[11]M. Nishiyama *et al.*, Supercond. Sci. Technol. **17**, 1406 (2003).
[12]C. Krutzler *et al.*, Phys. Rev. B **74**, 144511 (2006).
[13]M. Angst *et al.*, Phys. Rev. B **71**, 144512 (2005).
[14]S. Lee *et al.*, Physica C **397**, 7 (2003).
[15]A. Vajpayee *et al.*, Supercond. Sci. Technol. **20**, S155 (2007).
[16]C. H. Cheng *et al.*, Supercond. Sci. Technol. **16**, 1182 (2003).
[17]C. H. Cheng *et al.*, Supercond. Sci. Technol. **20**, 296 (2007).
[18]E. Martinez *et al.*, Phys. Rev. B **75**, 134515 (2007).

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