Effect of heavy-ion irradiation on the pinning properties of MgB_2

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Abstract

Pinning properties of MgB_2 superconductors irradiated with 5.8 GeV Pb-ions were studied. After the irradiation, enhancement of J_c was observed at high magnetic field range. We also found a suppression of magnetic flux creep by the irradiation. These results suggest that the defects introduced by the irradiation work as effective pinning centers.

Key words: MgB_2;heavy-ion irradiation;critical current density;flux creep

1. Introduction

The recent discovery of the superconductivity in metallic compound MgB_2 [1] with $T_c = 39$ K attracted worldwide interests from both fundamental and practical aspects because of its relatively high T_c value and simple structure. However, for practial applications, it is necessary to achieve large critical current densities J_c by introducing effective pinning centers into this material.

One of the promising approaches to enhance pinning properties is the introduction of defects by means of particle irradiation. In this paper, we report the effect of heavy-ion irradiation on the pinning properties of high-density MgB_2 polycrystalline sample. We show that the irradiation improves pinning properties, especially at high magnetic fields.

2. Experimental

High-density polycrystalline samples of MgB_2 were prepared from the mixture of Mg and B powders with a nominal composition ratio of 1.1: 2. Extra Mg was added to compensate for the loss of Mg during the synthesis. The powder was encapsuled in a BN crucible and sintered at 900 °C for 30 min under the pressure of 1.2 GPa. All the samples exhibited a sharp superconducting transition at 39 K, showing that they are good in quality.

Irradiation with 5.8 GeV Pb-ions was performed at Grand Accélateur National d'Ions Lourds (Caen, France) at room temperature. Several samples cut from the same pellet were irradiated along their smallest dimension ($< 100\mu$m) with four different fluences of $10^{10}, 5 \times 10^{10}, 10^{11}$ and 2×10^{11} ions/cm^2. TEM observation revealed that spherical amorphous defects about 20 nm in size are generated by the irradiation [2]. We did not see any appreciable change in T_c with the irradiation.

Magnetization measurements were performed with a SQUID magnetometer (Quantum Design MPMS-7, XL) equipped with a 7 T superconducting magnet. All the measurements were performed with the applied field parallel to the beam direction.

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3. Results and Discussion

Figure 1 shows the $J_c - B$ curves before and after the irradiation of 10^{11} ions/cm^2. The J_c value of a pristine sample was $\sim 1.2 \times 10^9$ A/m^2 at 20 K and 1 T, which is considerably high compared to the reported value for bulk samples [3], reflecting a good connectivity of the grains in the present sample. For all measured temperature range, the J_c was found to decay monotonically with magnetic field.

After the irradiation, a decrease of J_c was observed at low magnetic fields. This may be attributed to the degradation of grain boundary connectivity by irradiation and/or the aging effect.

On the other hand, the J_c of high magnetic field was increased by the irradiation, which was more pronounced at lower temperatures. As shown in the inset of Fig. 1, the enhancement of J_c at high magnetic field was the largest at the irradiation fluences of 10^{11} ions/cm^2. A further increase of the irradiation fluence resulted in a decrease of J_c in this regime presumably due to a decrease in the superconducting volume fraction.

In fig. 2, we compare the normalized relaxation rate, $S \equiv -d \ln M(t)/d \ln t \approx (1/M_i) dM/d \ln t$ (M_i is the initial magnetization measured at the beginning of the relaxation experiment) for unirradiated and irradiated (fluence : 5×10^{10}) samples. We can see that the irradiation largely depress the magnetic flux creep.

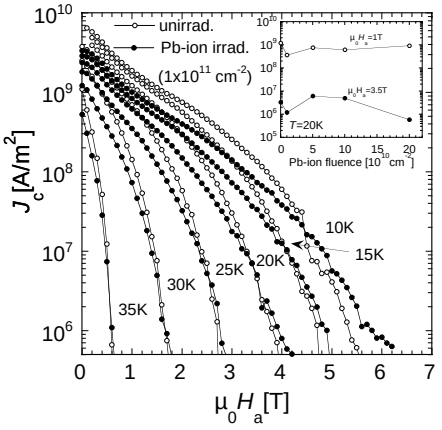

Fig. 1. Temperature dependence of $J_c - B$ curves of MgB_2 before and after Pb-ion irradiation (fluence:10^{11} ions/cm^2). Inset: Pb-ion fluence dependence of J_c.

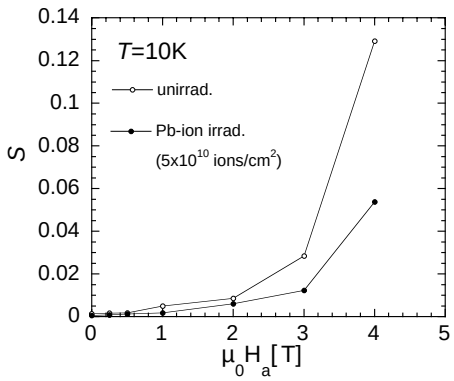

Fig. 2. Field dependence of normalized relaxation rate S before and after Pb-ion irradiation (fluence:5×10^{10} ions/cm^2) at 10 K

4. Conclusion

We present the studies of the high-energy irradiation effect on the pinning properties of MgB_2 polycrystalline samples. We found the irradiation improves both J_c and flux creep characteristic, especially at high magnetic fields. These result suggest that the irradiation defects work as effective pining centers.

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