Determination of critical current density in flux creep state for MgB_2

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Abstract

We propose a method to determine critical current density j_c for MgB_2 with flux creep from the real part of AC susceptibility (ACS), which facilitates the determination of j_c at different DC fields B_d in temperature range as wide as 5 - 38K . Influence of criterion E_c on j_c was studied by varying amplitude (B_{ac}) and frequency (f) of AC field. The result shows that it is not proper to obtain temperature dependence of j_c by measuring only the peak temperature of imaginary part of ACS.

Key words: j_c ;flux creep state; AC susceptibility;

1. Introduction

In the critical state model, the real or imaginary parts of ACS have been connected to j_{c0}, the j_c without flux creep [1] by the called ACS method. In addition to the analytical relation [1], j_c usually is determined based on the critical state model by ACS technique using the equation below:

$$j_{c0}(T_p) = B_{ac}(T_p)/\mu_0 d \tag{1}$$

Nevertheless, due to flux creep, the current density has already decayed before reaching j_{c0} and its magnitude depends on time and the position in the sample. Here we extend the method to the case with flux creep and determined j_c in a wider temperature range for a MgB_2 sample. Then influence of the criterion on j_c was studied.

It is shown that a spatially constant but time dependent $j(t = 1/f)$ smaller than j_{c0} inside the sample is a good approximation to describe the dynamics of highly non-linear flux creep [2]. Then the relations between χ' and j can be written formally as:

$$j_c(f, T_p) = B_{ac}(T_p)/\mu_0 d \tag{2}$$

$$\chi' = -1 + z'/2 (B_{ac} \leq \mu_0 j(f) d) \tag{3}$$

$$\chi' = \frac{(-1 + \frac{z'}{2}) cos^{-1}(1 - \frac{2}{z'}) + [-1 + \frac{4}{3z'} - \frac{4}{(3z')^2}](z' - 1)^{1/2}}{\pi} \quad (B_{ac} \geq \mu_0 j(f) d). \tag{4}$$

Here $z' = \frac{B_{ac}}{\mu_0 j(f) d}$, T_p is the temperature at which the imaginary part χ'' peaks and d is the half width of the slab. According to the definition, the critical current density is a j at certain criterion such as electric field E_c. Hence j_c extracted from the above equations is in fact the j at certain criterion. Here the electric field at the surface of the sample is used as E_c, i.e. $E_c \equiv E(0)$ [3,4], which can be approximately obtained by:

$$E_c = \frac{1}{4f} \int_0^{1/4f} E(0, t) dt = 4df B_{ac} \tag{5}$$

Here $E(0, t) = \int_0^d (-\frac{\partial B(x,t)|_{x=0}}{\partial t}) dx = 2\pi df B_{ac} cos(2\pi ft)$.

Note that the same case also takes place in other methods as long as flux creep is important [5,6] but it was rarely mentioned in previous ACS and VSM methods.

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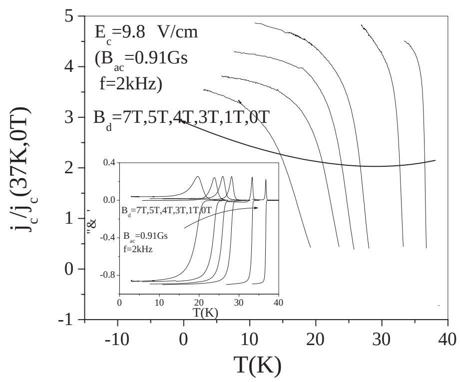

Fig. 1. $\chi(T)$ (insert) and corresponding $j_c(T)$ curves at $B_d = 7T$ and $5K \leq T \leq 39K$ for MgB_2

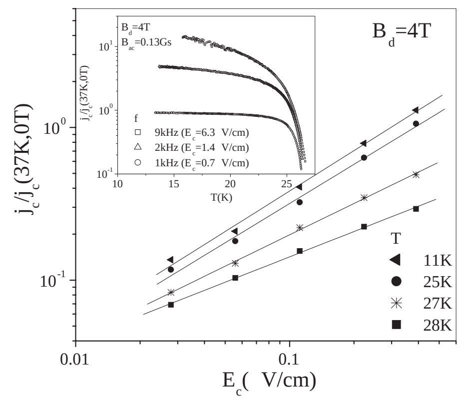

Fig. 2. Influence of f (E_c) on j_c determination at four different temperatures for MgB_2

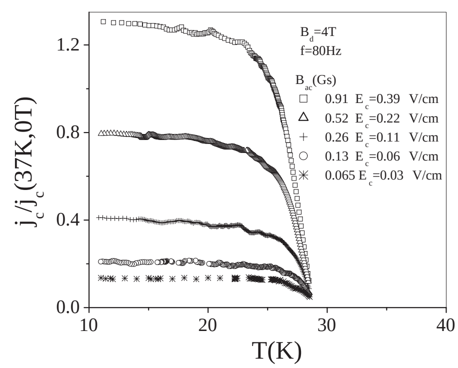

Fig. 3. Influence of B_{ac} (E_c) on $j_c(T)$ curves in magnetic measurement for MgB_2

2. Results and discussions

The sample used here is a sintered MgB_2 rectangular slab. From χ' data in the insert of Fig. 1 and equation (2) and (3), j_c in the range of 38K - 5K are determined and shown in Fig. 1, where $j_c(0T, 37K) = 10^3 A/cm^2$. Each $j_c - T$ curves are determined by a single $\chi' - T$ curve and easy to obtain in broader temperature range.

Shown in Fig. 2 are the $j_c(T, E_c)$ curves indicating the influence of f and T on the magnetic j_c. It is apparent that the higher the f, the larger the E_c, the higher the j_c, which coincides with the transport measurements [5,6]. For example, $j_c(9.8V/cm)$ is more than one order of magnitude larger than $j_c(0.7V/cm)$ at 11K. If this influence is extrapolated to j_c measurements by ACS in a wider frequency range, E.G. $0.1kHz \leq f \leq 10kHz$, one can expect that $j_c(10kHz)$ is approximately two orders higher than $j_c(0.1kHz)$. The fact that the $\chi' - T$ curve are dependent on f is a strong evidence that flux creep is also giant in MgB_2 and could not explained by any critical state model.

Because E_c is also proportional to B_{ac}, B_{ac} influences j_c as well. Shown in Fig.3 are examples of the influence by B_{ac}, where it is also seen that a larger B_{ac} corresponds to a larger E_c and thus a higher measured j_c. These experimental data, in addition to the above argument, show that it is not proper to determine temperature dependence of j_c from $j(T_p)$ measurement of peak temperature T_p of χ'' at different f or B_{ac} based on equation (1)[7] because shifting T_p by changing either f or B_{ac} simultaneously changes E_c as well.

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