

SOME UNIVERSAL PROPERTIES OF THE CRITICAL CURRENT IN HIGH-T_c CERAMICS

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We have presented a new contactless method for the determination of the local critical current density $j_c(B)$ and the effective magnetic permeability μ separately. Using this method we have carried out the investigation of the magnetic field dependence of j_c in ceramic samples of different structure. We have established that in spite of different values of j_c the dependence of j_c on B may be described by a single universal function in a wide region of magnetic fields. At low fields this function has a plateau and at higher fields changes as $B^{-3/2}$.

Earlier¹, we had developed a new contactless method for determination of the local critical current density j_c in ceramics using the measurements of the rf surface impedance $Z = R + iX$ of a sample. This method was founded on the critical state model equation²:

$$\text{curl } B = (4\pi/c)\mu j_c(B), \quad (1)$$

where B is magnetic induction, μ is magnetic permeability of ceramics. However, in¹ we could determine the product μj_c only. Here we consider the modified method which allows to measure the function $j_c(B)$ and parameter μ separately.

1. THE FOUNDATION OF METHOD

Let a sample is placed in the magnetic field $H=H_0 + h\cos\omega t$ directed parallel to the plate surface. Using (1) we can obtain the next formula for Z :

$$Z = \mu X_n F(x), \quad X_n = 2\pi\omega d/c^2 \quad (2)$$

$$x = h/h_p, \quad h_p = (4\pi/c)j_c(\mu H)d/2, \quad (3)$$

$$F(x) = (2/3\pi)x[1-(3\pi i/4)] \quad x < 1 \quad (4)$$

Here X_n is a reactance of a sample in a normal state, h_p is the amplitude of ac field corresponds to full penetration of ac induction into a plate. At $x>1$ a simple formula exists only for real part of F :

$$\text{Re } F(x) = (2/\pi x)(1-2/3x). \quad x > 1 \quad (5)$$

In accordance with (2)-(5) the function $R(H)$ increases with h at $x < 1$, and decreases at $x > 1$. So, $R(H)$ has a maximum at $x = 4/3$:

$$R_{\max} = 3(\mu\omega/c^2)d/2 = (3/4\pi)\mu X_n. \quad (6)$$

The equations (2)-(6) form the full system which

defines the parameters μ and j_c . To achieve the maximum of R in experiment it is suitable to measure the dependence of resistance R on a magnetic field H .

2. THE RESULTS AND DISCUSSIONS

We have studied the YBCO plates prepared by solid state reaction. To obtain the specimens with different grain sizes we changed the heat treatment temperature T_h in the region 870°C-950°C. The measurements of impedance were carried out at frequency $\omega/2\pi=1300$ Hz, $T=77$ K and in the magnetic field region 0 - 400 Oe.

Some results of our measurements of $j_c(B)$ are presented in Fig.1. It is seen the critical current density changes slowly at low magnetic fields. Such behaviour is not accidental. It is known that for single plane Josephson junction its critical current I deviates from maximum value I_c at $\Phi > \Phi_0$ where Φ and Φ_0 are the magnetic flux and the magnetic flux quantum correspondingly. In the case of ceramics the magnetic flux Φ is connected with the grain size a : $\Phi=2B\lambda_L$ (λ_L is London penetration depth). It is seen the width of a step decreases with T_h . This result is in agreement with the fact that the grain size increases with increasing of T_h . The evaluation of a obtained from the condition $\Phi \cong \Phi_0$ coincides with the direct observations. The value of μ for these samples changes in the range $0.05 < \mu < 0.95$.

As it is shown in Fig.1, the critical current density

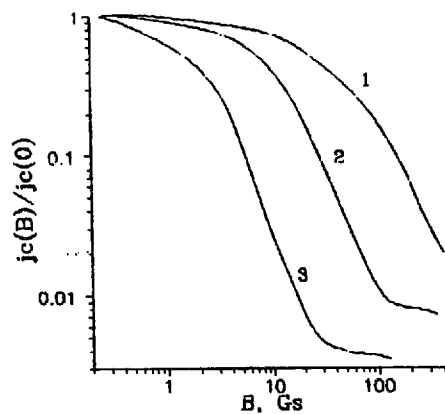


FIGURE 1

The dependence of j_c vs B in double logarithmic scale. Curve 1 - $T_h = 870^\circ\text{C}$, 2 - 930°C , 3 - 960°C .

begins to decrease sharply at higher fields. As it was established earlier^{3, 1}, the dependence of j_c vs B is described here by power function: $j_c \sim B^{-3/2}$. To our surprise this dependence takes place for all our samples despite their different structure. We supposed that such behaviour is connected with the type of granular contacts. To check this we have measured the function $j_c(T)$. We have found out that the dependence of j_c on $(1-T/T_c)$ is described by the power function with exponent equal to 2 for the samples prepared at $T_h < 920^\circ\text{C}$ and $3/2$ in the case $T_h > 920^\circ\text{C}$. This means the contact character changes with T_h from S-N-S type to S-N-I-N-S type⁴. So, we can conclude that the function $j_c(B)$ does not change when the character of contact changes radically.

These results are in accordance with the supposition that j_c is defined by the maximum current of single junction and depends on the junction geometry only⁵. The critical current for the single sphere like junction is described by the relation

$$I_c(H) = 2I_0 |J_1(\pi\Phi/\Phi_0)| / (\pi\Phi/\Phi_0), \quad (7)$$

where J_1 is Bessel function. At the condition $\Phi \gg \Phi_0$ the formula (7) leads to the dependence $I_c(B) \sim B^{-3/2}$. So, we may conclude that the function $j_c(B)$ is defined by the properties of a single Josephson junction. Thus we can suppose that the function $j_c(B)$ for any ceramics medium can be scaled to the single universal curve. Some results of our experiments are presented

in Fig.2. The points of different kinds correspond to different samples. It is seen that all experimental points lay near the theoretical curve obtained by averaging of (7).

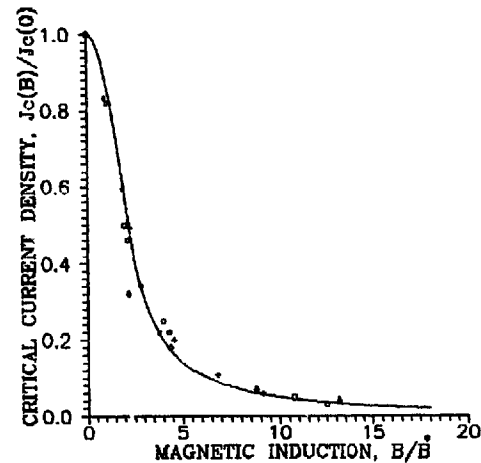


FIGURE 2

The universal dependence of j_c vs B .

Thus, we have established the universal behaviour of the function $j_c(B)$ in a wide range of magnetic fields. less than the first critical magnetic field of grains H_{c1g} . At $H > H_{c1g}$ Abrikosov vortices begin to penetrate into the grains and the function j_c tends to asymptotic value j_a which may be evaluated by relation: $j_a / j_c(0) \cong (\lambda_L / a)^{3/2}$. This result coincides with our experimental data.

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