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Measurement of critical current density of YBCO film by a mutual inductive method using a drive coil with a sharp iron core

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Abstract

Recent developments in high-temperature superconductors have facilitated the production of high critical current and large-area films by the PLD method or MOD method. Nondestructive measurement techniques for high quality films are of great importance to estimate superconducting properties, such as the critical current density, J_C. The inductive method using the third-harmonic voltage component, V_3, is a promising technique for the measurement of the properties of J_C. On inductive determination of J_C for high-J_C thin films and thicker films (thickness $d \geqslant 0.1$ mm), the drive coil must generate a magnetic field sufficiently large to break the complete field shielding of the film. Therefore, we investigated a mutual inductance technique using a drive coil with a sharp ferromagnetic core for investigation of the J_C of the PLD–YBCO film. As a result, an abrupt nonlinear increase in the voltage across the pick-up coil was detected after magnetic full penetration of the film, and the threshold of the drive current I_{th} was suppressed to 0.23–0.28 times as compared with that measured by the inductive method using the third-harmonic voltage, V_3. FEM analysis indicated the diameter of the excitation field region to be 0.6 mm in the case of a 0.4 mm φ iron core. The *E*–*J* characters measured by the mutual inductive method as a function of frequency agreed well with those measured by the inductive method using V_3.

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Keywords: Superconducting film; Critical current density; Inductive measurement

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1. Introduction

In recent years, high critical current and large-area superconducting YBCO films have been developed by the pulsed-laser deposition method [1–3] and the TFA–MOD method [4]. The inductive method using the third-harmonic voltage, V_3 [5–10], is one of the most promising and reliable nondestructive measurement techniques for determination of the critical current density, J_C, of high-temperature superconducting films. This inductive method using V_3 (the V_3 method) requires only a single drive coil and J_C is determined by detecting large nonlinear response V_3, when the applied ac field of the coil breaks complete shielding and penetrates through the superconducting film. According to recent reports, the electric field E versus current density J relationship (the E–J characteristics) was derived by measuring the frequency f dependence of the inductive J_C [6,8], and this inductive determination of J_C has been demonstrated for high-temperature superconducting thick films (thickness $d \geqslant 0.1$ mm) [7,9]. The mutual inductance method was developed by Scharnhorst as a more direct method to determine J_C in a non-destructive manner [11]. In this method, the superconducting film is sandwiched coaxially with a drive coil and a pick-up coil (2-coil method), and J_C can be measured by detecting the changes in mutual inductance of two adjacent coils at the breakdown of complete shielding when the critical current is reached. The transition temperature, T_C, can also be measured using the 2-coil method without any destruction of the superconducting specimens [5,11,12].

A single coil with air cores is generally used to measure the V_3 response to drive the current as we consider that unneedful harmonic voltages arise when a coil with a ferromagnetic core is used in the V_3 method. In the 2-coil method, the pick-up coil detects the fundamental voltage generated by the drive coil. Therefore, we consider that a drive coil with a ferromagnetic core can be used to measure J_C by detecting the breakdown of complete shielding of the film if the magnetic field density of the core is not saturated. For the recently developed high-J_C and thick-coated conductors, the drive coil must generate a magnetic field sufficiently large to break the strong magnetic shielding.

Here, we report a new 2-coil method using a drive coil with a sharp ferromagnetic iron core (Iron 2-coil method). We compared the J_C and E–J characteristics measured using this method with those determined by the V_3 method and by the four-probe transport method.

2. Experimental

A large-area $YBa_2Cu_3O_7$ film with a thickness of 0.6 μm was deposited on 2-inch φ $LaAlO_3(1\,0\,0)$ substrate by the pulsed-laser deposition method (Sample LD3T600, National Institute of Advanced Industrial Science and Technology, Ibaraki, Japan) [1,2,13,14] and a piece of this film measuring 15×15 mm was used for the measurement.

In V_3 measurement, a small flat coil was mounted just above the film and they were cooled in liquid nitrogen. Fig. 1 shows a block diagram of the electronic apparatus used to measure J_C by the V_3 method. Voltage and current of the drive coil, V_{in} and I_{in} respectively, were measured and monitored to calculate the impedance of the coil. We used a lock-in amplifier (NF5600, NF Electronic Instruments, Yokohama, Japan) to measure the

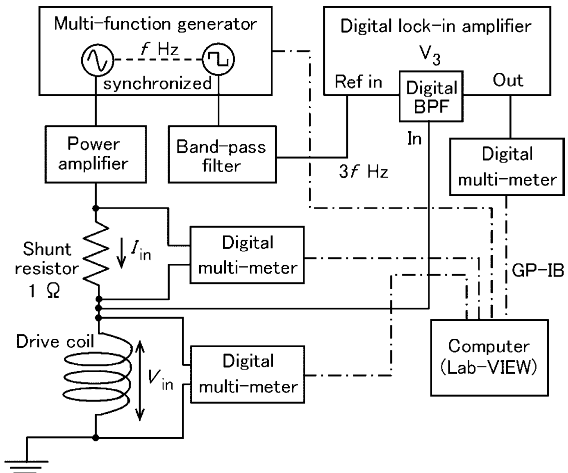

Fig. 1. Block diagram of the electronic apparatus used to measure J_C by the V_3 method.