Ac loss properties of YBCO superconducting tapes fabricated by IBAD-PLD technique

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Abstract. Temperature dependence of the ac loss in YBCO superconducting tapes fabricated by IBAD-PLD technique was investigated. The ac loss was measured with a saddle-shaped pickup coil by applying magnetic field perpendicular to the tape. Temperature dependence of $I_c$-$B$ characteristics was estimated from the observed magnetization curves. The $I_c$-$B$ curves normalized by the zero-field $I_c$ at the respective temperature coincided with one master curve regardless of temperature. $I_c$-$B$ characteristics of YBCO superconducting tapes are scaled with temperature. According, when the magnetization curves and the ac loss vs field amplitude curves are normalized by using the zero field $I_c$ at the respective temperature, they coincided with one master curve for any temperature from 4.2 to 77 K. It is verified that the magnetization and the ac loss are scaled with temperature.

1. Introduction

YBCO superconducting tapes are worldwide developed by various kind of fabrication technique. An individual tape length has reached 100-200 m and the critical current, $I_c$, has attained to 100-200A [1]. YBCO superconducting tapes show a high performance in critical current density, $J_c$, even in high magnetic field. The engineering $J_c$ in subcooled liquid nitrogen at 64 K of currently developed YBCO tapes is comparable to that of commercial NbTi wires in liquid helium at 4.2 K. In addition the engineering $J_c$ around 20 T at 20 to 30 K is much higher than that of Nb3Sn wires at 4.2 K. When the production processes to make a long and uniform tape with a high performance and a low cost are established, YBCO tapes will be widely applied not only to dc use but also to pulse and ac use in a wide range of temperature from 4.2 to 77 K. In advance to the practical use, it is necessary to have a clear grasp of the electromagnetic properties of YBCO tapes. It is well known that YBCO tapes have large anisotropy in ac loss property. In this paper, we first investigated the temperature dependence of the ac loss in a YBCO tape exposed to perpendicular field.

2. Ac loss measurement

Sample YBCO superconducting tapes were fabricated by IBAD-PLD technique [2]. The ac loss was measured by using a saddle-shaped pickup coil [3]. The bobbins of the pickup coils were made of AlN that is non-electric conductive and non-magnetic. The bobbins were connected to the cryocooler head.
by an AlN column and a brass column which were connected in series. A single YBCO tape with a length of 50 mm was inserted into the center of a saddle-shaped pickup coil horizontally so that external magnetic field was applied in perpendicular to the wide surface. The sample tape was cooled down to 35 K to 77 K by conduction. We also prepared a normal cryostat with a single vessel for the measurement with liquid helium at 4.2 K. The parameters of a sample YBCO tape is listed in table 1.

3. Magnetization curves and \( I_c \) estimation

Observed magnetization curves are shown in figure 1(a). The magnetization increased monotonically with decreasing temperature all over the magnetic field range. It is due to the increment of \( J_c \) according to the decrement of temperature. We estimated the \( I_c-B \) characteristics using the observed magnetization curves. We assumed that \( J_c \) property is uniform all over the tape and the magnetic field due to the shielding current is so small that we can regard the magnetic field inside a tape to be uniform and nearly equal to the external magnetic field. The magnetic moment due to the shielding current is given by \( m(B,T) = (I_c(B,T)/2)(w/2) \), where \( w \) is the width of a tape. Then \( I_c(B,T) \) can be estimated from the observed magnetization, \( M(B,T) = m(B,T)/wh \), by using the following expression.

\[
I_c(B,T) = 4hM(B,T) \quad (1)
\]

where \( h \) is a thickness of the superconducting layer. The estimated \( I_c-B \) curves are shown in figure 2. We can see that the \( I_c \) around zero field is nearly constant. We defined it as \( I_c0(T) \) and normalized the \( I_c-B \) curves by \( I_c0(T) \) at the respective temperature. The normalized \( I_c-B \) curves are shown in figure 3 in linear and logarithmic scale. We can see that the normalized curves coincide with one master curve. It means that the \( I_c-B \) property of the YBCO tape in perpendicular field is scaled with temperature.

| Table 1. Parameters of a YBCO tape fabricated by IBAD-PLD technique |
|--------------------------|------------------|
| Width                   | 10 mm            |
| Thickness of a Hastelloy tape | 100 μm         |
| Thickness of a superconducting layer | 1.5 μm        |
| \( I_c \) at 77 K       | 169 A            |

![Figure 1](image1.png)  
**Figure 1** (a) Observed magnetization curves and (b) the normalized ones by \( I_c0(T) \).
Next we proceeded to the scaling of magnetization. The normalized magnetization curves by $I_{c0}(T)$ are shown in figure 1(b). We can see that the major loops of the normalized magnetization curves coincide with each other. It is evident that the magnetization is also scaled with temperature.

4. Ac loss
The observed field amplitude, $B_m$, dependencies of the ac loss in a sample YBCO tape in perpendicular magnetic field are shown in figure 4 with temperature as a parameter. The breaking point of each ac loss curve corresponds to the effective penetration field, $B_{pe}$. As temperature decreases, the ac loss becomes smaller for $B_m < B_{pe}$ and becomes larger for $B_m > B_{pe}$ according to the increment of $J_c$.

The ac loss should be also scaled with temperature according to the fact that the magnetization is scaled with temperature. Therefore we normalized the observed ac losses by $\mu_0 I_{c0}(T)^2$ and replotted...
against the normalized magnetic field amplitude, $b'_m = B_m / |H_0|_{c0}(T)$. The result is shown in figure 5. We can see that every normalized ac loss curve accurately coincides with one master curve regardless of temperature. It is verified that the ac loss in YBCO tapes is scaled with temperature.

5. Conclusion
We investigated the temperature dependence of ac losses in YBCO superconducting tapes fabricated by IBAD-PLD technique. We measured the magnetization curves and ac losses with a saddle-shaped pickup coil by applying perpendicular magnetic field. The $I_c$-$B$ characteristics at the respective temperature were estimated from the observed magnetization curves. We found out that the $I_c$-$B$ curves normalized by zero field $I_c$ at the respective temperature, $I_{c0}(T)$, coincide with one master curve regardless of temperature. It means that the $I_c$-$B$ property of YBCO tapes is scaled with temperature. When the magnetization curves and the ac loss vs field amplitude curves are normalized by $I_{c0}(T)$, they also coincided with one master curves. It was verified that the magnetization and the ac loss of YBCO tapes are scaled with temperature.

References
[1] Yamada Y et al 2006 "Activity in SRL Nagoya Coated Conductor Center for YBCO Coated Conductor by IBAD+PLD Method -high $I_c$ long conductor and a new nanostructure of bamboo structure effective for pinning- to be published in Advances in Cryogenic Engineering 50A Proceedings of ICMC, Keystone, USA Aug 30-Sept 2 (2005).
[2] Kakimoto K, Iijima Y and Saitoh T 2003 Physica C 392-396 Part 2 p 783
[3] Iwakuma M et al 2003 Supercond. Sci. Technol. 16 p 545