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Numerical analysis of magnetization of $HgBa_2Ca_2Cu_3O_{8+\delta}$ superconductor

$HgBa_2Ca_2Cu_3O_{8+\delta}$ 초전도체 자화의 수치적 해석

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Magnetization measurements have been carried out on grain aligned Hg-1223 with the applied field parallel to the c-axis. The temperature dependence of the lower critical field $H_{c1}(T)$ was determined by considering the effect of the surface barrier on the magnetization. $H_{c1}(T)$ have been determined from magnetic hysteresis loops within the framework of the modified Kim-Anderson critical-state model, where the surface barrier and the lower critical field are explicitly considered. At high temperature, $H_{c1}(T)$ is identified as $H_p(T)$. This results are agreed with the theory of Bean-Livinston surface barriers.

1. INTRODUCTION

The critical state model was proposed by Bean to describe the magnetic hysteresis of type II superconductors. This model is simple and effective for type II superconductors which have storng pinning. The modification of the critical state model was done shortly after the Bean model appeared. One of the modified critical state model has been widely used for study of magnetic properties is the Kim-Anderson critical state model. This model assumed that the critical current density J_c is a function of the applied field, and H_{c1} and surface barrier(ΔH) effects are neglected.

In the case of imperfect surface and nonclean sample, surface barrier effects should be diminished and the magnetization loop is symmetric. We consider the difference between H_p and H_{c1} is small, so H_{c1} is nearly the same as H_p. The Bean and Kim model describes it very well. But for the very clear samples near T_c, the Clem model describes asymmetric magnetization loop well. It totally neglected the bulk pinning and H_p is approximately equal to the thermodynamic field H_c. Also for the another method to determine the effect of the lower critical field H_{c1}, we used Kim-Anderson critical-state model proposed by Tochihara et al.[1]. They have calculated the initial magnetization curves and full hysteresis loops by considering the surface barrier and the lower critical field H_{c1} to magnetization of type-II superconductors within the framework of the modified Kim-Anderson critical state model. Using that model, we computed M(H) curves and fit it with experimental results to obtaining the $H_{c1}(T)$. We used grain aligned Hg-1223 sample and demagnetization effects are considered to determine the H_{c1}.

2. EXPERIMENT

Polycrystalline sample with the nominal compositions of Hg:Ba:Ca:Cu=1:2:2:3 was prepared by a solid-state reaction method using high-purity HgO, BaO, CaO, and CuO powders.

From these materials, an aligned composite sample was produced from monocrystallites of 2㎛ average size that were dispersed in 45min liquid epoxy and aligned in a 5T field. The volume fraction of superconductor in epoxy was about 9%, with sample containing approximately 30㎎ of powder.

The magnetic measurements of grain-aligned samples were performed using a commercial SQUID magnetometer(Quantum Design model MPMS). A scan length of 4 ㎝ was used and the temperature was stabilized to within ± 0.05 K prior to measurements. The magnetization M was measured as a function of the magnetic field H for H||c axis, and at fixed temperatures for the sample. Before each new T setting, the sample was brought to a temperature well above T_c and then cooled under zero applied field. Once the temperature was stabilized, the magnetic moment was measured at various applied magnetic fields H.

3. RESULTS AND DISCUSSION

Figure 1 (a), (b) show the hysteresis cycles(H||c) for several temperatures between 20K and 110K. The external applied fields for each temperature are larger than full penetration field H_p.

In the Kim-Anderson critical state model, the critical current density has the form

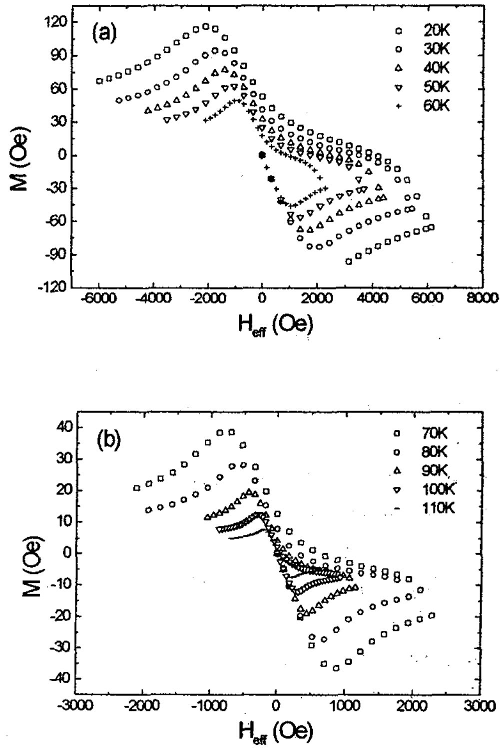

Fig. 1. Magnetization curve for H||c at temperature (a) 20K-60K, (b) 70K-110K

$J_c = k/(B_0 + |B_i|)$, where k and B_0 are constant. The parameter k, which is proportional to the critical current density, is considered to reflect the pinning force in a specimen. And Yasuoka et al. [2] suggested that B_0 is a closely correlated quantity to $\mu_0 H_{irr}$.

Using the expression for critical current density, Ampere's law, $\nabla \times B = \mu_0 J$, and $M = B/\mu_0 - H_{eff}$, the full hysteresis loops are obtained. In this parer we used the modified Kim-Anderson critical state model proposed by Tochihara et al.[1]. They have taken into consideration the surface barrier ΔH and H_{c1} to the magnetization of type-II superconductors in the critical state model studied by many workers[3-5]. According to Dunn et al.[6] the magnetization curve is somewhat complicated due to non-zero values of ΔH and H_{c1}, but the effective field in the sample H_{eff} may be described by the following expression,

$$H_{eff} = H - \frac{H}{|H|} H_{c1} - \frac{dH/dt}{|dH/dt|}$$

where H is the applied field. In the practical simulation for magnetization loops, we used the following fitting parameters, $p=(2\mu_0 \; k \; a)^{1/2}/B_o$, $H_p = B_o[(1+p)1/2 -1]/\mu_o$, ΔH and H_{c1}.

In Fig. 2 the fitting results are shown at several temperatures. The computed M(H) curves have a good agreement with the experimental data. From these process, we have obtained appropriate values of fitting parameters.

Figure 3 shows the temperature dependence of H_{c1} obtained by fitting results. Closed symbols represent the values of the extrapolating $(\Delta M)^{1/2}$ and $(\Delta M)^{1/3}$ to zero by proposed by Burlachkov et al.[7]. The magnetic field is corrected by the demagnetization factor n = 0.43 from the deviation of the Meissner state. The data points $H_{c1}(T)$ obtained fitting result have the similar behavior with the data points of $(\Delta M)^{1/3}$ considered Bean-Livinston surface barrier.

Figure 4 displays the temperature dependence of the magnetic field H_p, which is nearly equivalent to the experimental value from the minimum magnetization value at each temperatures.

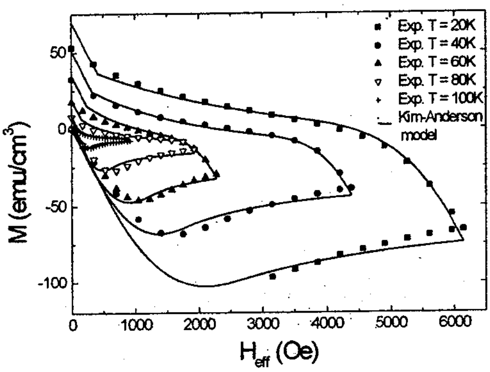

Fig. 2. Magnetization curves at temperature T=20, 40, 60, 80, 100K. Solid lines represent the calculated results and marked symbols are the experimental data points.

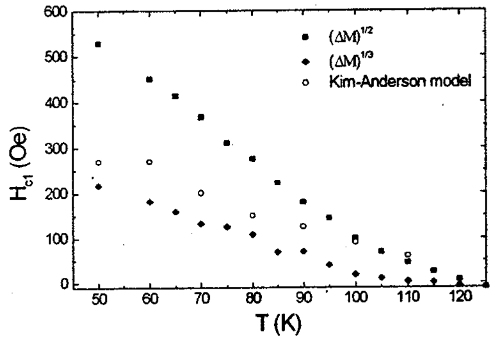

Fig. 3. Temperature dependence of lower critical field $H_{c1}(T)$

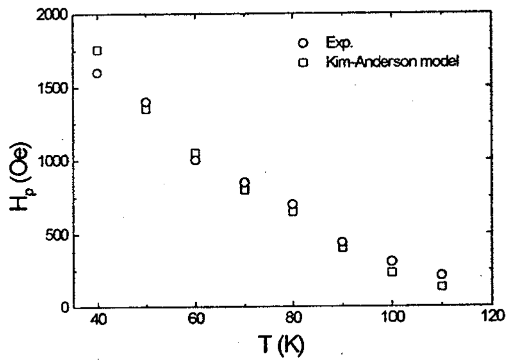

Fig. 4. Temperature dependence of penetration field $H_p(T)$

4. CONCLUSIONS

Using the Kim-Anderson critical state model, we have calculated the initial magnetization curve and full hysteresis loops for grain aligned Hg-1223. The hysteresis loops are fitted to Kim-Anderson model in the all temperature parameters, lower critical field H_{c1}, surface barriers ΔH, and full penetration field H_p at each temperature.

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