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# 中国核科技报告
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## FLUX CREEP IN FLUORINE-DOPING Bi-Pb-Sr-Ca-Cu-O BULK SUPERCONDUCTOR

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# 掺氟 Bi-Pb-Sr-Ca-Cu-O 大块超导体的磁通蠕动

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## 摘　要

实验研究了掺氟的 Bi-Pb-Sr-Ca-Cu-O 块状超导体的磁化和磁通蠕动，结果表明存在一些新的行为：当 100Oe< $H$ <1000Oe 时，$s = dM/d\ln t \propto H^{1/2}$；当 $H <$ 150Oe 时，$U_0(H) \propto \exp(-H/30)$；当 $H >$ 150Oe 时，$U_0(H) \propto H^{-\alpha}$，且 $\alpha = 3/2$ 。

# FLUX CREEP IN FLUORINE-DOPING Bi-Pb-Sr-Ca-Cu-O BULK SUPERCONDUCTOR

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## ABSTRACT

The magnetization and the flux creep in the fluorine-doping Bi-Pb-Sr-Ca-Cu-O bulk superconductor have been experimentally studied. The experimental results exhibit some new behaviours and suggest that $S = dM/d\ln t \propto H^{1/2}$ for the fields 100 Oe $< H < 1000$ Oe; $U_0(H) \propto \exp(-H/30)$ for the fields below 150 Oe and $U_0(H) \propto H^{-\alpha}$ with $\alpha = 3/2$ for the fields above 150 Oe.

## INTRODUCTION

The potential for application of the high $T_c$ oxide superconductors has produced a unprecedented amount of effort towards the understanding of their physical properties. Many of these applications will require high critical current density which will in turn make detailed knowledge of phycical properties, including the behaviours of creep and pinning of flux. According to the Anderson-Kim model of flux creep in conventional type Ⅱ superconductors,

$$U_0 = (H_c^2/8\pi) \cdot \xi^3 \quad (1)$$

$$S = dM/d\ln t = (rJ_c/3c)(kT/U_0) \quad (2)$$

Here, $U_0$ is the pinning potential of flux. $H_c$ is a thermodynamical critical field. $\xi$ is the coherent length. $r$ is a radius of cylinder sample. $c$ is light velocity. The coherent length in high $T_c$ oxide superconductors is much smaller than in conventional superconductor. Therefore, there is only a small pinning potential of flux. On the other hand, $kT/U_0$ is about $10^{-3}$ for conventional type Ⅱ materials while about $10^{-2}$ for high $T_c$ oxide superconductors. The high rate of flux creep, $S = dM/d\ln t$, makes the phenomena of flux creep are observed easyly in high $T_c$ oxide superconductors.

Recent articles published have explored the strong magnetic relaxation obeserved in Y-Ba-Cu-O[1~4], Tl-Ba-Ca-Cu-O[4~5] and Bi-(Pb)-Sr-Ca-Cu-O[5~8] sintered bulks and crystals. The melting phenomena of flux lattice have been obeserved in the temperature range below $T_c$ [9] These experimental results suggest that there is fairly weak pinning of flux.

In this paper we report the creep and pinning of flux in the flourine-doping Bi-(Pb)-Sr-Ca-Cu-O bulk superconductor by means of dc magnetization measurements.

## 1 EXPERIMENTAL METHODS

The sample with the nominal composition $Bi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_{y-x}F_x$ was synthesized by the solid state reaction. The powder mixture of $Bi_2O_3$, $SrCO_3$, $CaCO_3$, PbO. CuO and $CuF_2$ was heated at 760℃ for 15 h in air, then, was pressed into pellets of 12 mm in diameter and 2 mm in thickness under 49 MPa pressure. The pellets were sintered at 780℃ for 72~160 h, then, were cooled in air or in furnance to room temperature. The sample was cut into a cylinder. The X-ray diffraction indicates that there are the multiple phases and no fluoride or other impure phase, but 110 K phase is dominant. The measurement of Meissner effect at 20 Oe shows that superconducting $T_c$ in which the diamagnetism begin to appear is 113 K and 85 K phase does not yet appear until 77.3K as shown in Fig. 1. The amount of fluorine in the sample, $x$, is smaller than 1.2[10].

The magnetization and its relaxation were measured by a ballistic galvanomenter connected to two opposite series pick up coils. The magnetic field which was produced by a liquid nitrogen cooling copper solenoid paralleled to the axis of cylinder sample. The homogeneity and stability of magnetic field are sufficient to ensure the right observation in experiments[11]. The experimental procedure consists of zero-field-cooling (ZFC) sample from well above the transition temperature to the desire one, turning on a magnetic field, $H$, and then, observing the magnetization as the function of magnetic field or the time.

## 2 EXPERIMENTAL RESULTS

### 2.1 Magnetization of sample

In Fig. 2, we plot the magnetization curve as the function of magnetic field, $H$, at 77.3K. The sample underwent the magnetization process of $0 \longrightarrow H_{max} \longrightarrow 0 \longrightarrow (-H_{max}) \longrightarrow 0 \longrightarrow H_{max}$. A peak magnetization field, $H_p$, is about 130 Oe, as shown by point $A$ in Fig. 2. The magnetization rapidly decrease with increasing field and is approximately reversible above 2200 Oe. A frozen magnetization of 0.72 emu/g or 2.72 emu/cm$^3$ at $H = 0$ is about 40% of the peak magnetization. The repeating magnetization make the peak magnetization remove towards lower field, and $H_p'$ is about 100 Oe (see the point $A'$ in Fig. 2). In comparison, the magnetization after peak value reduces more slowly with increasing field, and a frozen magnetization is about 0.27 emu/g at $H = 0$ for without fluorine Bi-(Pb)-Sr-Ca-Cu-O sample produced by similar sintering techniques.

### 2.2 Flux creep in the fluorine-doping Bi-(Pb)-Sr-Ca-Cu-O

In Fig. 3, we plot the dependence of magnetization upon the times in the field of 120 Oe at 77.3 K. It is clear to follow the law $M \propto \ln t$. However, $dM/d\ln t$ has the distinguished values before and after $9 \times 10^2$ seconds and it can be related to the existence of weak link superconductivity. The jumps of flux which appear during magnetic relaxation have been explained in Ref. [11].

In Fig. 4, we plot the rate of flux creep, $S = dM/d\ln t$, in various fields. It can be seen that there is a maximum in the field range of 900~1500 Oe; that in the field lower than 200 Oe, the rate of flux creep changes with field to be steeper. In the field range of $H_{c1} < H < 200$ Oe, the field is near the peak magnetization field, thus the distribution and the gradient of flux density present a severe change with magnetic field. This is perhaps the reason of the more rapid change of $S = dM/d\ln t$ with magnetic field.

For the Bi-Sr-Ca-Cu-O, the field dependence of the rate of flux creep, $S = dM/d\ln t$, follows the law $S \propto H^{2}$[12]. In our experimental result of the fluorine-doping Bi-(Pb)-Sr-Ca-Cu-O, it follows the law $S \propto H^{1/2}$ for fields 100 Oe$< H <$1000 Oe, as shown in Fig. 5. We have observed the similar result on other samples. This indicates that the field dependence of the rate of flux creep exhibits some new heaviours for the fluorine-doping Bi-(Pb)-Sr-Ca-Cu-O.

## 2.3 Flux pinning potential

In the frame-work of flux creep model, the pinning potential of flux, $U_0$, is related to magnetization and its relaxation rate in the following equation:

$$U_0 = (5/c)kT\Delta M/(dM/d\ln t) \qquad (3)$$

where $\Delta M$ is the hysteresis in magnetization. $U_0$ value of our sample induced from Eq. (3) is 0.16 eV$\sim 8\times10^{-4}$ eV for the magnetic fields from 50 Oe to 2000 Oe. From the practical point of view, flux creep at much higher field should be noted. However the hysteresis in magnetization decreases rapidly with increasing magnetic field at 77.3 K as shown in Fig. 2, it is impossible to estimate $U_0$ at higher magnetic field at 77.3 K from Eq(3).

In Fig. 6, we plot the field dependence of pinning potential in the range of the field from 50 Oe to 2000 Oe. In Fig. 7, we replot these data as log $U_0$ vs $H$. From this plot, the field dependence of pinning potential follows a exponential law for the fields below 150 Oe,

$$U_0(H) \propto \exp(-H/30) \qquad (4)$$

In the inset of Fig. 7, we replot these data as log $U_0$ vs log $H$ for the fields above 150 Oe. Thus we can represent these data by following function,

$$U_0(H) \propto H^{-\alpha} \qquad (5)$$

with $\alpha = 3/2$.

Flux creep measurements on conventional type Ⅱ superconductors have previously observed a field dependence of $U_0$, the average pinning potential of flux is monotonously decreasing towards zero at $H_{c2}$[13]. This presumably reflects the field dependence of the relevant activation volume. For high $T_c$ oxide superconductors, the field dependence of $U_0$ follows Eq. (5), however, $\alpha$ value is distinguished, for example, $\alpha = 2$ for $YBa_2Cu_3O_y$ and $Tl_2Ba_2Ca_2Cu_3O_y$ bulks[ ] and $\alpha = 1/2$ for $H // C$ and $\alpha = 0.16$ for $H \perp C$ in $Bi_2Sr_2Ca_{0.8}Cu_2O_y$ crystal[ ]. This implies that the field dependence of $U_0$ for high $T_c$ oxide superconductor is considerably steeper.

Up to now, the research of the behaviour of flux pinning in low field is not yet sufficient. However, it is of importance owing to the existence of weak link superconductivity in high $T_c$ oxide bulk superconductors. Eq. (4) given firstly in this paper reflects the decrease of the average pinning potential is much steeper. This represents presumably the behaviour of flux pinning in weak link superconductors.

The effect of fluorine-doping on the behaviour of flux creep and pinning of flux in Bi-(Pb)-Sr-Ca-Cu-O wants yet to be further studied.

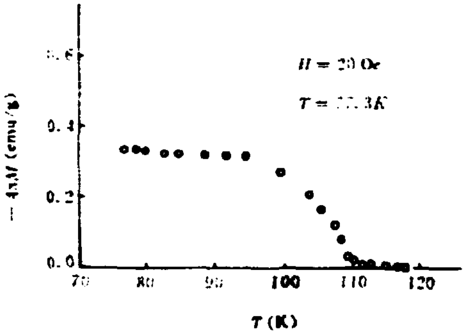


Fig. 1. Meissner effect of the fluorine-doping $Bi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_{y-x}F_x$ at 20 Oe.

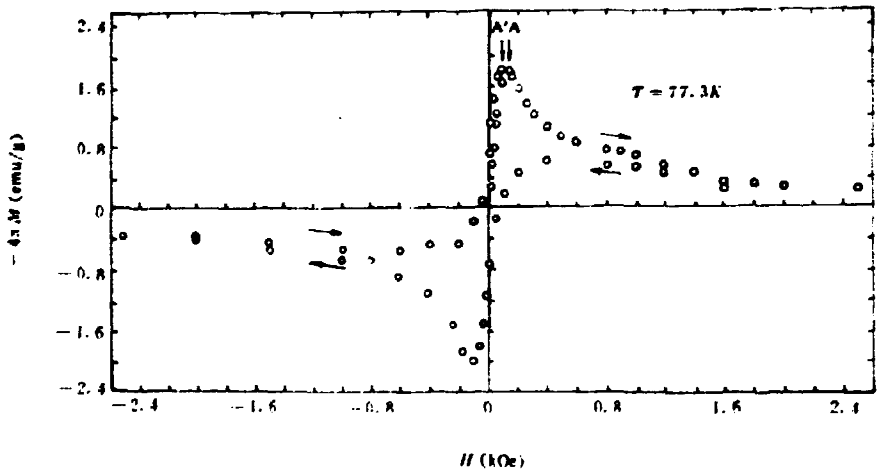


Fig. 2. Field dependence of the magnetization of $Bi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_{y-x}F_x$ bulk superconductor.

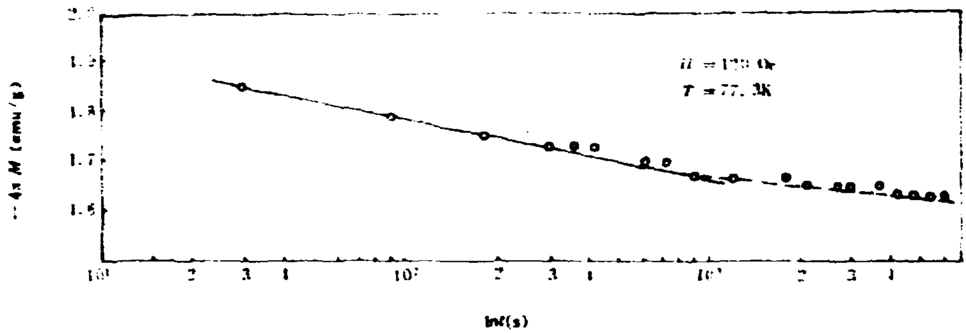


Fig. 3. The magnetization decay as the function of ln t at 120 Oe at 77.3 K.

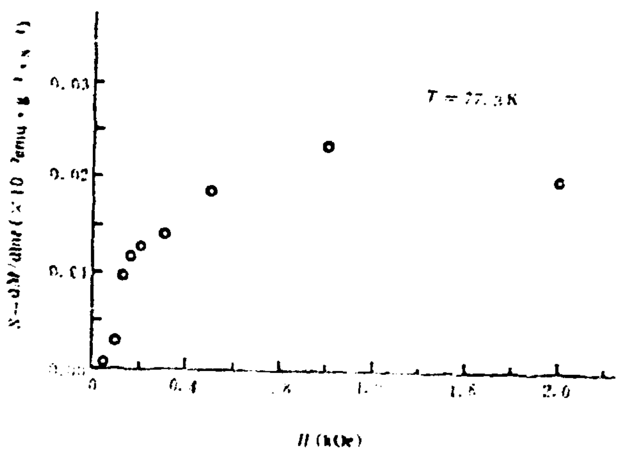


Fig. 4. The dependence of the rate of flux creep upon magnetic field at 77.3 K.

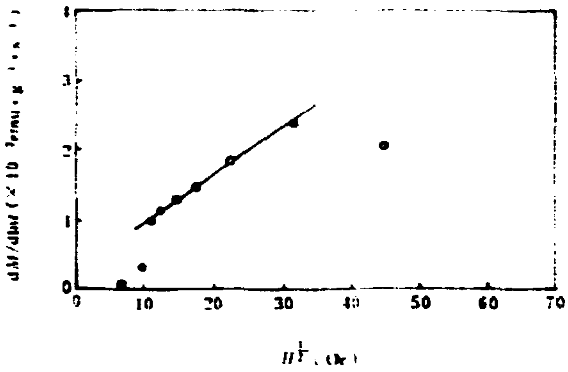


Fig. 5. The dependence of $S = dM/d\ln t$ vs $H^{1/2}$ of $Bi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_{y-x}F_x$ bulk superconductor at 77. 3 K.

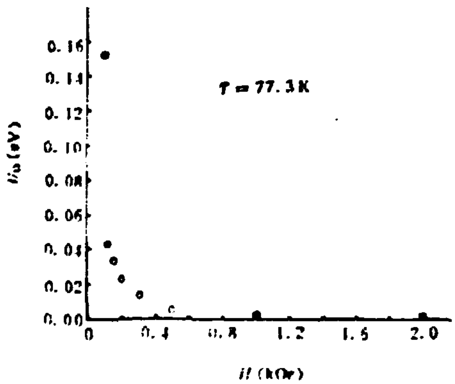


Fig. 6. The field dependence of $U_0$ in $Bi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_{y-x}F_x$ bulk superconductor at 77. 3 K.

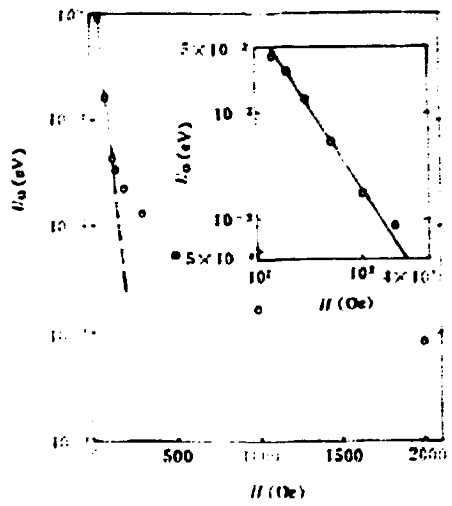


Fig. 7. The dependence of $U_0$ upon $H$ of $Bi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_{y-x}F_x$ bulk superconductor.

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