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EXPERIMENTAL WORKSHOP ON HIGH TEMPERATURE SUPERCONDUCTORS & RELATED MATERIALS (BASIC ACTIVITIES)

12 - 30 MARCH 1990

CRITICAL CURRENTS
Part III

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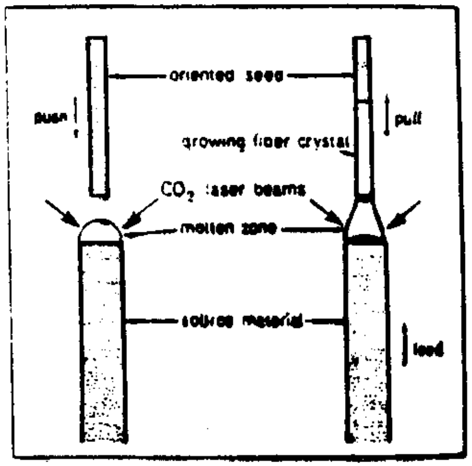
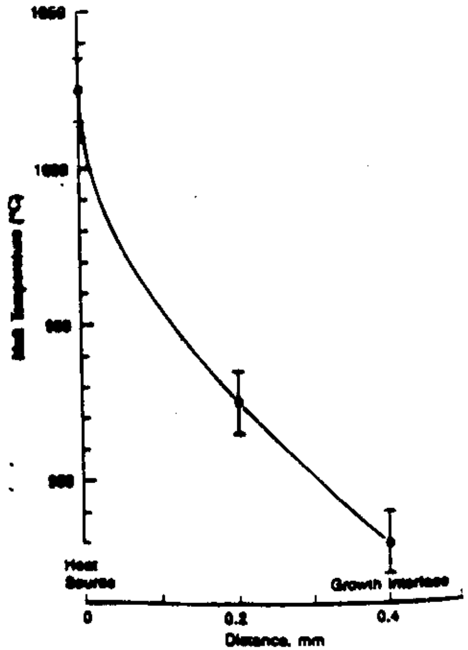
Bi – Sr – Ca – Cu – O
[Kapitulnik et al., Science]

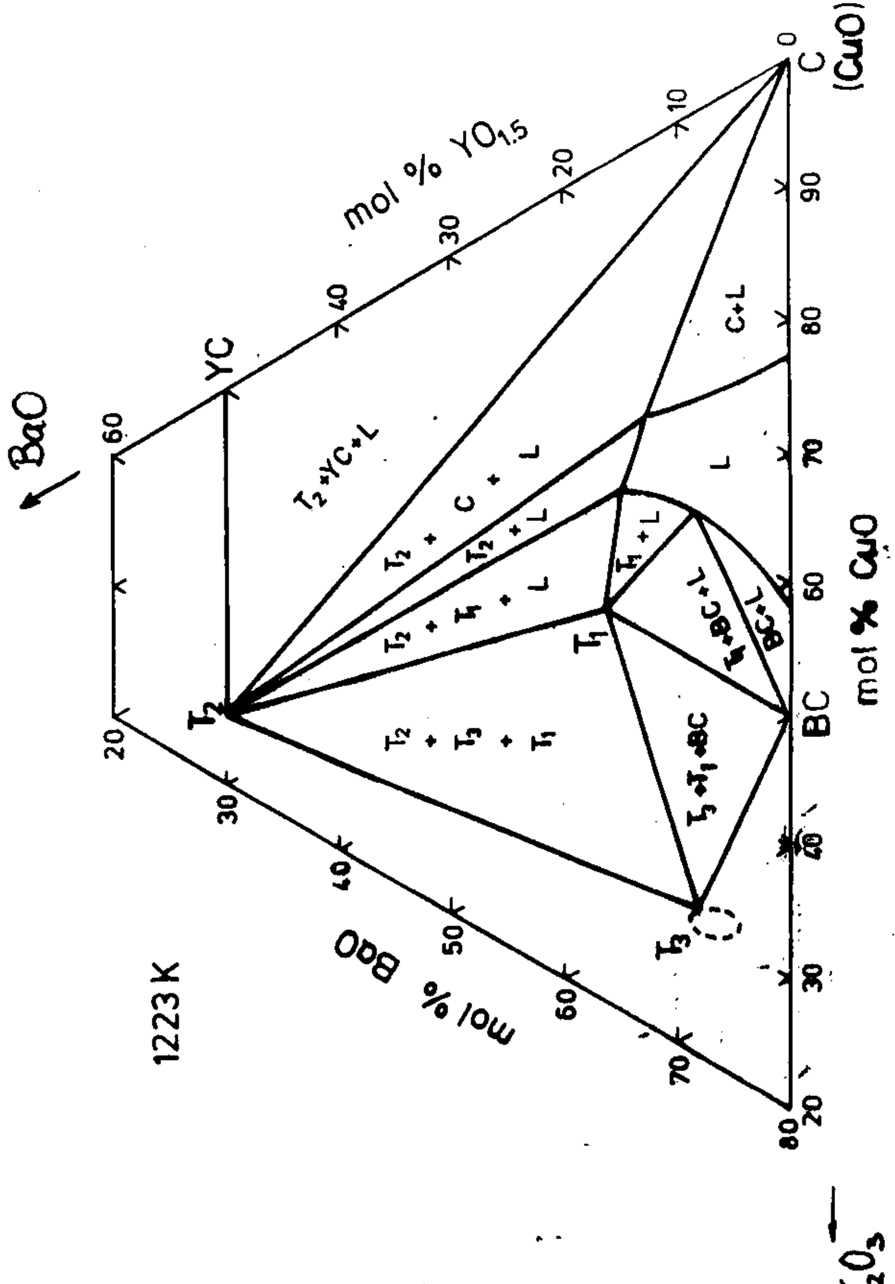
(2212)





At 68K:

$J_c(0) = 6 \cdot 10^4$ A/cm !



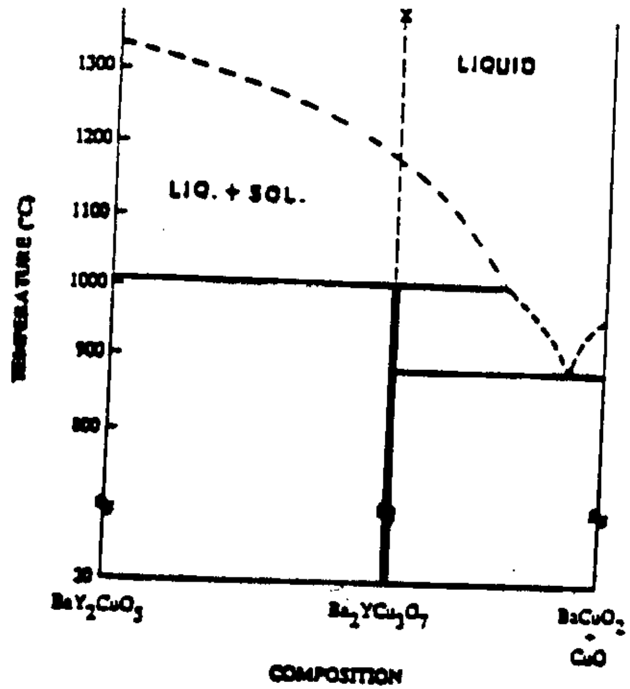
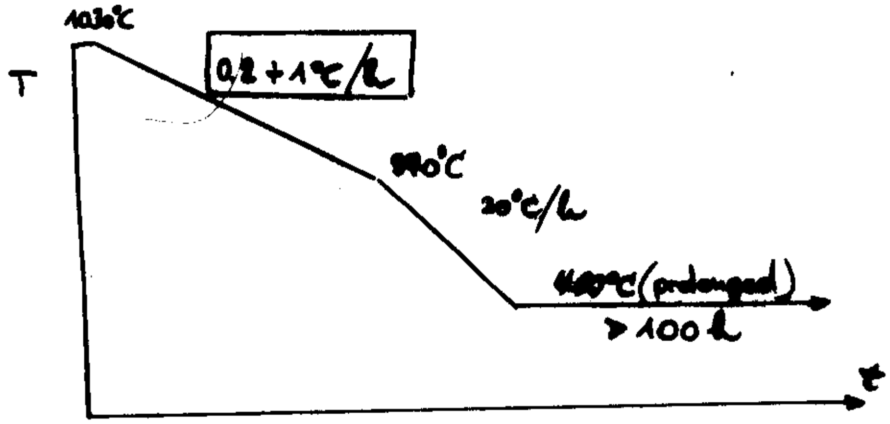


FIG. 1. Qualitative sectional phase diagram near the $YBa_2Cu_3O_{7-\delta}$ superconducting phase.

Single crystals of $YBa_2Cu_3O_{7-x}$

Flux method, CuO flux

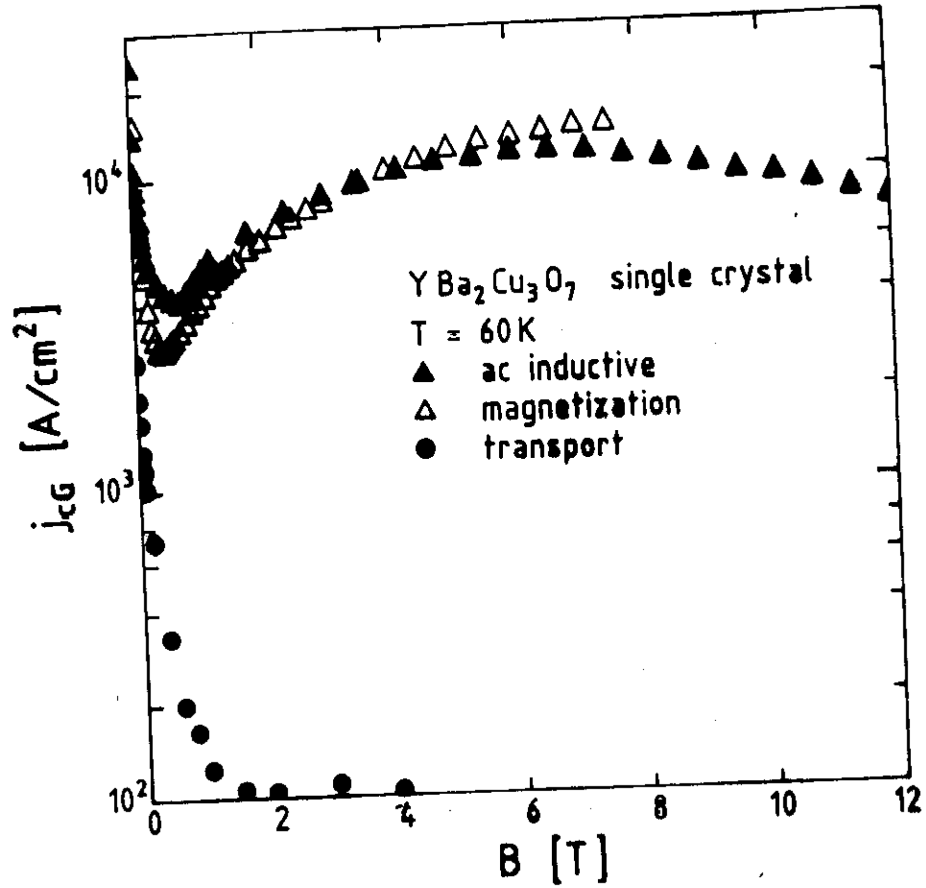
Crucible materials, Al_2O_3, Au



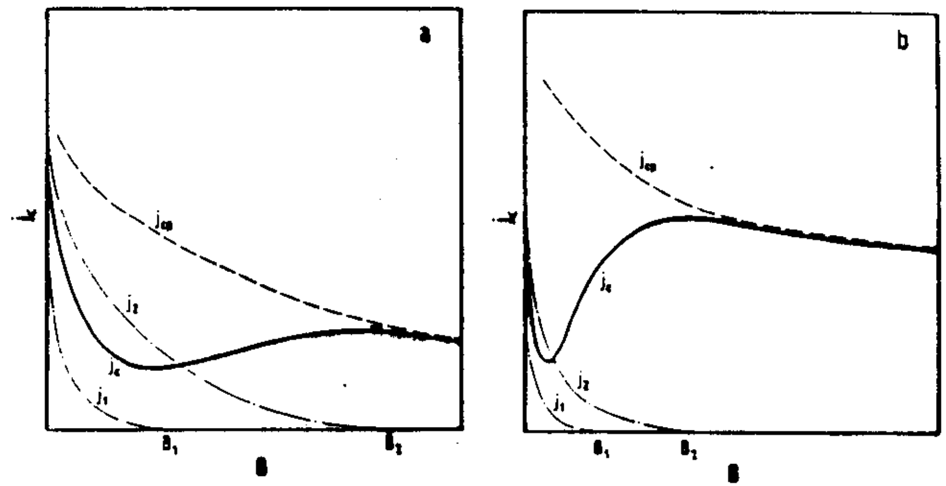
Results : $> 5°/h$: $d_c \leq 0.1$ mm
$T_c \approx 80 \div 91$ K
$\rho_{100K} < 80\ \mu\Omega cm$

≤ 0.5 °C/h : $d \leq 2$ mm
$T_c \approx 87$ K (in Al_2O_3)
$\approx 90 \div 91$ K (in Au)
$\rho_{100K} \approx 80 \div 100\ \mu\Omega cm$

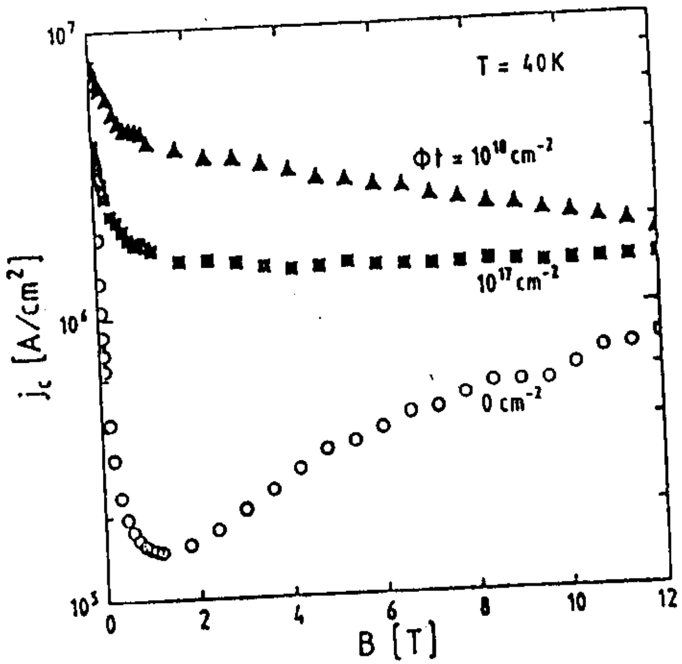
weak links due to 1% Al substitution!



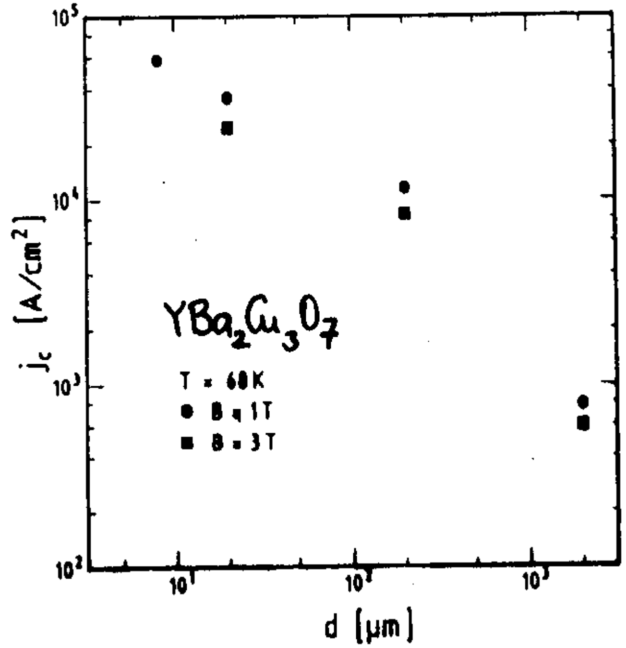
YBa2Cu3O7 single crystal
T = 60K
ac inductive
magnetization
transport
jcG [A/cm2]
B [T]



a
b
B

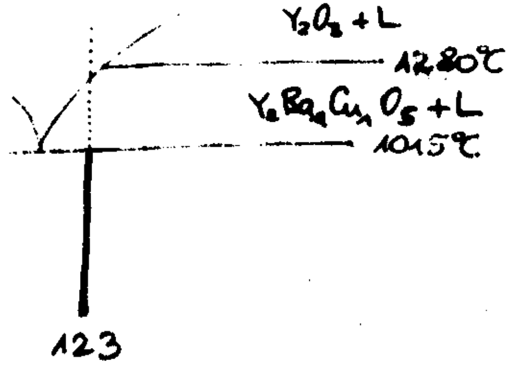


"WEAK LINK" INTRAGRAINS
(MONOCRISTAL)



Melt Textured Growth:

— Jin et al.



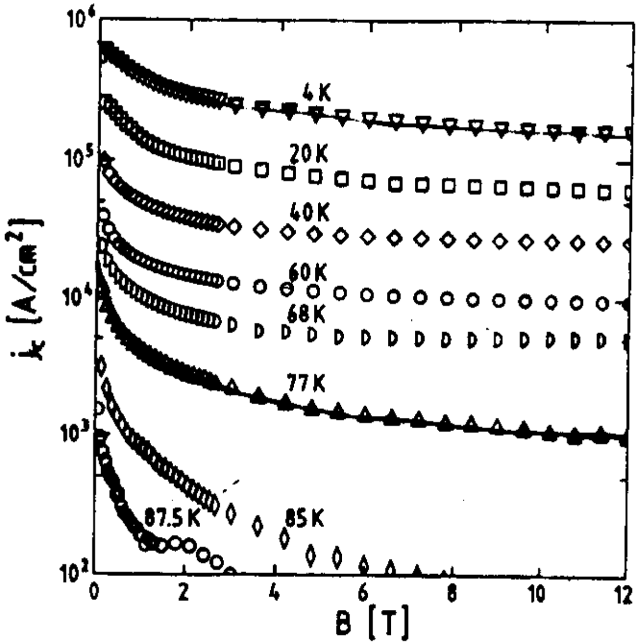
— Murakami et al. : $J_c \approx 10^4 A/cm^2$ bei 1T, $\approx 10^3 A/cm^2$ bei 10T } 77K

— Salama et al. $J_c = 7.5 \times 10^4 A/cm^2$ (0T, 77K, 1ms)

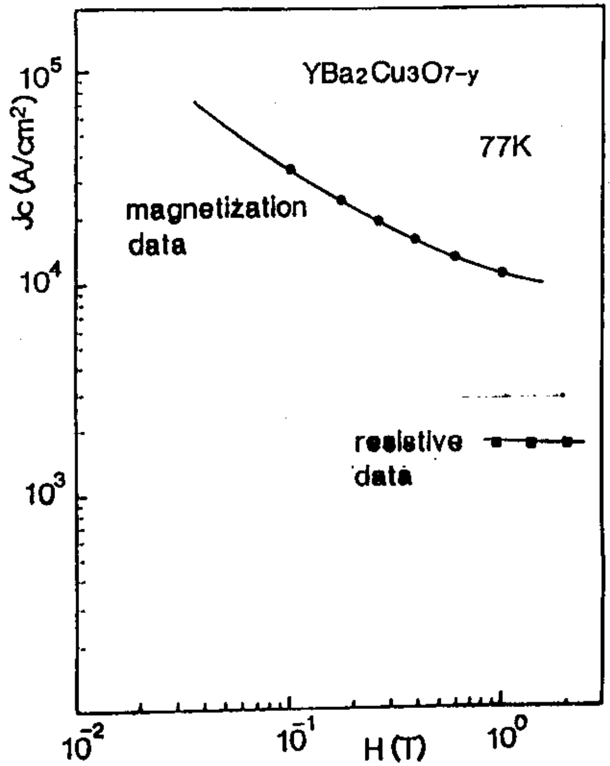
$J_c = 1.8 \times 10^4 A/cm^2$ (0T, 77K, >1s)

Murakami et al.

YBa$_2$Cu$_3$O$_7$: melt textured growth



77K: not longer weak link character



(Salama)

(Murakami)

Melt Textured Samples

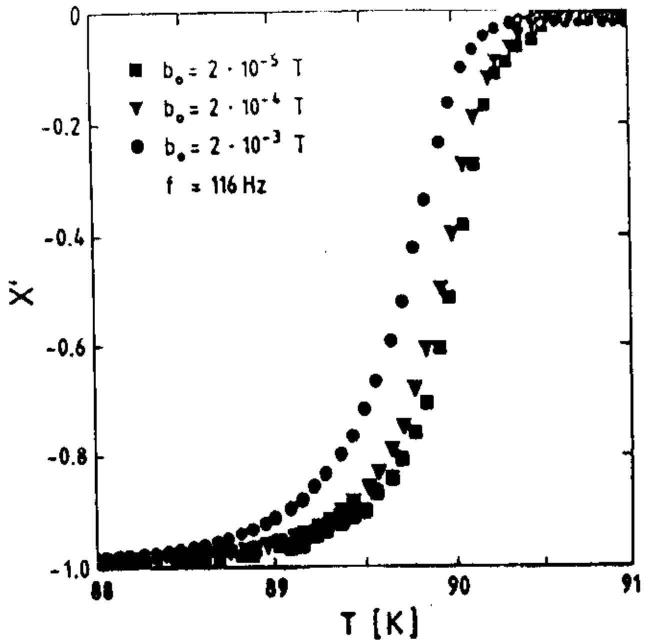


Fig. 2

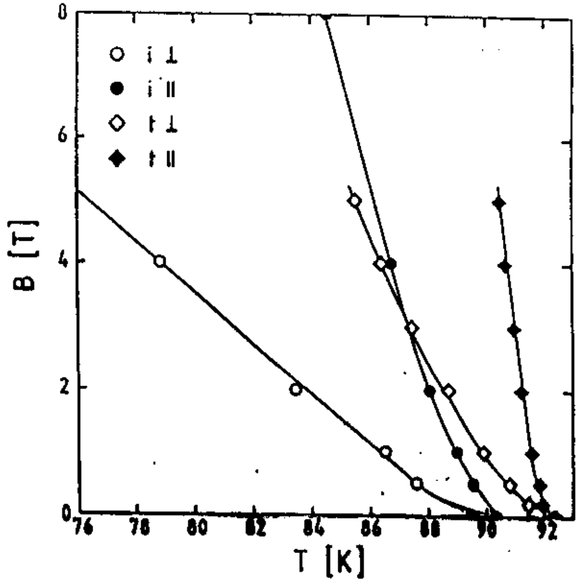


Fig. 1

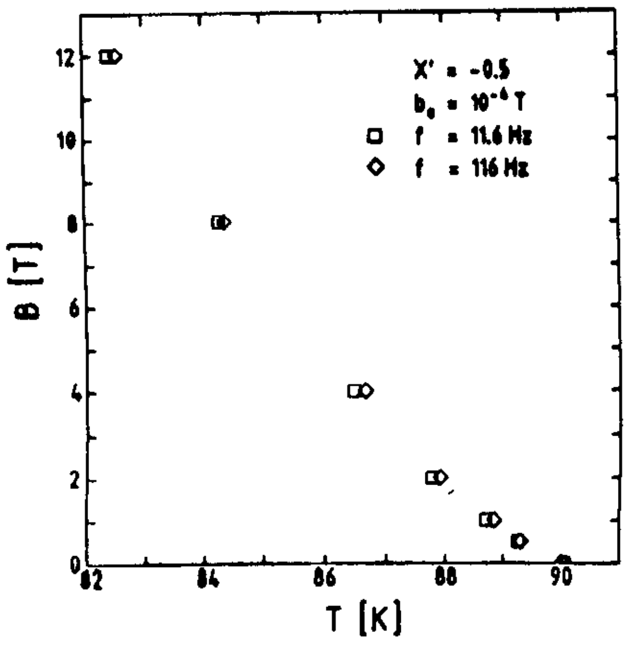


Fig. 3

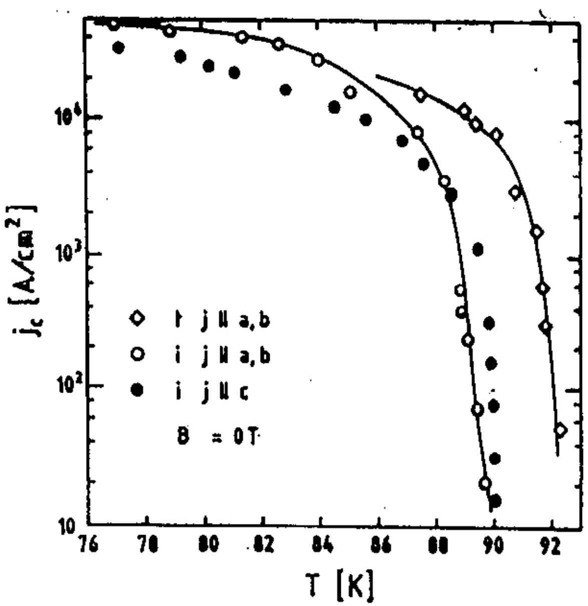


Fig. 2

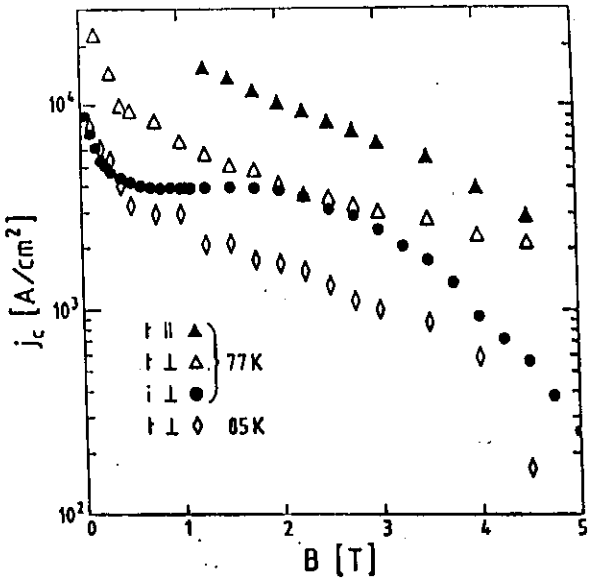


Fig. 3

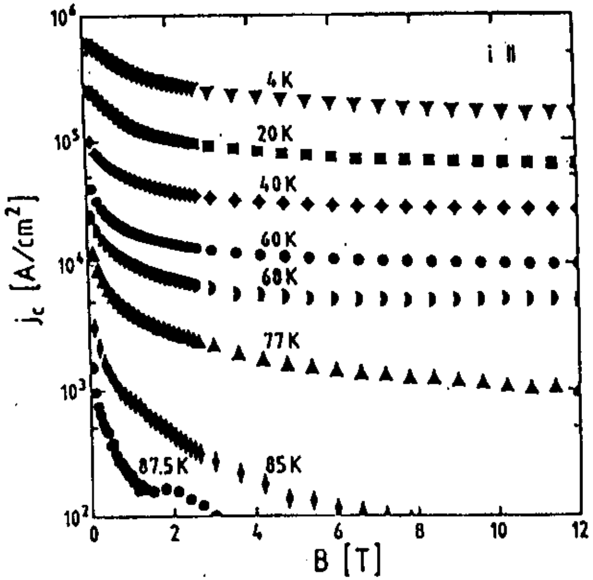


Fig. 4a

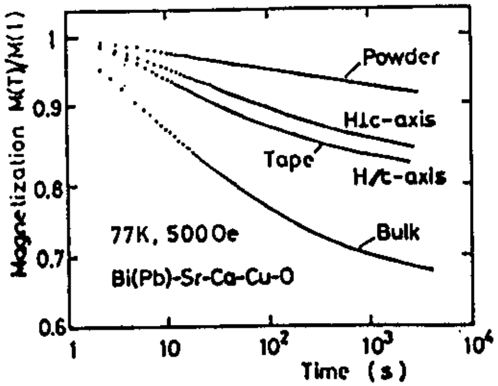
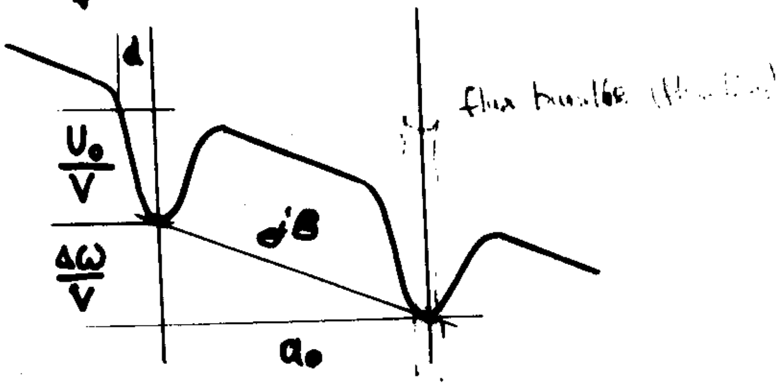


FIGURE 2
Magnetic relaxation at 77K and 500Oe of tape, bulk and powder samples

Thermally activated flux creep

U_0, ΔW : absolute (flux bundle)

$\frac{U_0}{V}$, $\frac{\Delta W}{V}$: normed (flux line)



$U_0 = j_{c0} B V d$

$\Delta W = j B V a_0$

$\Delta W = U_0 \frac{j}{j_{c0}} \left(\frac{a_0}{d}\right)$

j_{c0} : non-relaxed critical current density

j : instantaneous, relaxed cr. c. density

V : Bundle volume

a_0 : jumping distance

d : Width of potential well
~ reversible displacement

U_0 : Pinning potential

At temperature T, 'particle' jumps with a rate

$$R = \Omega_0 \cdot e^{-\frac{U_0}{k_B T}}$$ (non directional)

(Ω_0: jumping frequency)

Voltage leads to directional jumping:

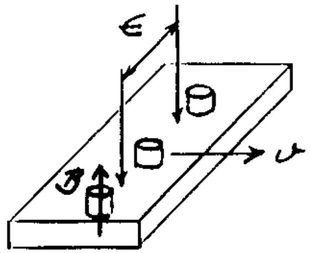
$$R_f = \Omega_0 \cdot e^{-\frac{U_0 - \Delta W}{k_B T}}$$

$$R_b = \Omega_0 \cdot e^{-\frac{U_0 + \Delta W}{k_B T}}$$

ΔW = Energy picked up by 'particle' when introducing a voltage

→ jumping rate :

$$R_{net} = 2 \Omega_0 \, e^{-U_0/k_B T} \sinh\left(\frac{\Delta W}{k_B T}\right)$$



Mit Bewegung der Flußlinien verbund neu E-Feld

$$E = vB$$

$$E = R_{net}\, a_0\, B$$

$$E = 2 a_0 B \Omega_0\, e^{-\frac{U_0}{k_B T}} \sinh\left(\frac{U_0}{k_B T}\frac{j}{j_{c0}}\right)$$

If j_c has a variation of $j_{c0}\frac{k_B T}{U_0}$, E varies by e

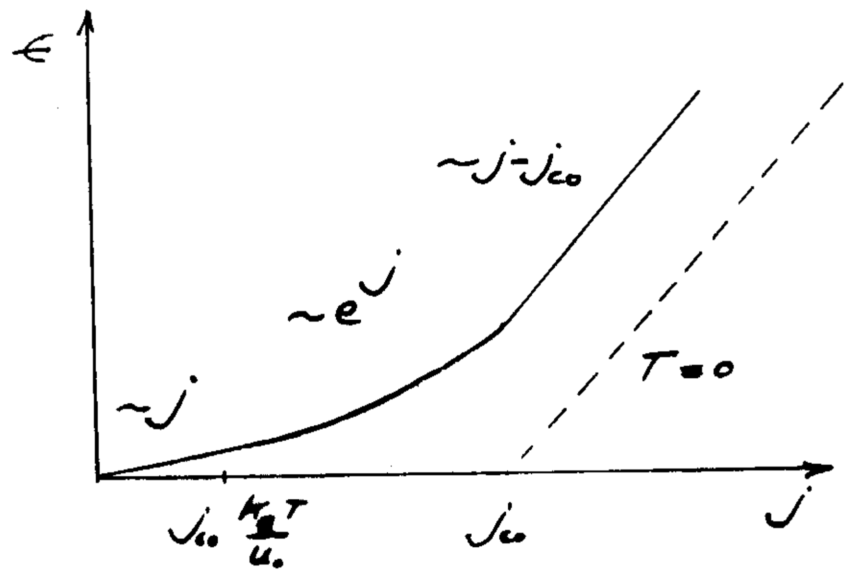
Different cases :

$\sinh x \rightarrow \frac{e^x}{2}$, $x \gg 1$

$\sinh x \rightarrow x$, $x < 1$

$U_0 < k_B T$	$U_0 > k_B T$
–	$\Delta W > k_B T$
$\Delta W < k_B T$	$\Delta W < k_B T$

: $U_0 > k_B T$

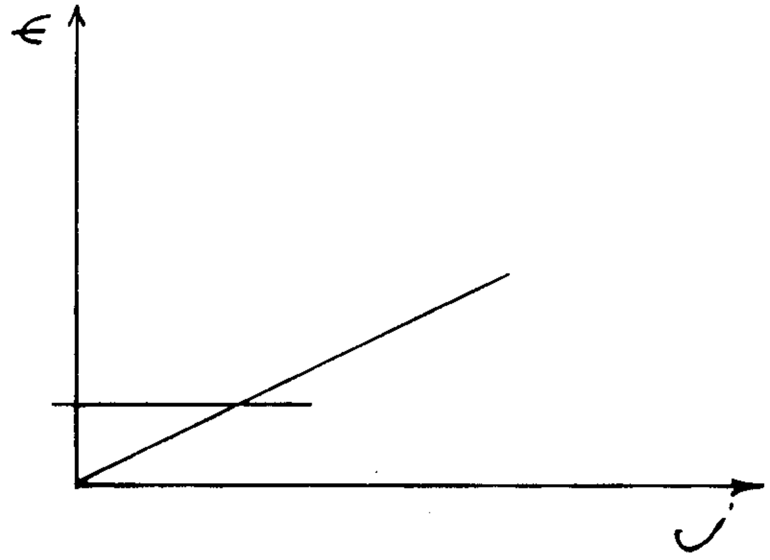


$$E = \rho_f (j - j_{c0}) + E_{c0}, \qquad j > j_{c0}$$

$$= a_0 B \Omega_0\, e^{-\frac{U_0}{k_B T}\left(1 - \frac{j}{j_{c0}}\right)}, \qquad j_{c0}\frac{k_B T}{U_0} < j \leq j_{c0}$$

$$= 2 a_0 B \Omega_0 \frac{U}{k_B T}\frac{j}{j_{c0}} \cdot e^{-\frac{U_0}{k_B T}}, \qquad j \leq j_{c0}\frac{k_B T}{U_0}$$

$U_0 \lesssim k_B T$



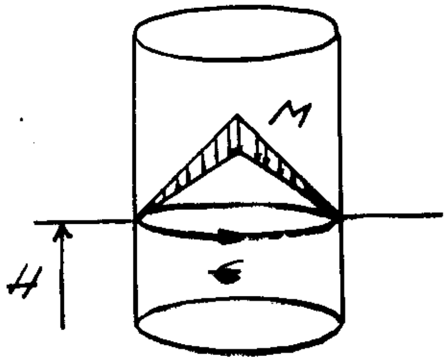
$$\epsilon = \rho_s j ,$$

$$\rho_s = 2 a_0 \nu \Omega_0 \frac{U_0}{k_B T} \frac{1}{j_{c0}} e^{-\frac{U_0}{k_B T}}$$

- Finite voltmeter resolution
- Short sample length

→ lead to finite j_c's.

Electrodynamics of Flux Creep



Cylinder with radius in an external fiel

Faraday'sches Gesetz

$$\text{rot}\, \vec{\epsilon} = -\frac{\partial \vec{B}}{\partial t}$$

$$\epsilon = -\frac{1}{2\pi R} \frac{\partial \Phi}{\partial t}$$

Bean'sches Modell

$$j = J \frac{M}{R}$$

$$\Phi = \frac{2}{3} \pi \mu_0 R^3 j$$

Φ eliminieren

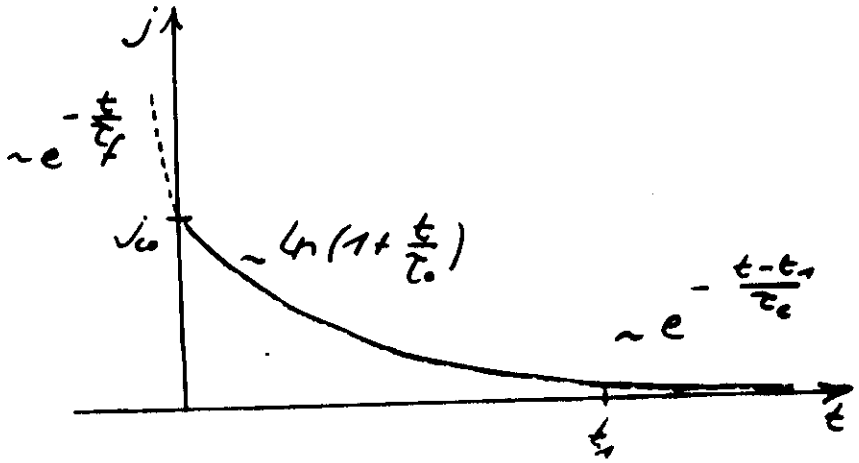
$$\epsilon = -\frac{1}{6} \mu_0 R^2 \frac{dj}{dt}$$

ϵ eliminieren

DGL für $j = j(\epsilon)$

Time dependence of j_c

$u_0 > k_B T$



$$---- \; j(t) = j_{c0} + \Delta j_{c0}\, e^{-\frac{t}{\tau_f}}$$

$$\tau_f = \mu_0 R^2 / 6 \rho_f \ldots \lesssim 10^{-6}\,s$$

$$—— \; j(t) = j_{c0}\left[1 - \frac{k_B T}{u_0} \ln\left(1 + \frac{t}{\tau_0}\right)\right]$$

$$\tau_0 = \frac{1}{6} \mu_0 \frac{R^2}{a_0 \Omega_0} \frac{k_B T}{u_0} \frac{j_{c0}}{B}, \sim 10^{-6} \ldots 10^{-12}\,s$$

$$j(t) = j_{c0} \frac{k_B T}{u_0} e^{-\frac{t - t_1}{\tau_c}}, \quad t > t_1 \sim e^{\frac{u_0}{k_B T}}$$

$$\tau_c = \frac{1}{2} \tau_0\, e^{\frac{u_0}{k_B T}}$$

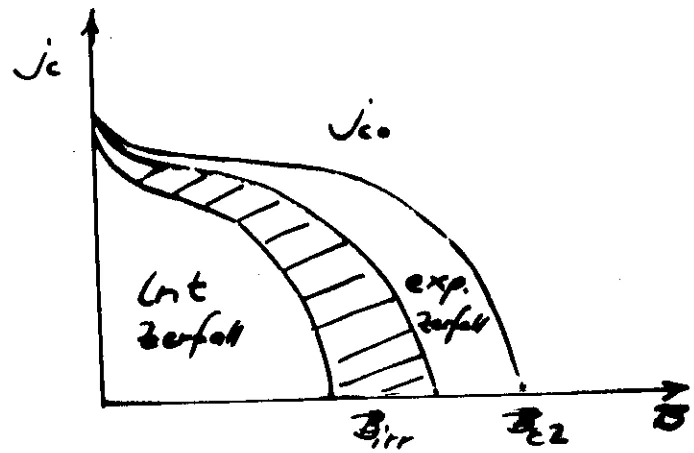
$u_0 \lesssim k_B T$

$$j(t) = j_{c0}\, e^{-\frac{t}{\tau_s}}, \quad t \geq 0$$

$$\tau_s = \mu_0 R^2 / 6 \rho_s$$

$$\tau_f \ll \tau_s \ll \tau_c$$

Irreversibility Line



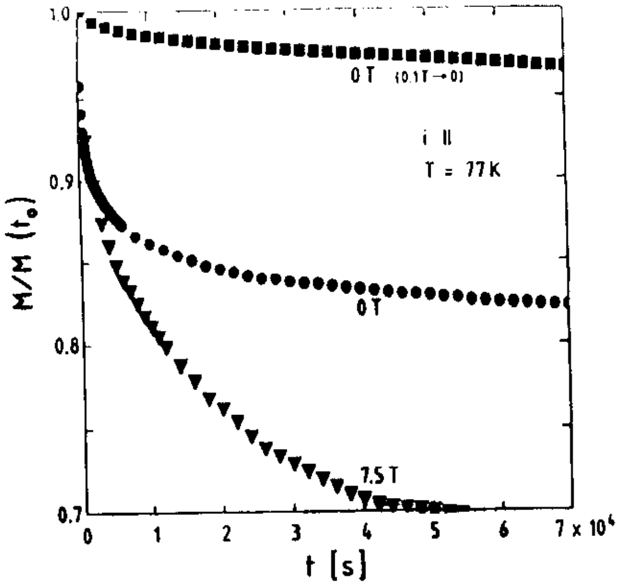


Fig. 1

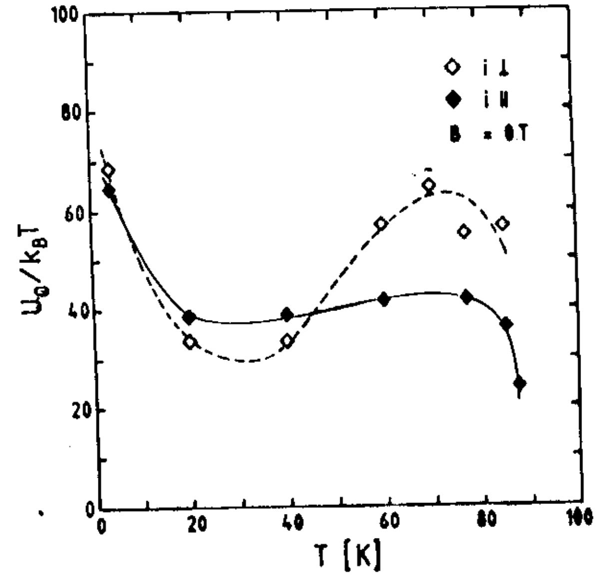
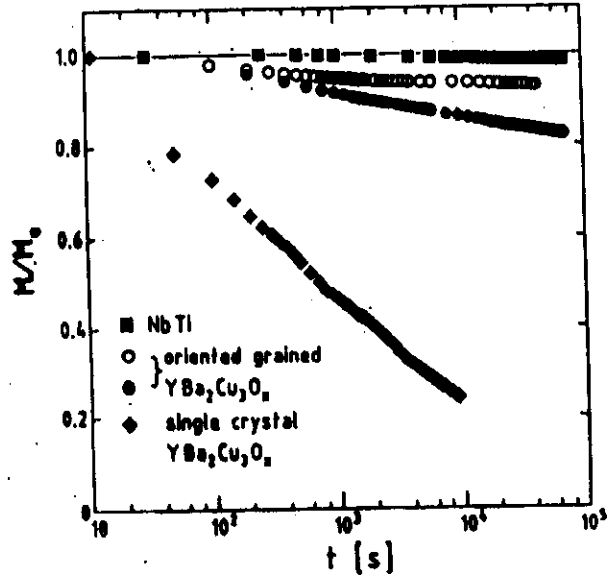


Fig. 2

Comparison with Nb 49 wt.% Ti

$T_c = 9\,K$

$j_c(4.2\,K, 0T) = 3.5 \cdot 10^5 \frac{A}{cm^2}$



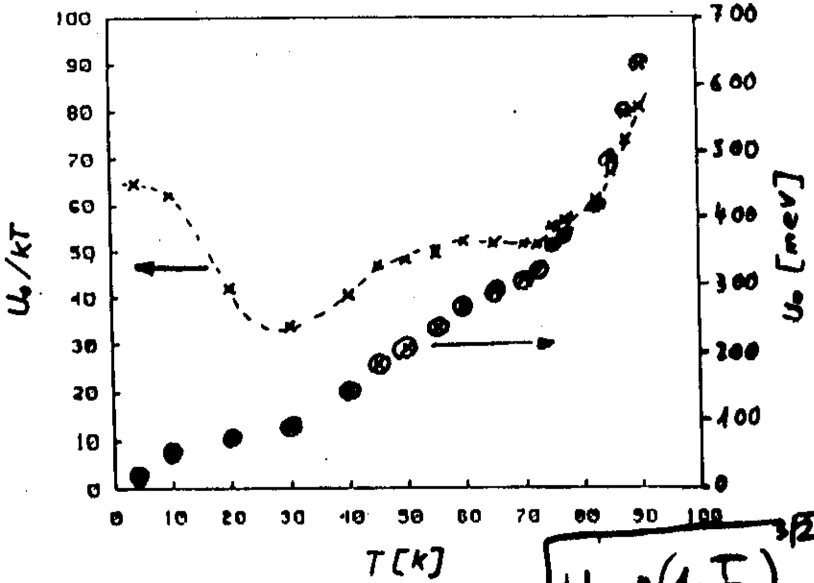
$B = 0T$

- ■ 4.2 K
- ○ 77 K ⊥
- ● 77 K ∥
- ◆ 60 K ∥

		U_0/k_BT	U_0 [meV]
oriented grained $YBa_2Cu_3O_x$ 77 K	∥	41	272
	⊥	55	365
NbTi	4.2 K	487	176
	7.5 K	182	118
single crystal $YBa_2Cu_3O_x$	60 K	8	41

$B = 0T$ $\quad B \perp a,b$ $\quad t_s = 75s$

$B_s = 3T$ $\quad \dot{B} = 12 mT/s$



$U_0 \sim \left(1-\frac{T}{T_c}\right)^{3/2}$ $\quad k_0 \sim \left(1-\frac{T}{T_c}\right)$