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INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
34100 TRIESTE (ITALY) - P.O.B. 586 - MIRAMARE - STRADA COSTIERA 11 - TELEPHONE: 2240-1
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EXPERIMENTAL WORKSHOP ON HIGH TEMPERATURE SUPERCONDUCTORS & RELATED MATERIALS (BASIC ACTIVITIES)

12 - 30 MARCH 1990

THIN FILMS
Part II

WERNER SCHINDLER

Physikalisches Institut II
Universität Erlangen
Erwin Rommel Strasse 1
D-8520 Erlangen
Federal Republic of Germany

Thin Films

W. Schindler
Physikalisches Institut
Universität Erlangen

Preparation Methods:

- rf/dc - sputtering
- electron beam evaporation
  Molecular beam epitaxy (MBE)
- laser ablation
- Chemical vapour deposition (CVD)
- and other methods ...

In principle not possible to grow $YBa_2Cu_3O_{7.0}$, but only $YBa_2Cu_3O_{6+x}$

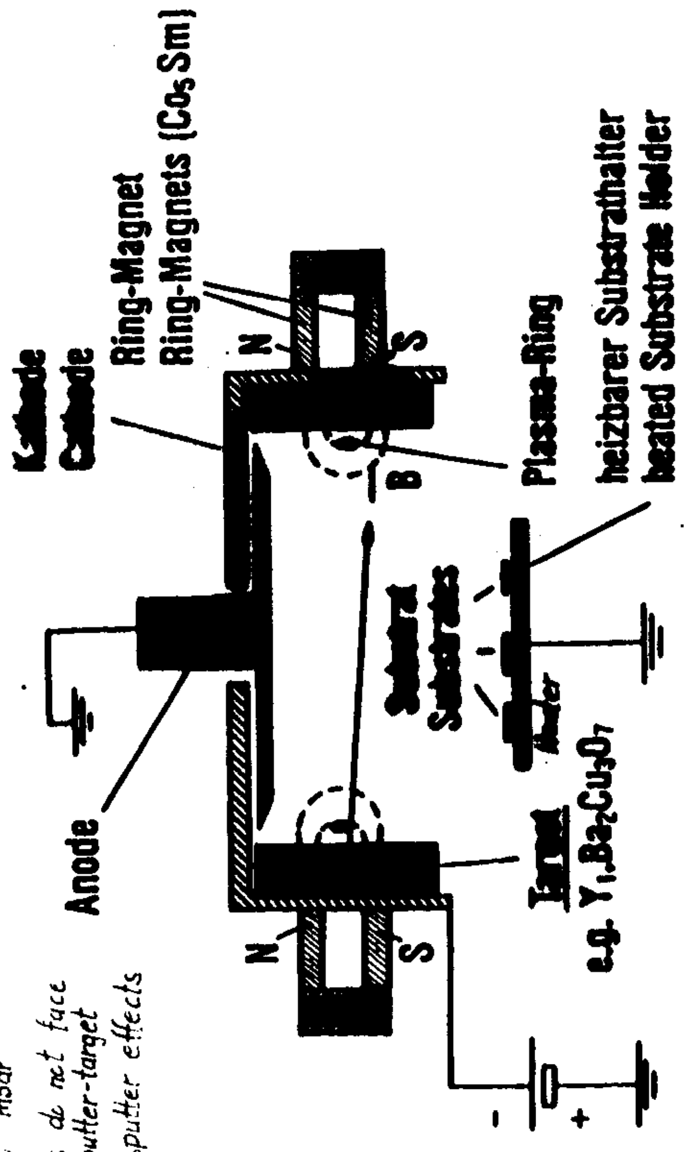
nearly all thin film preparation methods require vacuum conditions.

tetragonal phase, epitaxial growth on special substrates with matching lattice constants.

- $SrTiO_3$
- MgO
- $LaAlO_3$

DC- Sputtering

for example: J. Geerk, G. Linker, O. Meyer
Kernforschungszentrum Karlsruhe

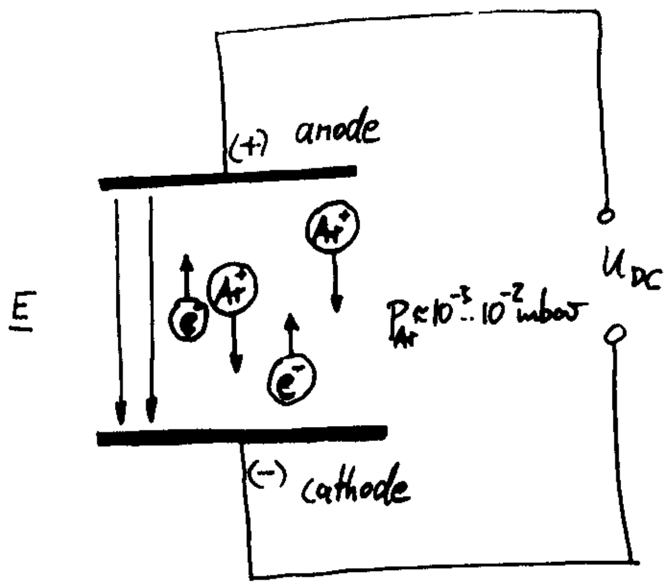


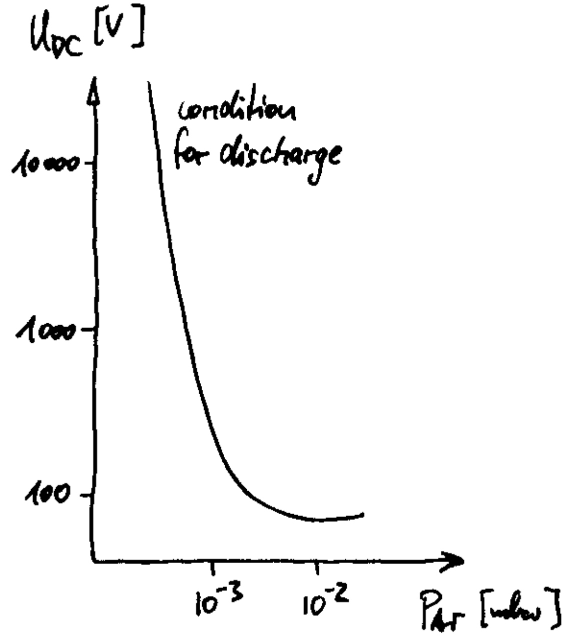
substrates outside of discharge

- Composite target
- DC-voltage 120 - 180 V
- $P_{O_2} \approx 5 \cdot 10^{-1}$ mbar
- substrates do not face the sputter-target

→ no re-sputter effects

The Sputtering Process





- there are always some free electrons
- they are accelerated
- they push neutral atoms and ionize them
- the generated new electrons are accelerated themselves, push and ionize atoms

  like an avalanche at sufficient high pressure
- positive charged ions are accelerated to the cathode, negative charged ions to the anode.

  $E_{ion} = \Delta U$ (eV)

- bombardment of cathode as well as anode.
- if $E_{ion} \gtrsim 50eV$:

  sputtering out of surface atoms of cathode or anode

  The rate strongly depends on the target atoms! "preferential sputtering"

For thin film preparation:

- Mount the target onto cathode
- Mount the substrate onto anode

↓

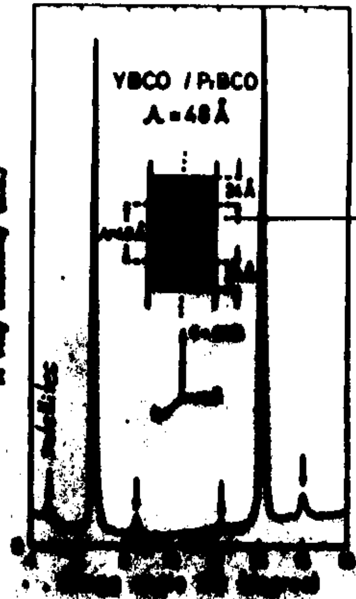
Deposition of sputtered atoms onto substrate

<u>but:</u> ions, which are accelerated to the anode sputter off the growing film "resputtering"

→ change the geometry so, that substrate is out of discharge!

<u>YBCO/PrBCO Superlattices</u>

J.-M. Triscone et al.
Université de Genève
M.G. Karkut
Université de Rennes I
Phys. Rev. Lett. 64, ... (1990)

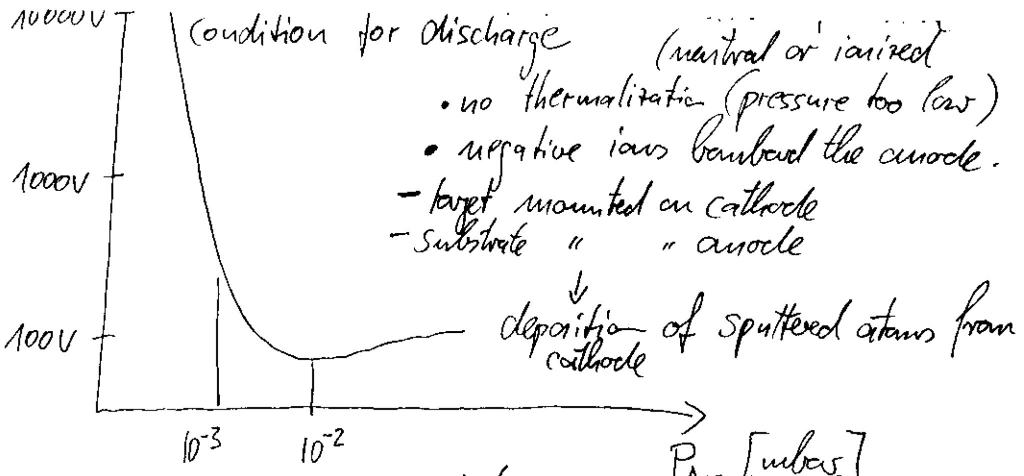


<u>x-ray-diffractogram</u>

Substrate: MgO
total thickness ≈ 1500Å

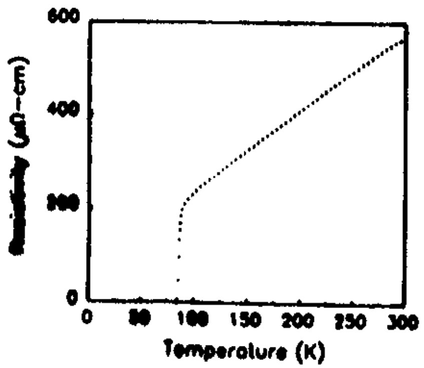
Epitaxial ... $YBa_2Cu_3O_{7-x}$ films on silicon
with buffer layers

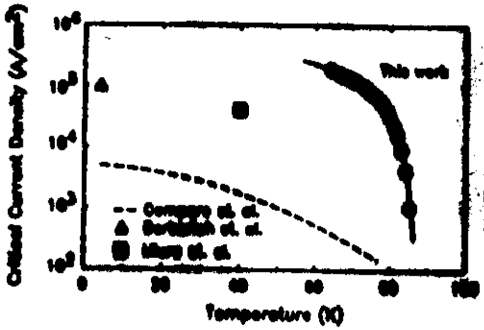
Microelectronics



but: sputtering at substrate by accelerated ions

$BaTiO_3$ / $MgAl_2O_4$ / Si

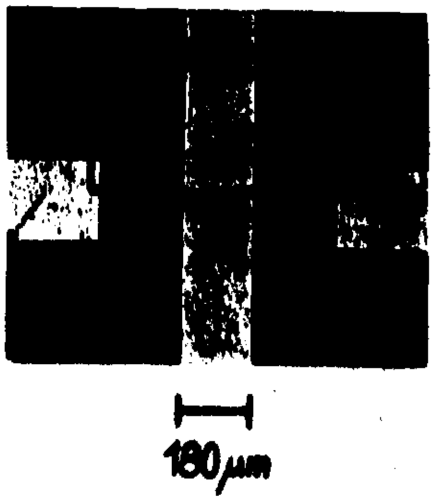


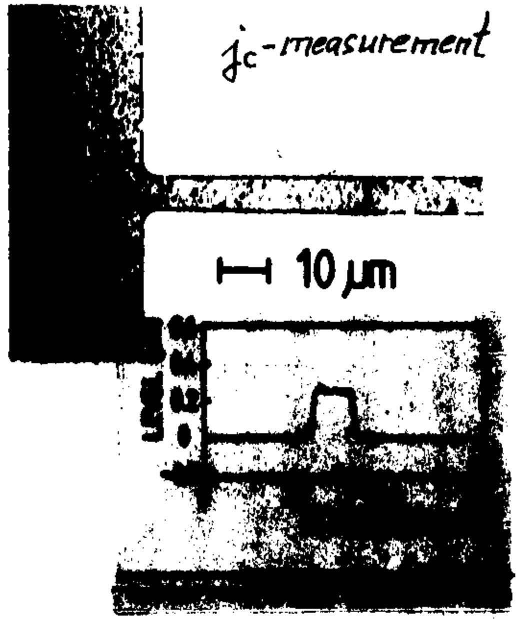


X.D. Wu et.al., Bellcore
S. Miura, NEC Corporation

Appl. Phys. Lett. 54, 754 (1989)

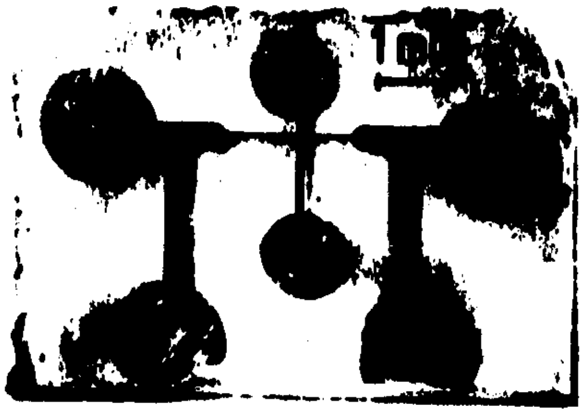
Optical micrograph of an etched $YBa_2Cu_3O_{7-x}$ - thin film:





j_c-measurement

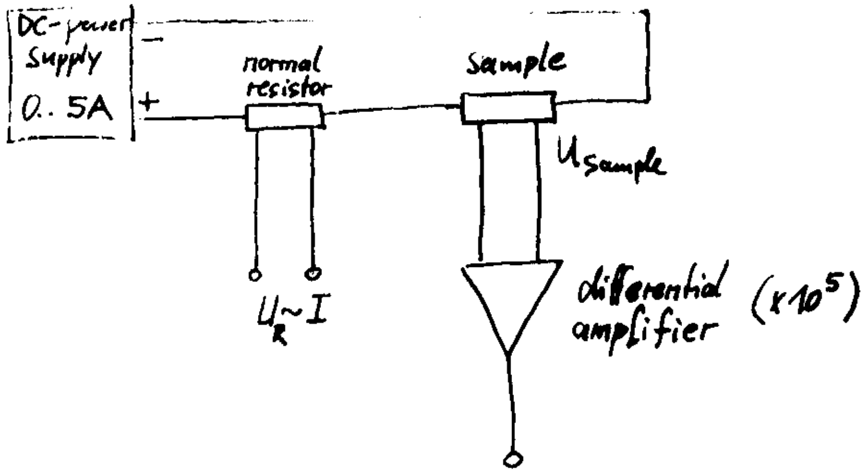
• Photolitography
• Wet etching process



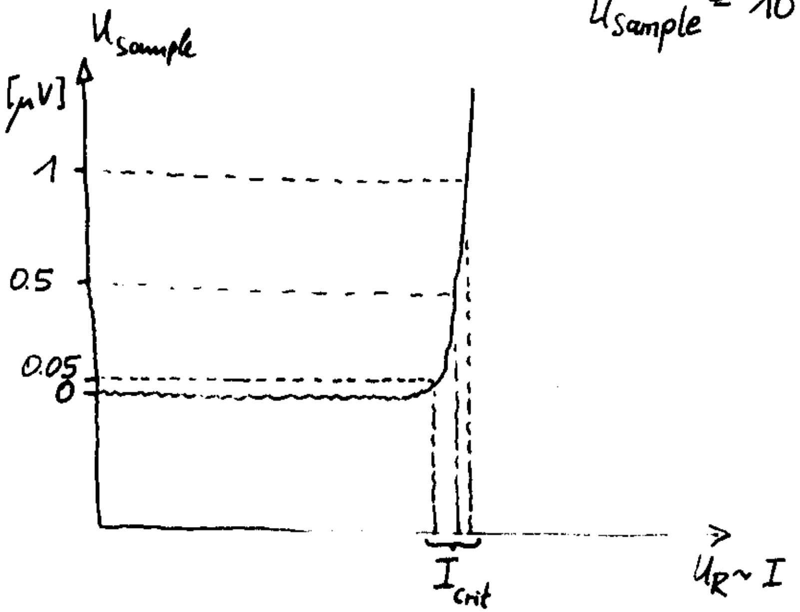
Hall-Effect

• thin film of photoresist onto surface of superconductor film
• mask with desired pattern
• exposure and development
• wet etching by phosphoric acid (diluted).

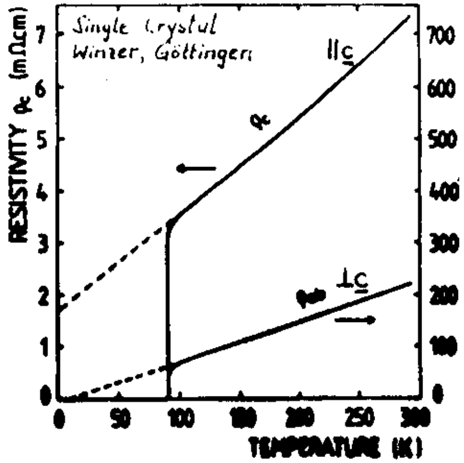
Measurement of critical current:



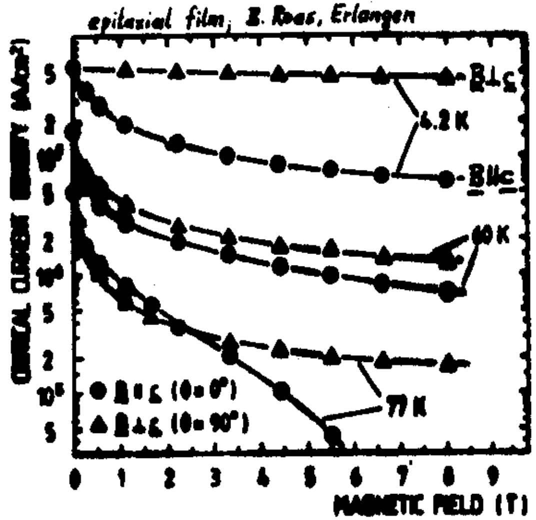
$U^*_{sample} = 10^5 \cdot U_{sample}$



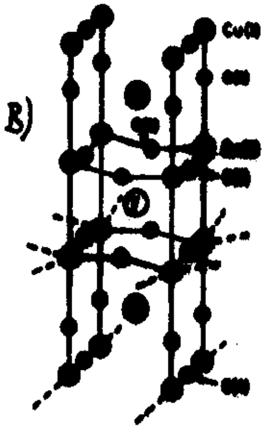
Anisotropic Behaviour of $YBa_2Cu_3O_{7-x}$



↑ R(T, θ,

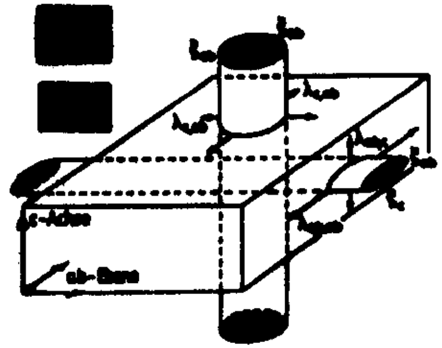


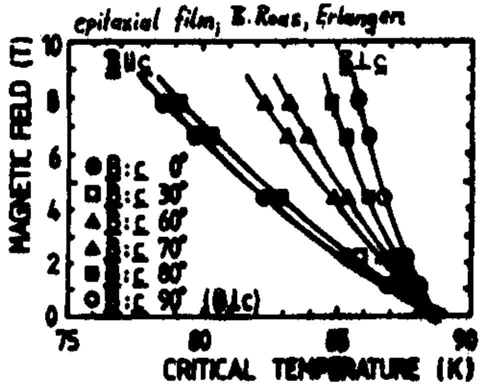
$j_c(T,\theta,B)$ ⟵

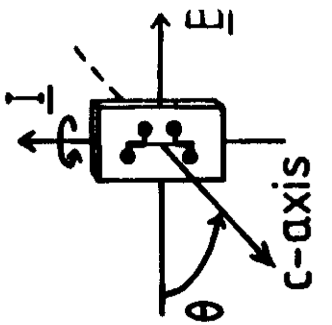


↓ $B_{c2}(T,$

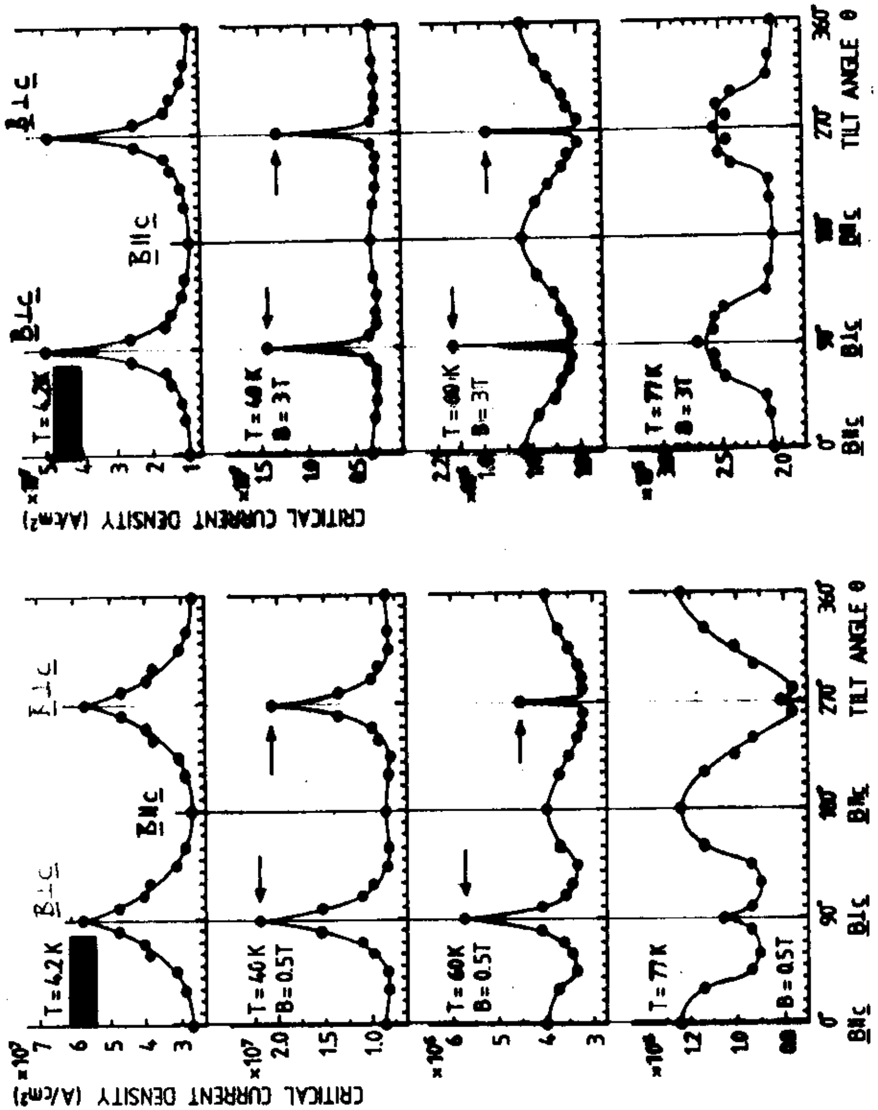
$\xi_{ab} \approx 20$ Å $\quad \xi_c \approx 3$-4 Å





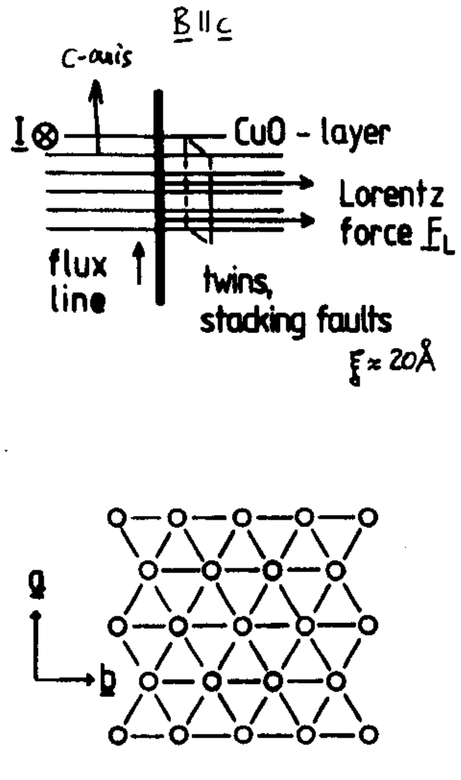


→ : surface and film-substrate interface roughness, strain → different pinning potential

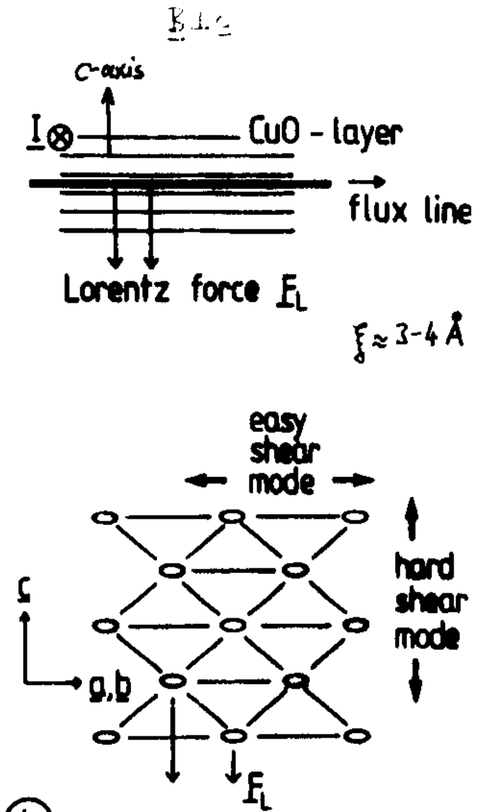


J_c angular dependence on the magnetic field direction

B. Roas et al. Phys. Rev. Lett. 64



(a)



(b)

- pinning at twin boundaries, stacking faults

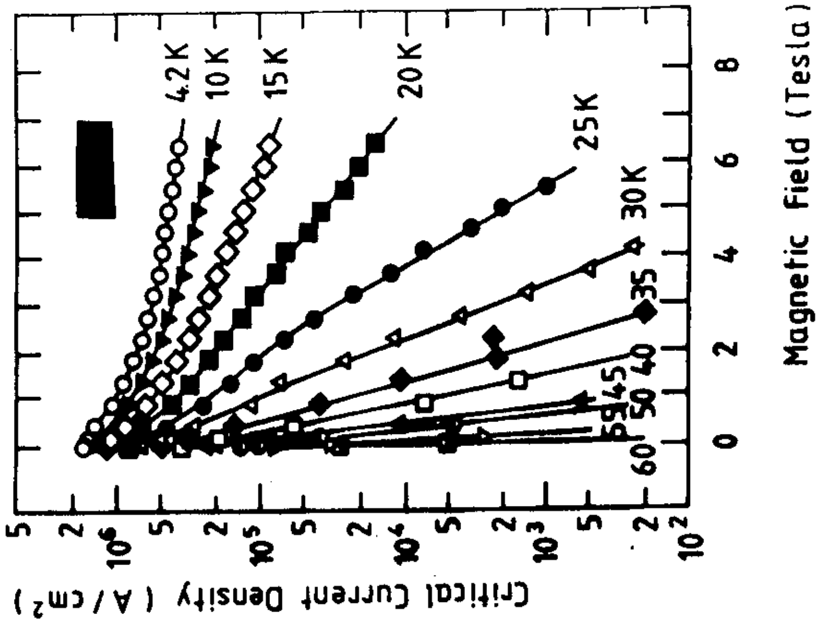
- intrinsic pinning between CuO planes (modulation of the order parameter along the c-axis direction)

  M. Tachiki, S. Takahashi, Sol. State Commun. 70, 291 (1989)

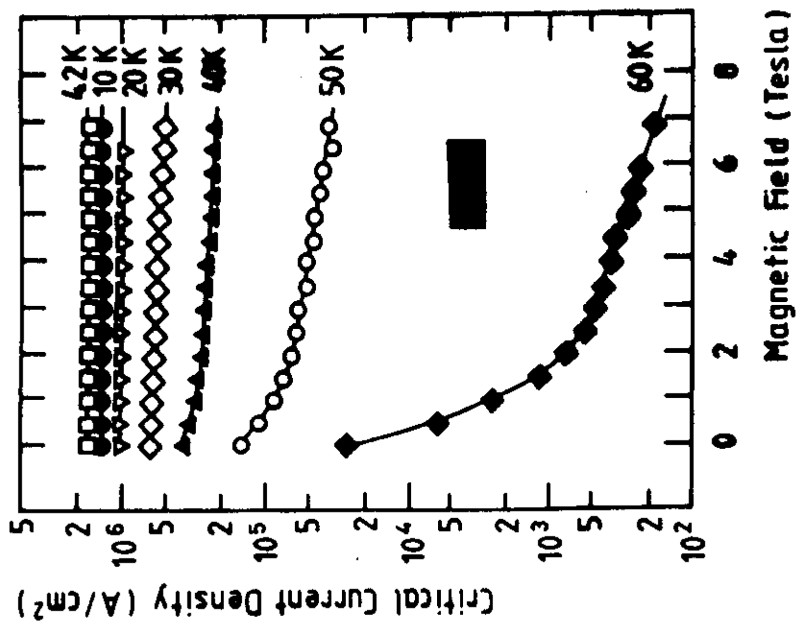
- anisotropy of the shear modulus of the flux line lattice.

  V.G. Kogan and L.J. Campbell Phys. Rev. Lett. 62, 1552 (1989)

Universität ... Erlangen

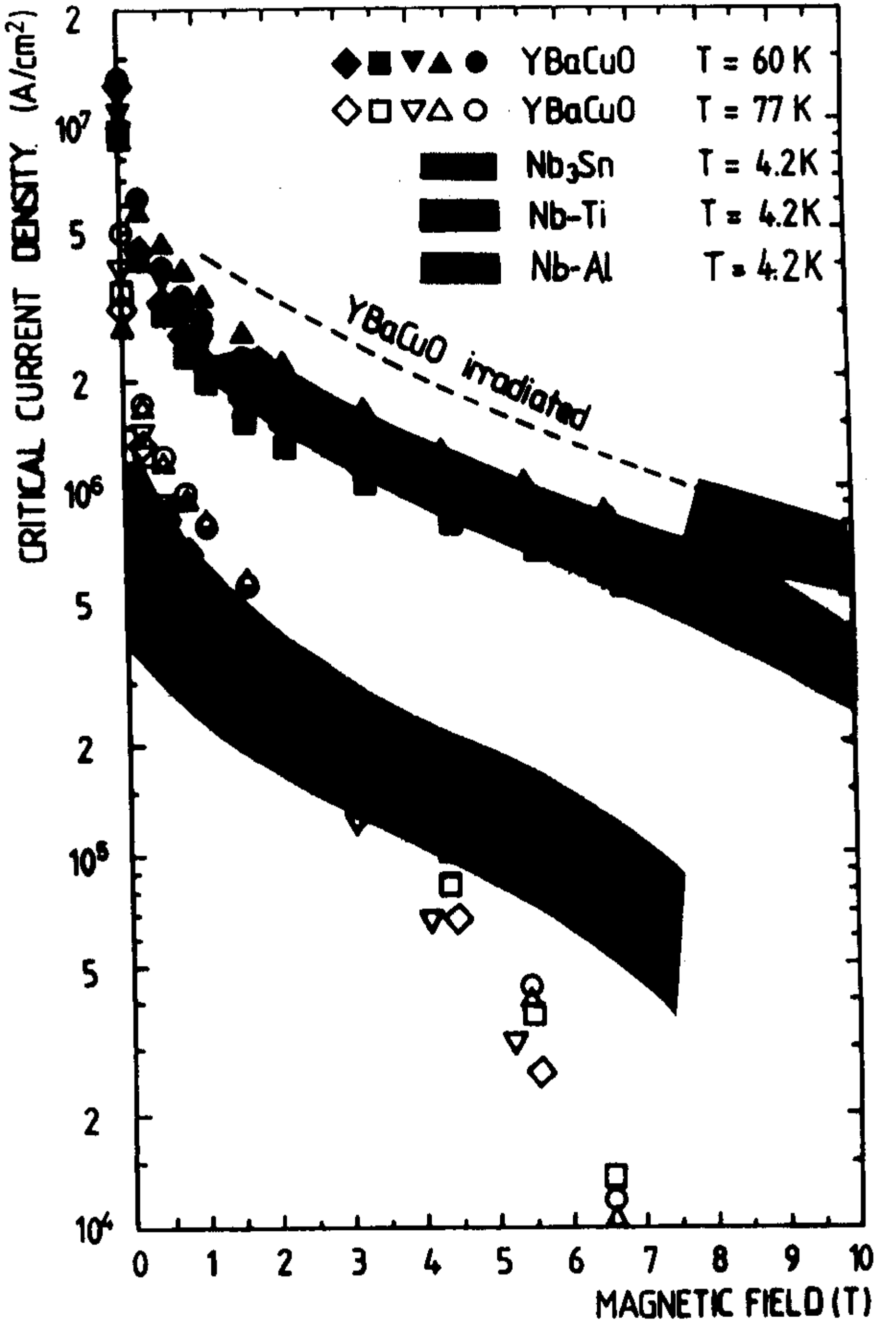


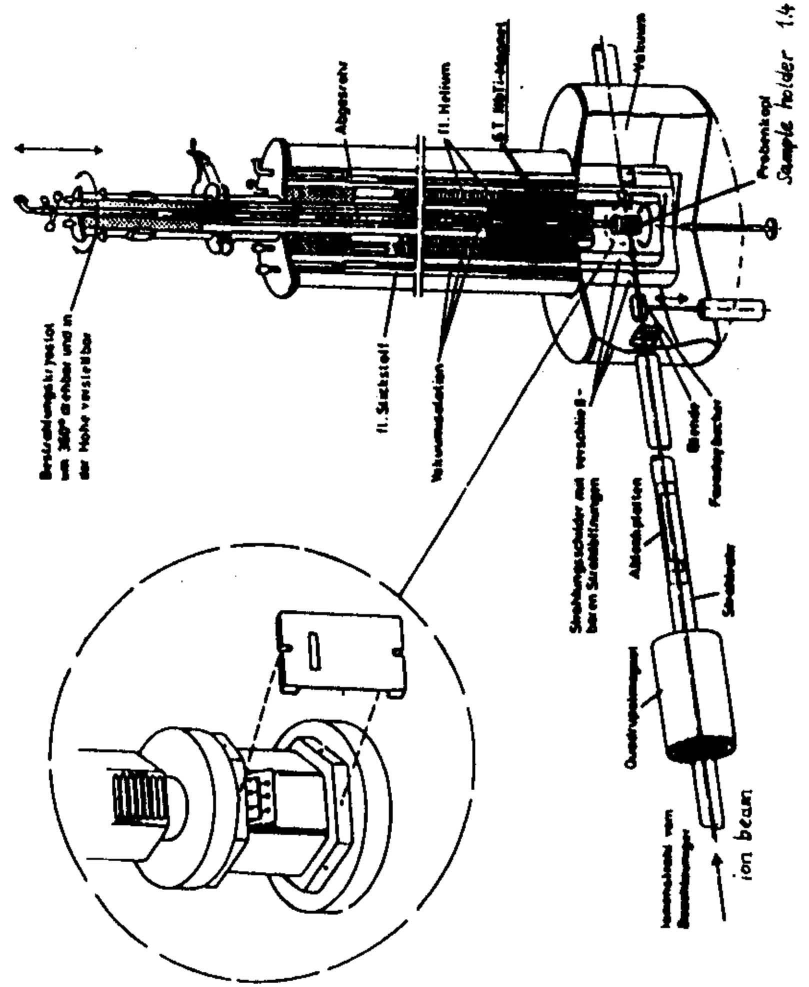
$Bi_2Sr_2CaCu_2O_{8-x}$



Extremely anisotropic critical current densities

Critical Currents

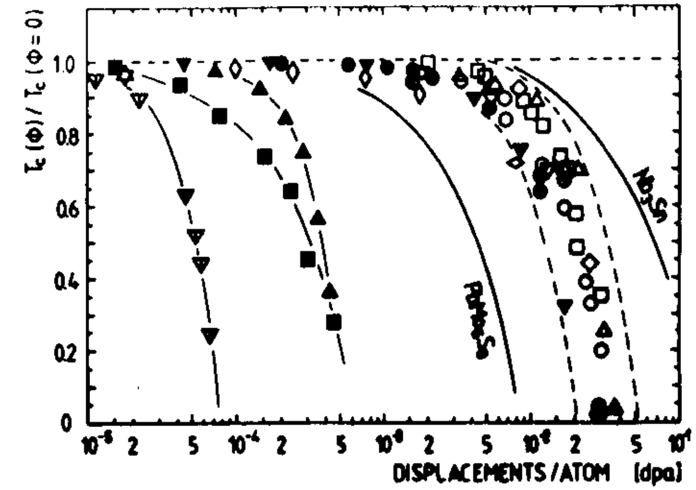




Low Temperature Irradiation Facility

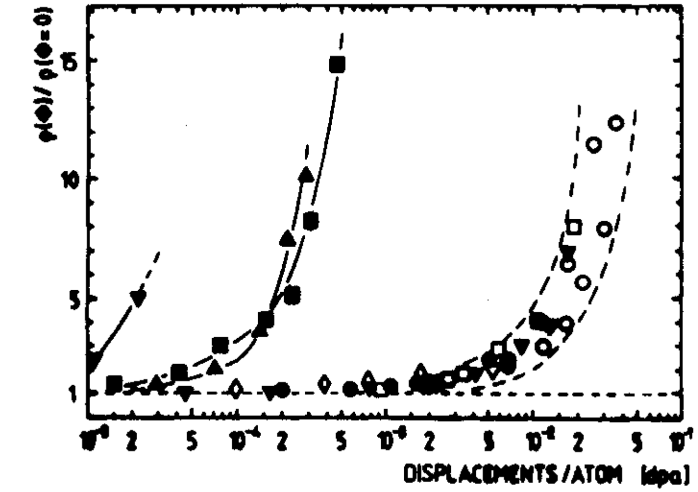
Tieftemperaturbestrahlungsanlage am Erlanger Tandem van de Graaff Beschleuniger.

T_c decreases



Resistivity increases

Mean free path decreases



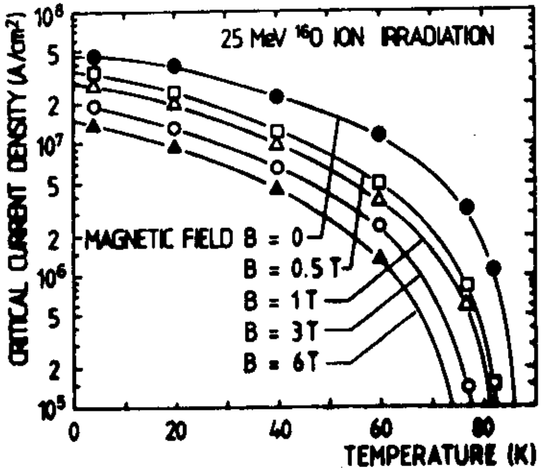
Irradiation experiments

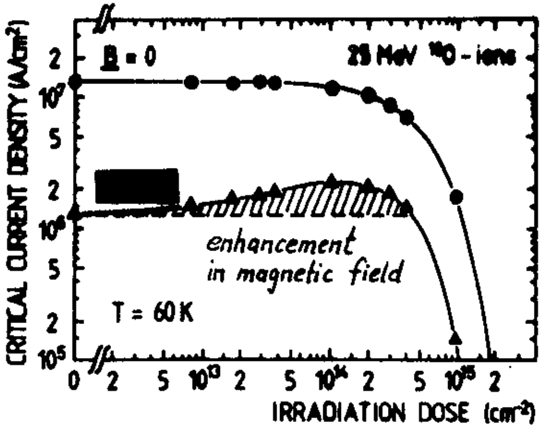
▼	6 MeV	^{4}He	Laser-films Univ/Siemens Erl. HMI Berlin TU München
●	25 MeV	^{16}O	
■	120 MeV	^{84}Kr	
▲	173 MeV	^{129}Xe	
×	0.1 MeV	n	
□	300 keV	^{1}H	KfK (Karlsruhe)
△	0.8 MeV	^{14}N	AT & T (USA)
▽	1 MeV	^{16}O	IBM (USA)
○	1 MeV	^{20}Ne	AT & T (USA)
◇	2 MeV	^{40}Ar	AT & T "
●	3.5 MeV	^{9}Be	AT & T "
◇	25 MeV	^{16}O	Univ Erlangen
◊	120 MeV	^{16}O	JAERI (Japan)
◆	2.9 GeV	^{84}Kr	Caen (France)
▼	3.5 GeV	^{129}Xe	Caen (France)

thickness of films: 1000 - 5000 Å

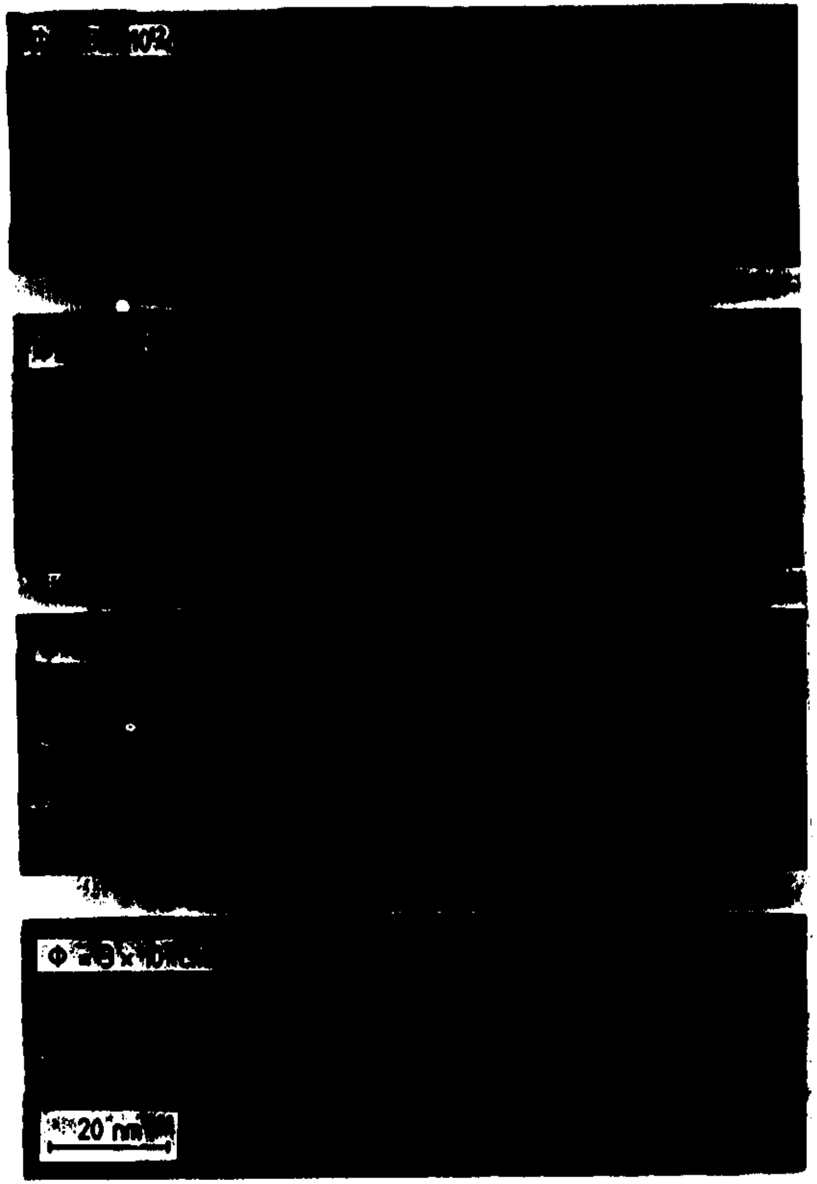
mean range of projectiles > 5 μm

Chevrel- and A15: Uni Erlangen





irradiation defects → additional pinning centres



Neutronenbestrahlung epitaktischer 123-Filme

(Laserablation. Siemens AG)

Messung von Transportstromdichten

j_c vor Bestrahlung > $2 \cdot 10^7$ A/cm²

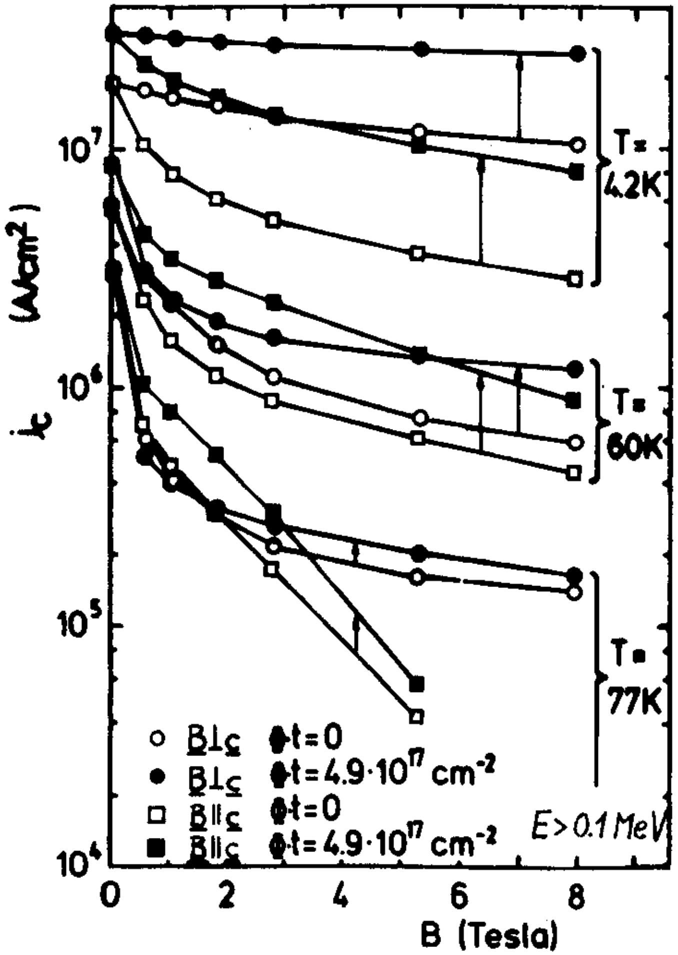
[redacted]

Bestrahlungsdefekte erhöhen das Pinning analog zu den A15-Supraleitern (z.B. Nb_3Sn)

W. Schindler
&
G. Saemann-Ischenko

1) H. Gerstenberg
FRM, TU München

2) B. Roas, Uni
L. Schultz (Siemens)



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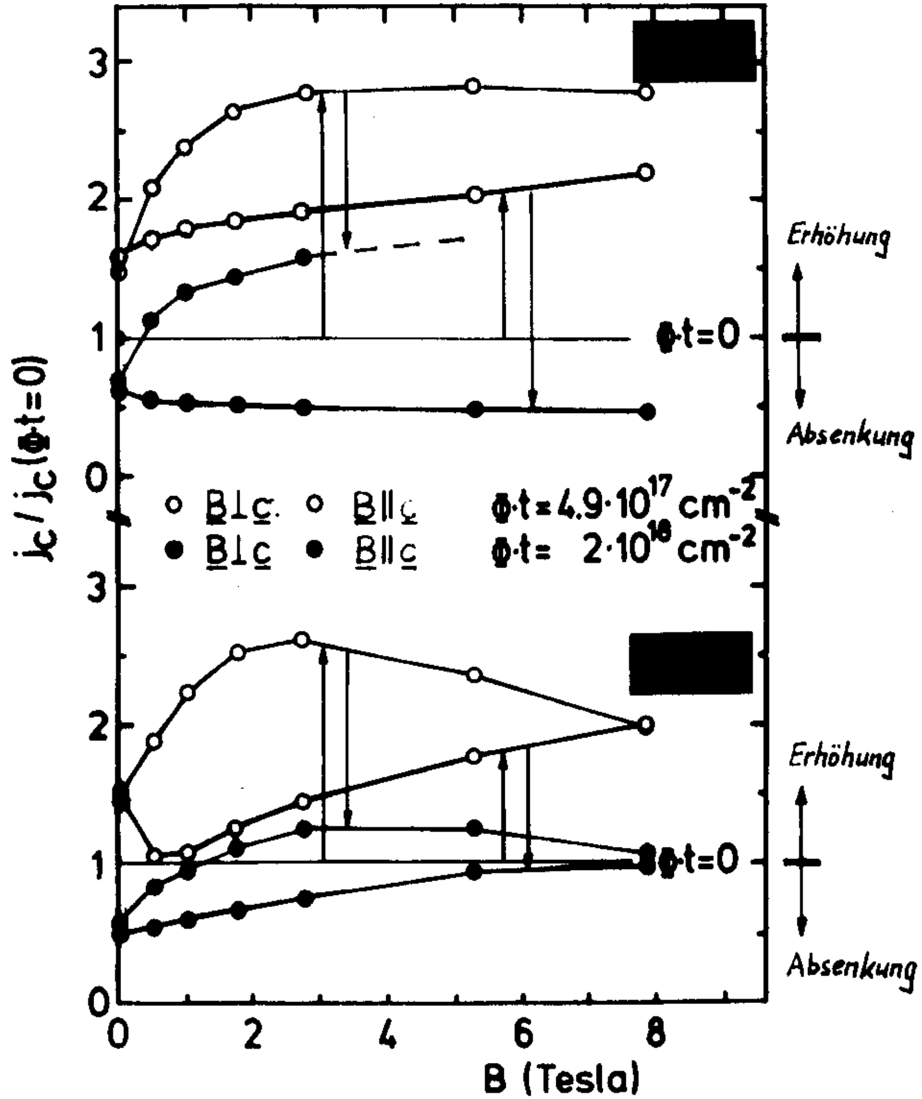
25

Relative j_c-Änderung:



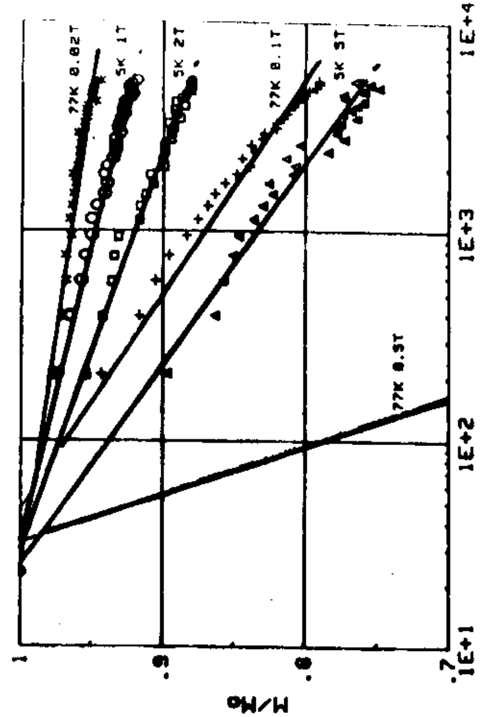
Flux creep in the mixed

P. Fischer et al., Sol. State Commun. 72, ...

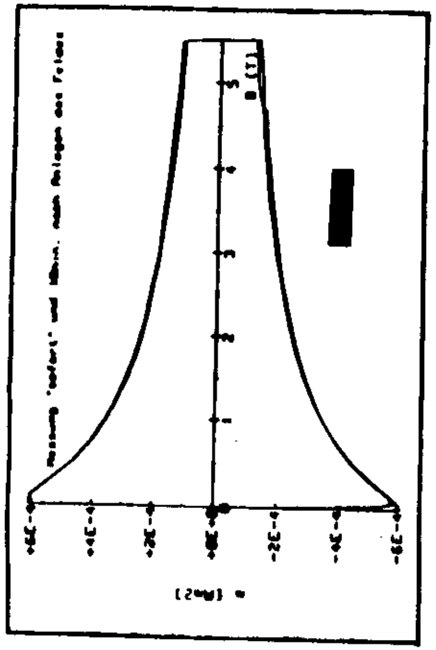
$$M(t) = M(0)\left(1 - \frac{k_B T}{U_0} \cdot \ln\left(1 - \frac{t}{t_0}\right)\right)$$

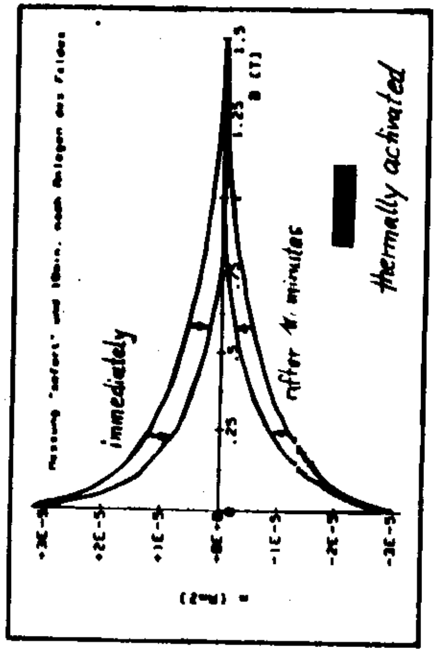
$t_0 \approx 10^{-6} \ldots 10^{-12}$ sec

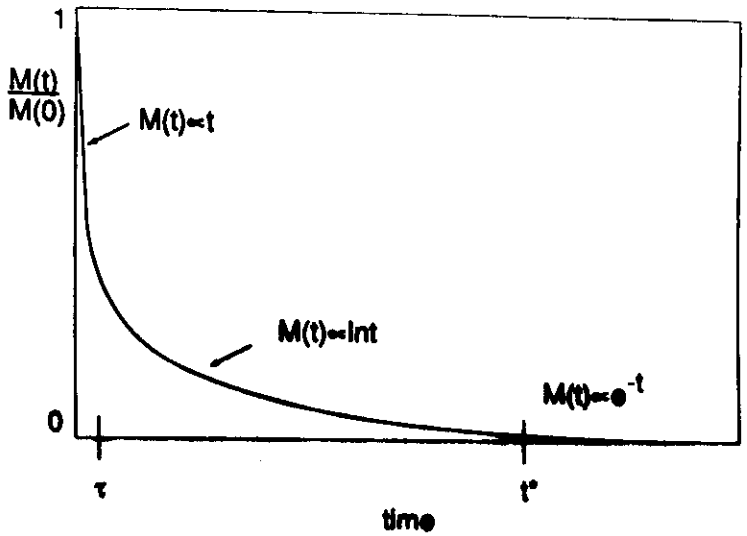
M(t):



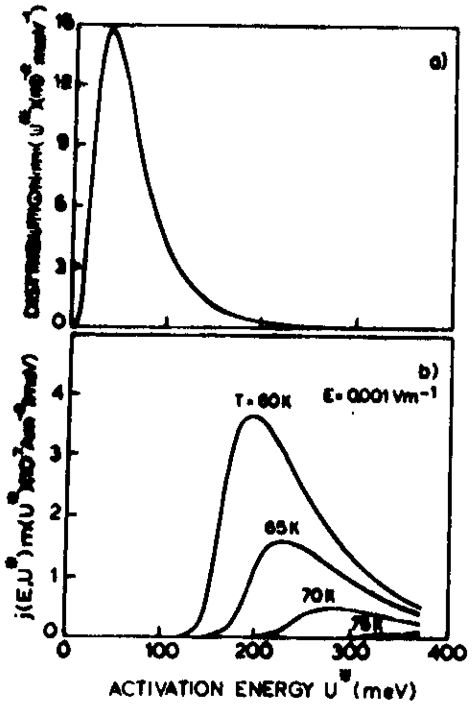
M(B):







Distribution $m(U^*)$ of activation energies U^* at $T=0$ and $B=0$:



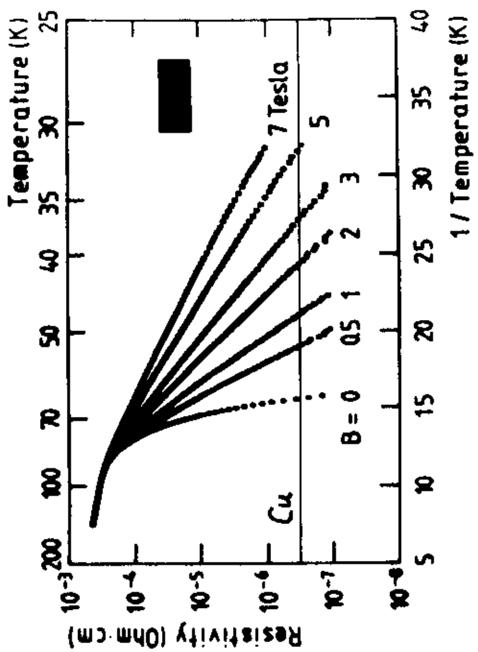
Contribution of domains with activation energy U^* to the total current j for various temperatures.

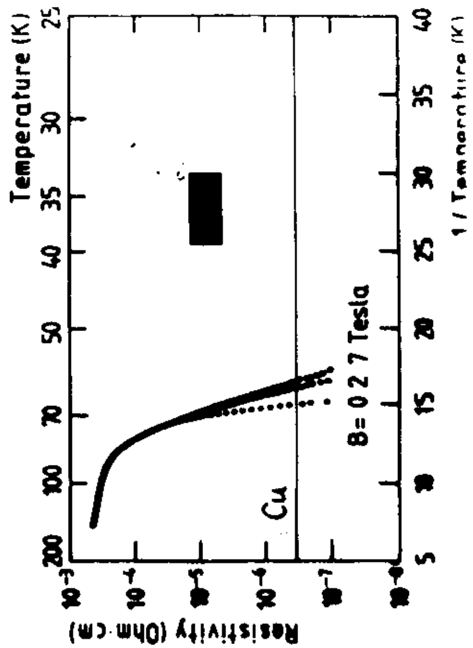
C.W. Hagen & R. Griessen

R. Griessen, J.G. Lensink, T.A.M. Schröder, B. Dam

"Critical Currents in High-T_c-Superconductors, Karlsruhe 1988"

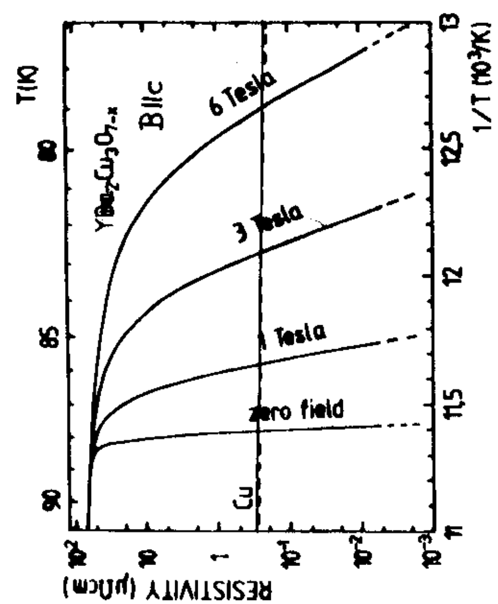
Y. Yeshurun and A.P. Malozemoff, Phys. Rev. Lett. 60, 2202 (1988)





$Bi_2Sr_2CaCu_2O_{8-x}$

F. Schmitt



also T.T.M. Palstra, B. Batlogg, L.F. Schneemeyer and

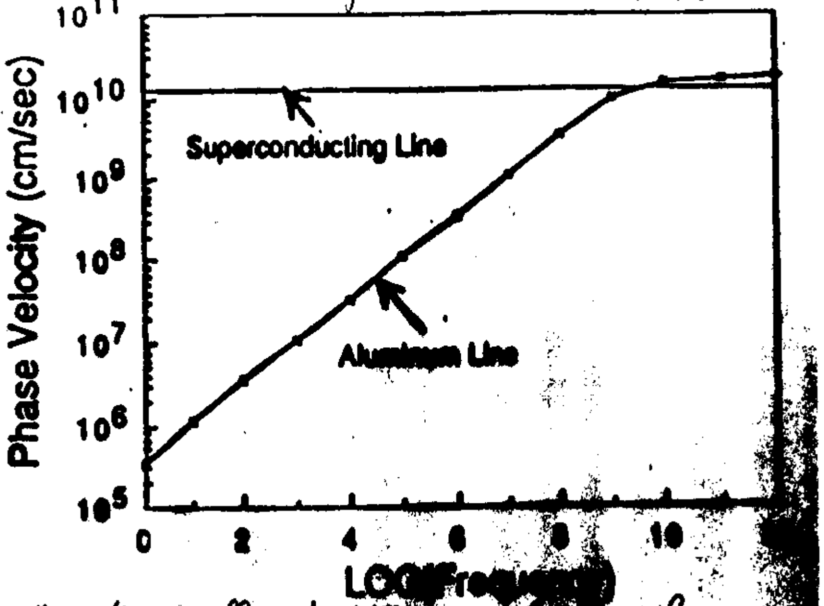
Applications of high-T_c-superconducting films:

- Microwave devices (resonator, filter, delay line, etc.)
- DC-squids
- Superconducting wiring in microelectronics (dispersion free, no losses)

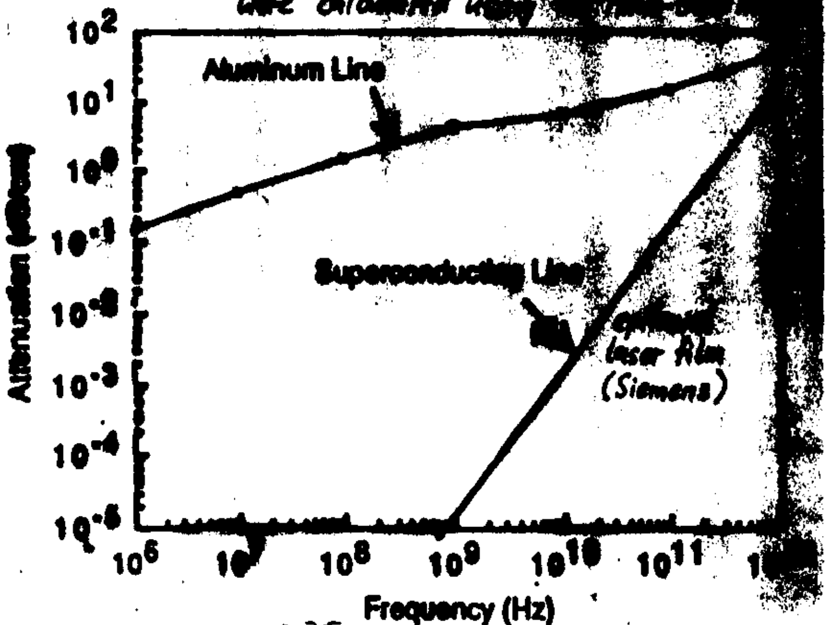
Requirements:

- low surface resistance R_s, high Q
- micro structuring
- high current density ($> 10^6 \frac{A}{cm^2}$)
- large area
- multilayer structures

Phase velocity as a function of frequency for superconducting and aluminum microstrip lines with $W = 2\mu m$, $t_c = 0.5\mu m$, $t_d = 1\mu m$ and $t_g = 1\mu m$. These values were calculated using the Monte-Carlo method.



The attenuation coefficient at 77K as a function of frequency for superconducting and aluminum microstrip lines with $W = 2\mu m$, $t_c = 0.5\mu m$, $t_d = 1\mu m$ and $t_g = 1\mu m$. These values were calculated using the Monte-Carlo method.



F. Pease

Basic physical problems

Anisotropy
→ epitaxial growth

Flux creep

Application

Demonstrations of
microwave properties
squids

↘ ↙

Reality

preparation of epitaxial films
in the laboratory
on special substrates
[illegible] layers
other substrates with buffer layers
! small scale !

↓

technical production

- reproducibility
- other substrates (compatible with microelectronics)
- large area (3")
- basic physical problems ?

collection Saemann-Ischenko