Superconductivity above H_{C2} as a probe for Niobium RF-cavity surfaces

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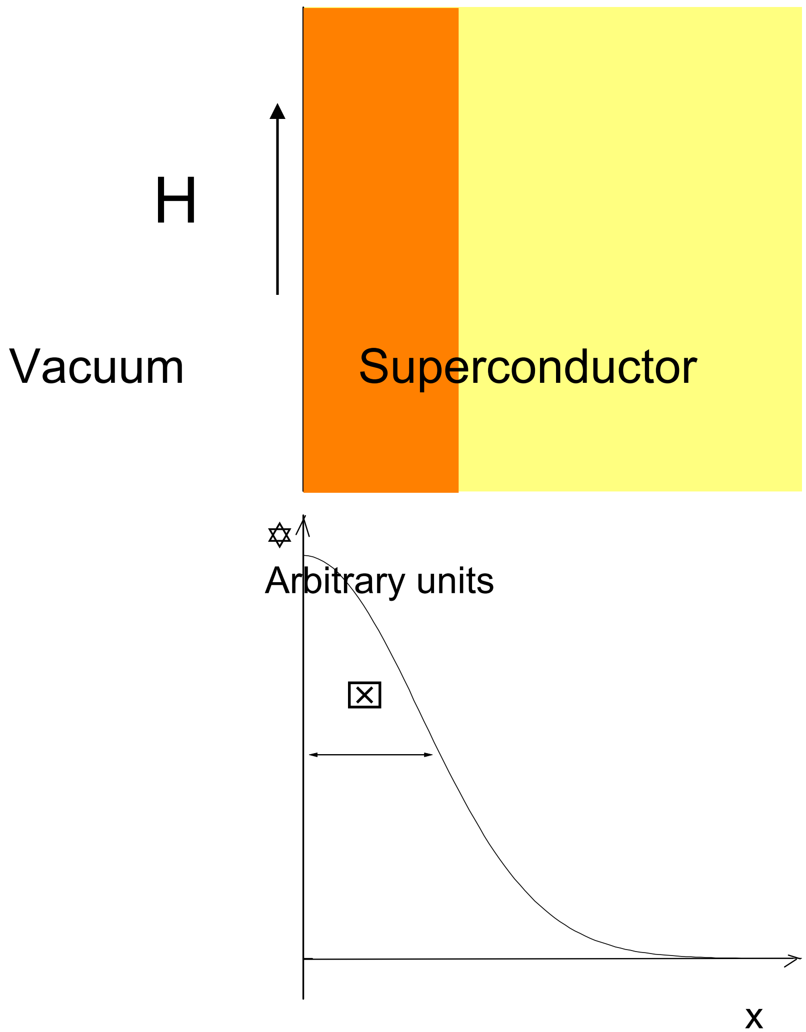
SURFACE SUPERCONDUCTIVITY

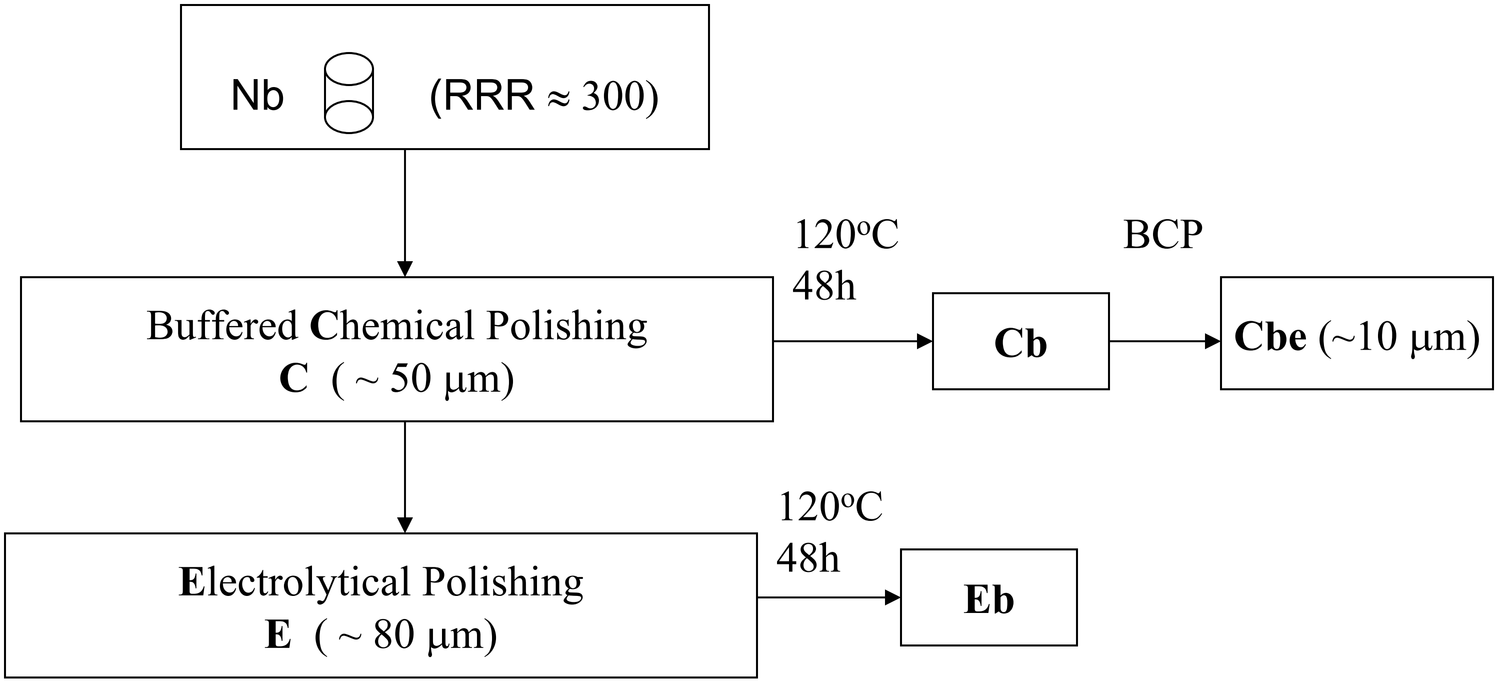


H_{C3}=1.695 H_{C2}

Saint-James & de Gennes, Phys. Lett, 1963

For Nb ⊠ ”50nm

RF field ●”50 nm

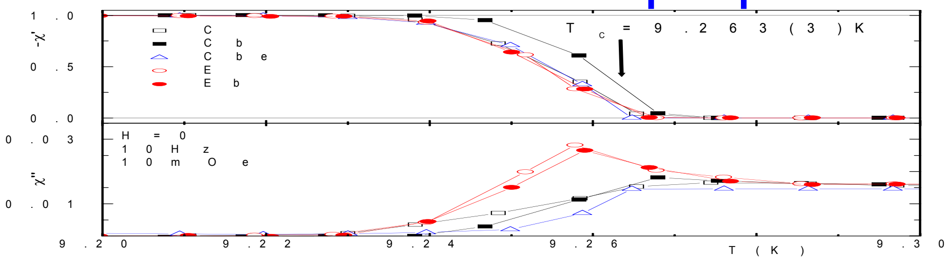


- Volume characterization
- Surface characterization: $\cdot\,\chi(H, H_{AC}, \omega, T) \Rightarrow H_{C3}$

  $\cdot\,M(H) \Rightarrow J_C$

- Summary + Conclusions

Volume properties: T_C , ❐$_n$



$$\chi_{cyl}(\omega) = \frac{2\, I_1(u)}{u\, I_0(u)} - 1\,, \qquad u = \frac{a}{\lambda_{ac}}$$

$$\lambda_{ac} = \sqrt{\frac{\rho_{ac}}{i\omega\mu_0}}$$

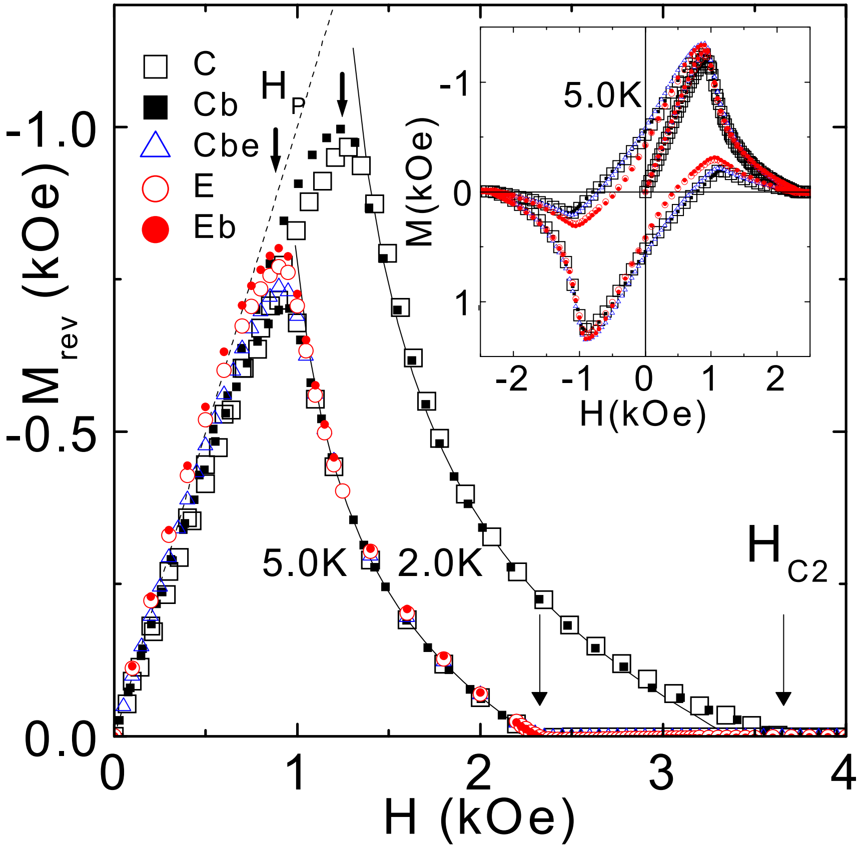
E. Maxwell & M. Strongin, PRL, 1963

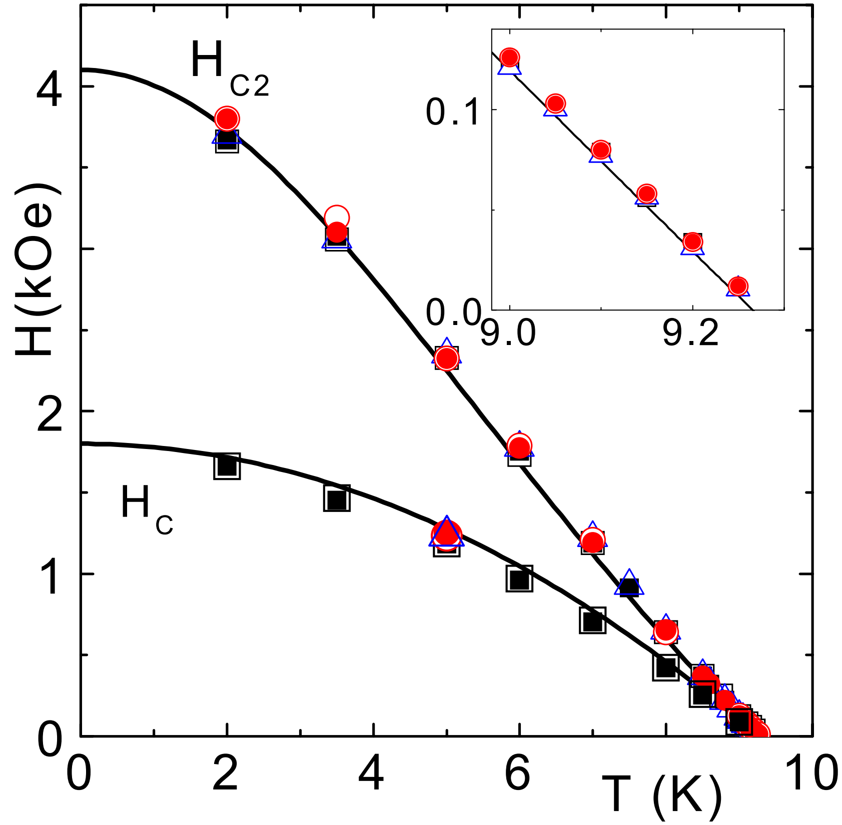
Inversion routine

J. Kötzler et al., PRL, 1994

➊ RRR✇300(50)

Upper critical field: H_{C2}





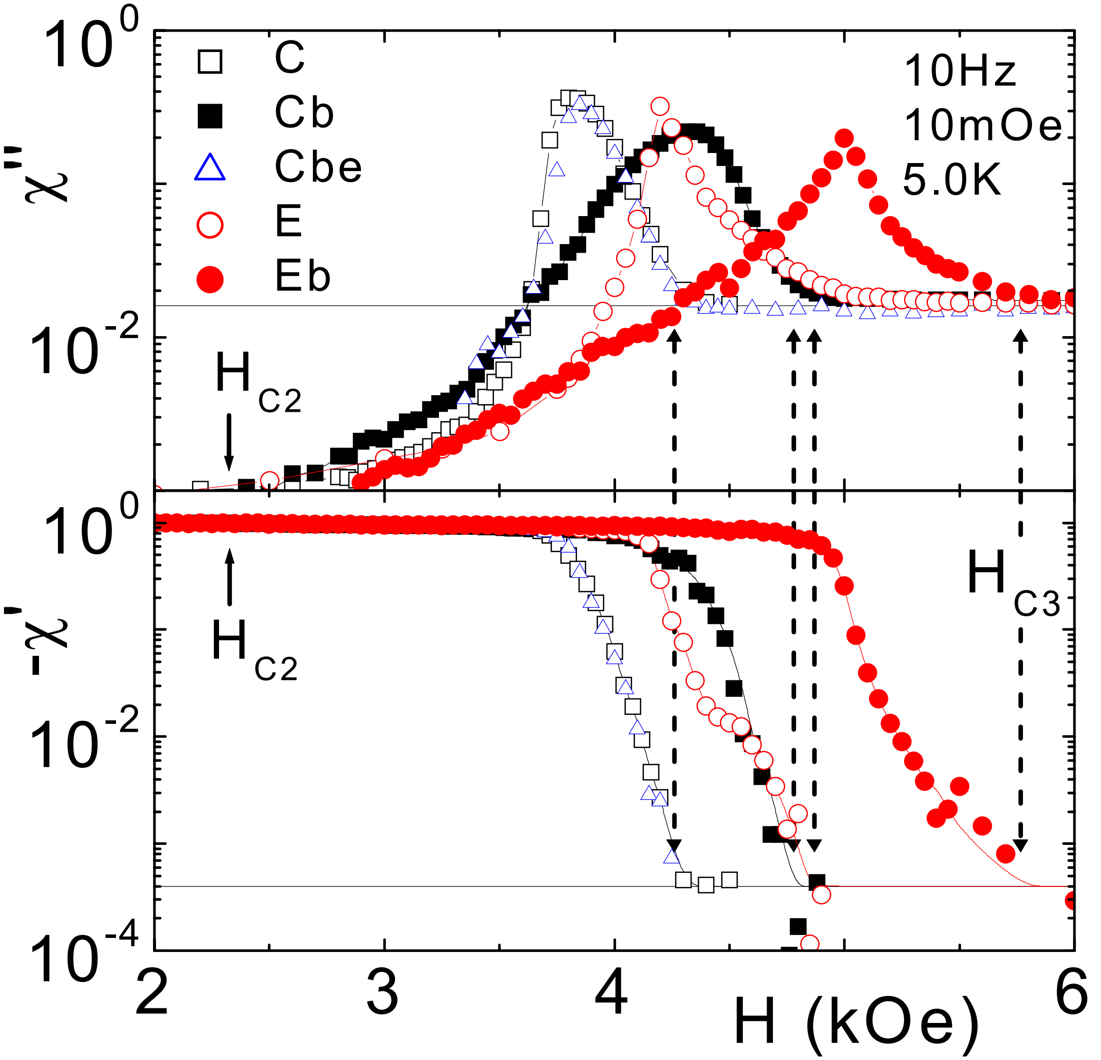
$$H_{C2}(T) = H_{C2}(0)\left(\frac{1-(T/T_C)^2}{1+(T/T_C)^2}\right)$$

$\xi_{GL}(0) = 28.5(2)$nm

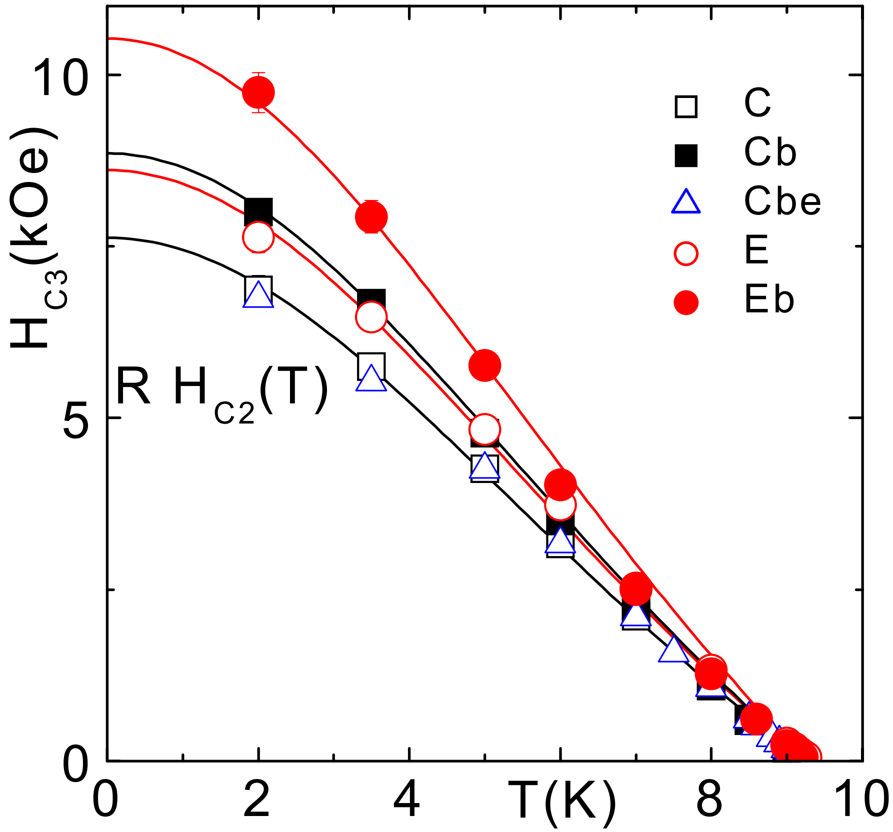
$\lambda_{GL}(0) = 48(2)$nm

$\Rightarrow \kappa_{GL}(0) = 1.68(2)$

Nucleation of surface superconductivity



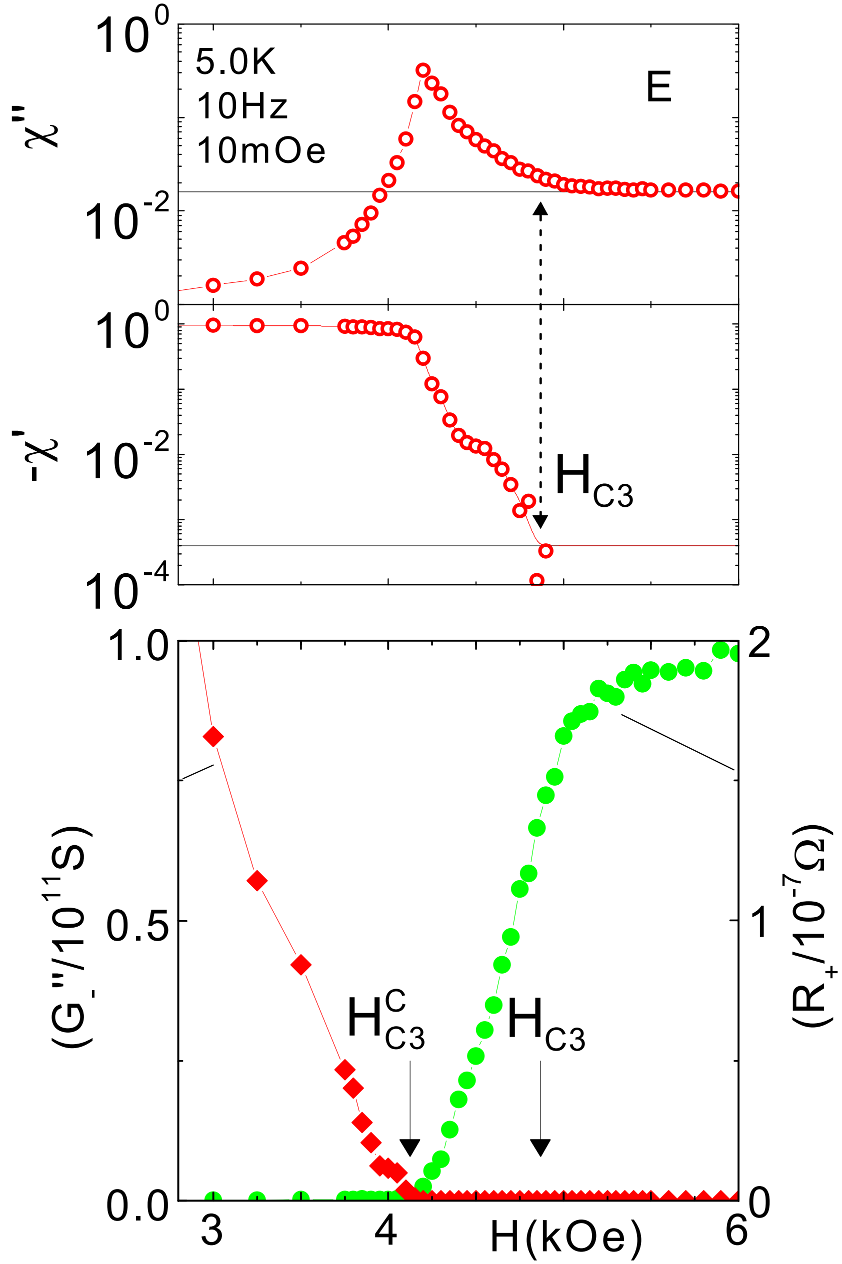
Temperature variation of H_{C3}

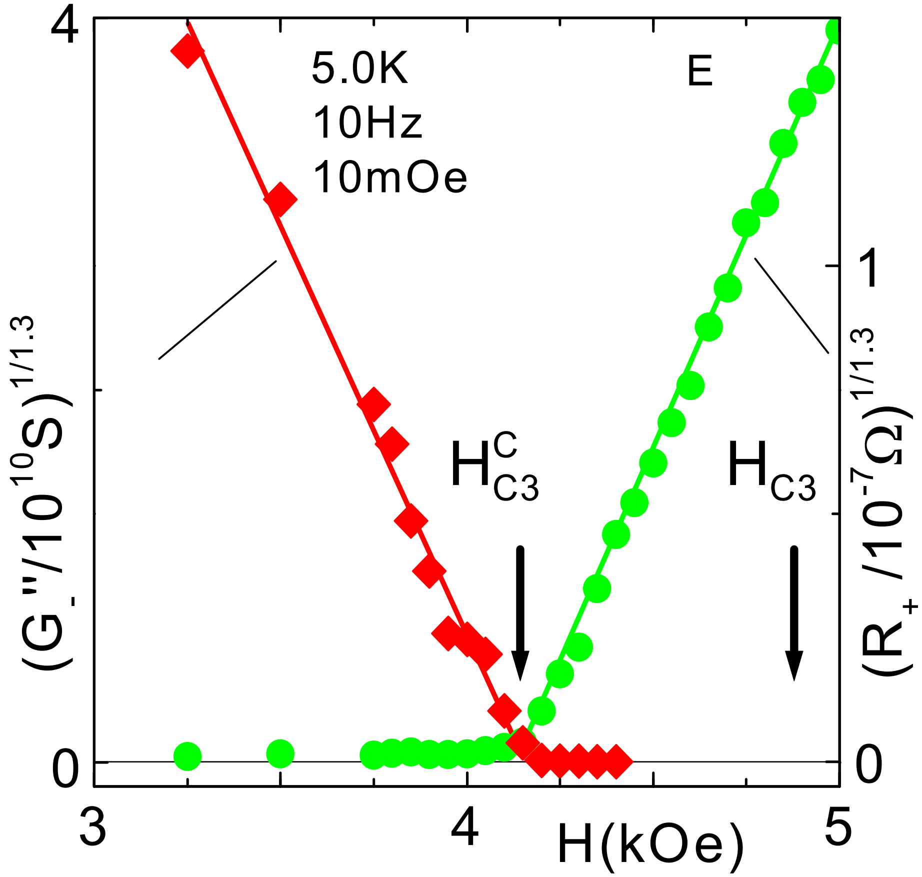


	C,Cbe	Cb	E	Eb
H_{C3}/H_{C2}	1.86(3)	2.16(3)	2.10(3)	2.57(2)

Surface conductance $G = G' - iG''$

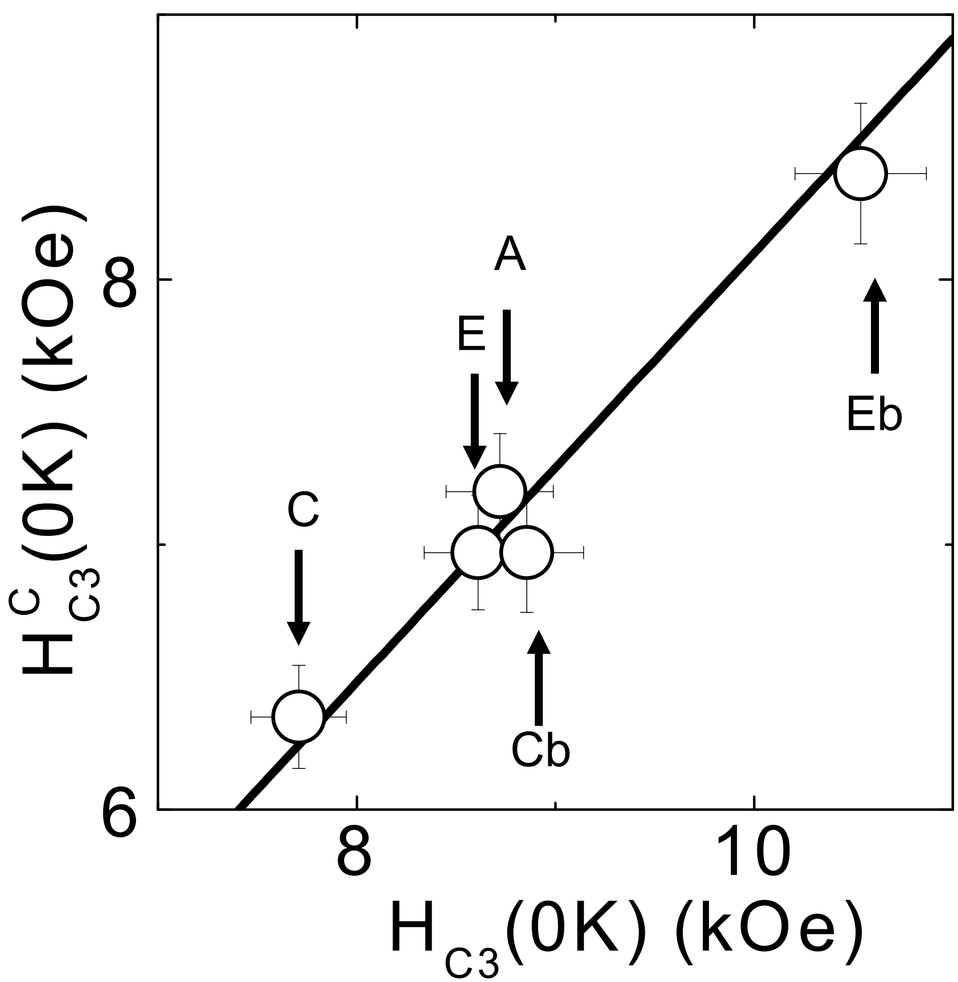
$$G = 2a\sigma$$



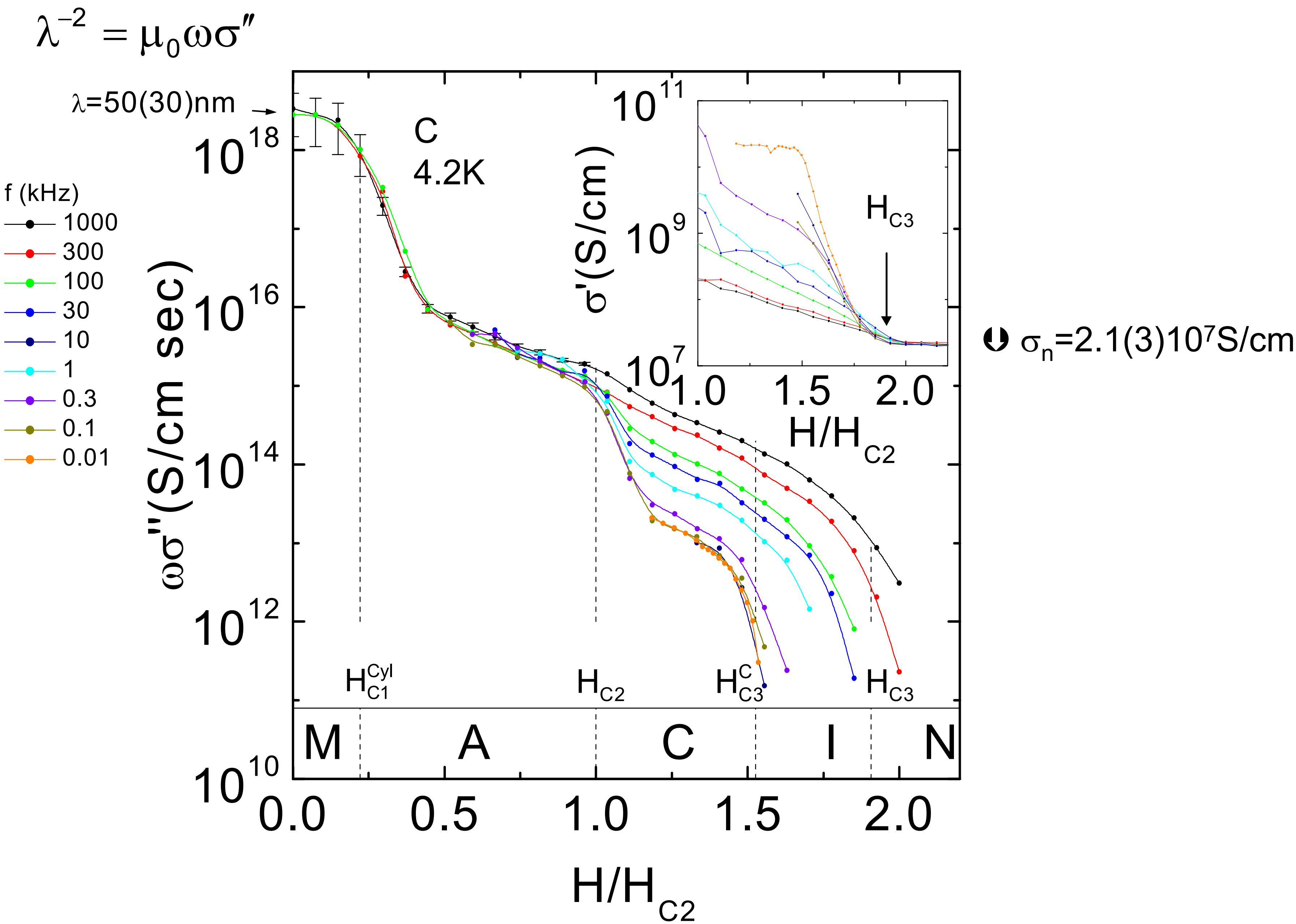


$$G_-'' \propto \left(H_{C3}^{C} - H\right)^{\nu} \qquad R_+ \propto \left(H - H_{C3}^{C}\right)^{\gamma}$$

	E,Eb	C,Cb
ν	1.3(1)	1.4(1)
γ	1.3(1)	1.05(10)

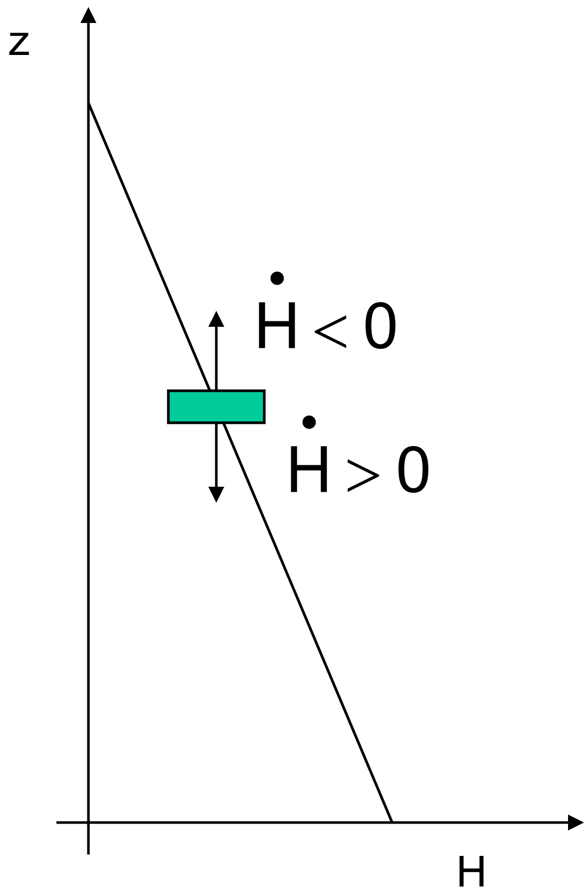


$$\frac{H^{C}_{C3}}{H_{C3}} = 0.81(2)$$



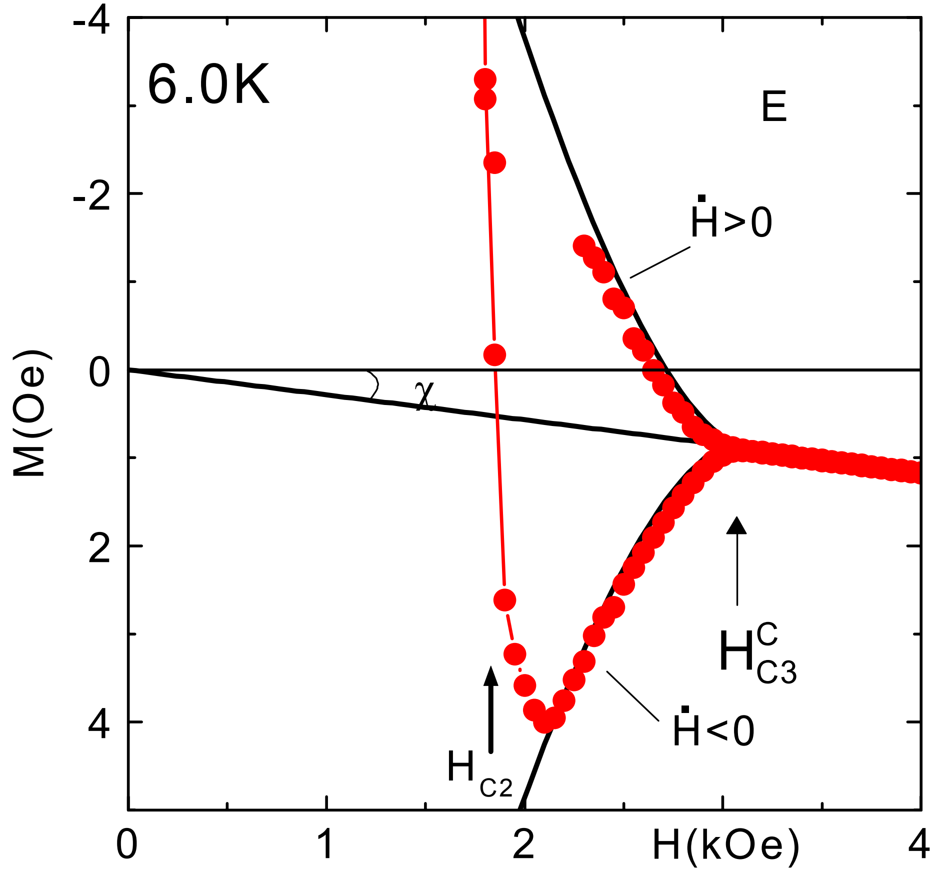
λ^-2 = μ0ωσ″
λ=50(30)nm
C
4.2K
f (kHz)
1000
300
100
30
10
1
0.3
0.1
0.01
ωσ''(S/cm sec)
10^18
10^16
10^14
10^12
10^10
H_C1^Cyl
H_C2
H_C3^C
H_C3
M
A
C
I
N
0.0
0.5
1.0
1.5
2.0
H/H_C2
σ'(S/cm)
10^11
10^9
10^7
1.0
1.5
2.0
H/H_C2
H_C3
σn=2.1(3)10^7S/cm

Gradient technique

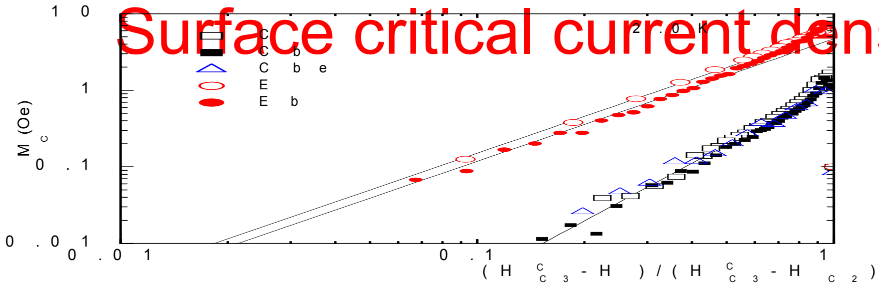


Surface critical current density

$M = M_C + \chi H \quad M_C = J_C$



Surface critical current density $J_C=M_C=M-\chi H$

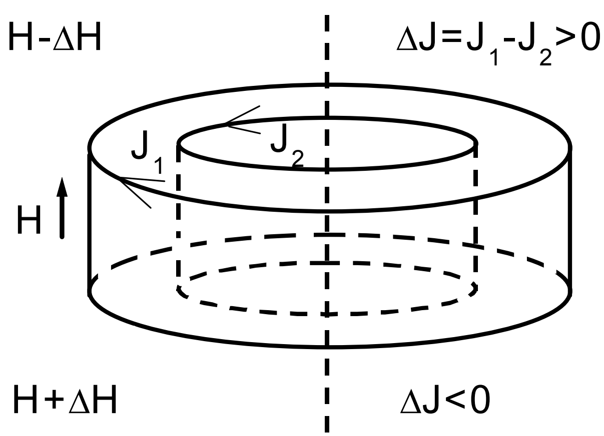


	$M_C(H_{C2})$	α
C, Cb, Cbe	1.1(2)	2.5(3)
E	6.0(3)	1.6(1)
Eb	4.7(3)	1.6(1)
Fink & Barnes, PRL, 1965	≈ 8	1.5
Abrikosov, JETP, 1965	≈ 300	1.5

$$M_C(H) = M_C(H_{C2})\left(\frac{H_{C3}^{C} - H}{H_{C3}^{C} - H_{C2}}\right)^{\alpha}$$

$$M_C(H_{C2}) = \pm\eta\, H_{C,th}\left(\frac{2\lambda}{R}\right)^{1/2} G\left(\frac{H}{H_{C2}}\right)$$

Fink & Barnes, PRL, 1965

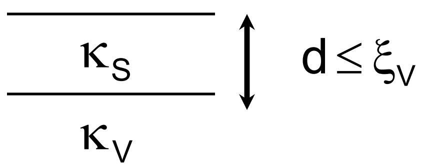


H_{C3}/H_{C2}

Saint-James & de Gennes GL	C,Cbe	Cb	E	Eb	BCS (Hu & Koreman, Phys. Rev., 1969)
1.695	1.86(3)	2.16(3)	2.10(3)	2.57(2)	1.925 – 5.22

Naive model: H_{C3} increases if the coherence length at the surface decreases
=> if the normal electrons mean free path ℓ at the surface decreases

Model by Shmidt
(Moscow:Nauka),1967



$$\chi(\xi_0/\ell) = \frac{\kappa_V}{\kappa_S}$$ Gor 'kov, JETP, 1960

dirty $\quad \chi \underset{\ell \to 0}{\cong} 1.33 \frac{\ell}{\xi_0} \to 0$

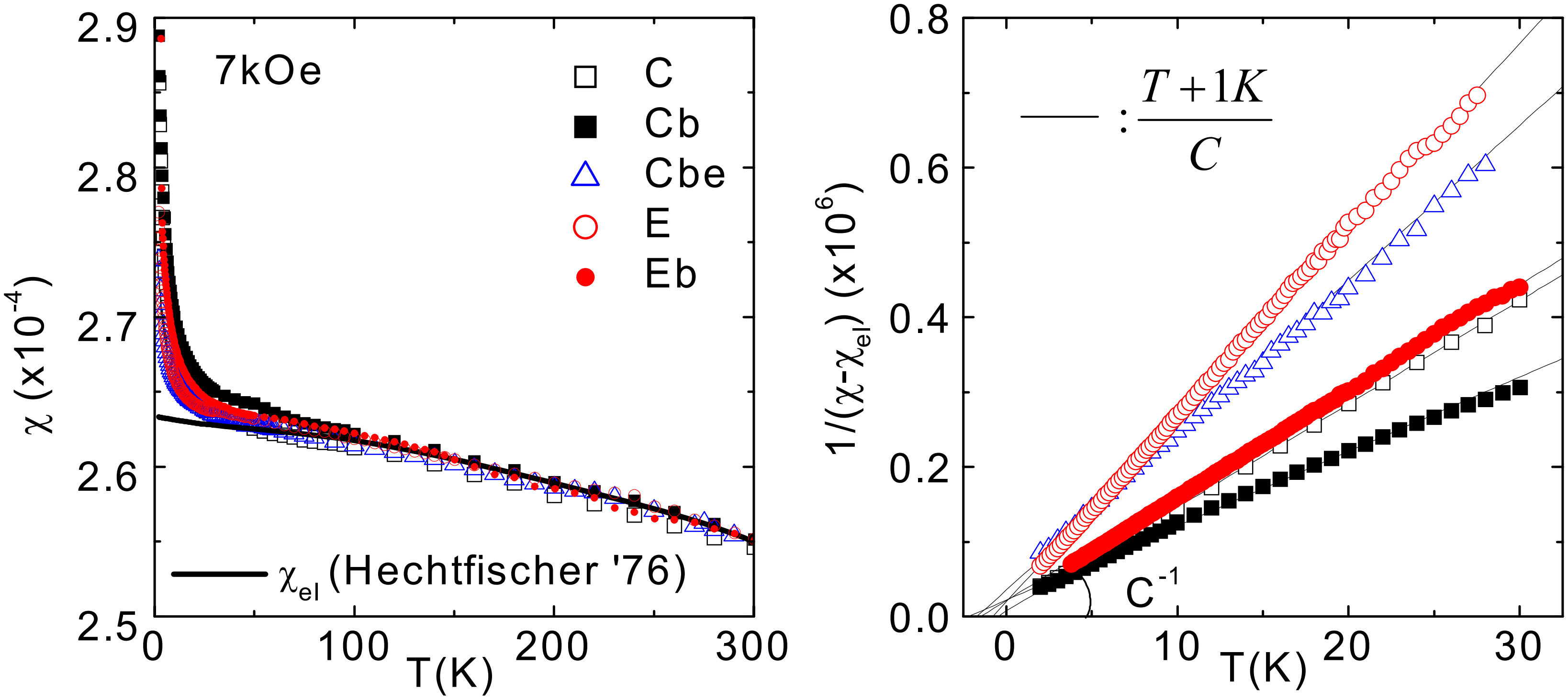
clean $\quad \chi \underset{\ell \to \infty}{\cong} 1 - 0.884 \frac{\xi_0}{\ell}$

impurities in a layer of thickness d

$$\frac{H_{C3}}{H_{C2}} = 1.67\left(1 + \left(1 - \chi(\xi_0/\ell)\right)\sqrt{1.7\frac{d}{\xi_V}}\right); \qquad \frac{H_{C3}}{H_{C2}} \le 3.8$$

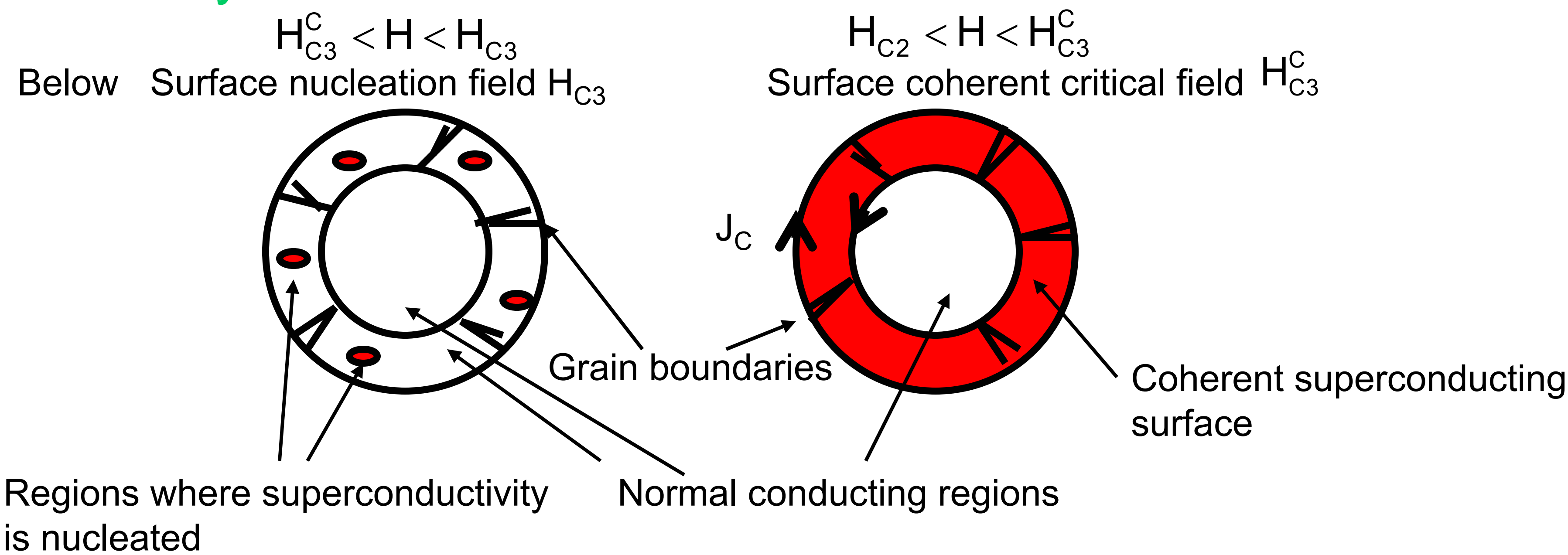
	C,Cbe	Cb	E	Eb
$\chi(\xi_0/l) \le$	0.91	0.77	0.80	0.59
dirty $d(\text{nm}) \ge$	2.5	6.5	6	12
clean $\ell(\text{nm})) \le$	436	169	192	92

Dirty: H_{C3} increases if d increases
Clean: H_{C3} increases if ℓ decreases



	C	Cb	E	Eb	Cbe
C(μK)	72.3(1)	100.6(7)	40.2(3)	71.0(1)	48.3(4)

Summary Conclusions



Electropolishing: increase of H_{C3}

increase J_C => stronger coupling across grain boundaries

Baking: increase H_{C3} => decrease of the normal electron mean free path at the surface => impurities inclusion

no change of J_C => grain boundary coupling unchanged

Open questions

magnitude of C

frequency dependence might help to study weak links

Surface critical field H_{C3}