COLD RF GUN,
or

one of possible ways to the 200 MV/m in 1300 MHz RF GUN

Vladimir Vogel, Klaus Flöttmann, Siegfried Schreiber

DESY

7 September 2010

Context

- Materials and gradient
- Some properties of pure metals in low temperature region
- RF GUN design
- Plan

Cold Linac (SC)

$\neq$

Normal temperature Gun

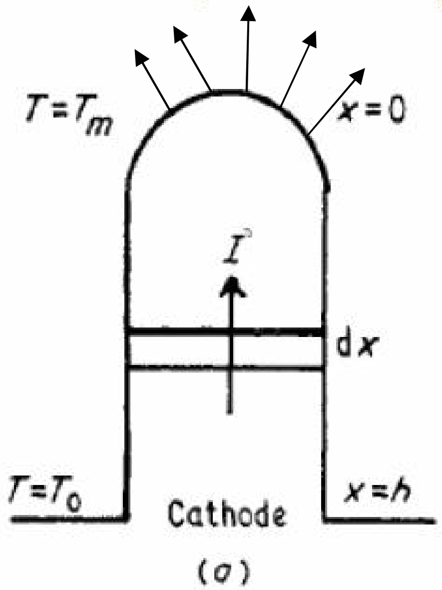
low emittance -> high gradient in long pulse $$\varepsilon \propto \sqrt{\frac{Q}{\sqrt{P}}}$$

Gradient – new materials, (we have **only one** GUN)
Dissipated power - low temperature + “pulses inside the pulse” mode

Gradient

Analytical estimates for a cylindrical tip

For a cylindrical protrusion heat conduction is described by:



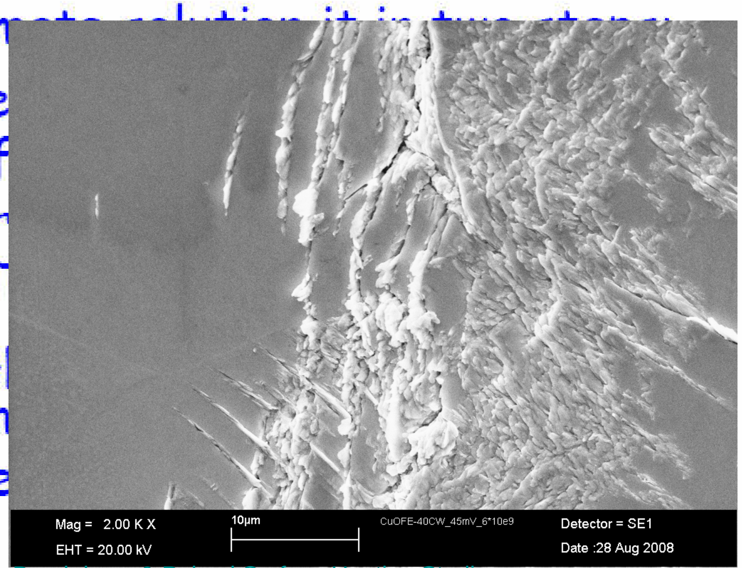
$$C_V \frac{\partial T}{\partial t} = K \frac{\partial^2 T}{\partial x^2} + J^2 \rho$$

$$\rho = \rho_0 \frac{T}{T_0}.$$

Williams & Williams, J. Appl. Rhys. D, 5 (1972) 280

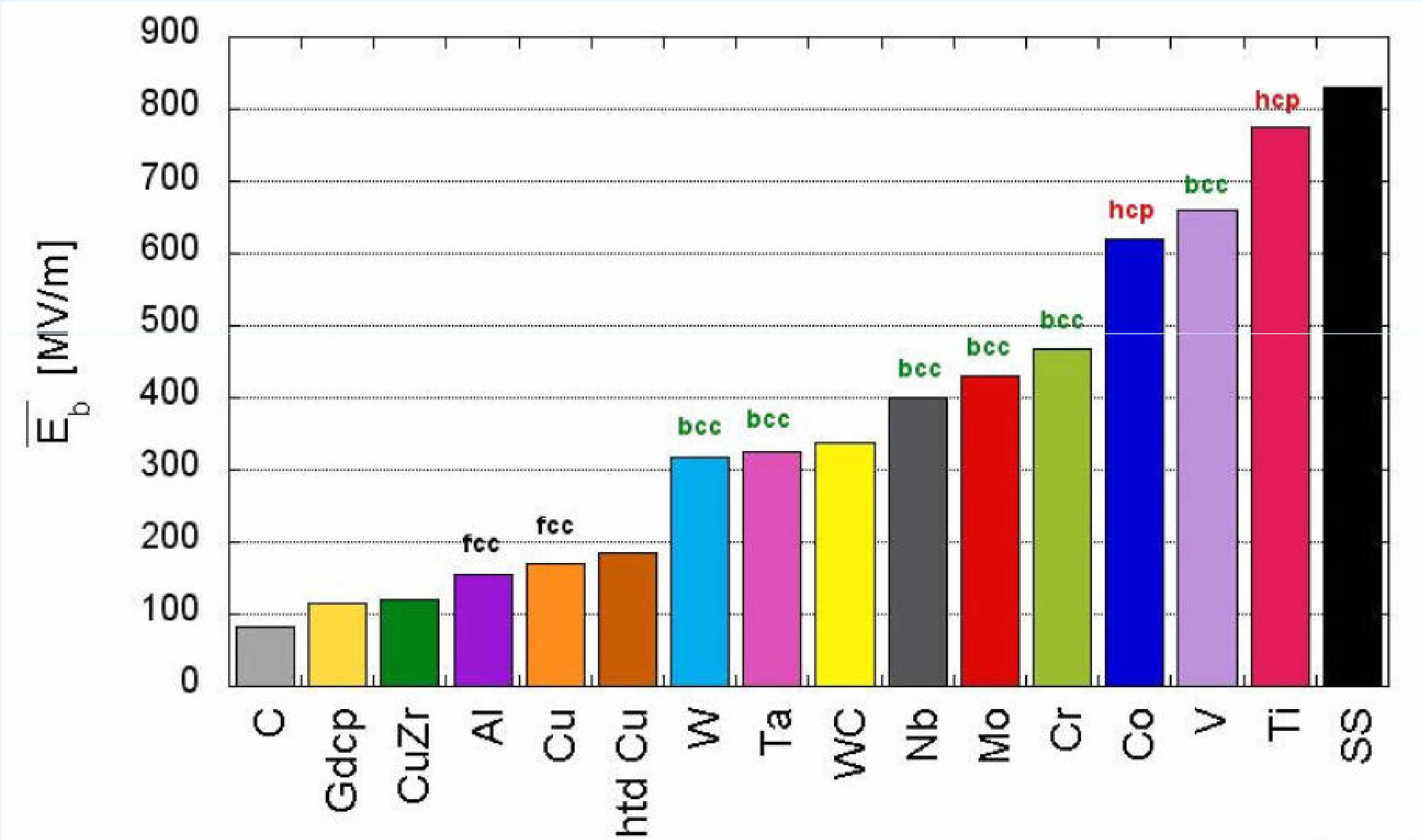
Let's get approxim

1. Solve it in ste
side is zero) f
density requir
temperature
2. Solve time de
approximation
required to re



Breakdown & Pulsed Surface Heating Studies: Thermal Fatigue behavior versus Grain Orientation
by Markus AICHELER (Ruhr-Universitaet Bochum)

Ranking materials by crystal structure?

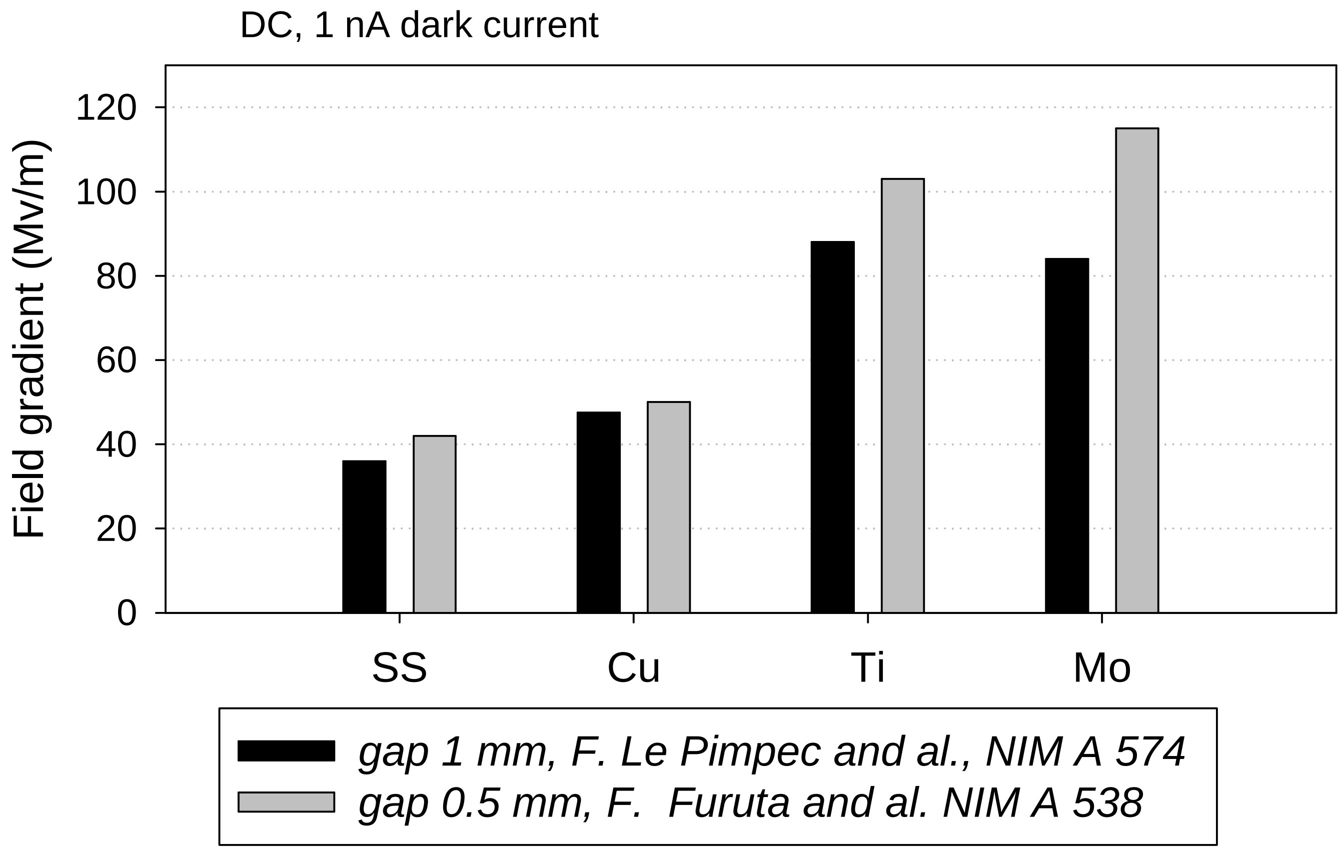


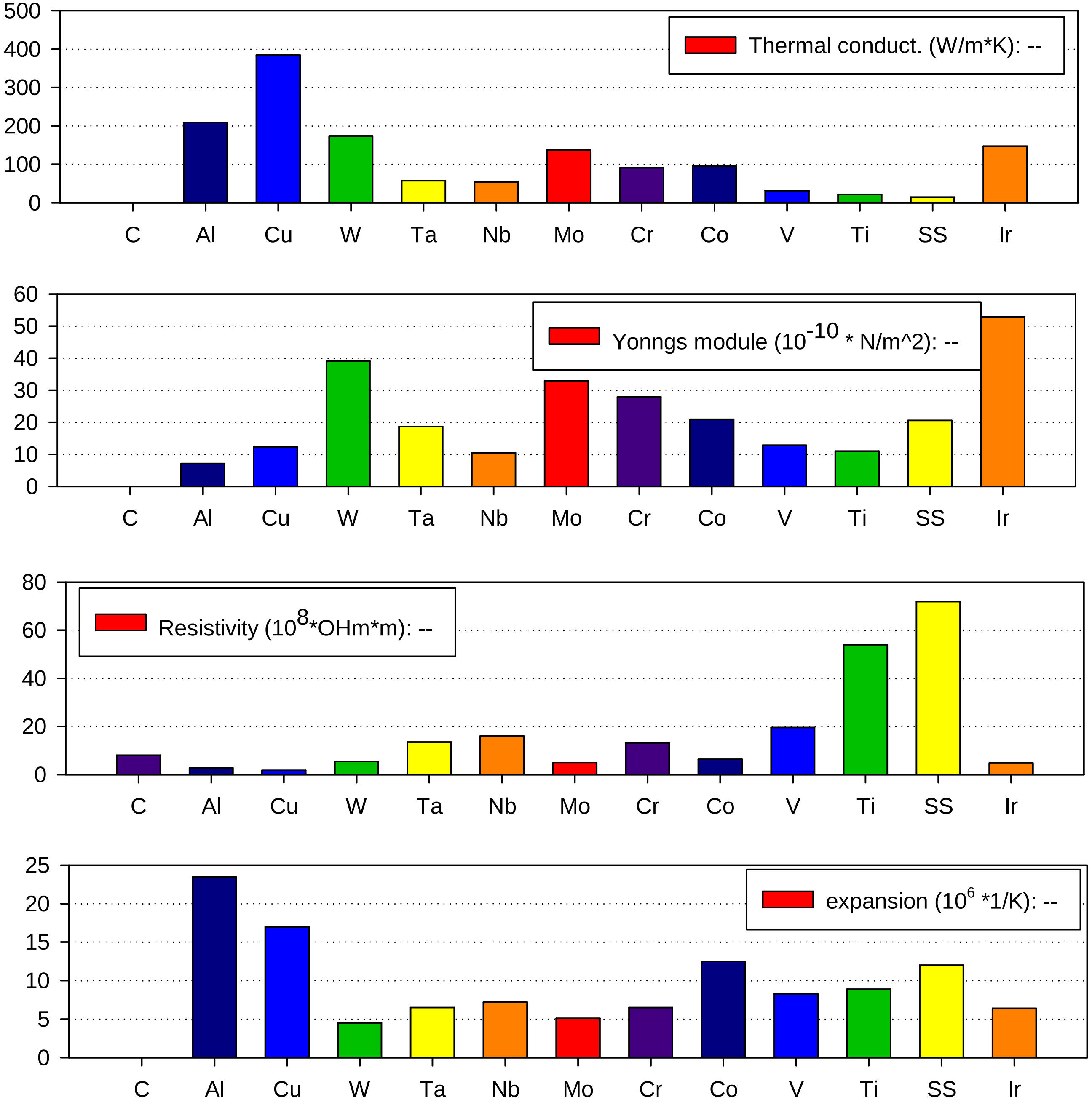
dc breakdown conditioning and breakdown rate of metals and metallic alloys under ultrahigh vacuum

A. Descoeudres,* T. Ramsvik, S. Calatroni, M. Taborelli, and W. Wuensch

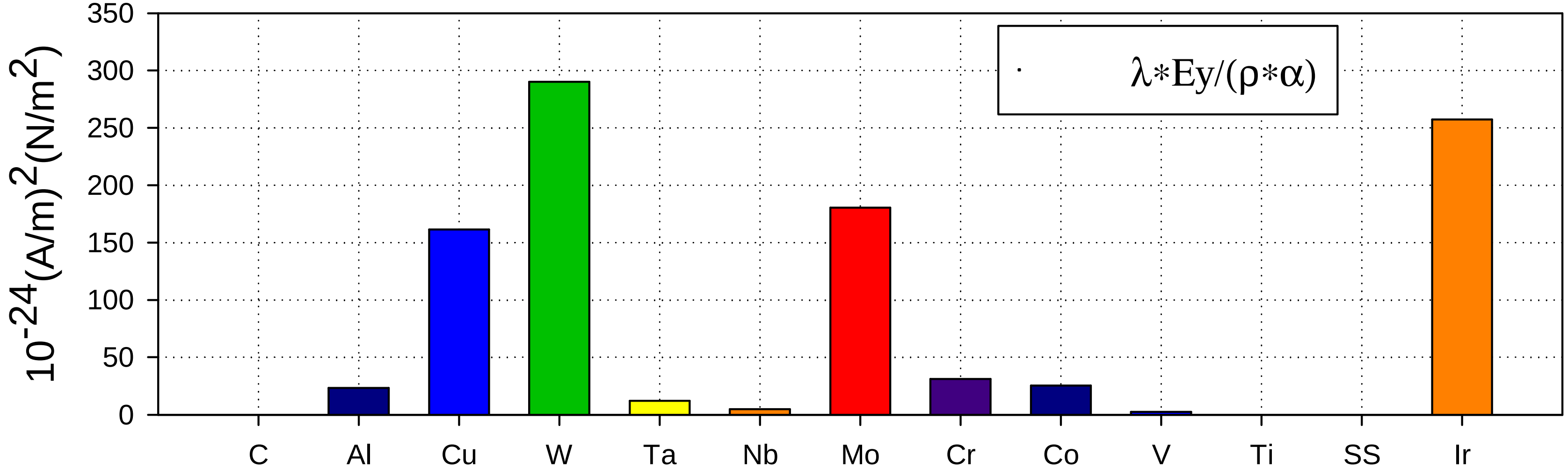
European Organization for Nuclear Research, CERN, 1211 Geneva 23, Switzerland

(Received 8 January 2009; published 24 March 2009)

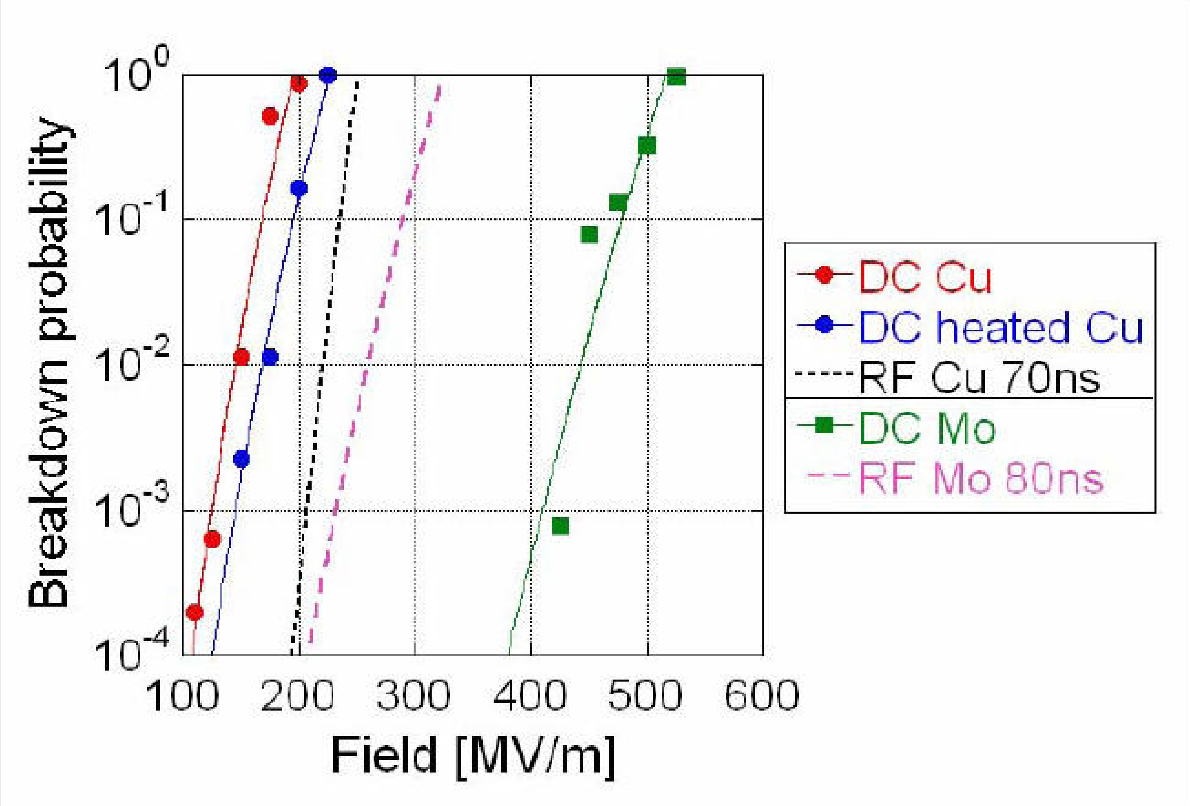

DC, 1 nA dark current
Field gradient (Mv/m)
0
20
40
60
80
100
120
SS
Cu
Ti
Mo
gap 1 mm, F. Le Pimpec and al., NIM A 574
gap 0.5 mm, F. Furuta and al. NIM A 538


Thermal conduct. (W/m*K): --
0
100
200
300
400
500
C
Al
Cu
W
Ta
Nb
Mo
Cr
Co
V
Ti
SS
Ir
Yonngs module (10^-10 * N/m^2): --
0
10
20
30
40
50
60
C
Al
Cu
W
Ta
Nb
Mo
Cr
Co
V
Ti
SS
Ir
Resistivity (10^8*OHm*m): --
0
20
40
60
80
C
Al
Cu
W
Ta
Nb
Mo
Cr
Co
V
Ti
SS
Ir
expansion (10^6 *1/K): --
0
5
10
15
20
25
C
Al
Cu
W
Ta
Nb
Mo
Cr
Co
V
Ti
SS
Ir

Temperature ~ 300 K



Breakdown rate vs field : DC

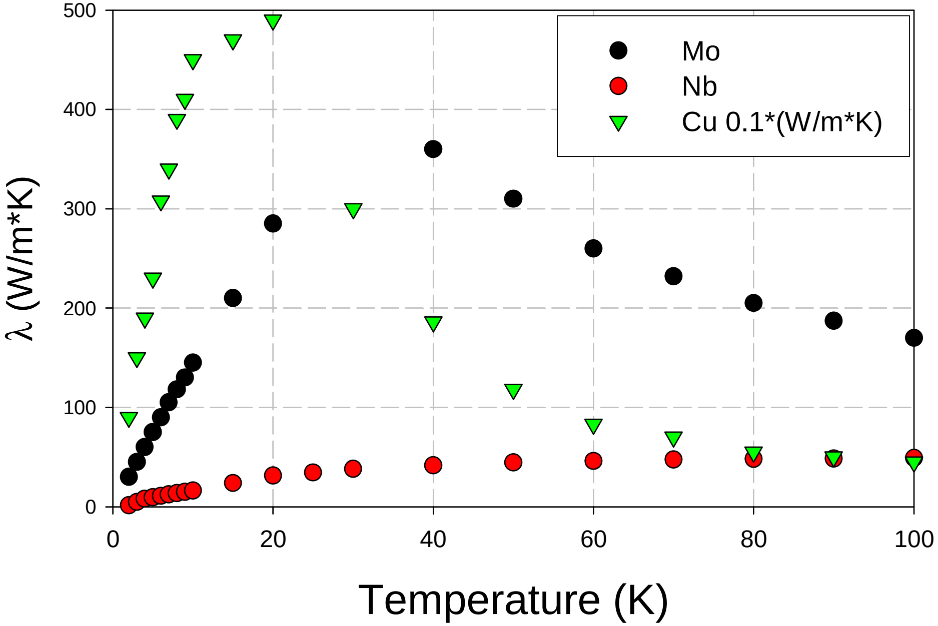


NB: RF data are plotted vs surface field

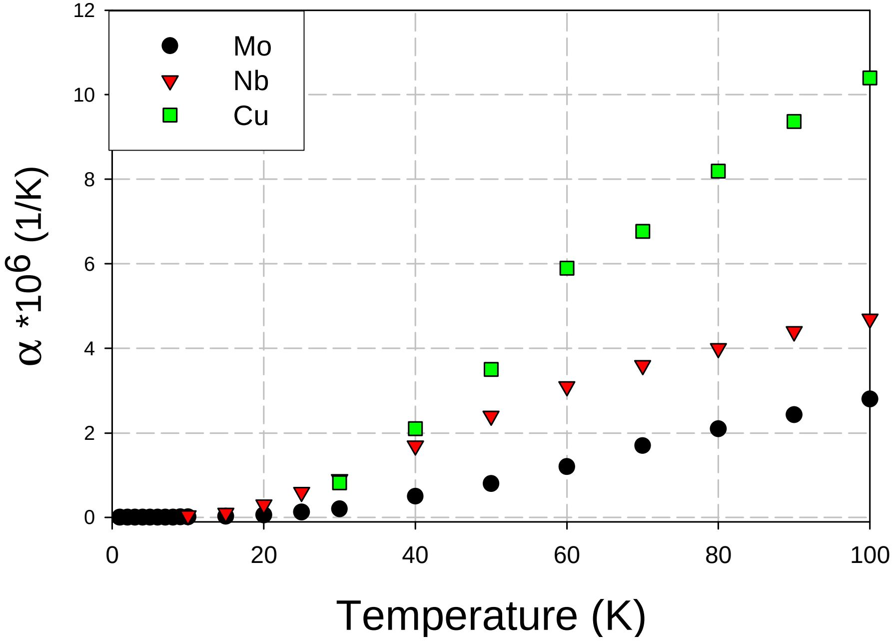
Same trend as in RF measurements → comparison possible

Dissipated power

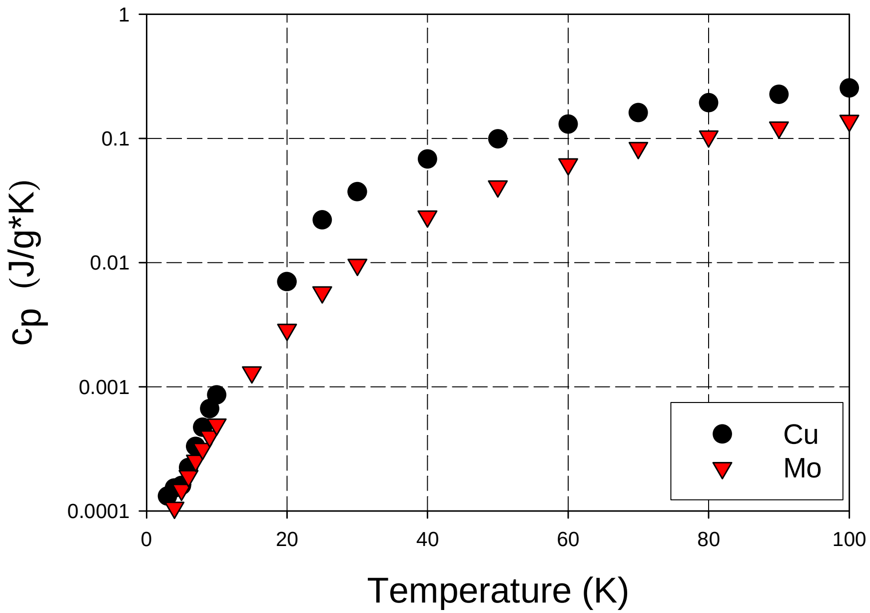
Thermal conductivity (*Au, Ag, Ir, W, Pt…*)



Thermal expansion

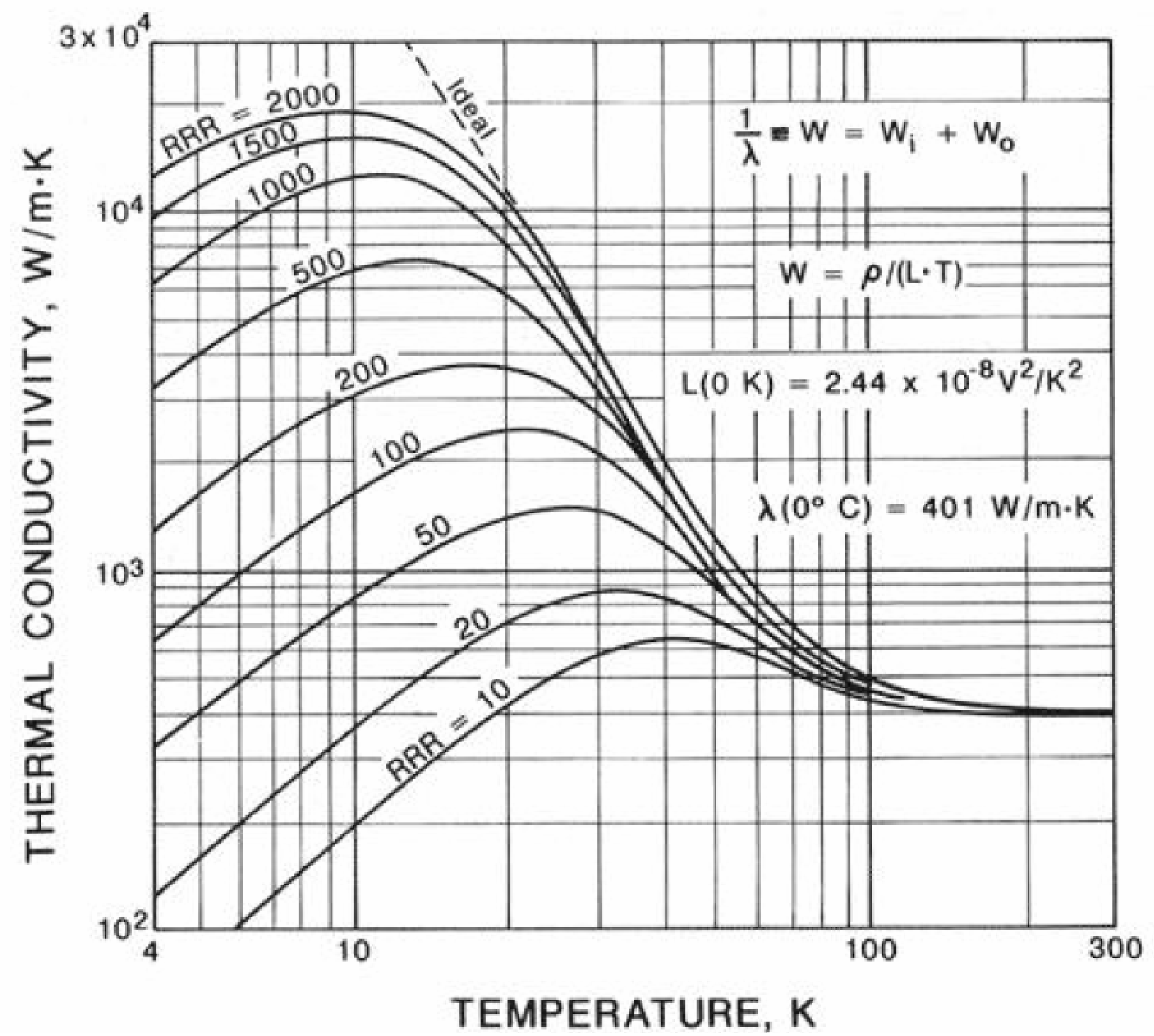


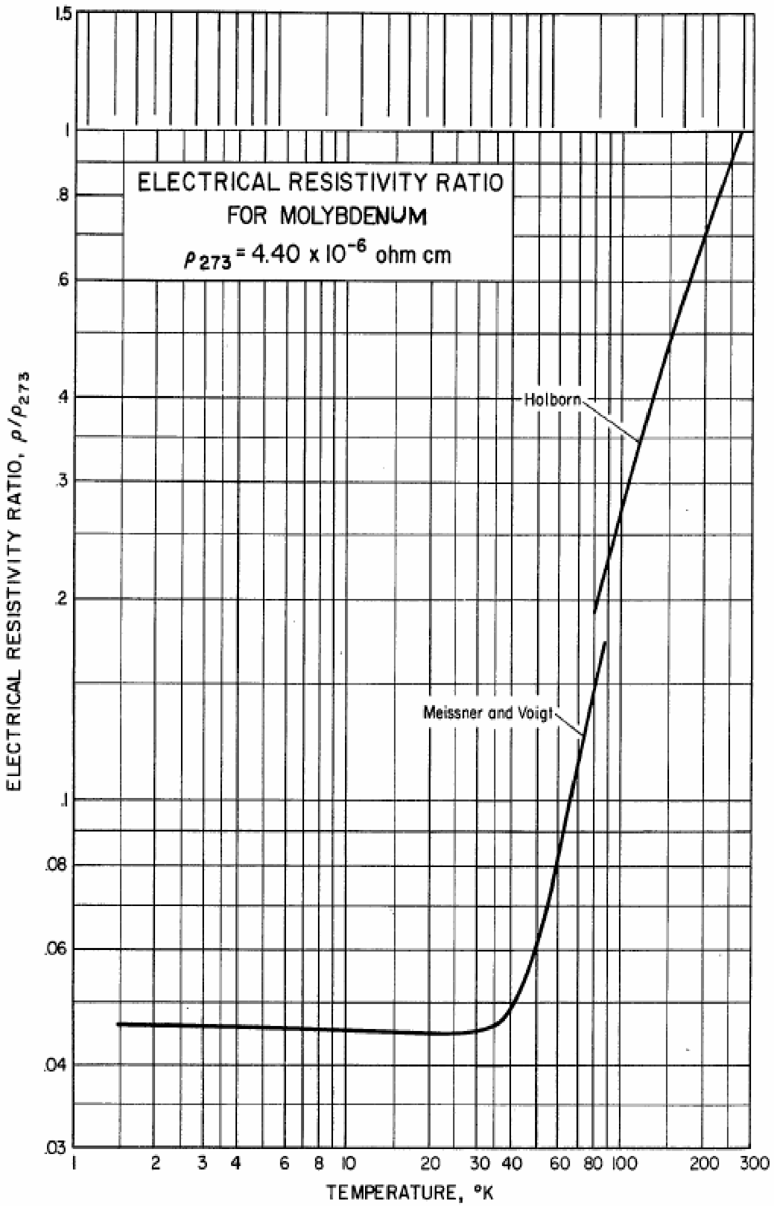
Hydrogen 20.3 K
Neon 27 K



L.A. Novickiy, I G. Kozhevnikov
"Thermo physical properties of materials in the low temperature region"
Moscow 1975. In Russia

http://www.copper.org/resources/properties/cryogenic/homepage.html





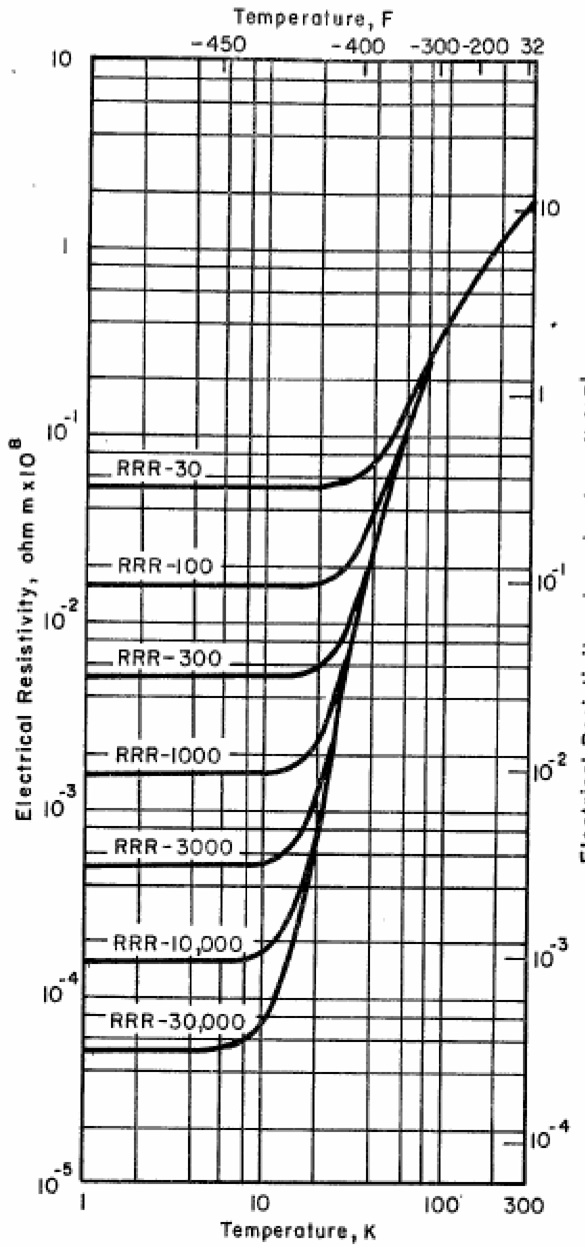
BROOKHAVEN NATIONAL LABORATORY
SELECTED CRYOGEN DATA NOTEBOOK

VOLUME II
SECTIONS X-XVIII

Compiled and Edited by

J.E. Jensen W.A. Tuttl
R.B. Stewart[1] H. Brechn
A.G. Prodell

[1]Worcester Polytechnic Inst. and National Bureau of Sta
Institute of Technology, Rapperswil, Switzerland



ELECTRICAL RESISTIVITY VERSUS TEMPERATURE FOR COPPER

DESY RF GUN5 *(V. Paramonov, K. Floettmann,..)*

f =1300 MHz, Trf = 1 mS, Hpmax= ~ 100kA/m

$Lt=(\lambda*\tau/(\gamma*Cp))^{1/2}$

$\Delta Ts=(\tau*\rho*f*\mu/\gamma*\lambda*Cp)^{1/2}*(Hp)^2$

	T (K)	ρ (Ohm*m)	Cp (J/kg*K)	λ (W/m*K)	δ (m)	Lt (m)	ΔTs (K) 60 MV/m	P (W/m²) 60 MV/m	ΔTs (K), τ = 10μS 200 MV/m
Cu	300	$1.72*10^{-8}$	385	384	$1.83*10^{-6}$	$3.3*10^{-4}$	46.2	$4.7*10^{7}$	51
	20	$(2.35*10^{-11})^{*}$	(7)^	(4900)^	$6.7*10^{-8}$	$8.9*10^{-3}$	3.5	$1.7*10^{6}$	4
Mo	300	$5.7*10^{-8}$	251	137	$3.33*10^{-6}$	$2.3*10^{-4}$	>160	$8.5*10^{7}$	>180
	25	$(2.58*10^{-11})^{\#}$	(5.77)^	(300)^	$7.1*10^{-8}$	$2.2*10^{-3}$	15.4	$1.8*10^{6}$	17

Not included anomalous skin effect !!!

* - (*Frey, Haefar)?* “Tieftemperatur technologie” 1981, p. 5.1.1-1(11/74)

- *А.Н. Великородный,Е.А. Игнатьева* “Электро и теплосопротивление молибдена при низких температурах” , http://vant.kipt.kharkov.ua/TABFRAME.html

^ - *Л.А. Новицкий, И.Г.Кожевников* “Теплофизические свойства материалов при низких температурах”, Moscow 1975.

A CRYOGENIC RF MATERIAL TESTING FACILITY AT SLAC*

Jiquan Guo#, Sami Tantawi, David Martin, Charles Yoneda
SLAC National Accelerator Laboratory, Menlo Park, CA, U.S.A.

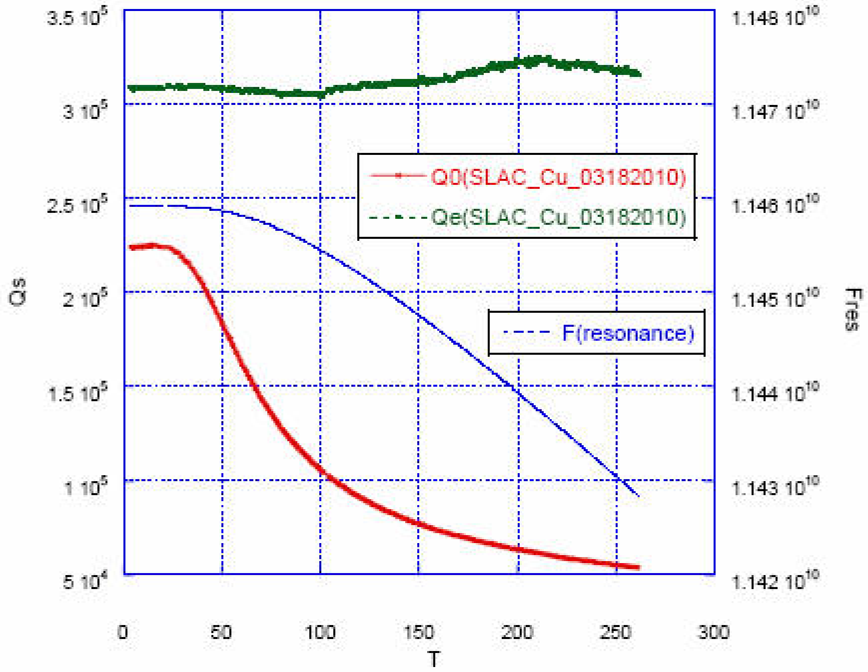
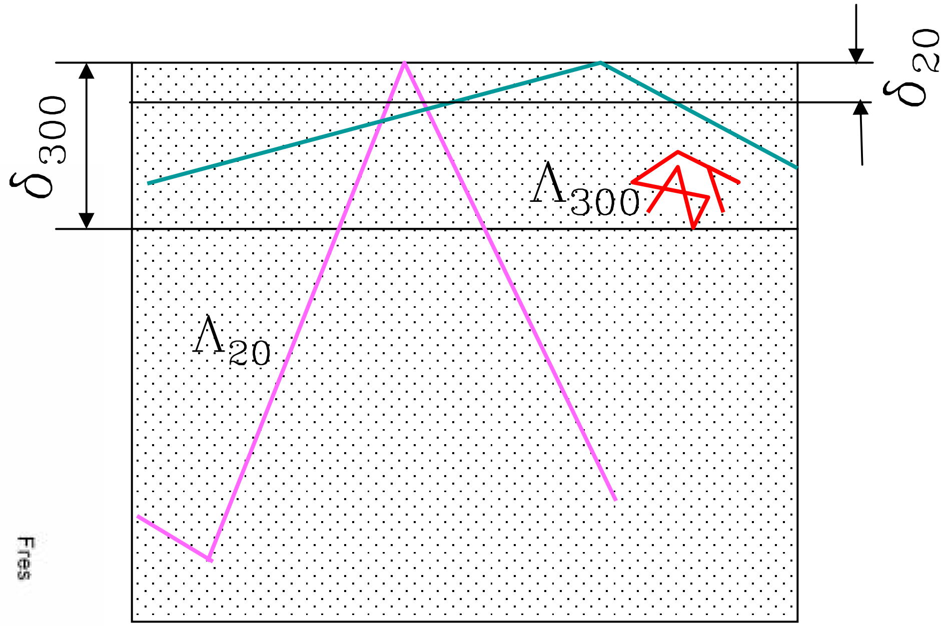


Figure 4: Low power measurement of the SLAC copper sample



Anomalous skin effect

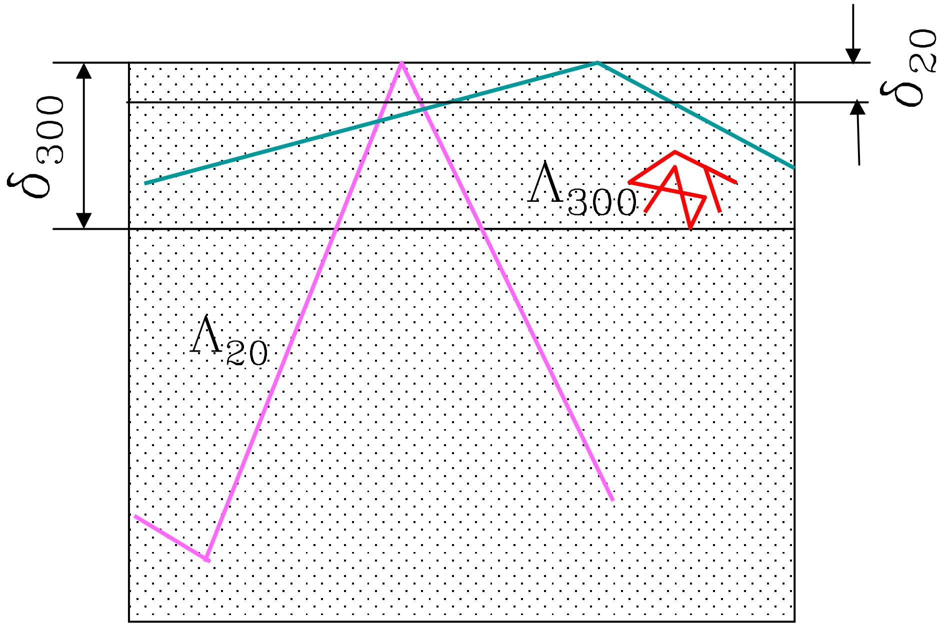
$$\delta = \sqrt{\frac{\rho}{\mu_0 \pi * f}}$$

$$\overline{\Lambda} = \frac{h * 3^{1/3}}{\rho * e^2 * n^{2/3} * (8\pi)^{1/3}}$$

$$R_{an} = \sim \left(\frac{c^2 \cdot \Lambda \cdot \rho}{\beta \cdot f}\right)^{-1/3} \cdot f(R) \cdot g(N)$$

R ~ *reflection factor for electron*

N ~ RRR

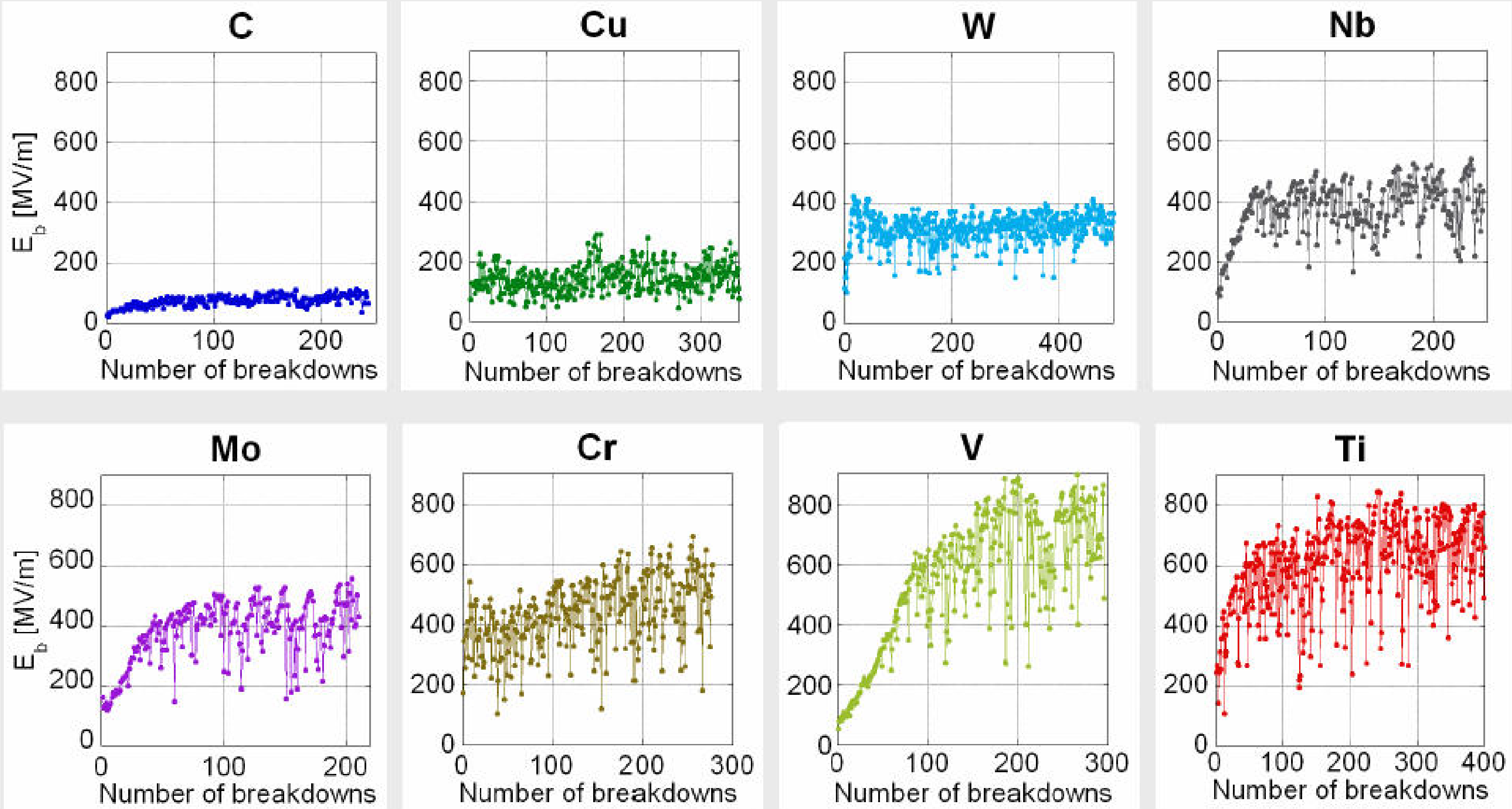


	δ/Λ, T=300 K 1.3 GHz	δ/Λ, T=20 K 1.3 GHz	δ/Λ T=300 K 11.4 GHz	δ/Λ T=20 K 11.4 GHz	Q_{20}/Q_{300} 11.4GHz	**Q_{20}/Q_{300} 1.3GHz**
Cu	27	**2.4*10^{-3}**	16	0.81*10^{-3}	**4.4 (exp)**	**~ 6.2 (estim)**
Mo	47	**2.3*10^{-3}**				~ 6

DESY GUN 5
60 MV/m ~ 6.18 MW, dT = 46 K

Cold GUN
60 MV/m - ~ 1 MW dT ~ 7.5 K

Conditioning curves of pure metals



assumption: ‘good material’ = refractory ; oxides easily reduced

Mo T=20 K

$$\lambda_{20} \approx 3 \cdot \lambda_{300}$$

$$\frac{d\lambda_{20}}{dT} \geq 0$$

$$c_{p20} = 0.1 \cdot c_{p300}$$

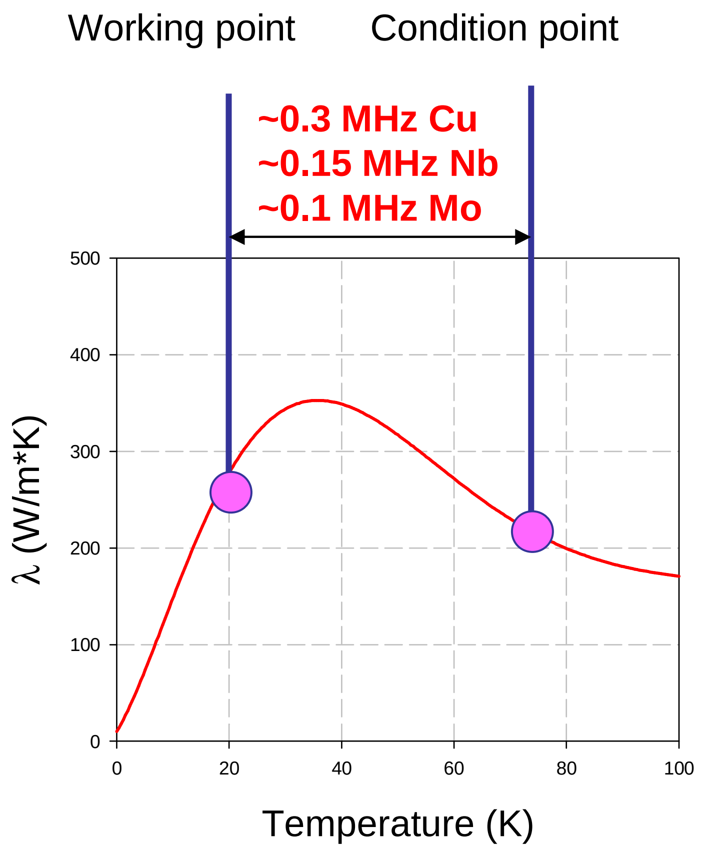
$$\frac{dc_{p20}}{dT} \geq 0$$

$$\alpha_{20} = 0.04 \cdot \alpha_{300}$$

$$\frac{d\alpha_{20}}{dT} \approx 0$$

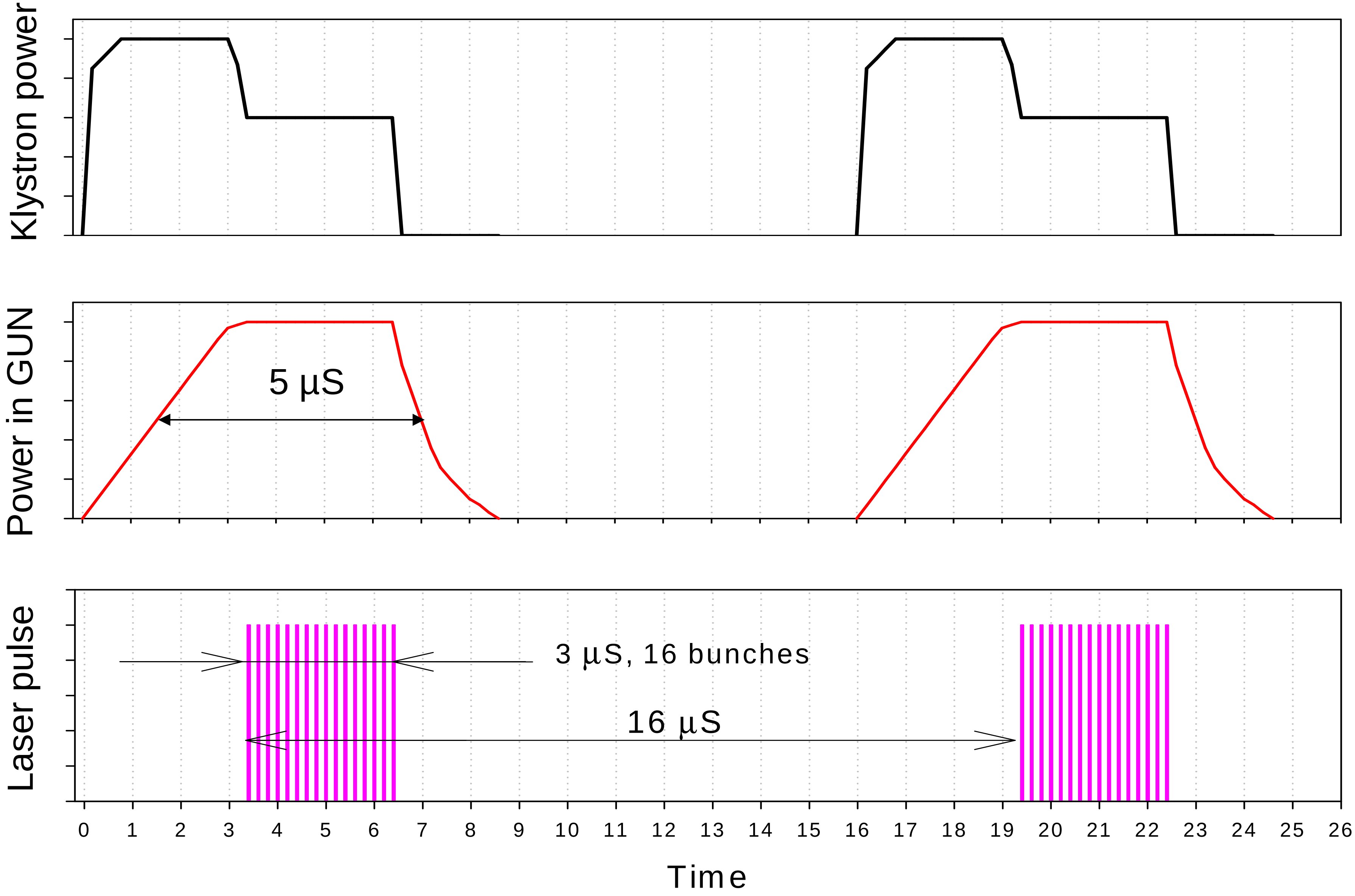
$$Rs_{20} \approx \frac{1}{6} \cdot Rs_{300}$$

$$\frac{dRs_{20}}{dT} \approx 0$$



No reason for the breakdown in standard BD model. We can expect 60 MV/m ~ 1 ms pulse and 200 MV/m for 3 - 5 μS pulse

“pulses inside the pulse” mode,
We need: 5 MHz laser and 10 MW 3.5 MHz bandwidth klystron
first test at the FLASH has already started. **Power reduction 16/5=3.2**



Total power losses reduction.

Cold GUN + PiP mode
6.2*3.2 = 19.8

GUN5 (1 mS RF) - 62 kW, Cold GUN + PiP – 3.2 kW

Liquid Hydrogen
T boiling = 20.3 K
*Cp = 8000 ÷ 12000 J/kg*K*
Θ evaporation ~ 454 kJ/kg
ρ = 71 kg/m³

Liquid Neon
T boiling = 27 K
*Cp = 1880 J/kg*K*
Θ evaporation ~ 84-89 kJ/kg
ρ = 1207 kg/m³

H_2 : For 1 kW
evaporative cooling: - 8 kg/hour
liquid cooling (ΔT = 2 K) - 180 kg/hour, (2.5 m³)

1. DESY has experience to use liquid Hydrogen.

2. Next year in Hamburg will be build liquid Hydrogen gas station for cars and buses (~ 700 kg/day)

Oversize cavity:

Example:
TM020 in first half cell
TM010 in second cell

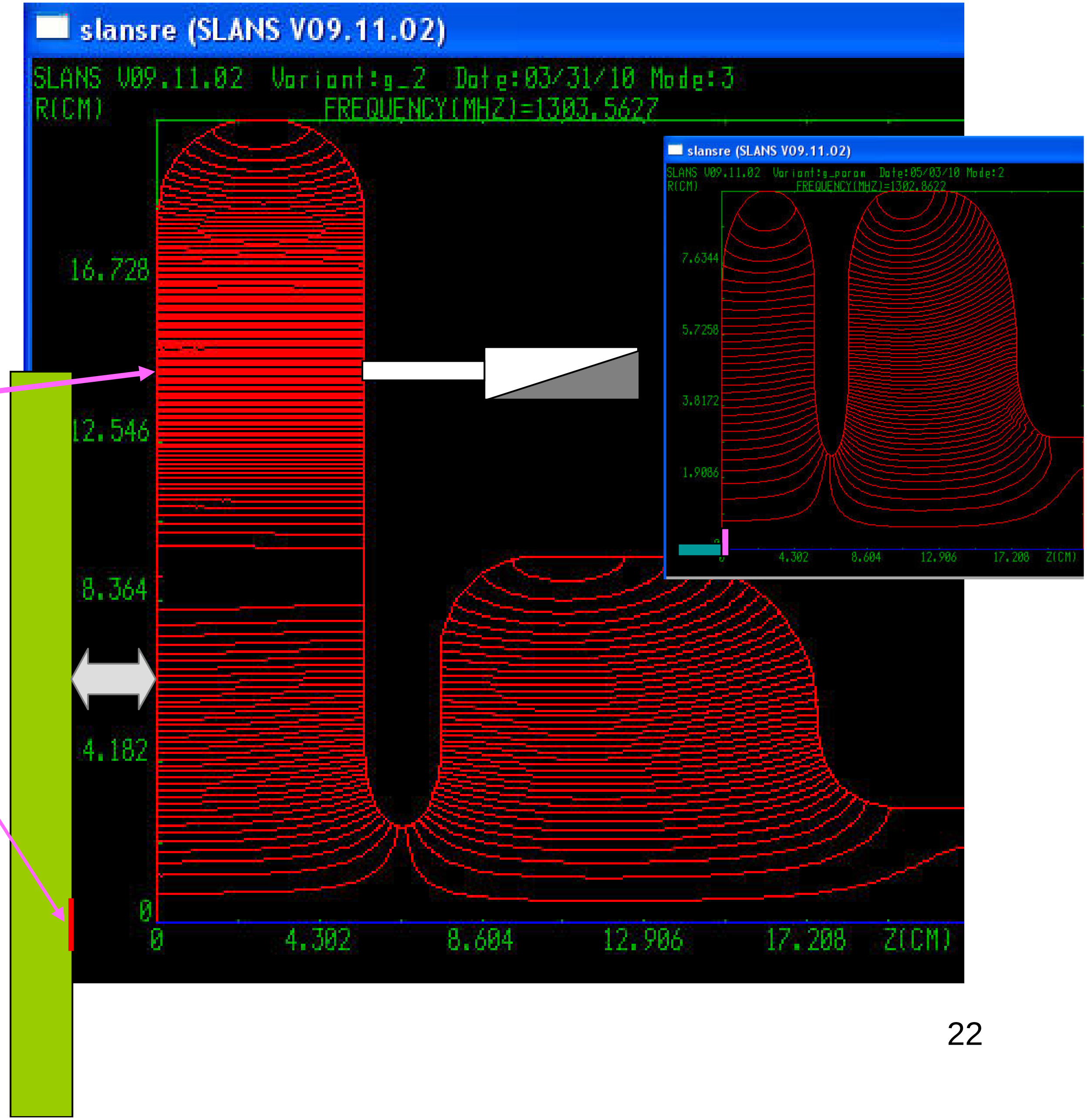
1. No tangential current for TM020, slot for cathode changing, damp for HOMs

2. More spaces for input couplers.

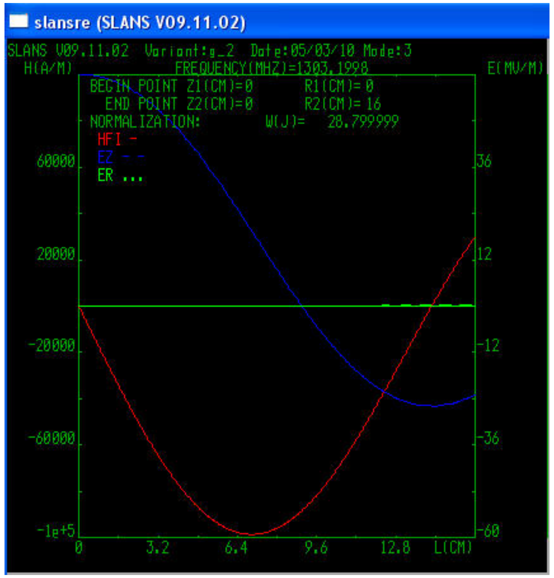
3. No cathode holder, direct Cs2Te film to the replaceable part of cavity.

4.Cathode part of cavity can be made from the other material

5. Place for probe, without overheating



TM020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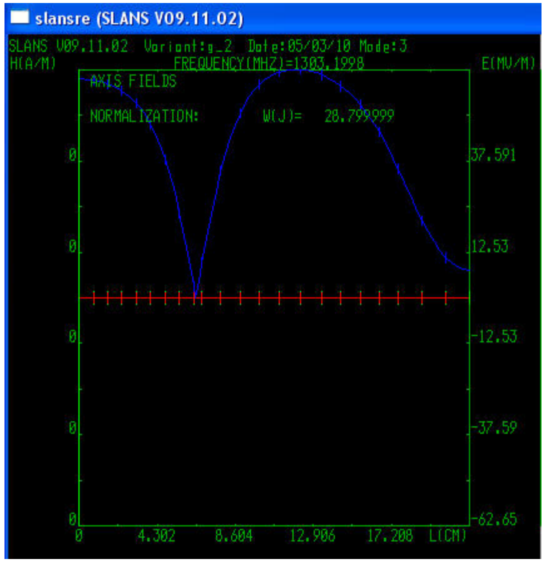
SLANS V09.11.02 Variant:g_2 Date:05/03/10 Mode:3
FREQUENCY(MHZ)=1303.1998
BEGIN POINT Z1(CM)=0 R1(CM)=0
END POINT Z2(CM)=0 R2(CM)=16
NORMALIZATION: W(J)= 28.799999
HFI
EZ
ER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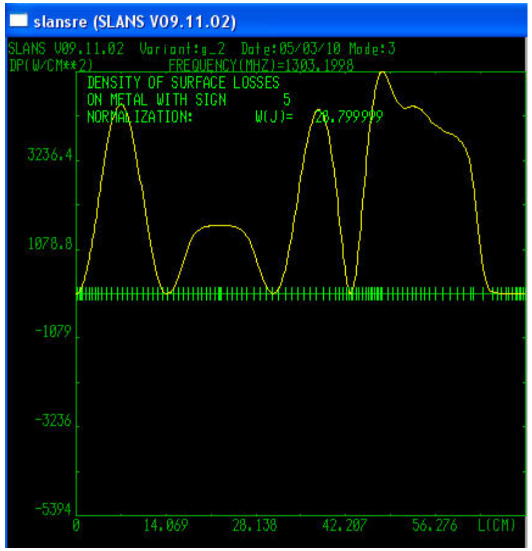
AXIS FIELDS
NORMALIZATION: W(J)= 28.799999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SLANS V09.11.02 Variant:g_2 Date:05/03/10 Mode:3
FREQUENCY(MHZ)=1303.1998
DENSITY OF SURFACE LOSSES
ON METAL WITH SIGN 5
NORMALIZATION: W(J)= 28.799999

TM010


slansre (SLANS V09.11.02)
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FREQUENCY(MHZ)=1303.7303
BEGIN POINT Z1(CM)=0 R1(CM)=0
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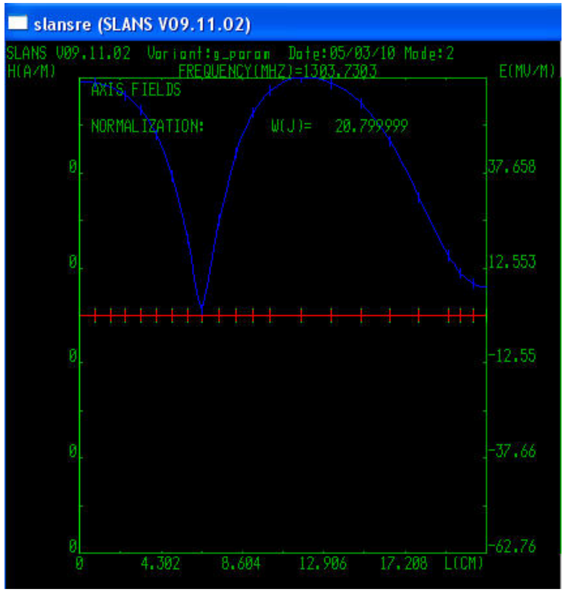
NORMALIZATION: W(J)= 20.799999
HFI
EZ
ER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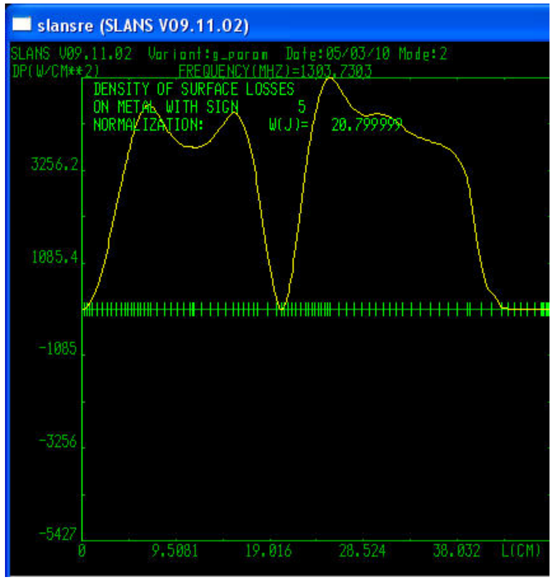
FREQUENCY(MHZ)=1303.7303
AXIS FIELDS
NORMALIZATION: W(J)= 20.799999


slansre (SLANS V09.11.02)
SLANS V09.11.02 Variant:g_param Date:05/03/10 Mode:2
FREQUENCY(MHZ)=1303.7303
DENSITY OF SURFACE LOSSES
ON METAL WITH SIGN 5
NORMALIZATION: W(J)= 20.799999

At first, property of different materials in low temperature region for 1300 MHz.

1.

low RF power: **Cavity's in the cryostat, (Q) 1300MHz?**

(test of Ir, Mo and W, maybe in the SLAC “mushroom” cavity?)

2.

Thermal conductivity, specific heat and resistivity for Cu, W, Ir and Mo.
(Universities and research Institute)?
Cavity shape calculation and design. (DESY, INR)

3.

Low temperature, Dark current study (Cu, Mo, Ir). (DESY, PITZ)

4.

Liquid Hydrogen or Neon ? (DESY, Air Liquid)

5.

High power RF test. (DESY, PITZ, REGAE)

Conclusion

- The uncommon values of the thermal conductivity of some metals, such as Cu, Mo, W and Ir in the range of temperatures of approximately 20 degrees of Kelvin, will allow us to increase the accelerating gradient in the RF GUN and to decrease heat losses.

Acknowledgement

- Mikhail Yurkov and Evgeny Shneydmiller
- Denis Kostin
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- Xenia Singer
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- Valentin Paramonov
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