20 K Cold RF-photo Gun

Vladimir Vogel,
Klaus Flöttmann, Siegfried Schreiber, Dirk Lipka, Xenia Singer and Sven Lederer

Materials and gradient

Some properties of pure metals in low temperature region

Cold RF-photo GUN design

HELMHOLTZ
GEMEINSCHAFT

DESY

Motivation

Super conductive Linac

$\neq$

Normal temperature RF Gun

$$P_{cavity} \sim G^2 * R_{\#} * T_{RF}$$

Low emittance -> high gradient

Dissipated power -> low temperature (DESY RF GUN #5, Tiris = 72℃ + 46℃ pulse heating)

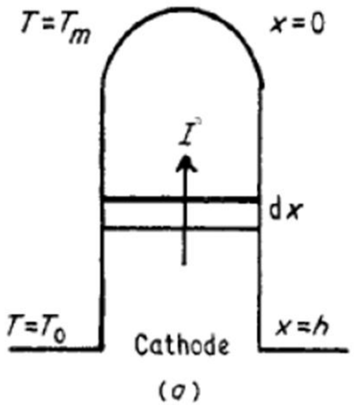
Gradient –> new materials, (we have **only one** RF GUN !!!)

Dark current –> new geometry + new materials

Breakdown mechanisms

Analytical estimates for a cylindrical tip

For a cylindrical protrusion heat conduction is described by:



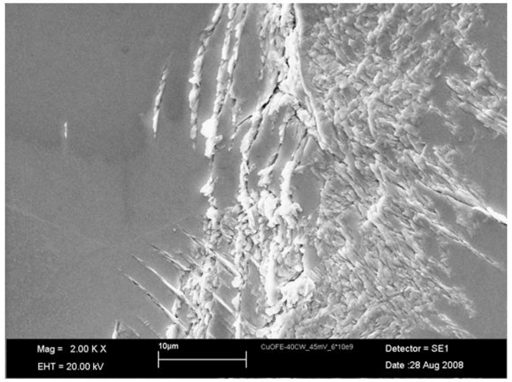
Williams & Williams, J. Appl. Rhys. D, 5 (1972) 280

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

Let's get approximate solution it in two steps:

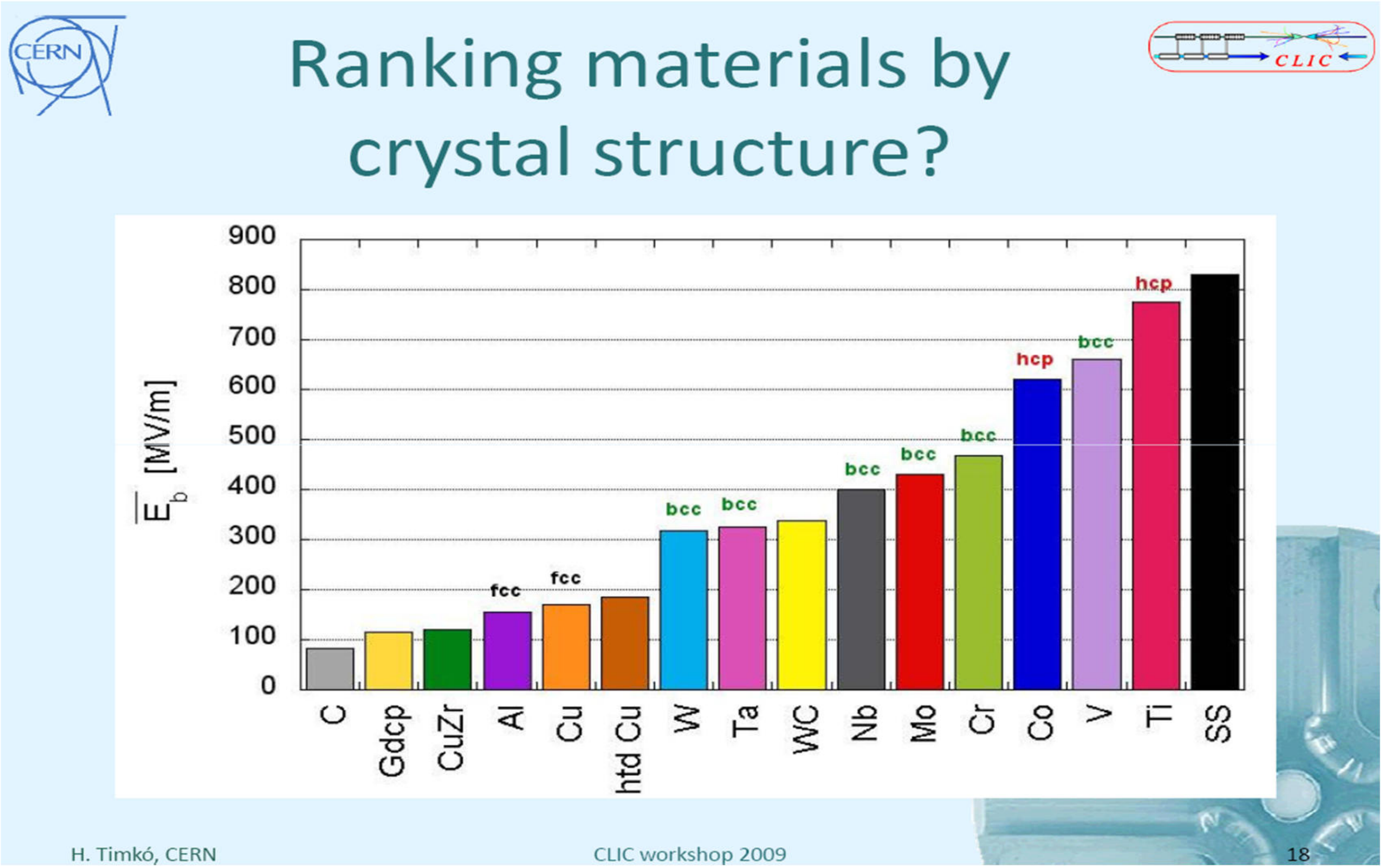
1. Solve it in steady-state (i.e. left hand side is zero) for a threshold current density required to reach melting temperature T_m
2. Solve time dependent equation in linear approximation to get the threshold time required to reach melting temperature

Alexej Grudiev, New RF Constraint. May. 2008



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

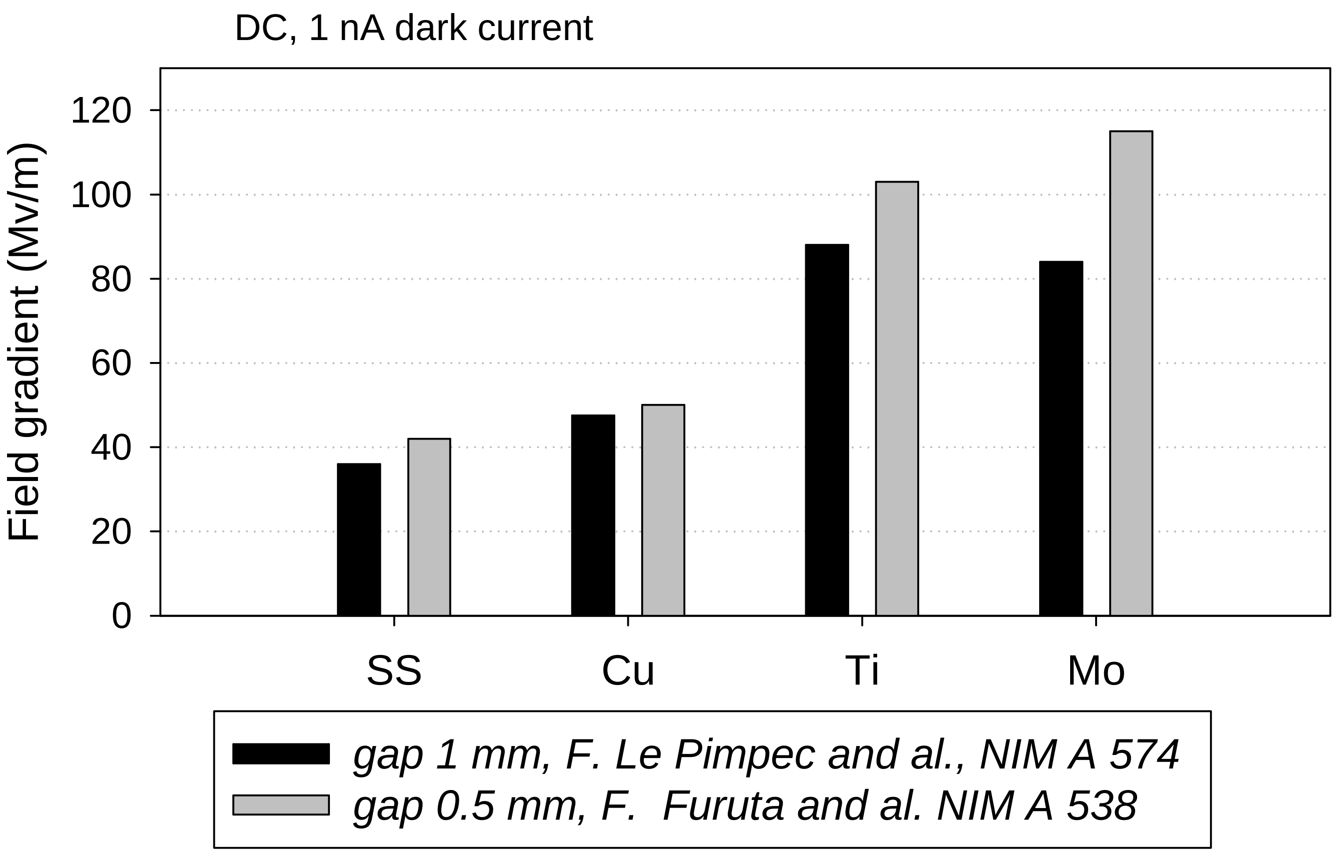
Breakdown study, pulse DC



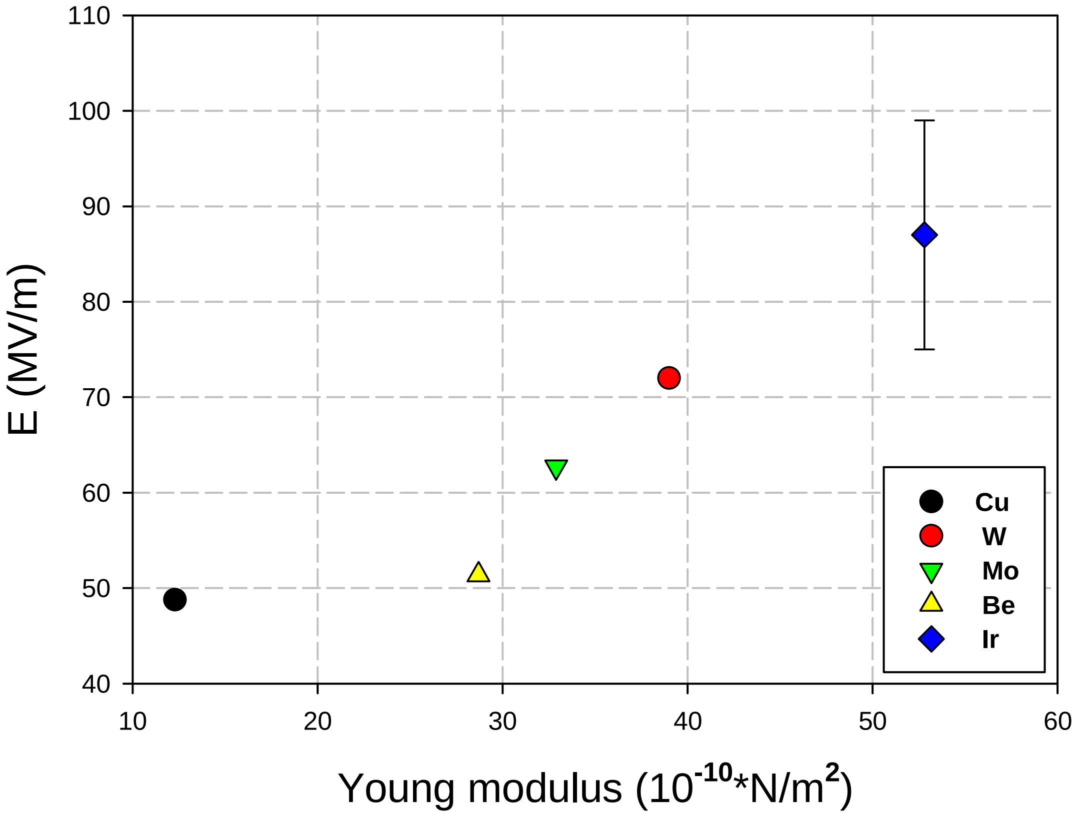
dc breakdown conditioning and breakdown rate of metals and metallic alloys under ultrahigh vacuum

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 dark current



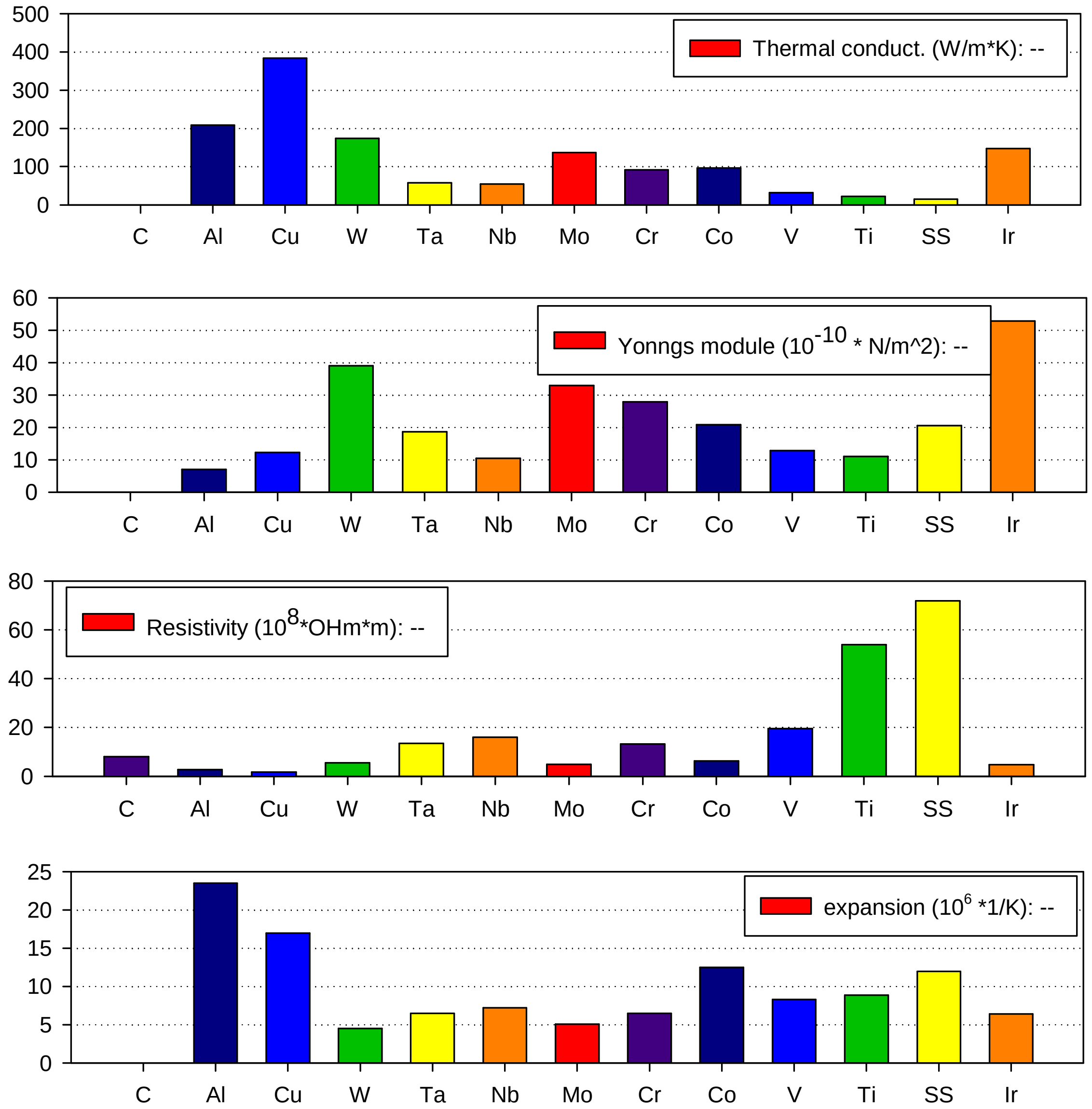
Gradient in the pressurized cavity.



Maximum stable gradient as a function of the Young's modulus for different materials.
RF frequency 805 MHz, Hydrogen pressure ~ 100 bar. (data from (#), for Iridium the approximation)

#) R. Sah, A. Dudas and al., "RF Breakdown Studies Using Pressurized Cavities" PAC 2011, MOP046, NY, USA (2011)

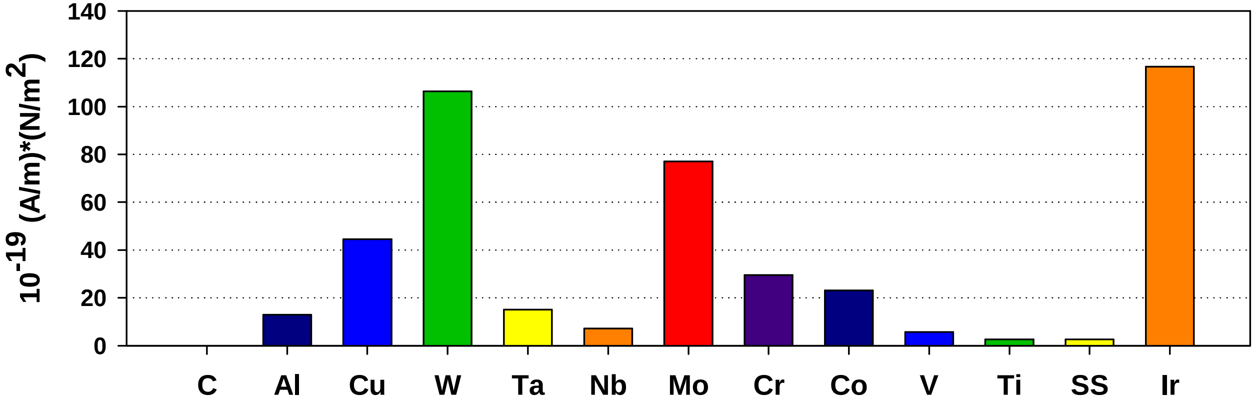
Some property of pure metals in normal temperature

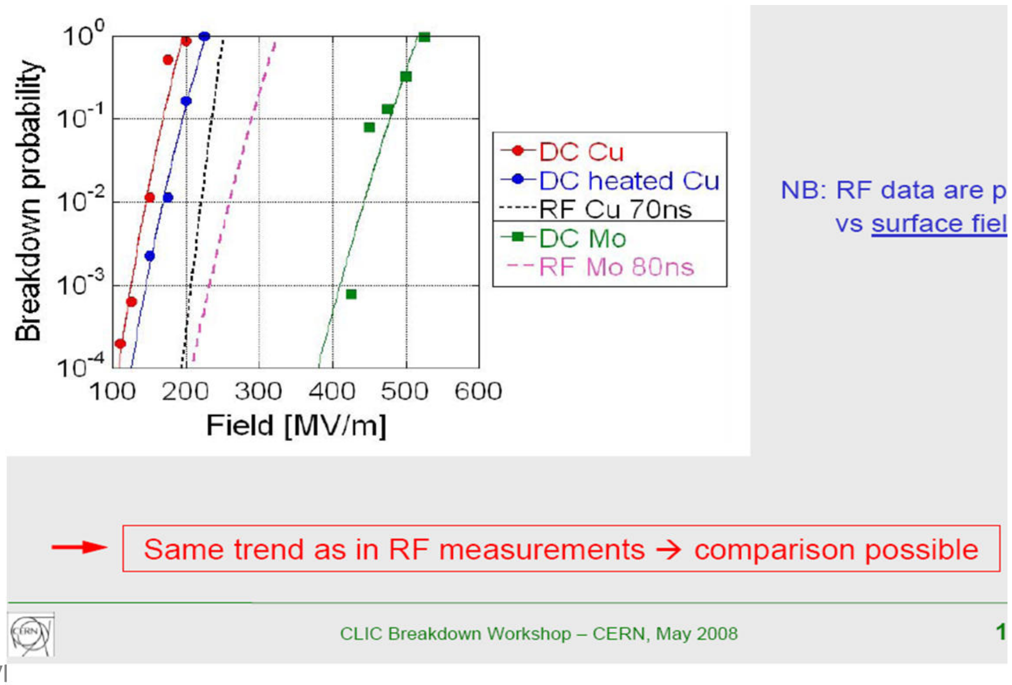


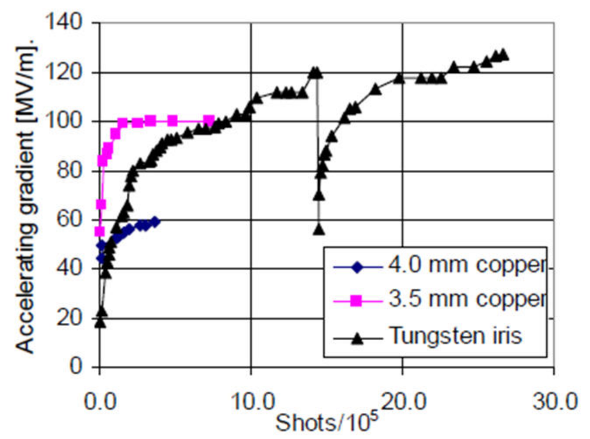
Ranking materials: RF, high gradient

Temperature ~ 300 K

$$Ey*(\lambda/\alpha\rho)^{0.5}$$





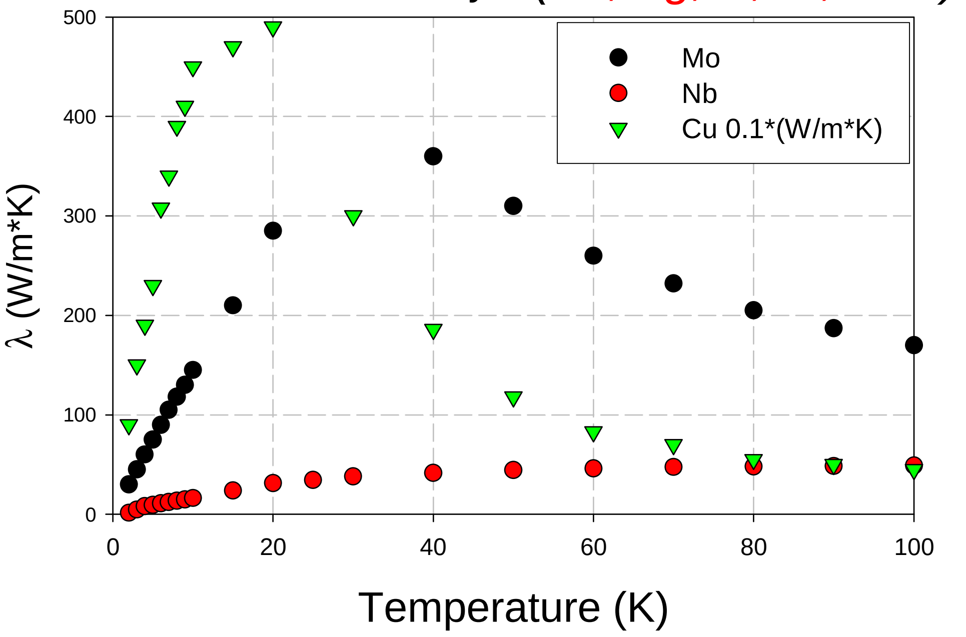


CLIC HIGH-GRADIENT TEST RESULTS

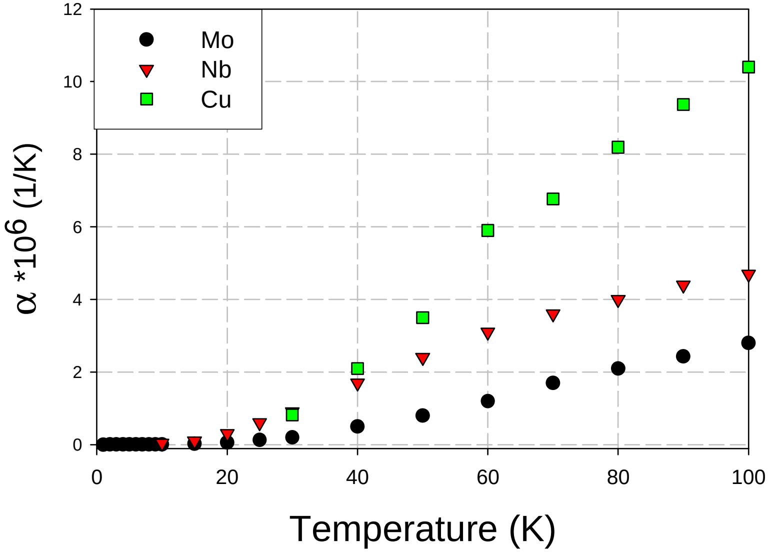
H. H. Braun, S. Döbert, I. Syratchev, M. Taborelli, I. Wilson, W. Wuensch
CERN, Geneva, Switzerland

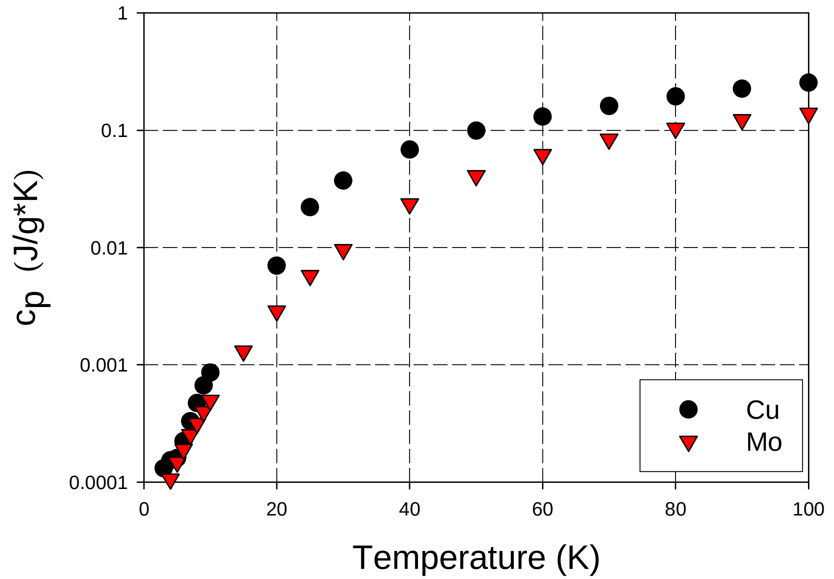
Some properties of pure metals in low temperature

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



Thermal expansion

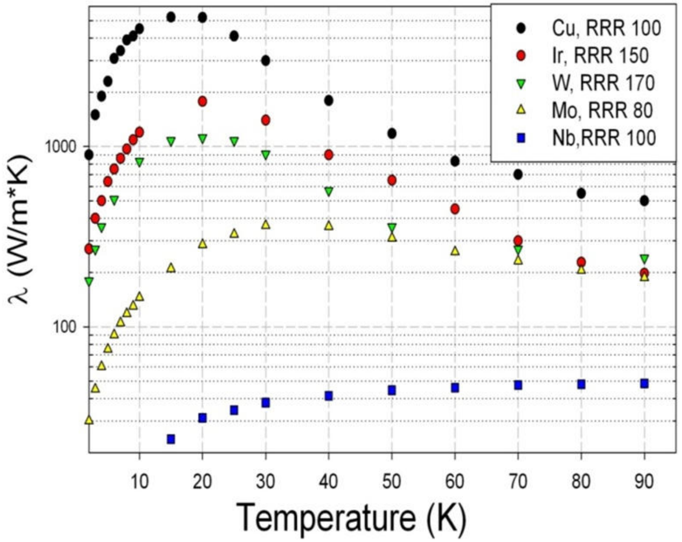


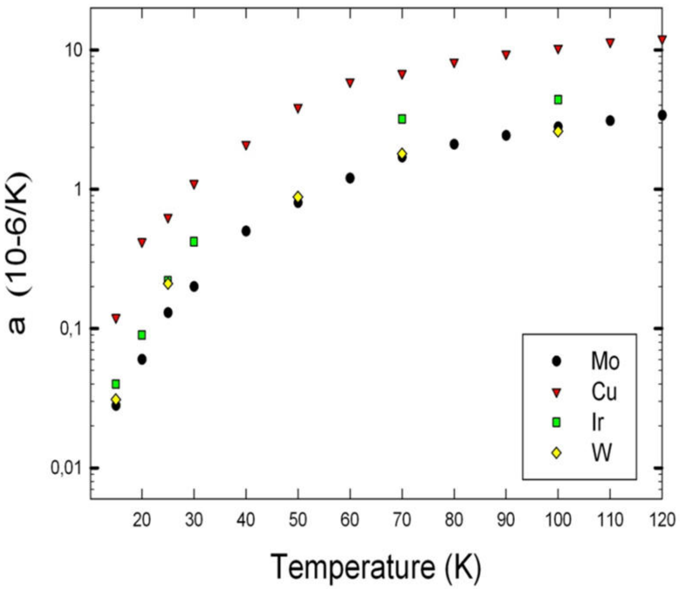


Helium 4.22 K
Hydrogen 20.3 K
Neon 27 K

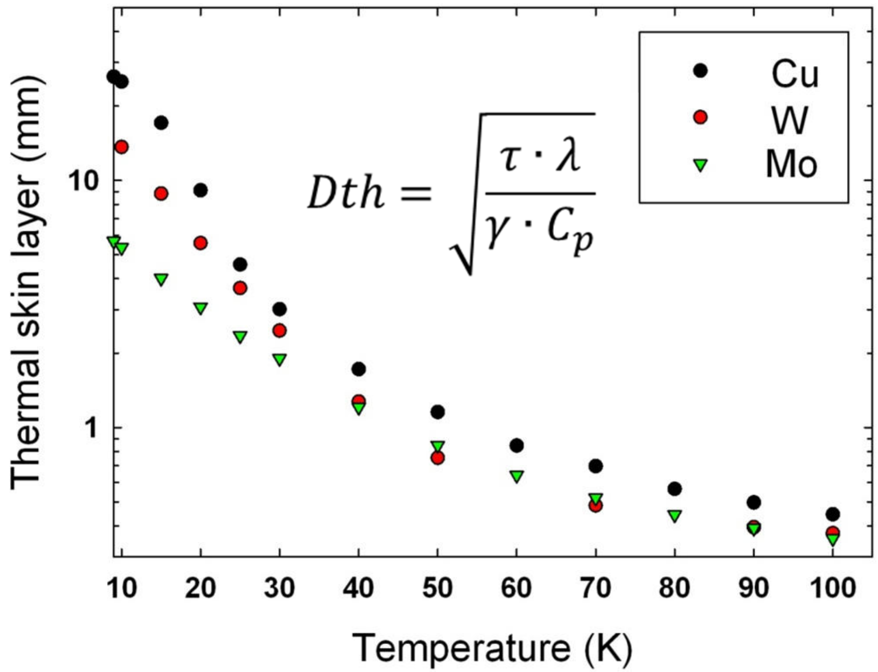
L.A. Novickiy, I G. Kozhevnikov "Thermo physical properties of materials in the low temperature region" Moscow 1975. In Russian

Some properties of pure Cu, W, Mo and Ir in low temperature



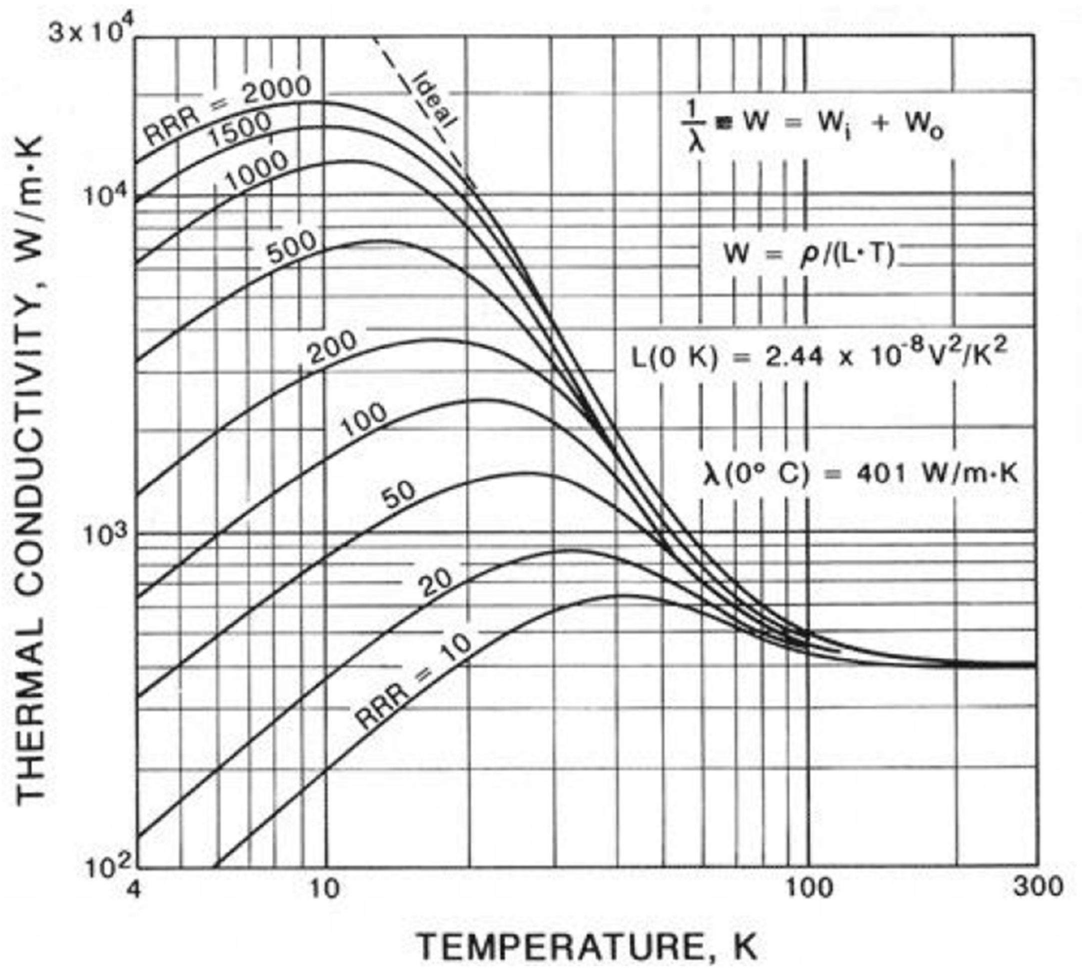


τ = 1 mSec



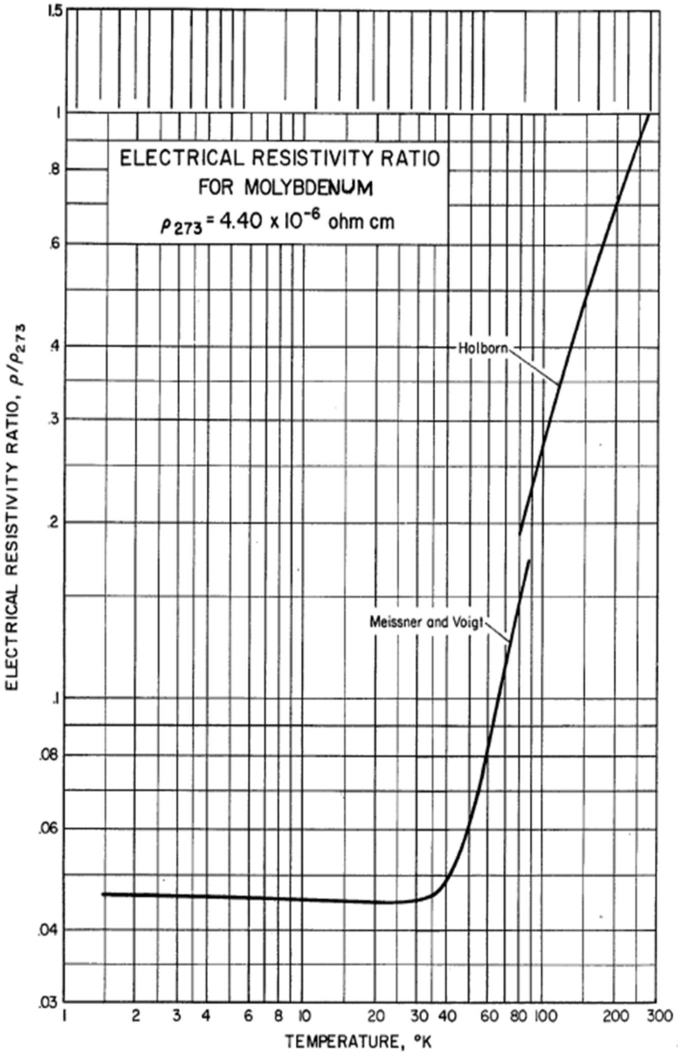
$$Dth = \sqrt{\frac{\tau \cdot \lambda}{\gamma \cdot C_p}}$$

Cupper, thermal conductivity



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

Electrical resistivity of Copper and Molybdenum



BROOKHAVEN NATIONAL LABORATORY
SELECTED CRYOGENIC
DATA NOTEBOOK

VOLUME II
SECTIONS X-XVIII

Compiled and Edited by
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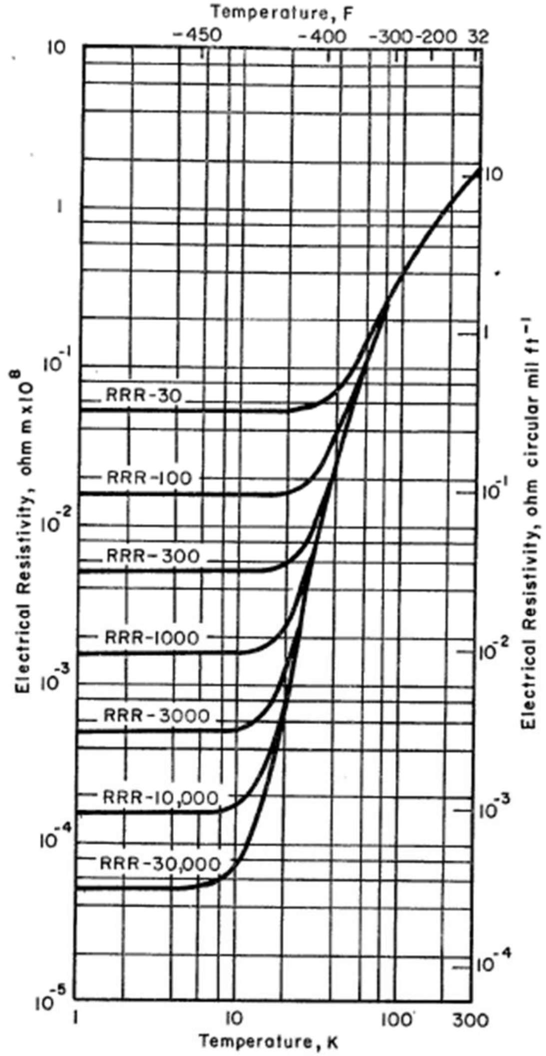


ELECTRICAL RESISTIVITY VERSUS TEMPERATURE FOR COPPER

Thermal losses in the Gun for different materials

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
Cu	300	$1.72*10^{-8}$	385	384	$1.83*10^{-6}$	$3.3*10^{-4}$	46.2	$4.7*10^{7}$
	20	~ $5*10^{-11}$ **RRR~400**	~ 7	~6000	$9.8*10^{-8}$	$9.8*10^{-3}$	**4.6**	**$2.5*10^{6}$**
Mo	20	~ $8*10^{-11}$ **RRR~600**	~ 3.5	~360	$29.2*10^{-8}$	$3.2*10^{-3}$	**32**	**$3.2*10^{6}$**
W	20	~ $1.2*10^{-10}$ **RRR~450**	~ 2	~ 1600	$15.2*10^{-8}$	$6.5*10^{-3}$	**18**	**$3.9*10^{6}$**
Ir	20	~ $1.0*10^{-10}$ **RRR~450**	~ 3	~ 1900	$13.9*10^{-8}$	$5.3*10^{-3}$	**11.3**	**$3.5*10^{6}$**

Not included anomalous skin effect !!!

- *FreyIr, Haefar* "Tieftemperatur technologie" 1981, p. 5.1.1-1(11/74)
- *Л.А. Новицкий, И.Г.Кожевников* "Теплофизические свойства материалов при низких температурах", Moscow 1975.

Thermophysical properties of matter, IFI/PLENUM, NEW YORK-Washington 1970

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 electrons*

N ~ RRR

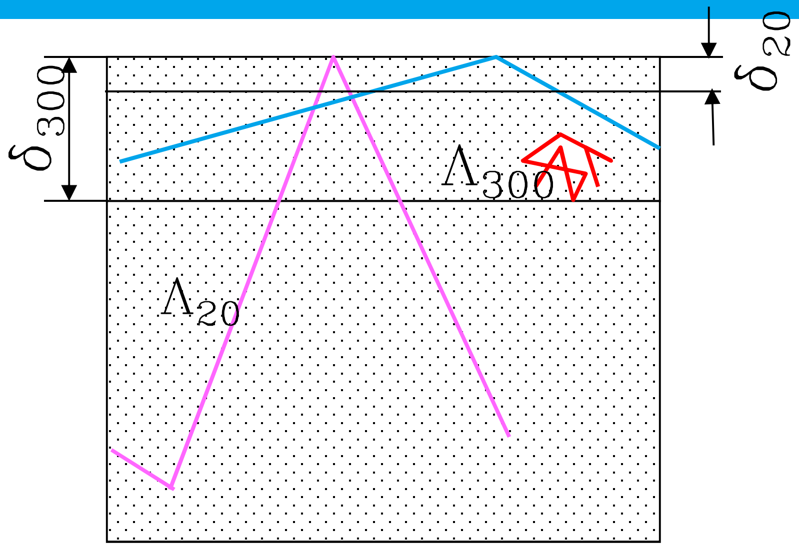
	δ/Λ, T=300 K 1.3 GHz	δ/Λ, T=20 K 1.3 GHz	δ/Λ T=300 K 11.4 GHz	δ/Λ T=20 K 11.4 GHz	Q_{20}/Q_{300} 11.4GHz	Q_{20}/Q_{300} 1.3GHz
Cu	27	**2.4*10^{-3}**	16	0.81*10^{-3}	**4.4 (exp)**	**~ 6.2 (estim)**
Mo	47	**2.3*10^{-3}**				~ 6

DESY GUN 5

60 MV/m ~ 6.18 MW

Cold GUN

60 MV/m - ~ 1 MW



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.

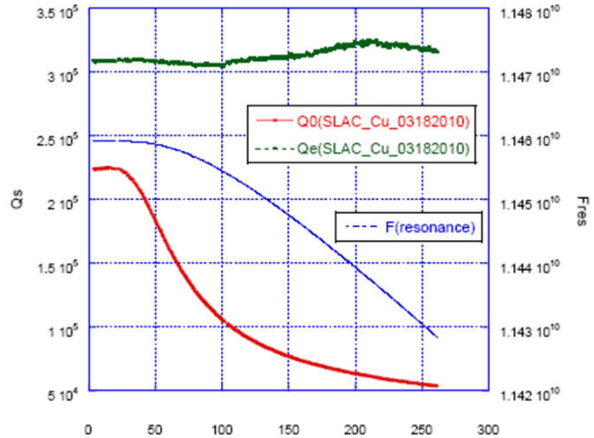
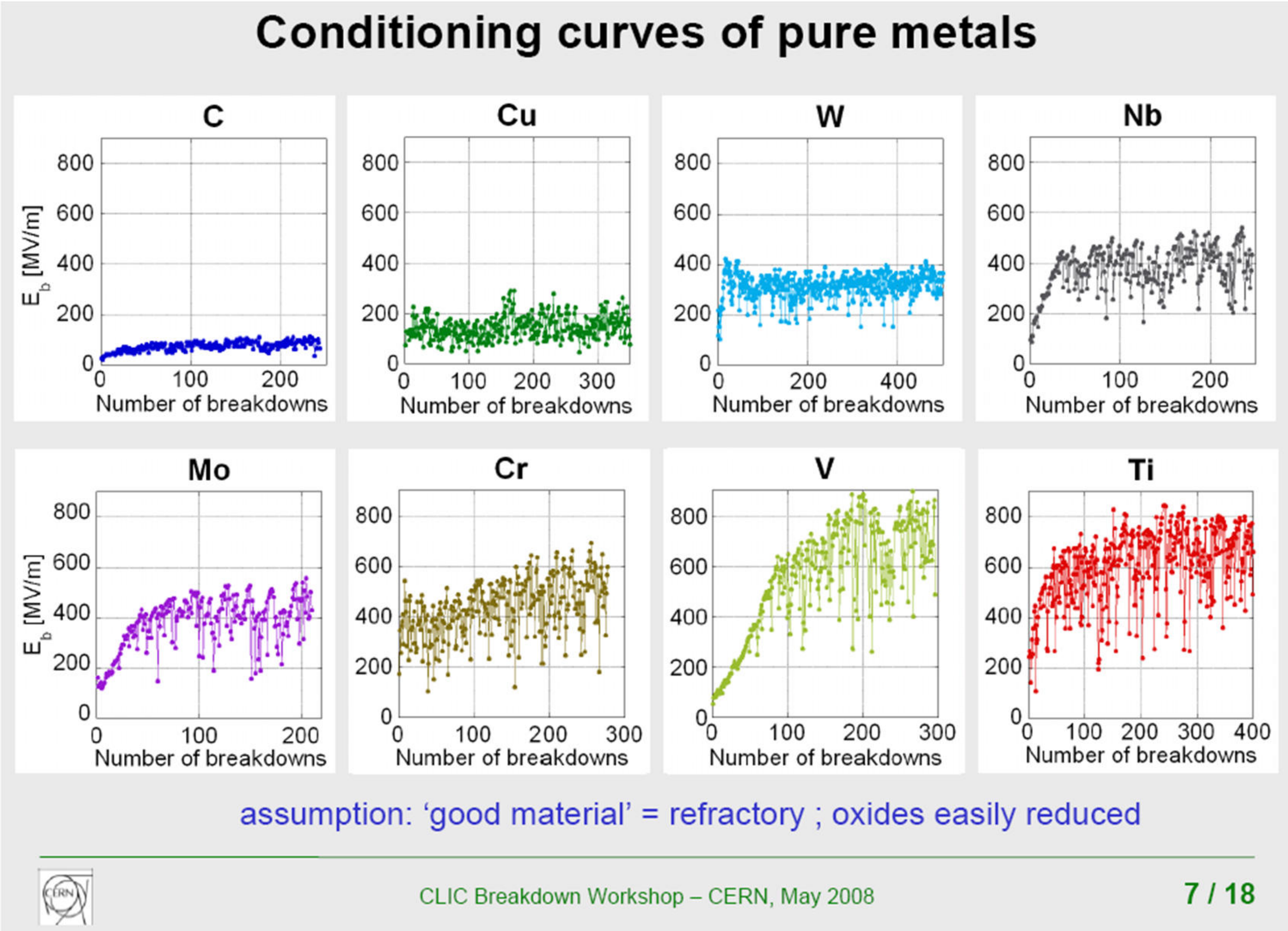


Figure 4: Low power measurement of the SLAC copper sample

Conditioning of pure metals in pulse DC mode



Cold GUN, regimes for conditions and for the normal operation

Mo T=20 K

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

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

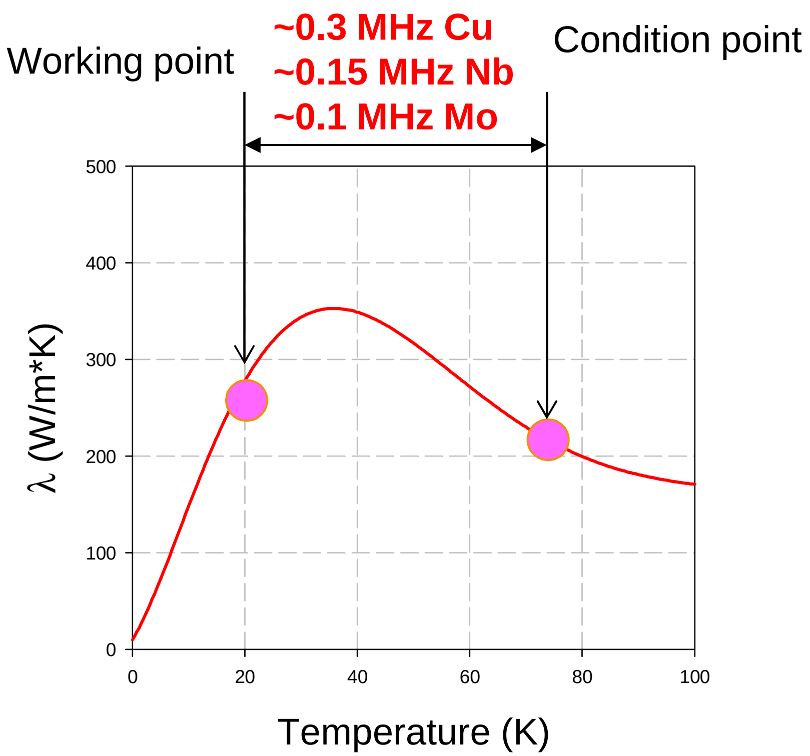
$$c_{p20} = 0.1 \cdot c_{p300}$$

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

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

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

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



No reason for the breakdown in standard BD model.

Problem: must be a possibility to change photocathodes in the RF GUN !!

1. From W, Ir and Mo we can easy make only very simple shapes like a disks.
2. At the moment we can only get from the industry very pure thin sheets of W, Ir and Mo with maximal sizes just about 100 mm.

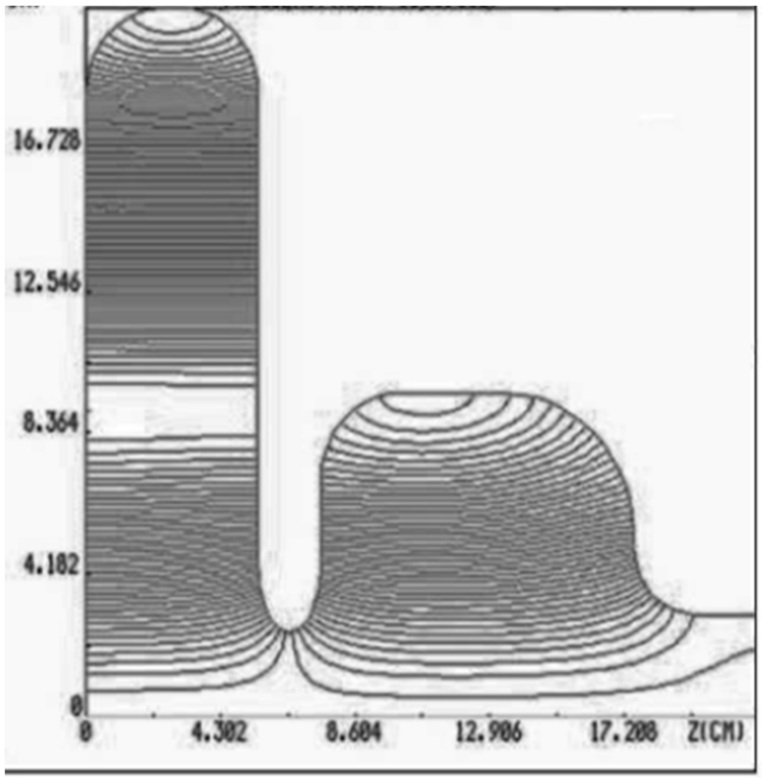
Solution #1

To make the first half cell of cavity as an oversized, operated on TM 020 mode at the working frequency.

\+ * a removable connection can be done without problems for TM020 mode in cavity, because there is a circumference where we don't have any of radial current,

  * the oversize cavity has a higher Q factor and can be cooled better due to larger surface.

\- * this type of cavity can only be done for a frequency more than 2.9 GHz because of the limitation on max size of available metals.



RF GUN cavity design

Oversize cavity:

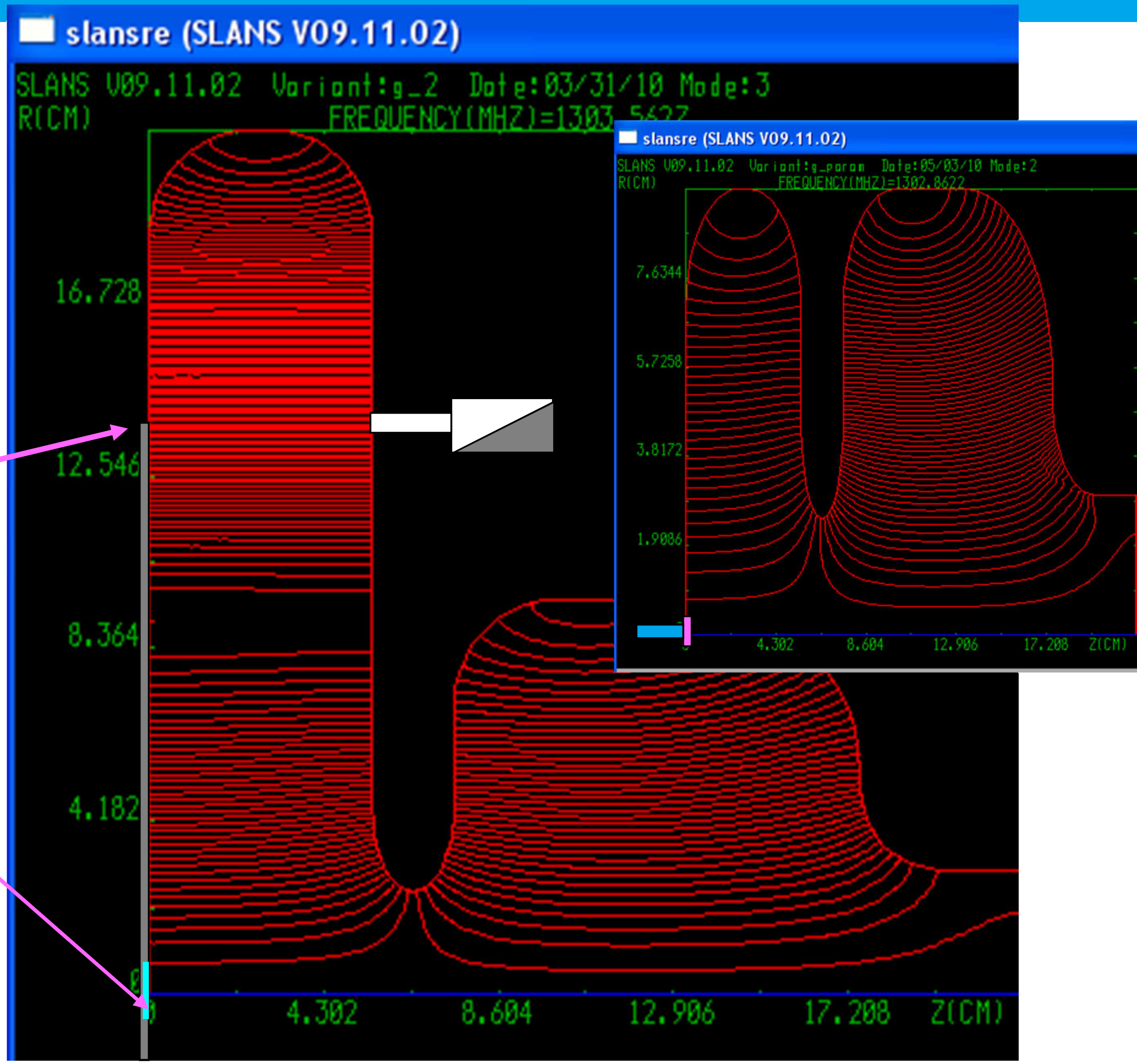
Example:
TM020 in first half cell
TM010 in second cell

1. *No tangential current for TM020, slot for cathode changing, damping of HOMs*

2. More space for input couplers.

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

4. Cathode part of cavity can be made from very hard material



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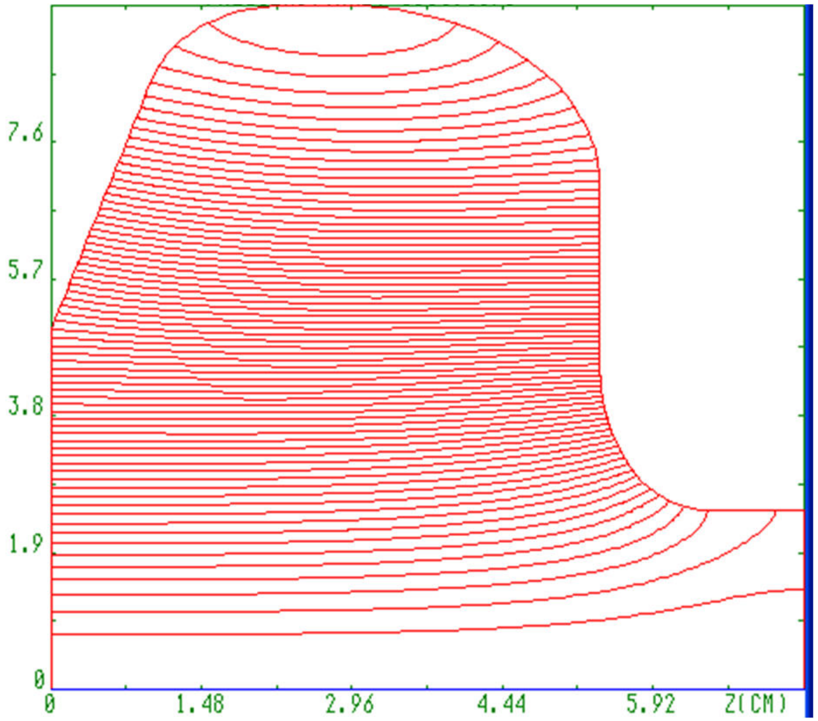


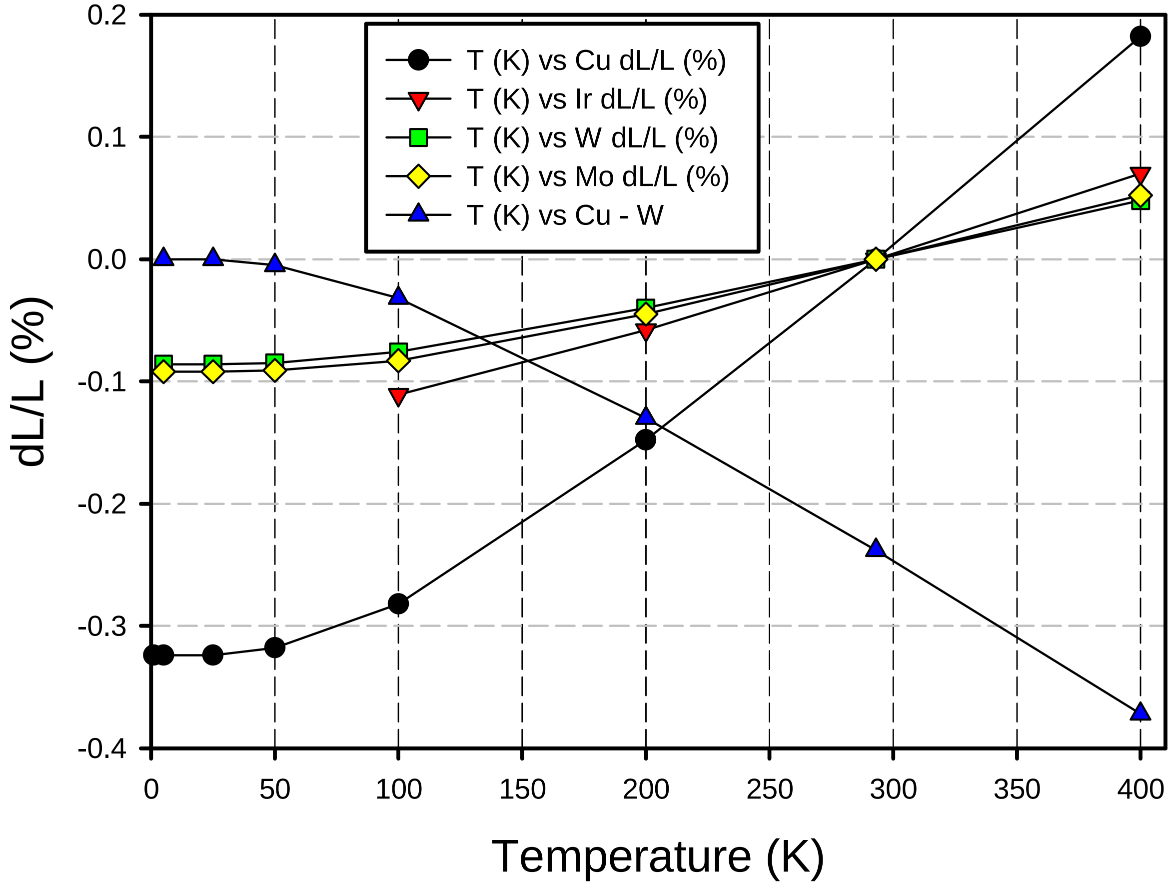
Solution #2

For removable connection, we can use a fact that a factor of thermal expansion for Cu for one side and W, Ir and Mo for the other have a big difference.

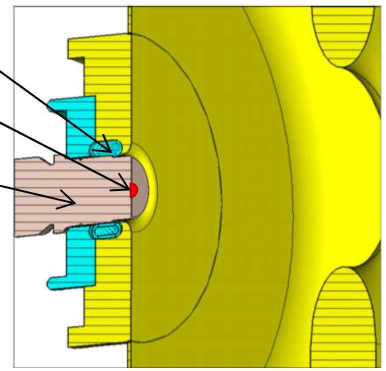
\+ * 1.3 GHz cavity can be produced using existing 100 mm sheets from the industry
 * over electrical fields that arise due to inaccuracies of fabrication in the contact area could be shielded by inner angle in the cavity.
 * easy to test on the existing DESY cryostats

\- * limitation of working cycles because of a peening.

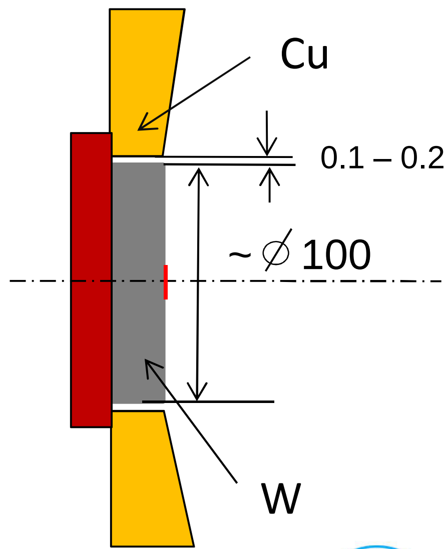
Removable connection of two kinds of metals (Cu + W, Ir or Mo) in one cavity



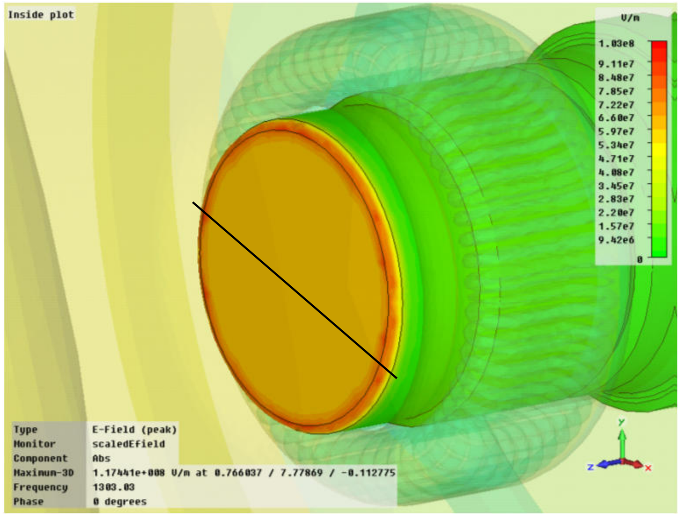
GUN #5

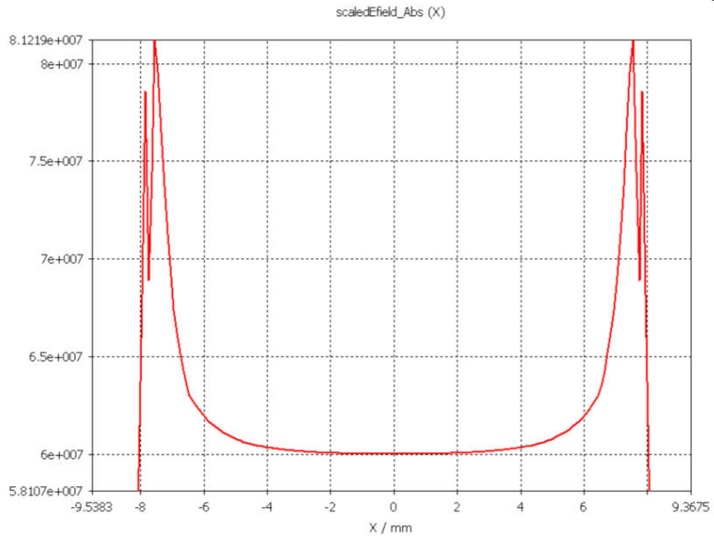


Cold GUN

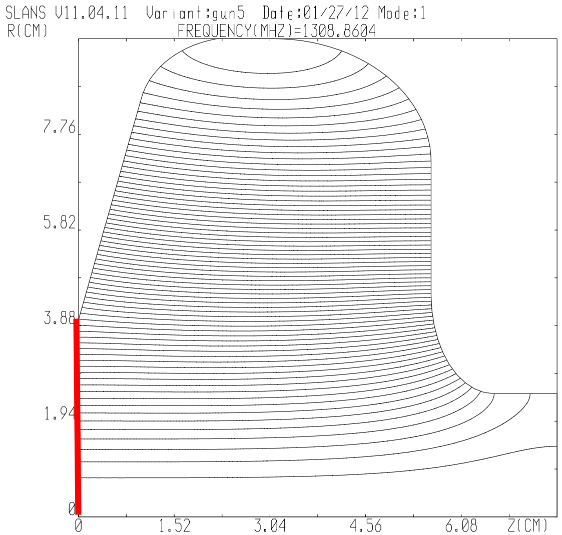


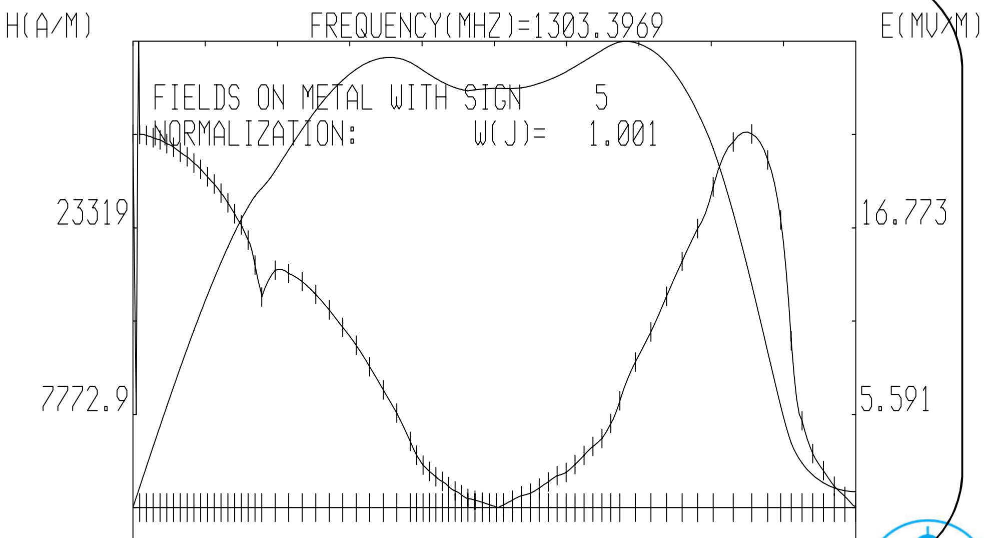
GUN #5





Cold GUN





Conclusion

Heating and thermal expansion in the normal conductivity RF-photo electron gun are the main limitations to achieve high accelerating gradient and consequently a low emittance beam. Some pure materials show a significant increase in thermal conductivity with a small coefficient of temperature expansion at temperatures around 20 degrees Kelvin. Possible materials are Molybdenum, Iridium or Tungsten. However, machining of these materials is very difficult. Therefore we propose a simplified shape for an L-band RF gun. We expect to achieve a significant increase in gradient for similar RF powers as used in the present DESY RF-gun. On the other hand, it would also be possible to increase the duty cycle keeping a moderate gradient and to decrease heat losses, frequency shift and dark current.

Thank you for attention!