

20 Kelvin cold High gradient RF gun

Materials and gradient

Some properties of pure metals in low temperature region

Cold RF-photo GUN design

Vladimir Vogel,

Motivation

Super conductive Linac



Normal temperature RF Gun

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

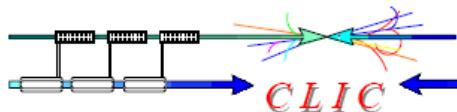
Low emittance -> high gradient

Dissipated power -> low temperature (DESY RF GUN #5, $T_{iris} = 72^\circ C + 46^\circ C$ pulse heating)

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

Dark current -> new geometry + new materials

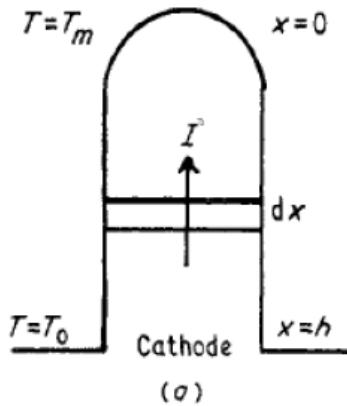
Breakdown mechanisms



Analytical estimates for a cylindrical tip



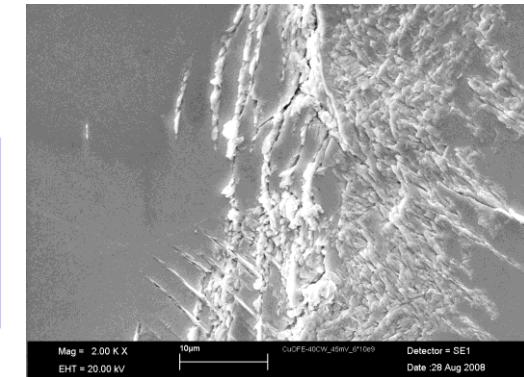
For a cylindrical protrusion heat conduction is described by:



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

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



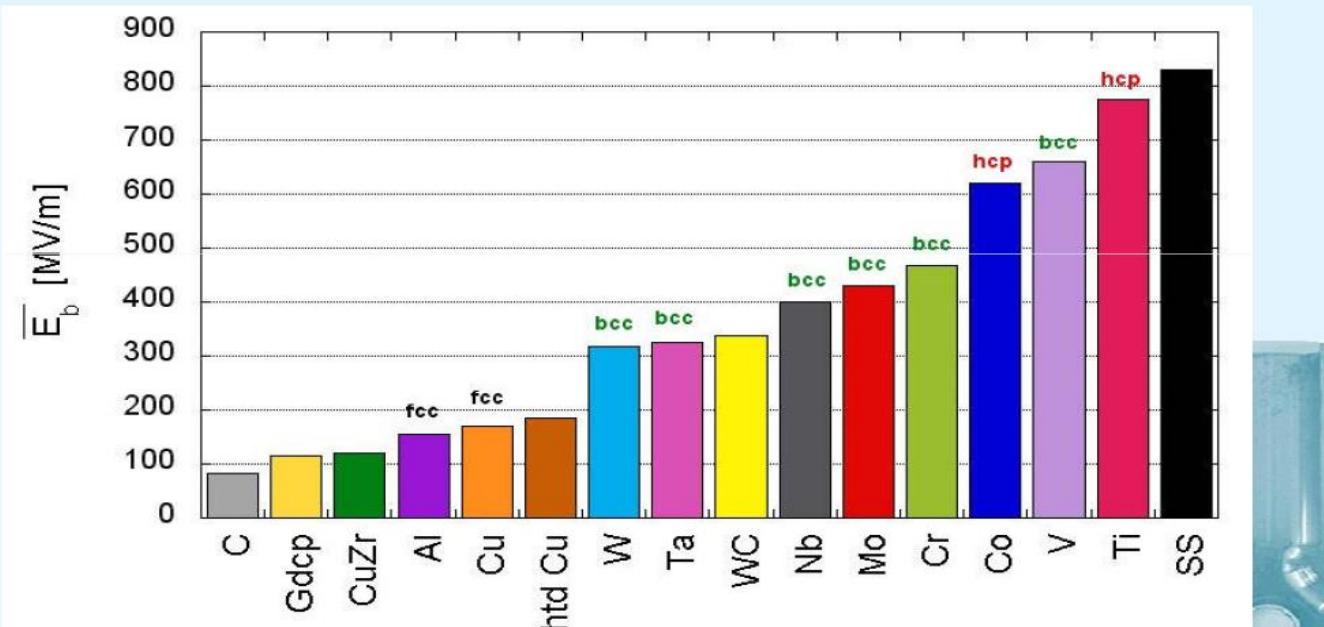
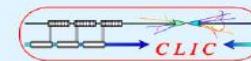
[Breakdown & Pulsed Surface Heating Studies:](#)
[Thermal Fatigue behavior versus Grain Orientation](#)
by Markus AICHELER (Ruhr-Universitaet Bochum)

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

Breakdown study, pulse DC



Ranking materials by crystal structure?



H. Timkó, CERN

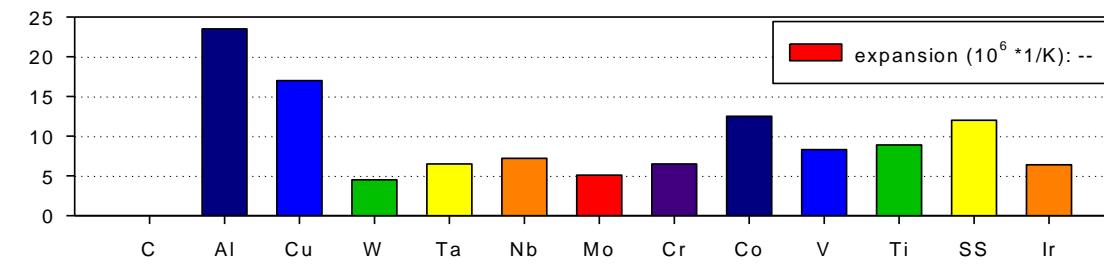
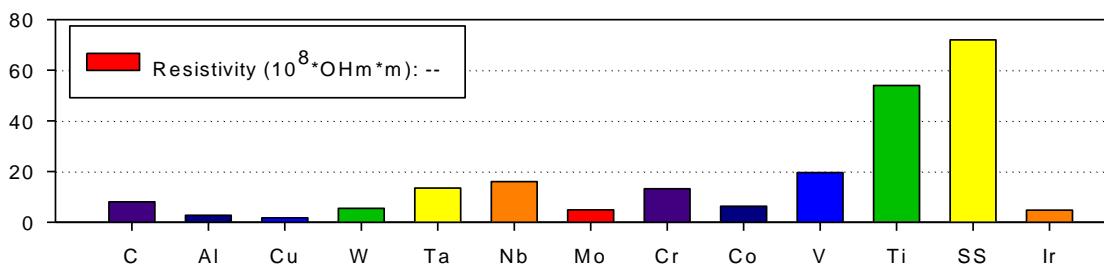
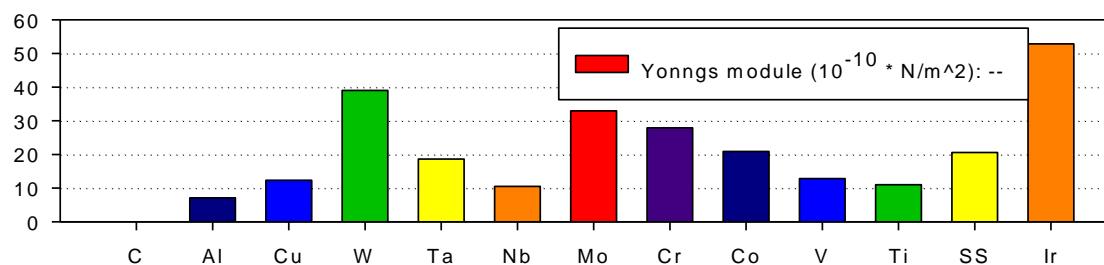
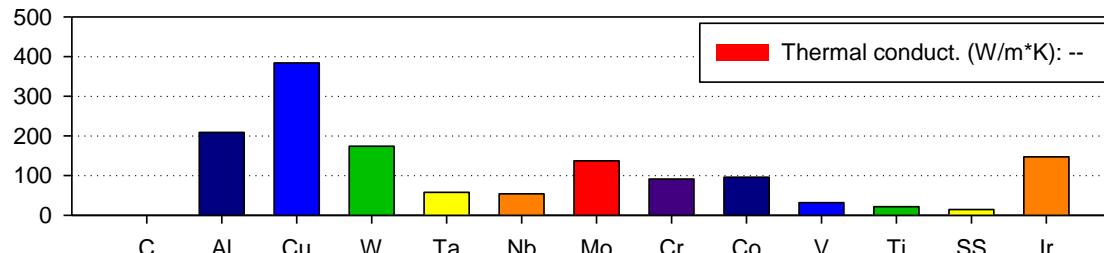
CLIC workshop 2009

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

A. Descoeuilles, * 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)

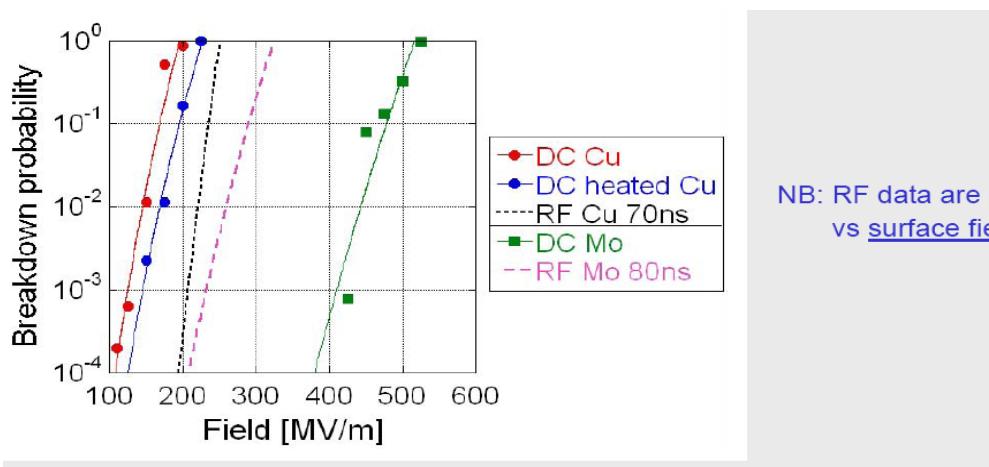
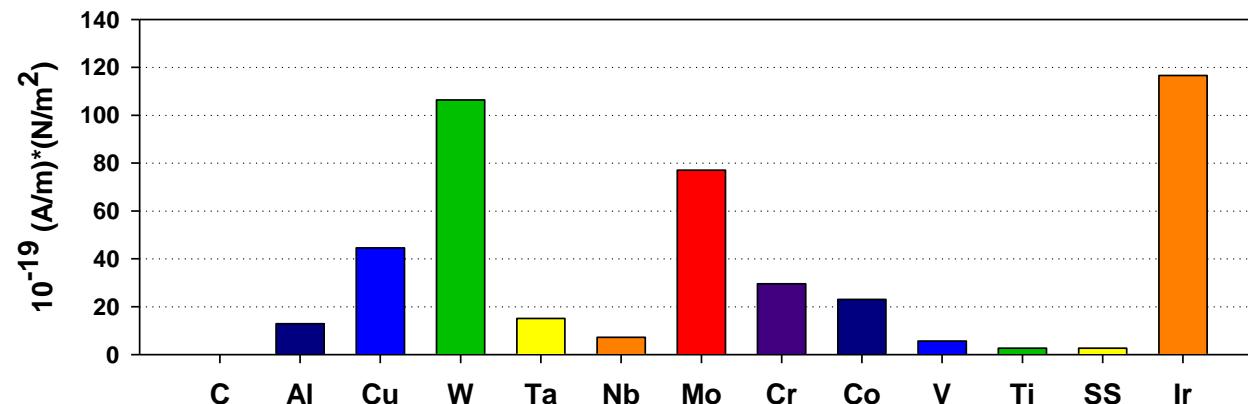
Some property of pure metals in normal temperature



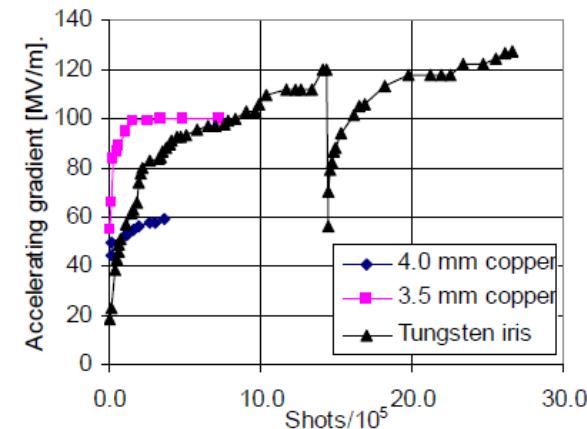
Ranking materials: RF, high gradient

Temperature ~ 300 K

$$Ey^*(\lambda_{ar})^{0.5}$$



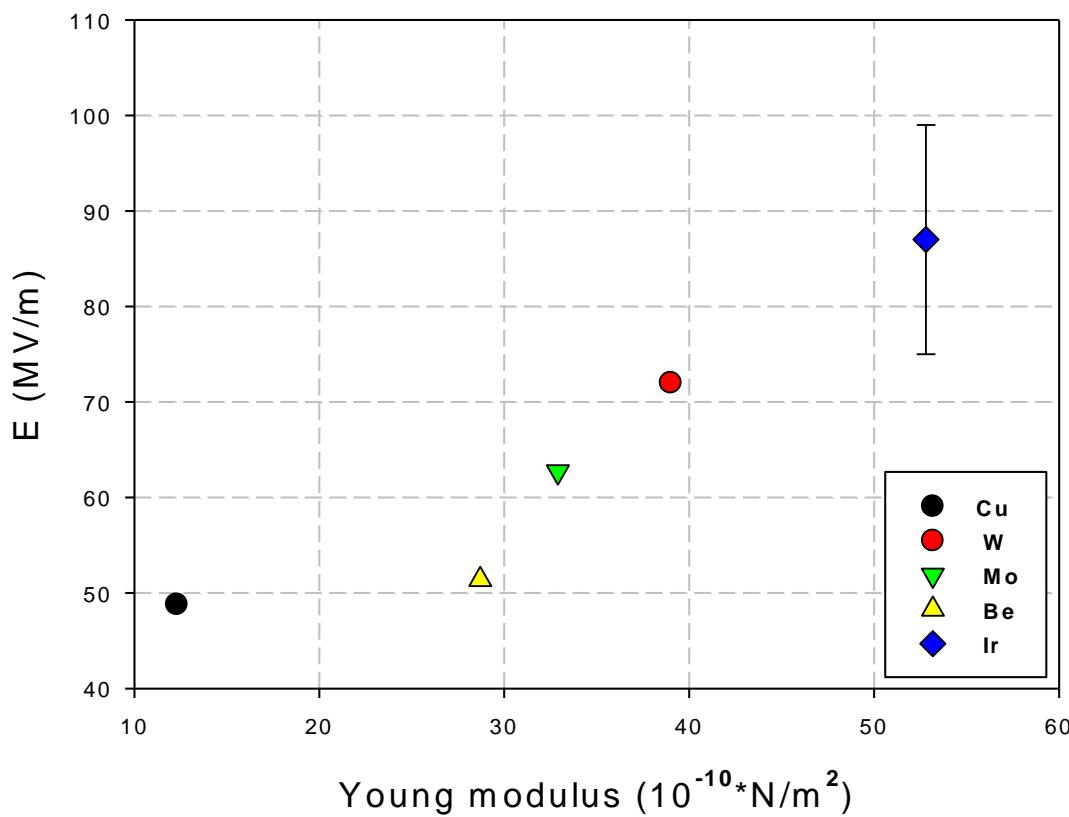
NB: RF data are p vs surface field



CLIC HIGH-GRADIENT TEST RESULTS

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

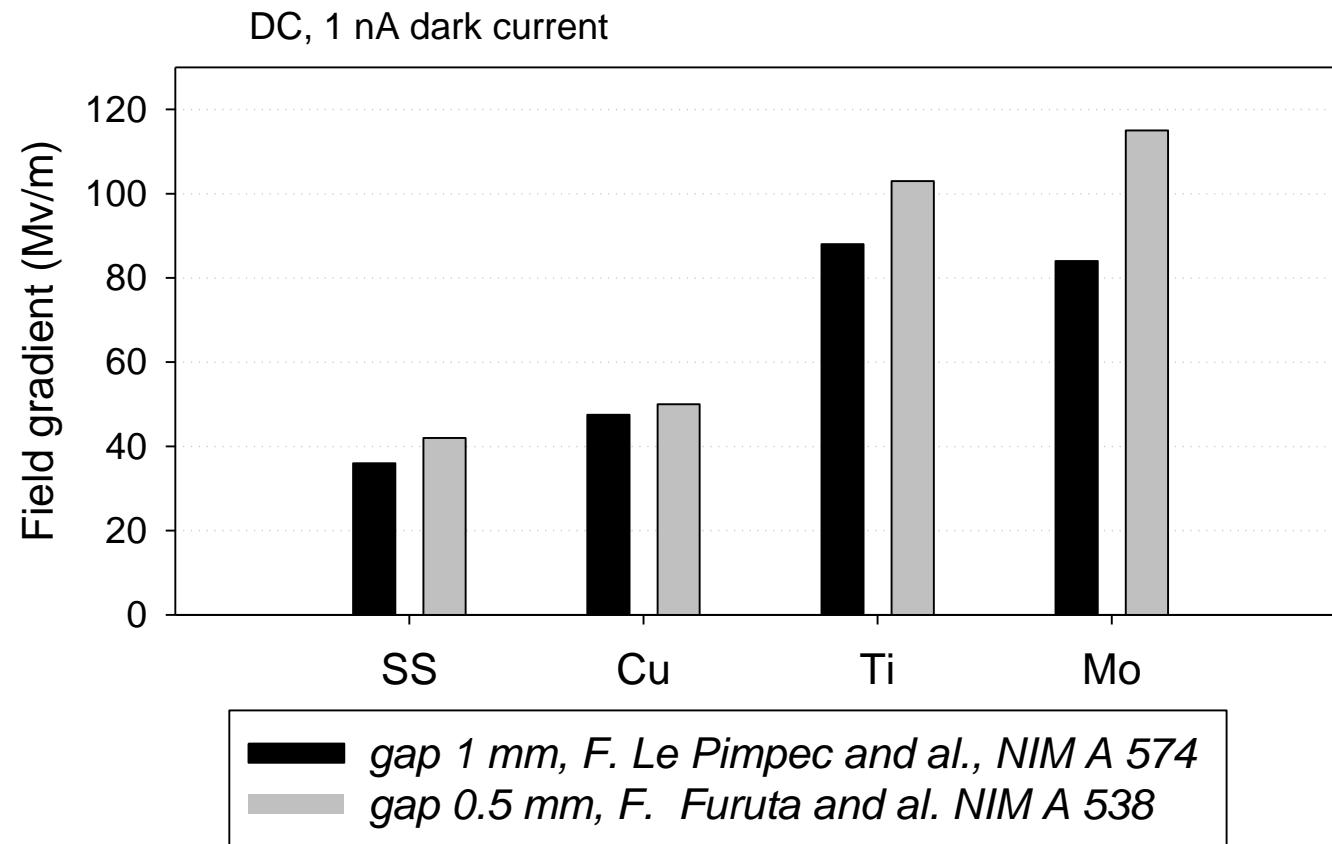
Gradient in the pressurized cavity.



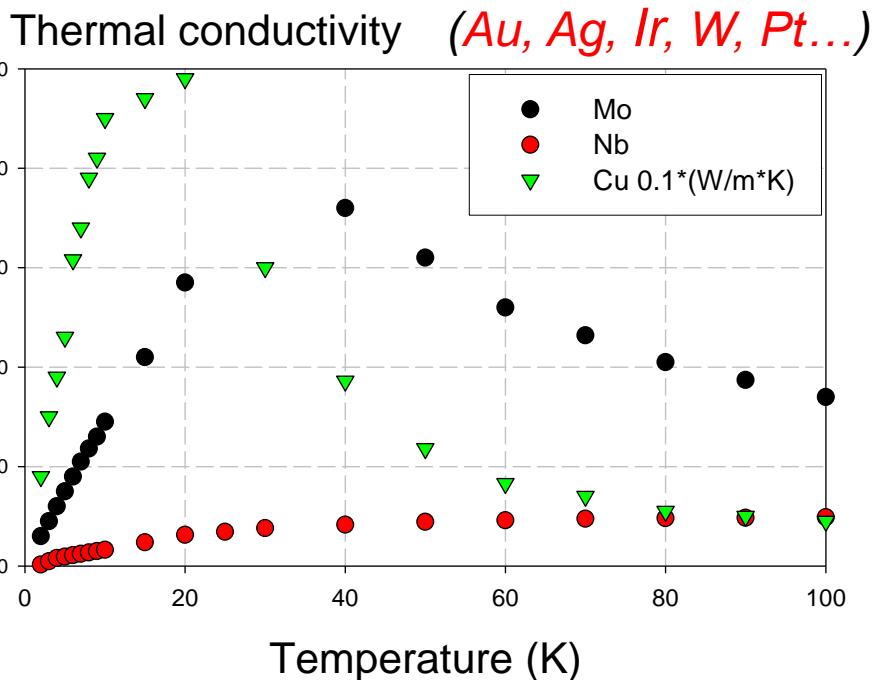
Maximum stable gradient as a function of the Young's modulus for different materials.
RF frequency 805 MHz, Hydrogen pressure ~ 100 bar. (data from (#), for Iridium the approximation)

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

DC dark current



Some properties of pure metals in low temperature

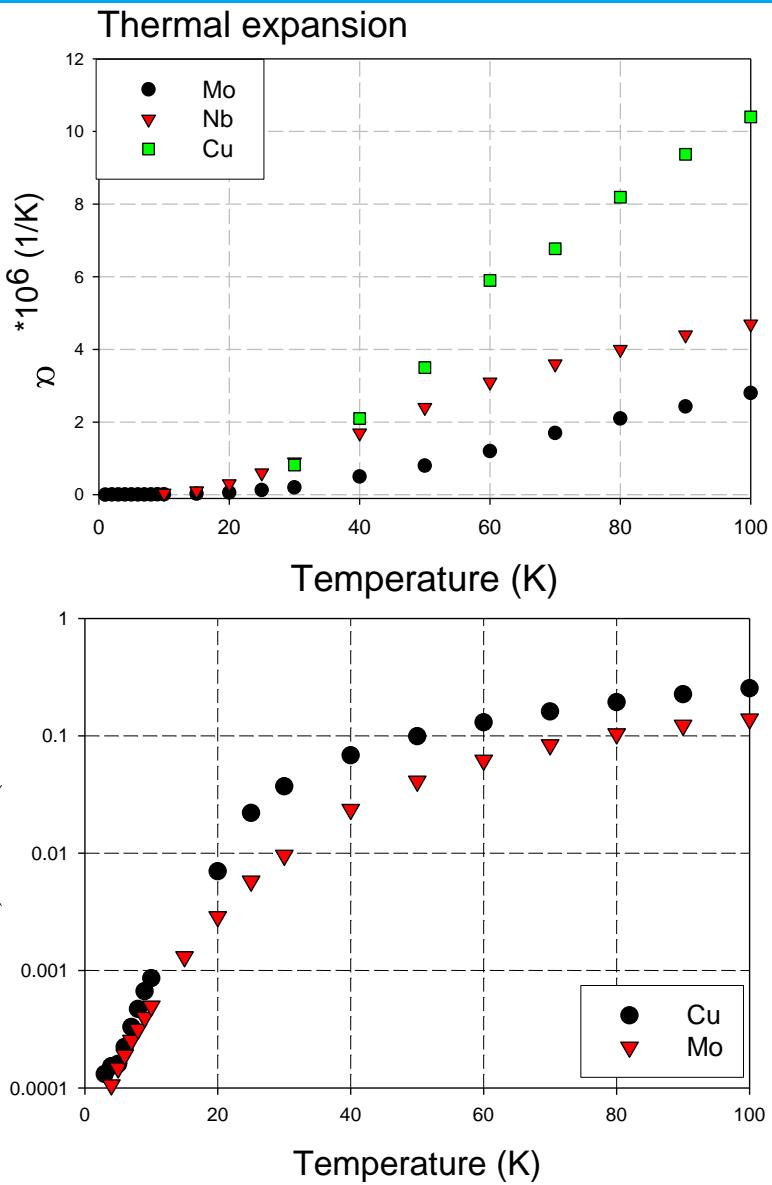


Helium 4.22 K

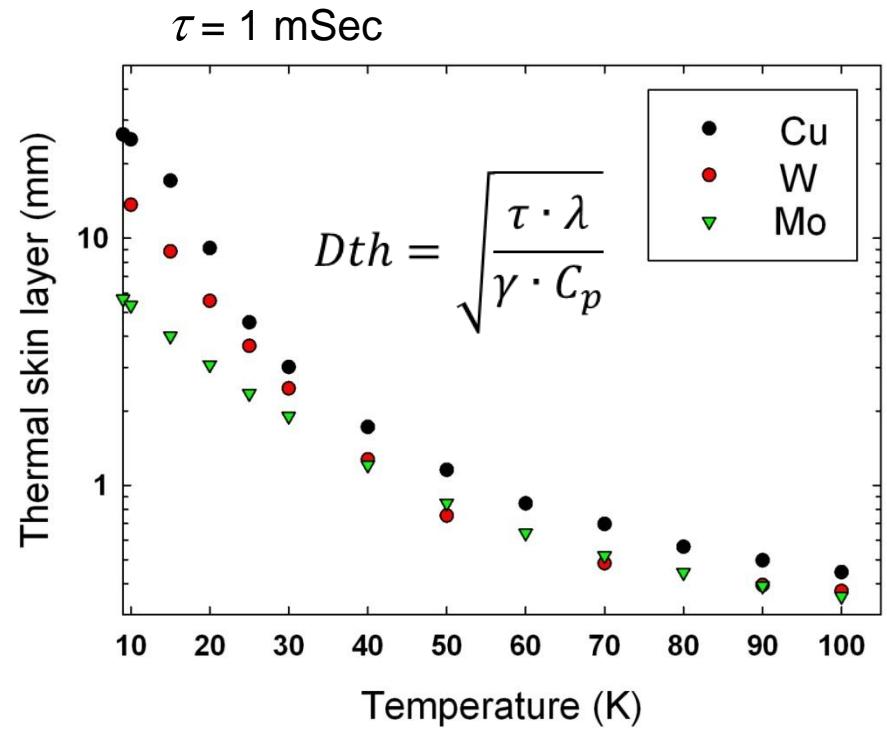
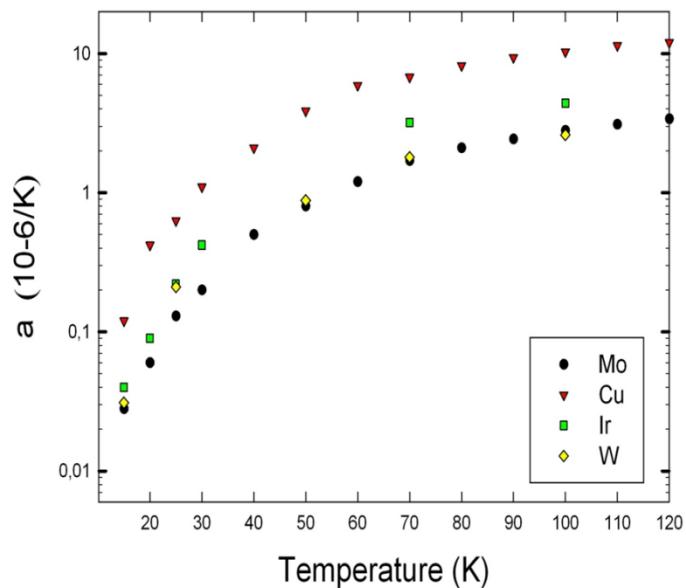
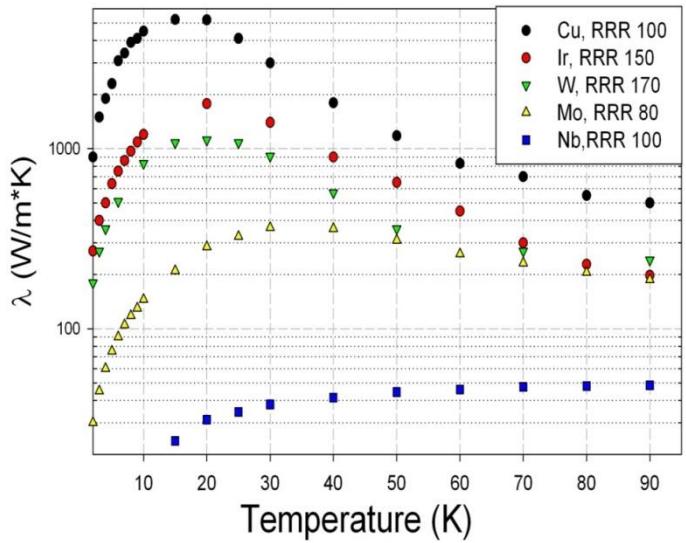
Hydrogen 20.3 K

Neon 27 K

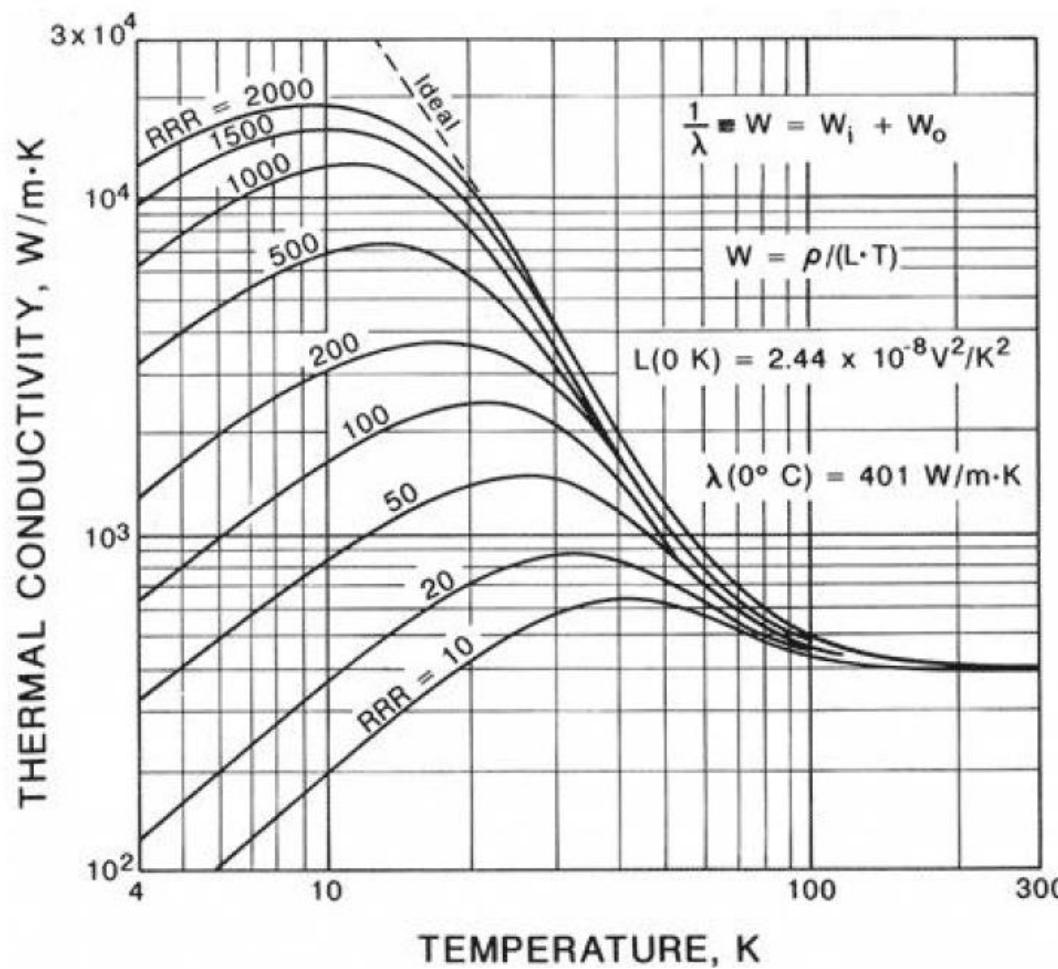
L.A. Novickiy, I.G. Kozhevnikov
 "Thermo physical properties of
 materials in the low temperature region"
 Moscow 1975. In Russian



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

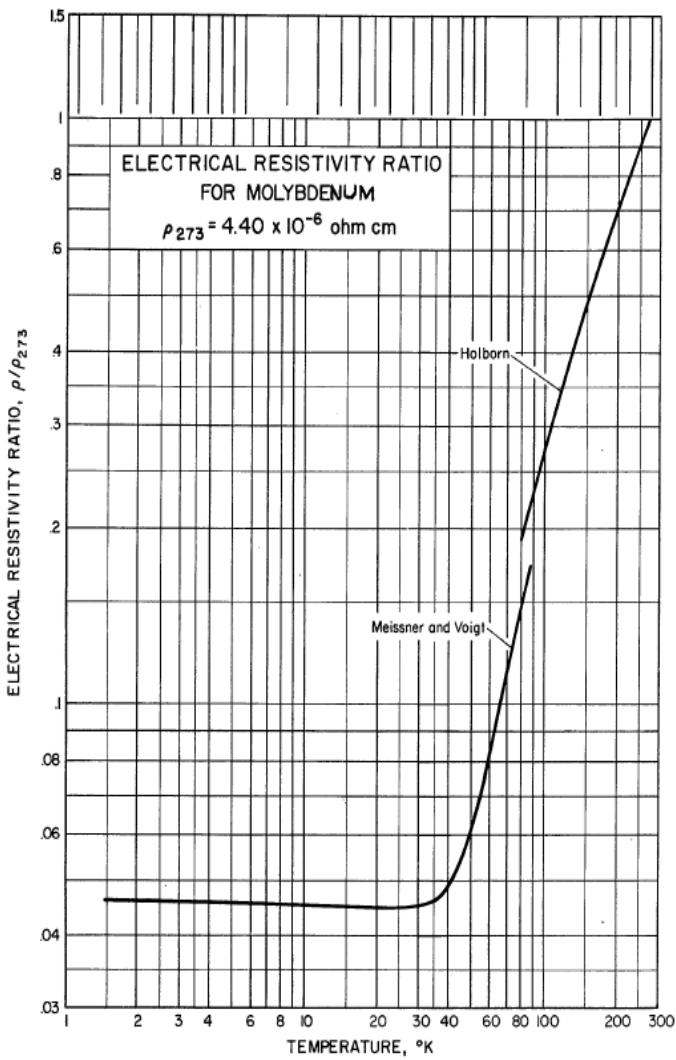


Copper, thermal conductivity



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

Electrical resistivity of Copper and Molybdenum

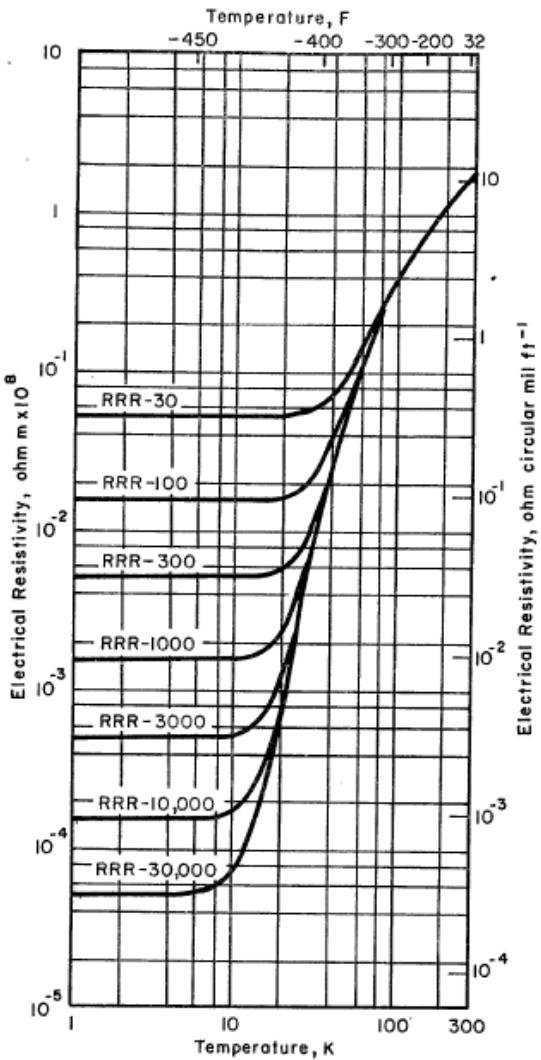


BROOKHAVEN NATIONAL LABORATORY SELECTED CRYOGENIC DATA NOTEBOOK

VOLUME II SECTIONS X-XVIII

Compiled and Edited by
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A.G. Prodell

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2. Institute of Technology, Rapperswil, Switzerland



ELECTRICAL RESISTIVITY VERSUS TEMPERATURE FOR COPPER

Thermal losses in the Gun for different materials

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

$f = 1300 \text{ MHz}$, $T_{rf} = 1 \text{ mS}$, $H_{pmax} = \sim 100 \text{kA/m}$

$$L_t = (\lambda * \tau / (\gamma * C_p))^{1/2}$$

$$\Delta T_s = (\tau^* \rho^* f^* \mu / \gamma * \lambda * C_p)^{1/2} * (H_p)^2$$

	T (K)	ρ (Ohm*m)	C_p (J/kg*K)	λ (W/m*K)	δ (m)	L_t (m)	ΔT_s (K) 60 MV/m	P (W/m ²) 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	$\sim 5 * 10^{-11}$ RRR~400	~ 7	~ 6000	$9.8 * 10^{-8}$	$9.8 * 10^{-3}$	4.6	$2.5 * 10^6$
Mo	20	$\sim 8 * 10^{-11}$ RRR~600	~ 3.5	~ 360	$29.2 * 10^{-8}$	$3.2 * 10^{-3}$	32	$3.2 * 10^6$
W	20	$\sim 1.2 * 10^{-10}$ RRR~450	~ 2	~ 1600	$15.2 * 10^{-8}$	$6.5 * 10^{-3}$	18	$3.9 * 10^6$
Ir	20	$\sim 1.0 * 10^{-10}$ RRR~450	~ 3	~ 1900	$13.9 * 10^{-8}$	$5.3 * 10^{-3}$	11.3	$3.5 * 10^6$

Not included anomalous skin effect !!!

- Freyrl, 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

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

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

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

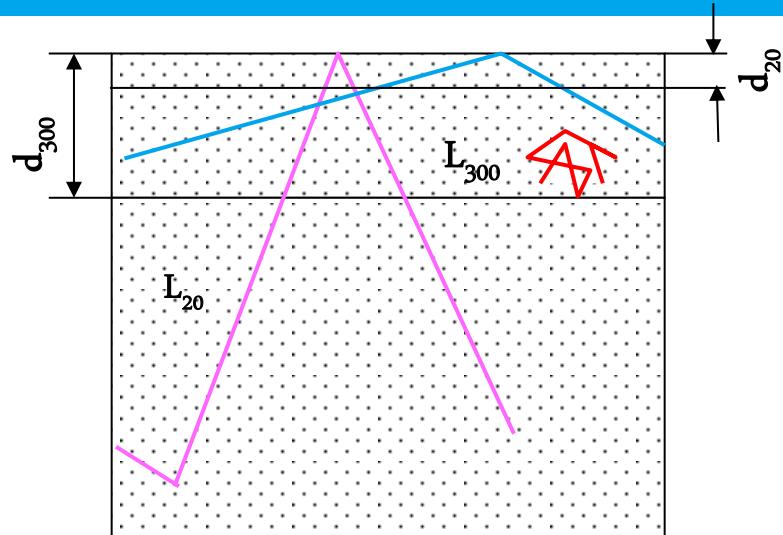
R ~ reflection factor for electrons

$N \sim RRR$

	d/L , T=300 K 1.3 GHz	d/L , T=20 K 1.3 GHz	d/L T=300 K 11.4 GHz	d/L 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.

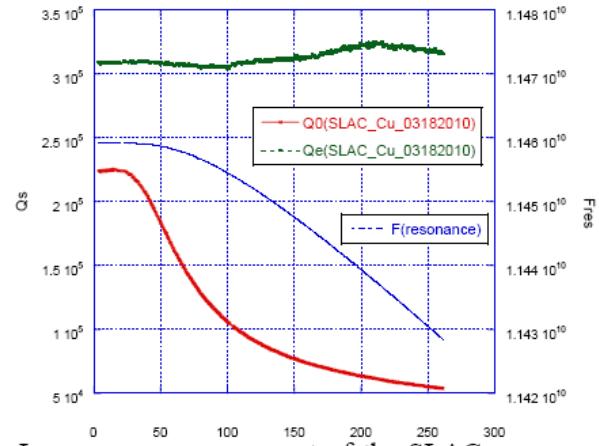
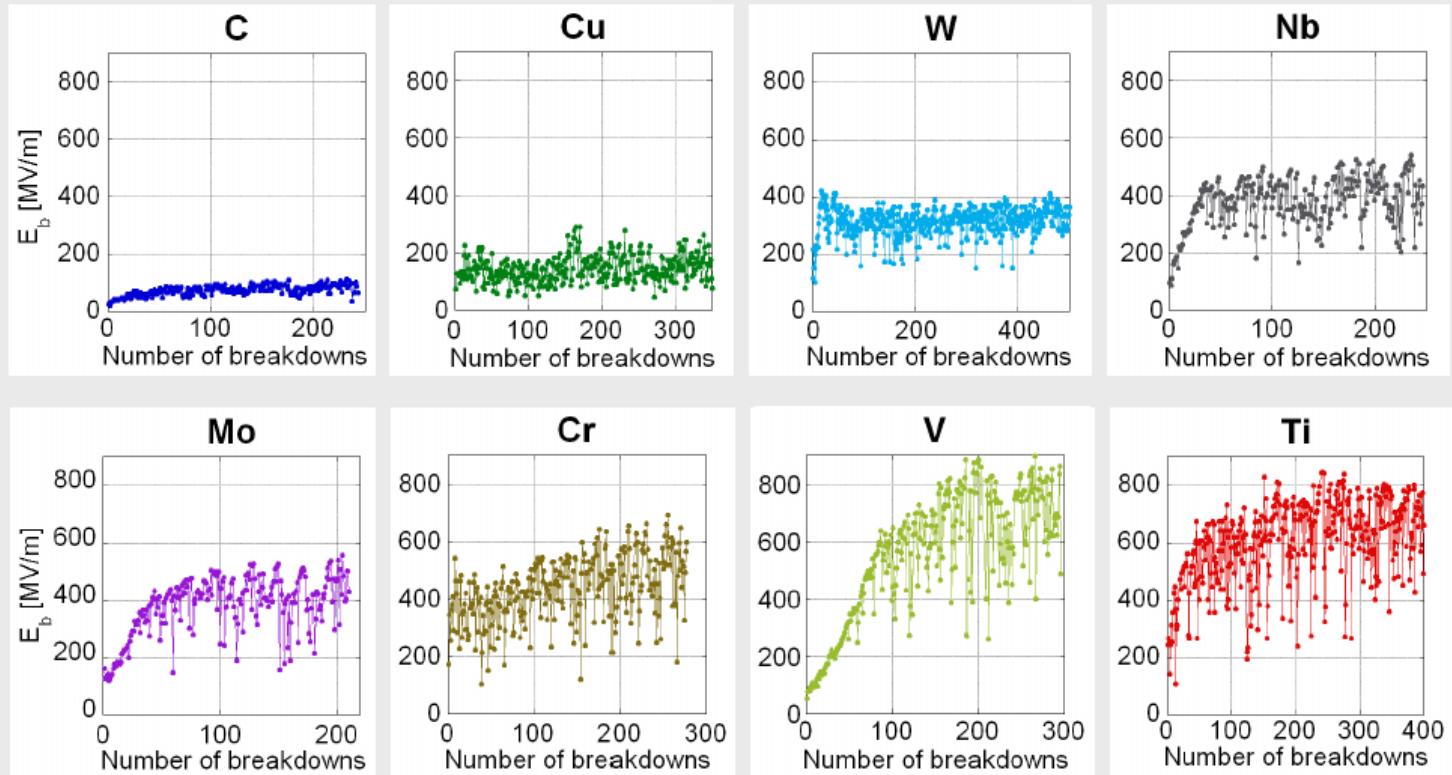


Figure 4: Low power measurement of the SLAC copper sample

Conditioning of pure metals in pulse DC mode

Conditioning curves of pure metals



assumption: 'good material' = refractory ; oxides easily reduced



CLIC Breakdown Workshop – CERN, May 2008

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Cold GUN, regimes for conditions and for the normal operation

Mo, Ir, W , T=20 K

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

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

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

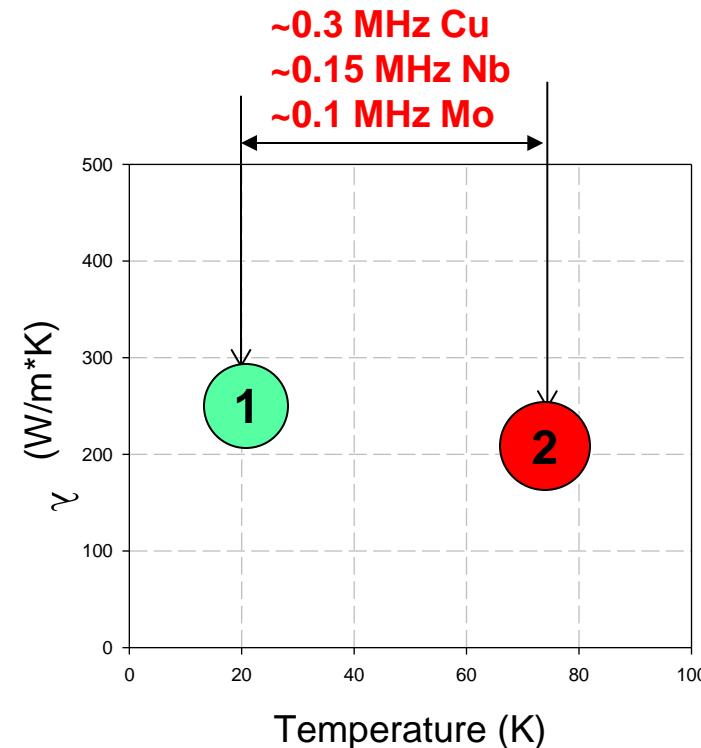
$$\frac{dc_{p20}}{dT} \geq 0$$

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

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

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

No reason for the breakdown in the standard BD model !!!



1

20 Kelvin ,working point, feedback “ON”

2

77 Kelvin , point for condition , feedback “OFF”

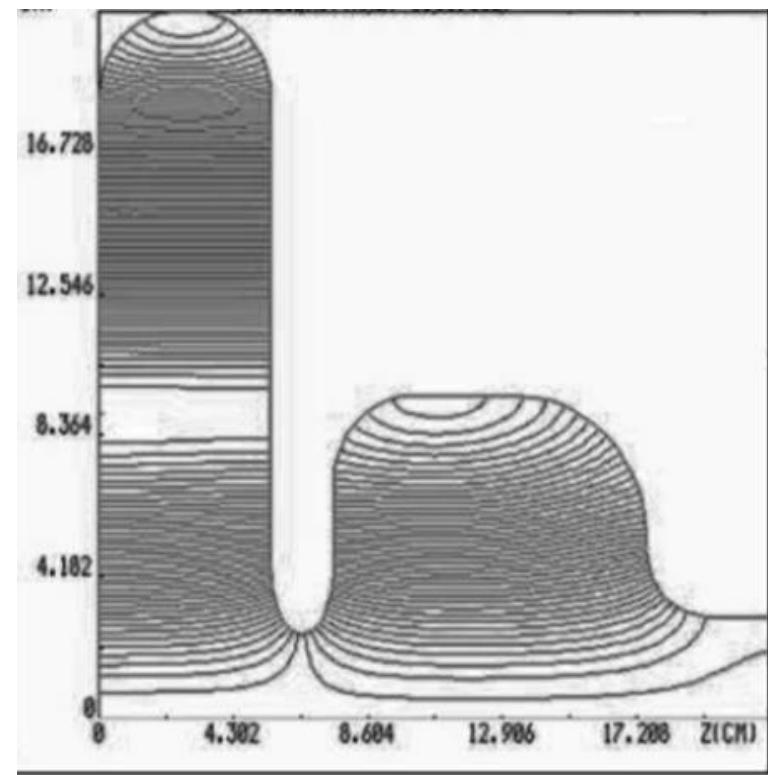
Problem: must be a possibility to change photocathodes in the RF GUN !!

1. From W, Ir and Mo we can easily 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 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.



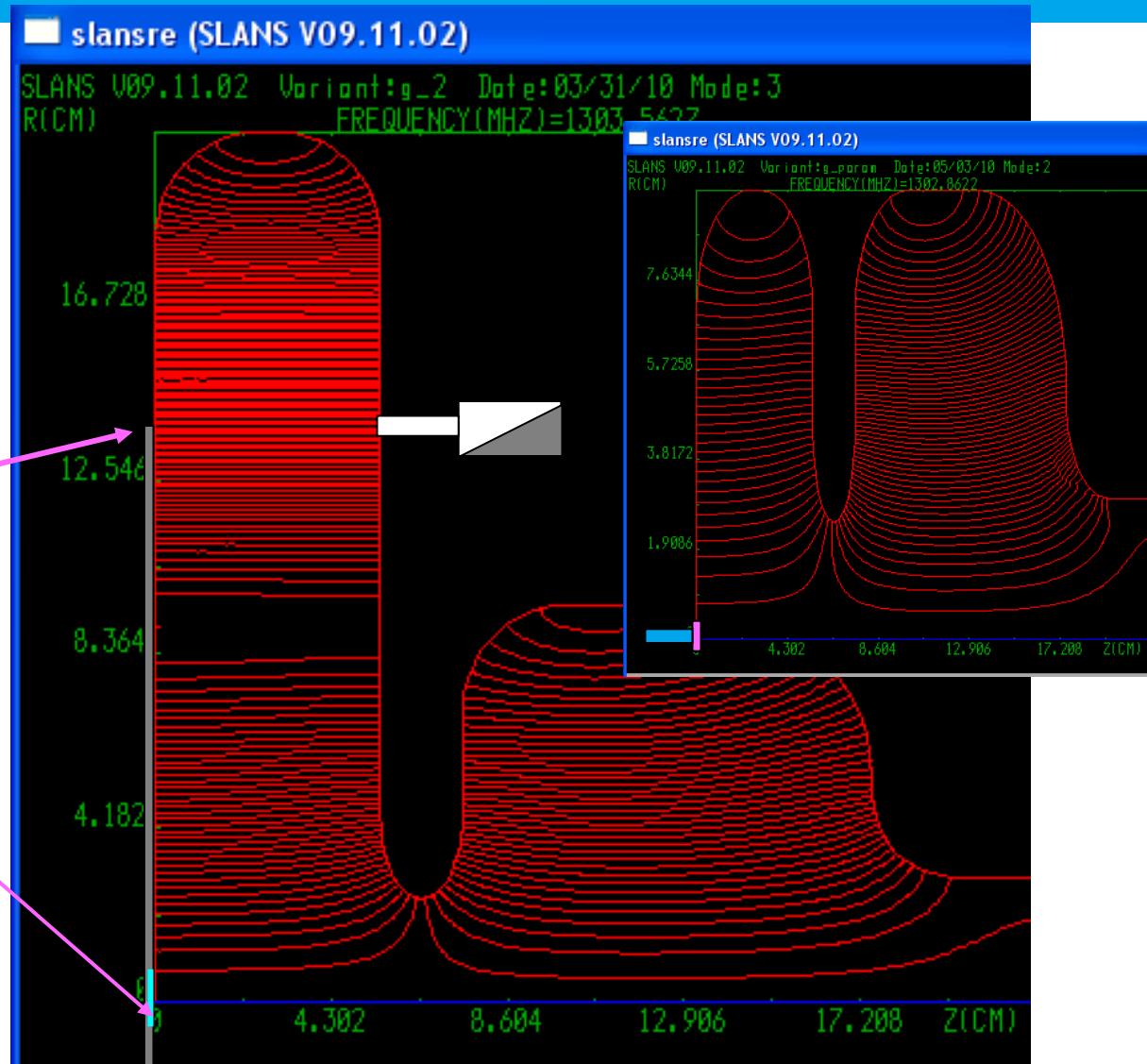
RF GUN cavity design

Oversize cavity:

Example:

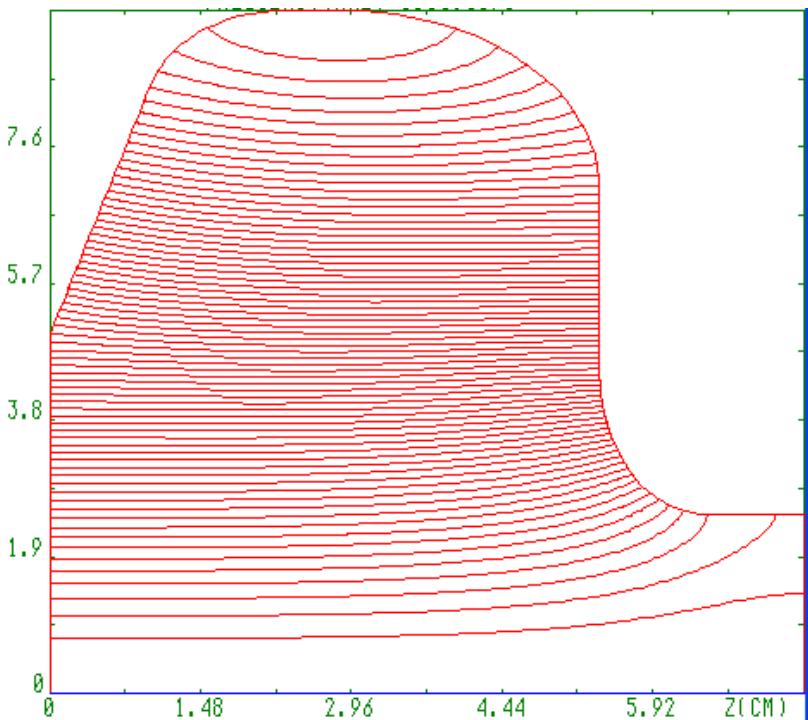
*TM020 in first half cell
TM010 in second cell*

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



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

1. From W, Ir and Mo we can easily 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.

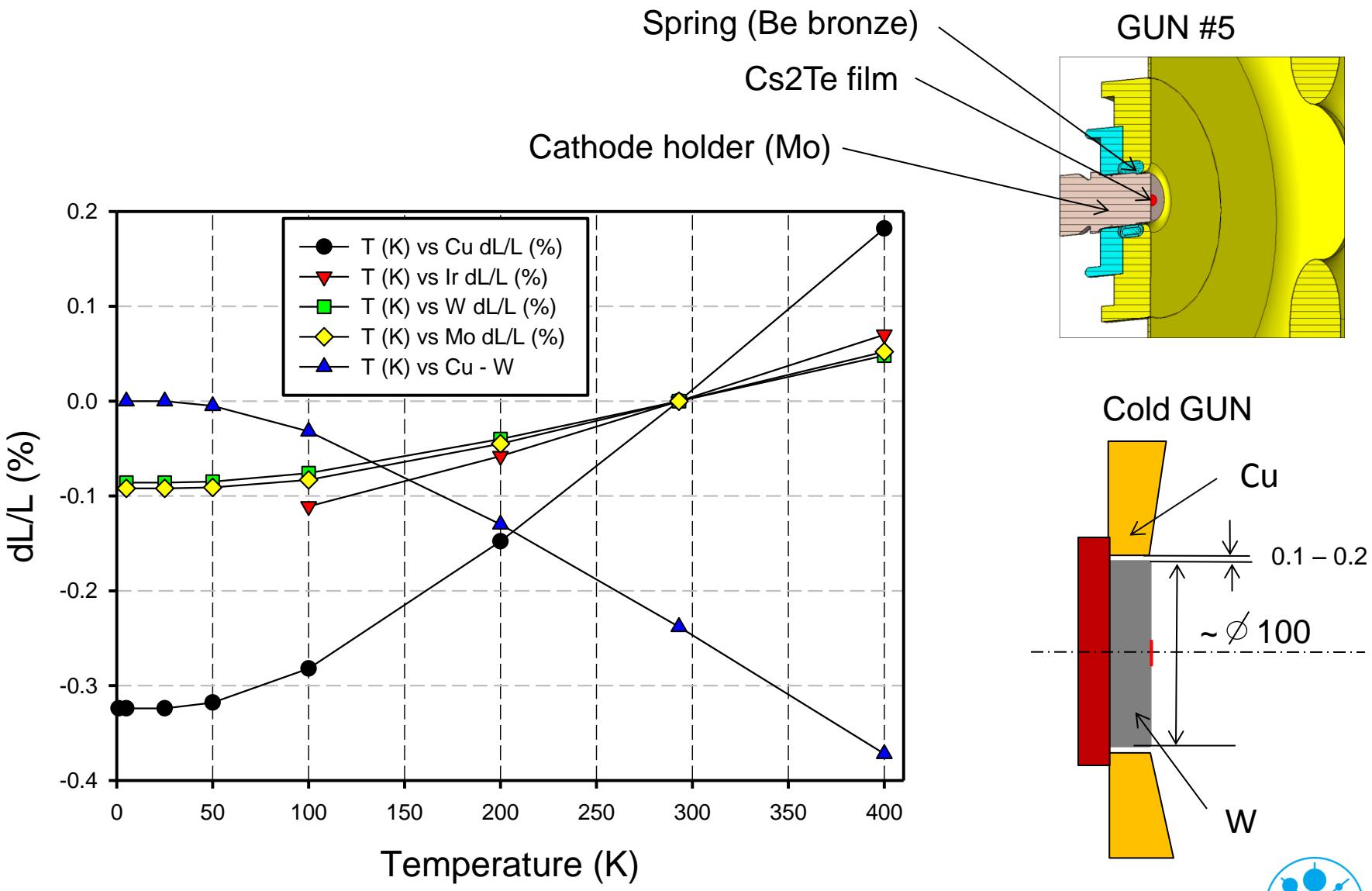


Solution #2

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.

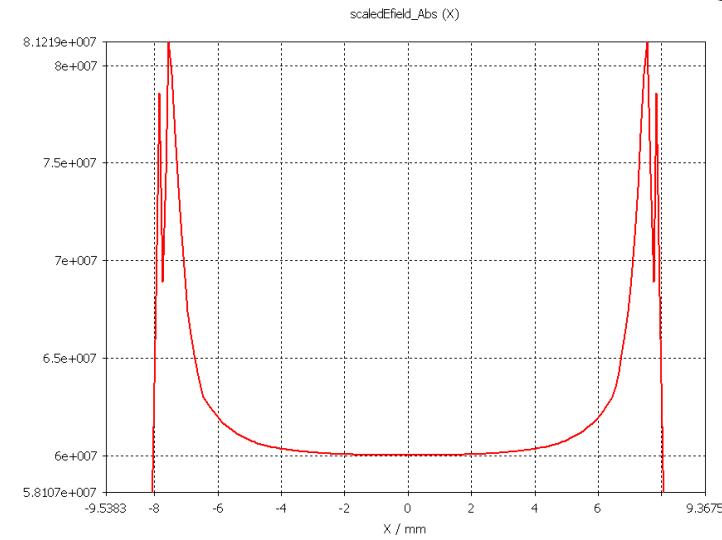
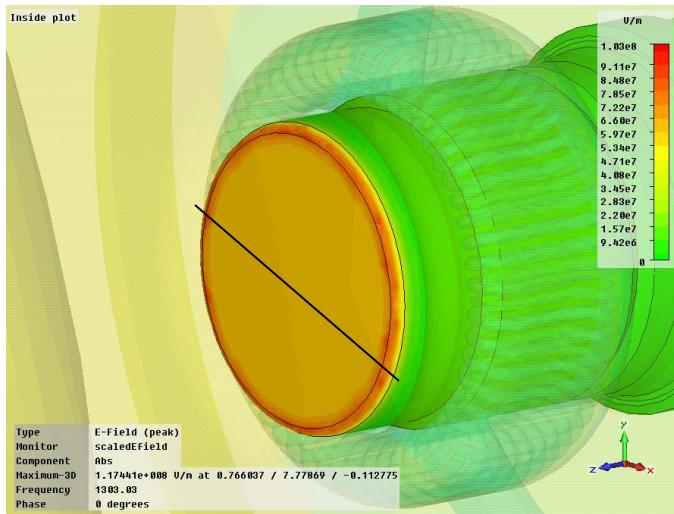
- + * 1.3 GHz cavity can be produced using existing 100 mm sheets from the industry
 - * over electrical fields that arise due to inaccuracies of fabrication in the contact area could be shielded by inner angle in the cavity.
 - * easy to test on the existing DESY cryostats
- * limitation of working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

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

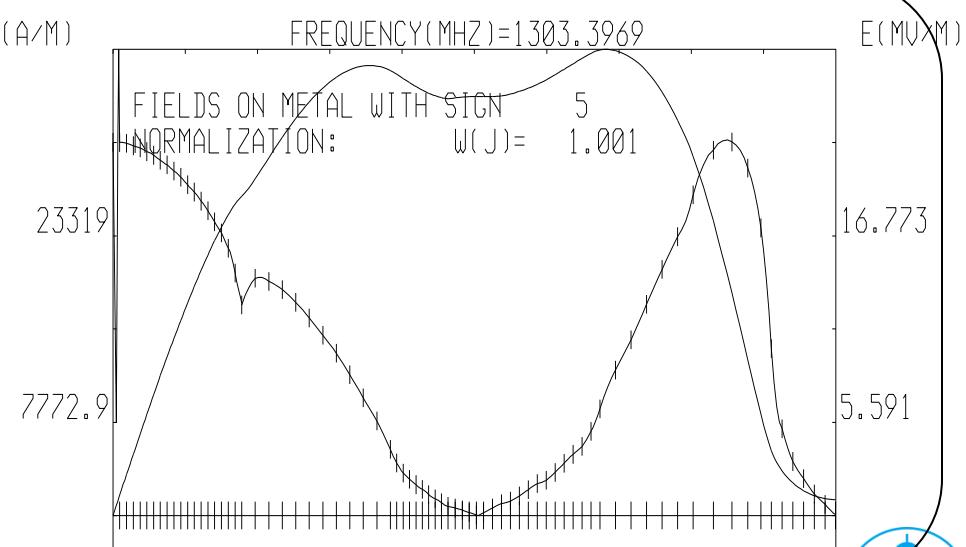
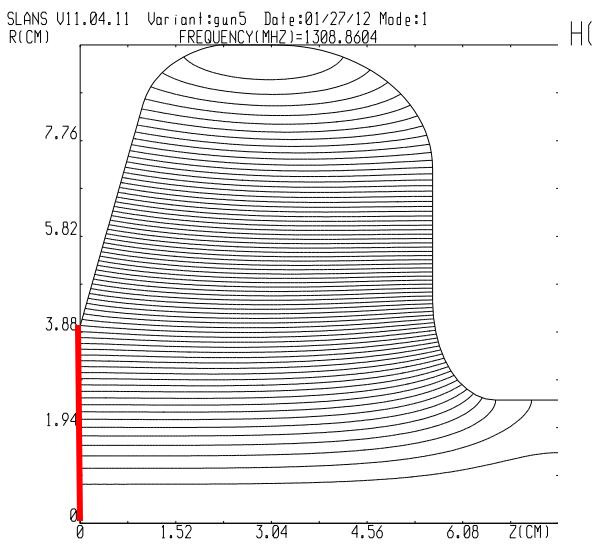


Over fields through of removable connection.

GUN #5



Cold GUN



“COLD GUN” team in DESY

Klaus Flöttmann, Siegfried Schreiber, Dirk Lipka, Xenia Singer

and Sven Lederer

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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 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!

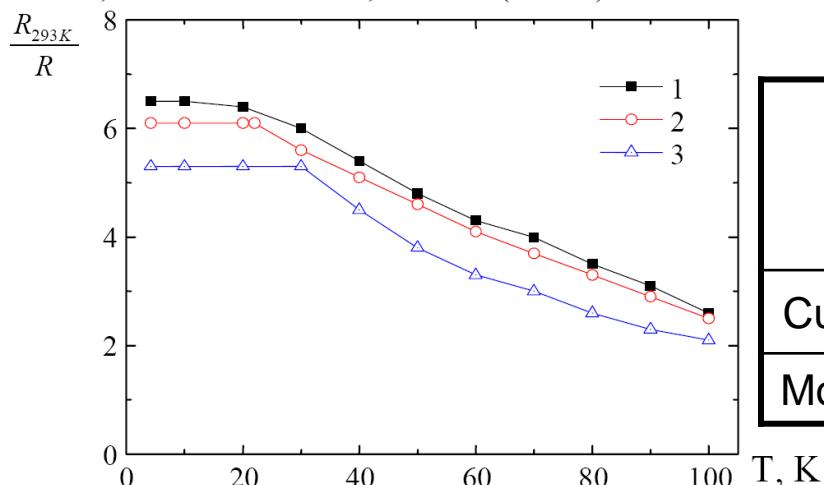
Backup

F = 5.25GHz

ON POSSIBILITY OF DEVELOPMENT OF HIGH-PERFORMANCE HIGH-FREQUENCY CRYOGENIC RESONANCE SYSTEM FROM YTTRIUM DOPED COPPER

V.A. Kutovoy, A.I. Komir, ISSN 1562-6016. BAHT. 2012. №4(80)

Национальный научный центр «Харьковский физико-технический институт»,
Харьков, Украина E-mail: kutovoy@kipt.kharkov.ua



	d/L, T=300 K 1.3 GHz	d/L, T=20 K 1.3 GHz	d/L T=300 K 11.4 GHz	d/L T=20 K 11.4 GHz	Q ₂₀ /Q ₃₀₀ 5.25GHz Cu+0.02 Y	Q ₂₀ /Q ₃₀₀ 5.25GHz Cu+0.02 Y
Cu	27	2.4*10⁻³	16	0.81*10 ⁻³	4.4 (exp)	6.1(exp) ?
Mo	47	2.3*10⁻³				~ 6.2 (estim)

Рис.9. Относительное изменение поверхностного сопротивления меди марок МОб, МОБ, МОБ+0,02Y в зависимости от температуры

Backup

Liquid Hydrogen

$T_{boiling} = 20.3 \text{ K}$

$C_p = 8000 \div 12000 \text{ J/kg}^{\circ}\text{K}$

$\Theta_{evaporation} \sim 454 \text{ kJ/kg}$

$\rho = 71 \text{ kg/m}^3$

H₂: For 1 kW

evaporative cooling:

8 kg/hour

liquid cooling ($\Delta T = 2 \text{ K}$):

180 kg/hour (2.5 m³ /hour)

Liquid Neon

$T_{boiling} = 27 \text{ K}$

$C_p = 1880 \text{ J/kg}^{\circ}\text{K}$

$\Theta_{evaporation} \sim 84\text{-}89 \text{ kJ/kg}$

$\rho = 1207 \text{ kg/m}^3$

Ne: For 1 kW

evaporative cooling:

42 kg/hour

liquid cooling ($\Delta T = 2 \text{ K}$)

862 kg/hour (0.7 m³ /hour)

Backup

Physica 104C (1981) 82–87
© North-Holland Publishing Company

POINT-TO-PLANE BREAKDOWN IN VACUUM AT CRYOGENIC TEMPERATURES

B. MAZUREK*, J.D. CROSS and K.D. SRIVASTAVA

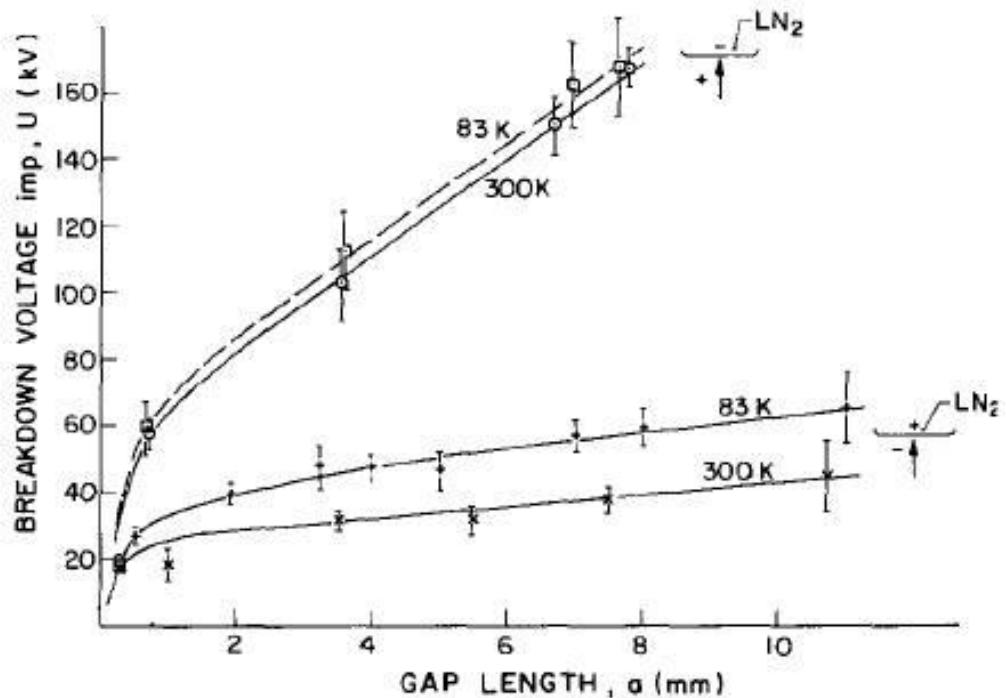


Fig. 4. Impulse breakdown voltage as a function of the gap length. Parameters: temperature of the plane electrode and polarity.

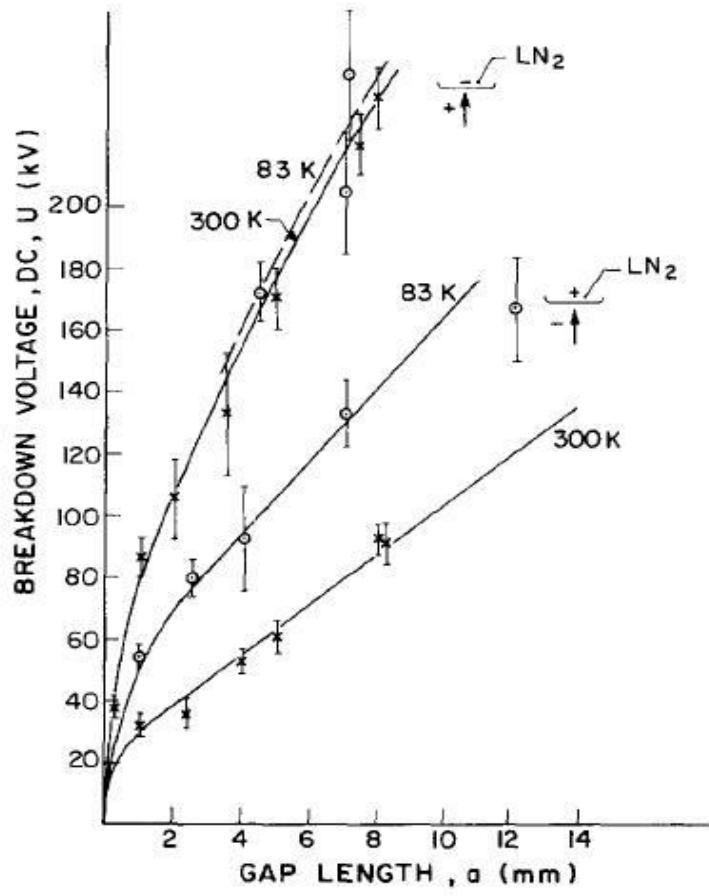


Fig. 3. dc breakdown voltage as a function of the gap length. Parameters: temperature of the plane electrode and polarity.

Backup

Breakdown for copper at 77 K and 293K

Properties of cryogenic insulants

J. Gerhold

Technische Universität Graz, Institut für Elektrische Maschinen und Antriebstechnik,
Kopernikusgasse 24, A-8010 Graz, Austria

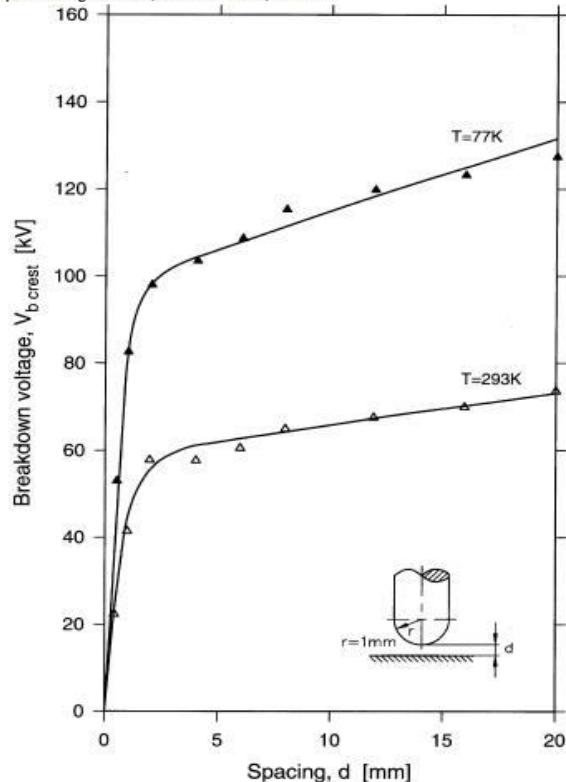


Figure 3. Breakdown in a non-uniform field vacuum gap; a.c.
voltage with copper electrodes

Backup

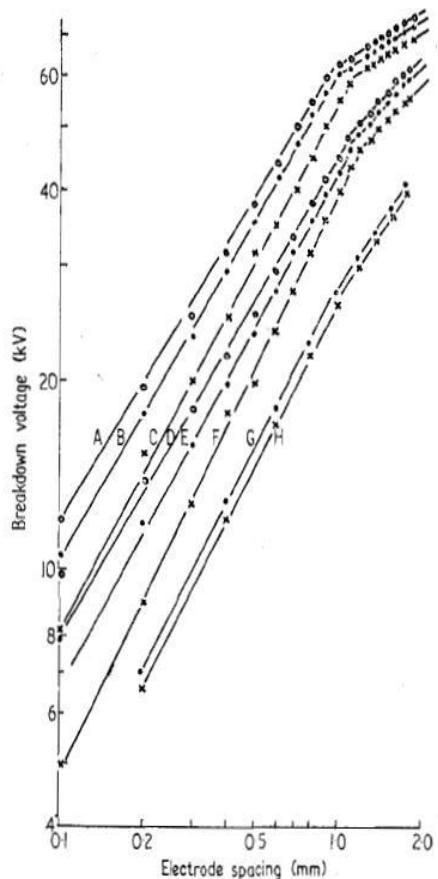
Breakdown voltage for Aluminum Copper and Gold

J. Phys. D: Appl. Phys., Vol. 7, 1974. Printed in Great Britain. © 1974

Prebreakdown currents and breakdown voltages in vacuum at cryogenic temperatures

R N Allan and A J Salim†

Department of Electrical Engineering and Electronics, UMIST, Sackville Street,
Manchester, M60 1QD



Curve	Electrode material	Temperature (K)	(symbol)
A	Aluminium	4.2	(○)
B	Aluminium	77.3	(●)
C	Aluminium	300	(×)
D	Copper	4.2	(○)
E	Copper	77.3	(●)
F	Copper	300	(×)
G	Gold	77.3	(●)
H	Gold	300	(×)

Figure 4. Logarithmic plots of breakdown voltage characteristics for gold, copper and aluminium electrodes.

Backup

Surface temperature rise as a function of the initial gun temperature.

1 ms RF pulse
Gradient 60 MV/m,
 $f = 1.3$ GHz,
material copper, RRR = 100.

