

Update on RF Breakdown Theory Since AAC06

Effect of backscattering

A fraction of the electrons incident on a metal surface are backscattered. The backscattering coefficient b depends only on the atomic number Z and is given by

$$b = A + BZ + CZ^2 + DZ^3$$

where $A = -5.23791 \times 10^{-3}$, $B = 1.5048371 \times 10^{-2}$, $C = -1.67373 \times 10^{-4}$, and $D = 7.16 \times 10^{-7}$. The fraction of electrons transmitted into the metal is $1-b$.

For a metal surface bombarded by electrons with a power density per unit area P_A , the temperature rise at time t_0 is

$$T = \frac{P_A}{X_0 C_s \rho} \int_0^{t_0} \operatorname{erf} \left\{ \frac{X_0}{[4D(t_0 - t)]^{1/2}} \right\} dt$$

To take backscattering into account, P_A must be multiplied by $1-b$.

Without backscattering, the surface field at breakdown scales as (AAC06 paper)

$$E_b \sim \left[\frac{T_m C_s}{(I/t_0)} + H \right]^{1/2}$$

To take backscattering into account, this expression must be multiplied by the factor $1/(1-b)^{1/2}$. The table below shows the effect of taking backscattering into account for selected metals.

Element	Z	Breakdown Field– No backscattering	Transmission Factor 1–b	Breakdown Field– with backscattering
Cu	29	1.0	0.69	1.0
W	74	1.20	0.52	1.39
SS	26	1.21	0.72	1.19
Nb	41	1.21	0.62	1.28
Mo	42	1.28	0.62	1.36
Ti	22	1.32	0.7	1.27
Cr	24	1.39	0.73	1.37
Be	4	2.53	0.95	1.88
C	6	~4	0.92	~3.5

TABLE 2. Breakdown Fields Normalized to Copper for Various Metals

1.00 –1.09	1.10–1.19	1.20–1.29	1.30–1.39	> 1.4
Cu 1.00	Al 1.10	Co 1.22	Re 1.31	Be 1.88
Ca 1.06	Mn 1.10	Os 1.27	Ru 1.31	
Tc 1.08	Zr 1.12	Ti 1.27	Mo 1.36	<i>Non-metals</i>
	Y 1.14	Nb 1.28	Cr 1.37	B 2.17
	Rh 1.15	Sc 1.29	V 1.37	C 3.55
	Ta 1.16		W 1.39	
	Mg 1.16			
	Fe 1.17			
	Ni 1.18			
	SS 1.19			
	Ir 1.19			

Periodic table of the elements

Period	Group Ia	Group IIa	Group IIIa	Group IVa	Group Va	Group VIa	Group VIIa	Group VIII	Group Ib	Group IIb	Group IIIb	Group IVb	Group Vb	Group VIb	Group VIIb	Inert Gases		
1	H ₁														H ₁	He ₂		
2	Li ₃	Be ₄									B ₅	C ₆	N ₇	O ₈	F ₉	Ne ₁₀		
3	Na ₁₁	Mg ₁₂	Transition Elements									Al ₁₃	Si ₁₄	P ₁₅	S ₁₆	Cl ₁₇	Ar ₁₈	
4	K ₁₉	Ca ₂₀	Sc ₂₁	Ti ₂₂	V ₂₃	Cr ₂₄	Mn ₂₅	Fe ₂₆	Co ₂₇	Ni ₂₈	Cu ₂₉	Zn ₃₀	Ga ₃₁	Ge ₃₂	As ₃₃	Se ₃₄	Br ₃₅	Kr ₃₆
5	Rb ₃₇	Sr ₃₈	Y ₃₉	Zr ₄₀	Nb ₄₁	Mo ₄₂	Tc ₄₃	Ru ₄₄	Rh ₄₅	Pd ₄₆	Ag ₄₇	Cd ₄₈	In ₄₉	Sn ₅₀	Sb ₅₁	Te ₅₂	I ₅₃	Xe ₅₄
6	Cs ₅₅	Ba ₅₆	La ₅₇	Hf ₇₂	Ta ₇₃	W ₇₄	Re ₇₅	Os ₇₆	Ir ₇₇	Pt ₇₈	Au ₇₉	Hg ₈₀	Tl ₈₁	Pb ₈₂	Bi ₈₃	Po ₈₄	At ₈₅	Rn ₈₆
7	Fr ₈₇	Ra ₈₈	Ac ₈₉	(Rf) ₁₀₄	(Ha) ₁₀₅													

Metals available from **Goodfellow** are in the white boxes

Key

Atomic weight
 Alloys ● Compounds ★
 Symbol and atomic number
 M Microfoil F Foil K Flake
 S Sheets (> 0.5 mm) Q Fabric
 W Wire R Rod P Powder
 L Lumps T Tube H Honeycomb
 X Sputtering Targets Z Single Crystal
 Note: Atomic weights shown as integers are for the most stable isotope of the element.

47.90 ●★ Ti ₂₂ MFSWRP TX	Lanthanides (rare earths)	140.12 Ce ₅₈ FWRP	140.91 Pr ₅₉ FWRP	144.24 Nd ₆₀ FWRP	145 Pm ₆₁	150.35 Sm ₆₂ FRP	151.96 Eu ₆₃ FWP	157.25 Gd ₆₄ FWRP	158.93 Tb ₆₅ FWRP	162.50 Dy ₆₆ FWRP	164.93 Ho ₆₇ FWRP	167.26 Er ₆₈ FWRP	168.93 Tm ₆₉ FP	173.04 Yb ₇₀ FWRP	174.97 Lu ₇₁ FP
	Actinides	232.04 Th ₉₀ FW	231.04 Pa ₉₁	238.03 U ₉₂ FW	237.05 Np ₉₃	244 Pu ₉₄	243 Am ₉₅	247 Cm ₉₆	247 Bk ₉₇	251 Cf ₉₈	254 Es ₉₉	257 Fm ₁₀₀	258 Md ₁₀₁	259 No ₁₀₂	260 Lw ₁₀₃

Relative breakdown fields compared to copper

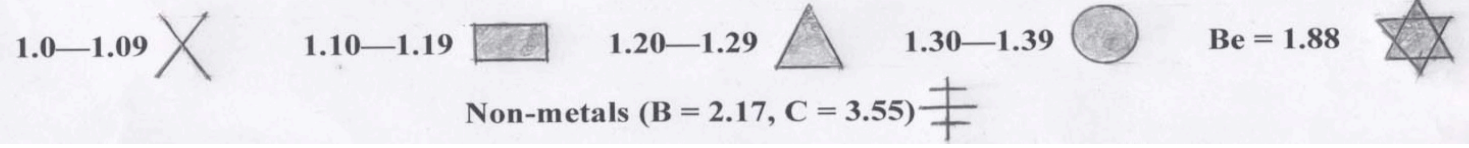


FIGURE 4. The breakdown field groups in Table 2 plotted on a periodic table of the elements

Taylor Cones

From Jon Orloff, *High Resolution Focused Ion Beams*, RSI **64**, 1105 (1993):

“A LMIS (liquid metal ion source) consists of a liquid metal held in some suitable way to which an electric field is applied strong enough to cause the metal to assume a conical shape---”.

“The cone apex is believed to have a radius of only about 5nm”

