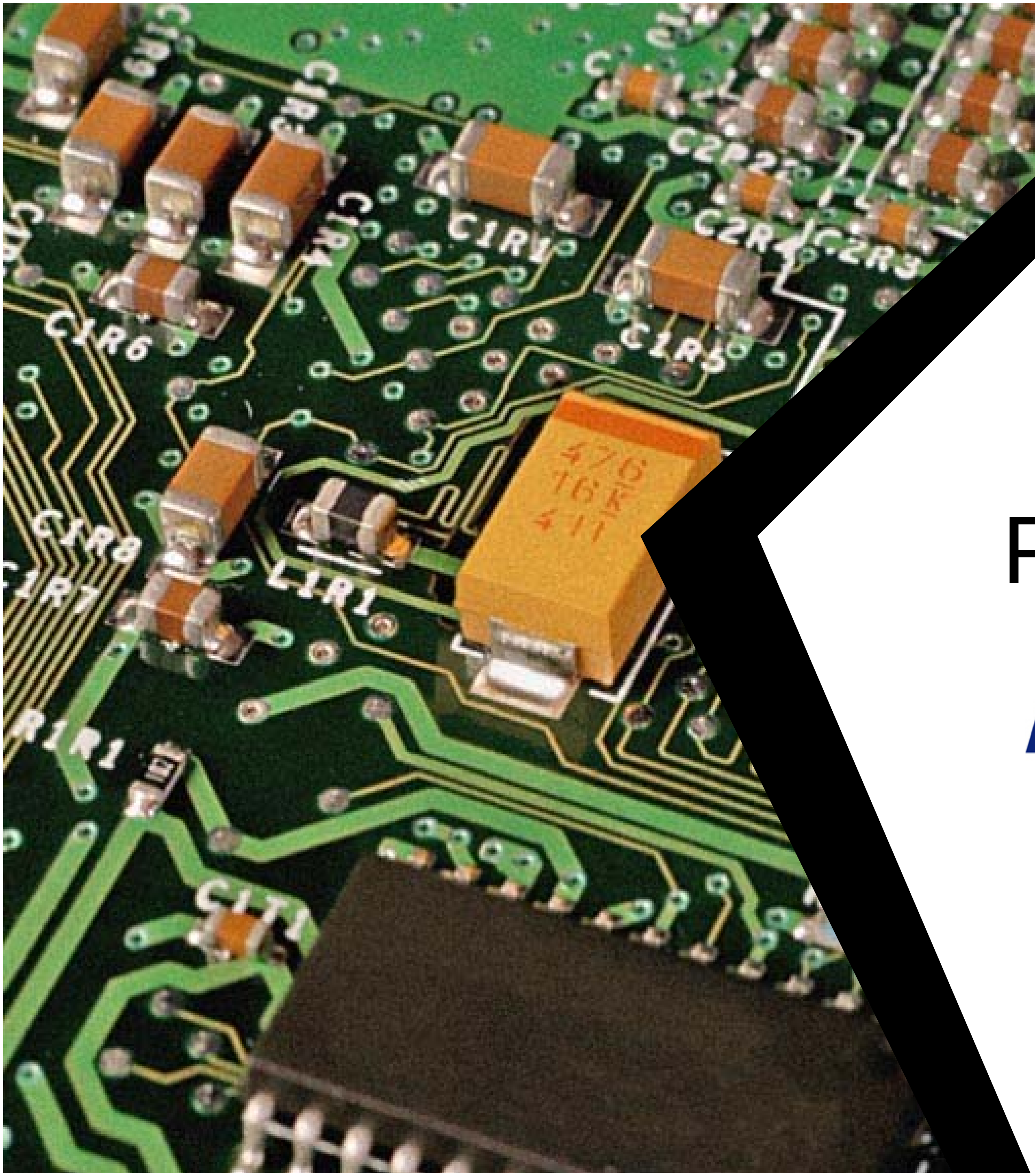

Materials
Structures
Performance

KEMET
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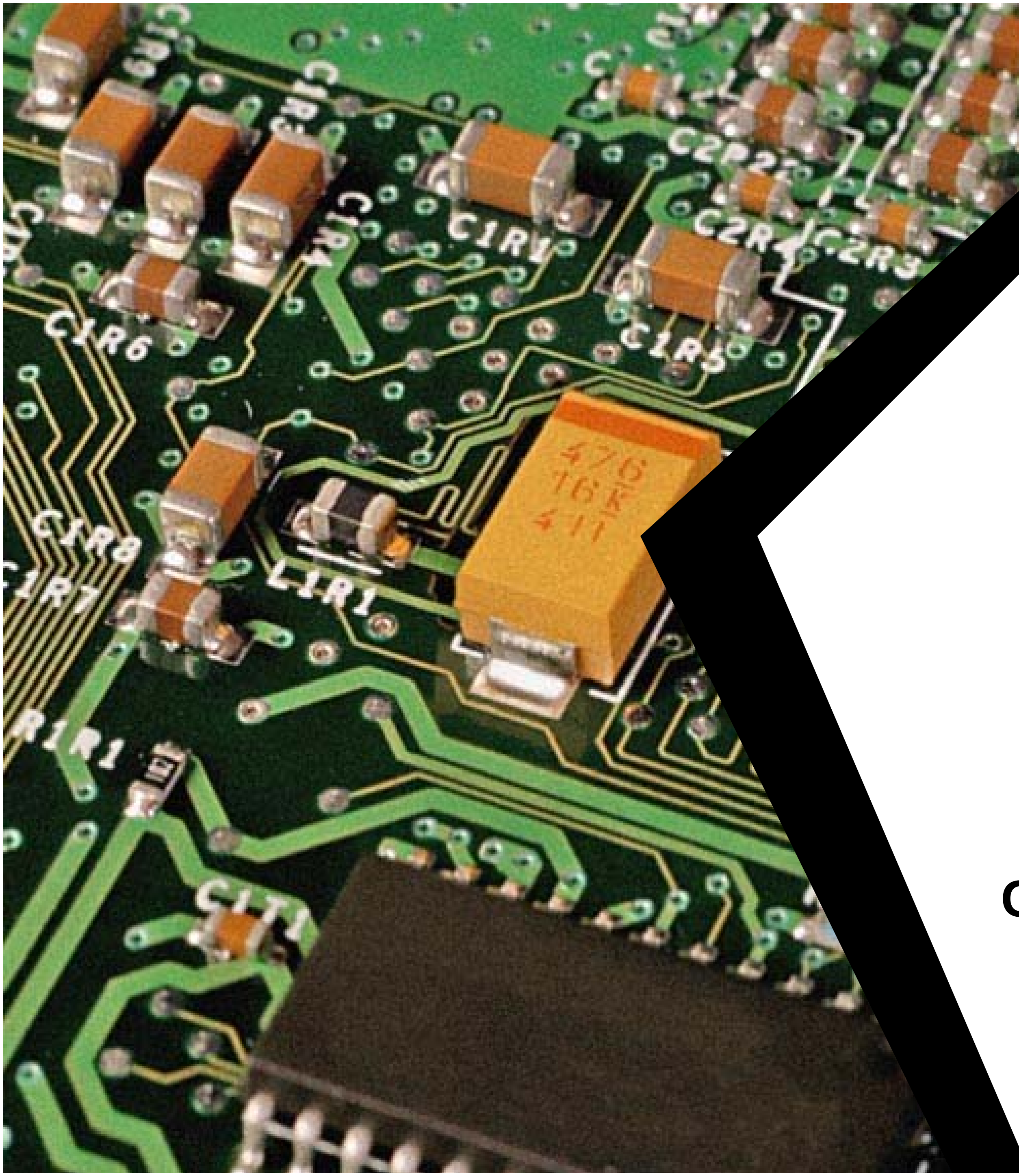
Applications-
Capacitor
Construction

Sept/Oct - 2006



Aluminum Electrolytic

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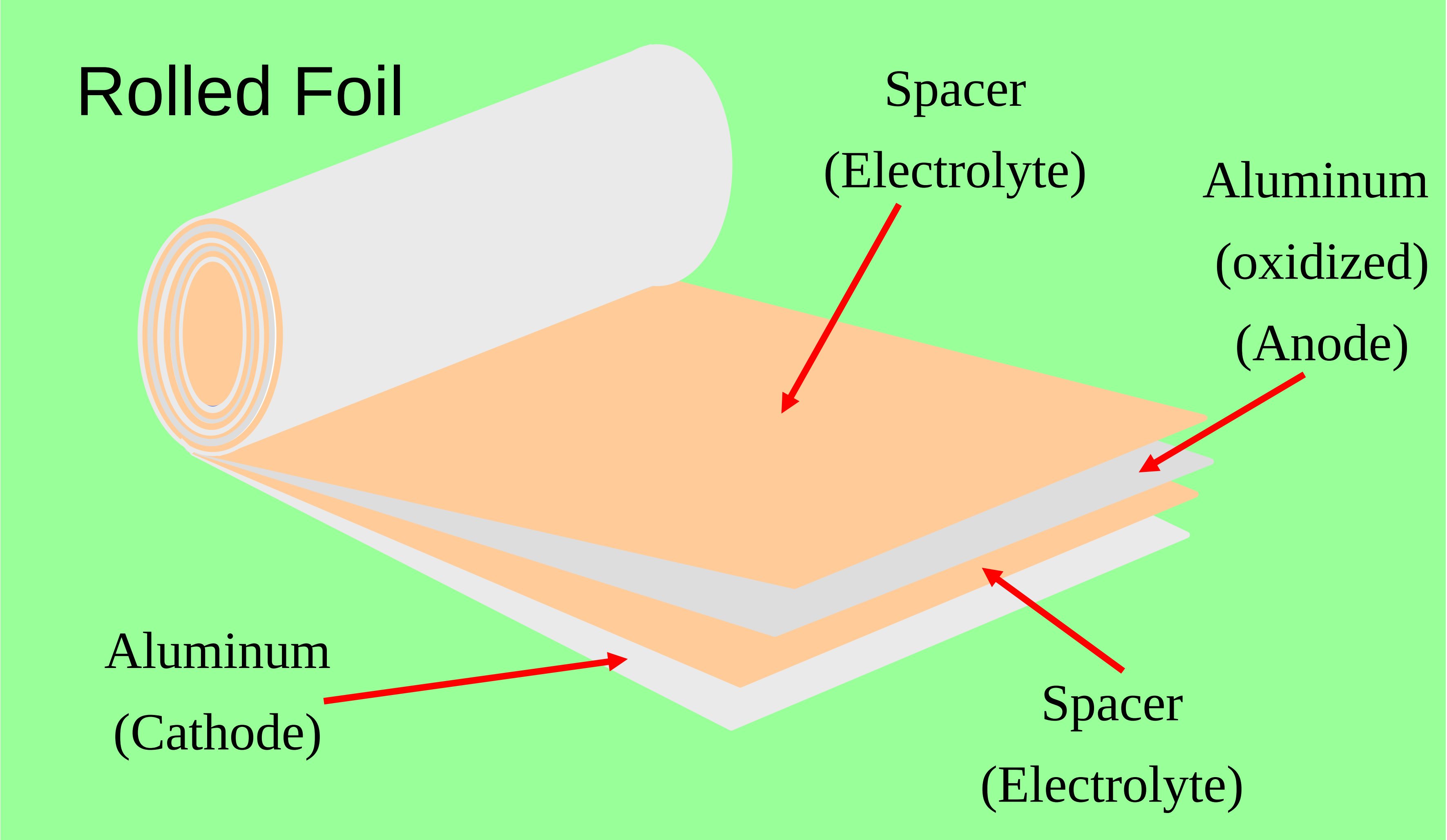
Construction and Materials

Construction of Alum. Electrolytic



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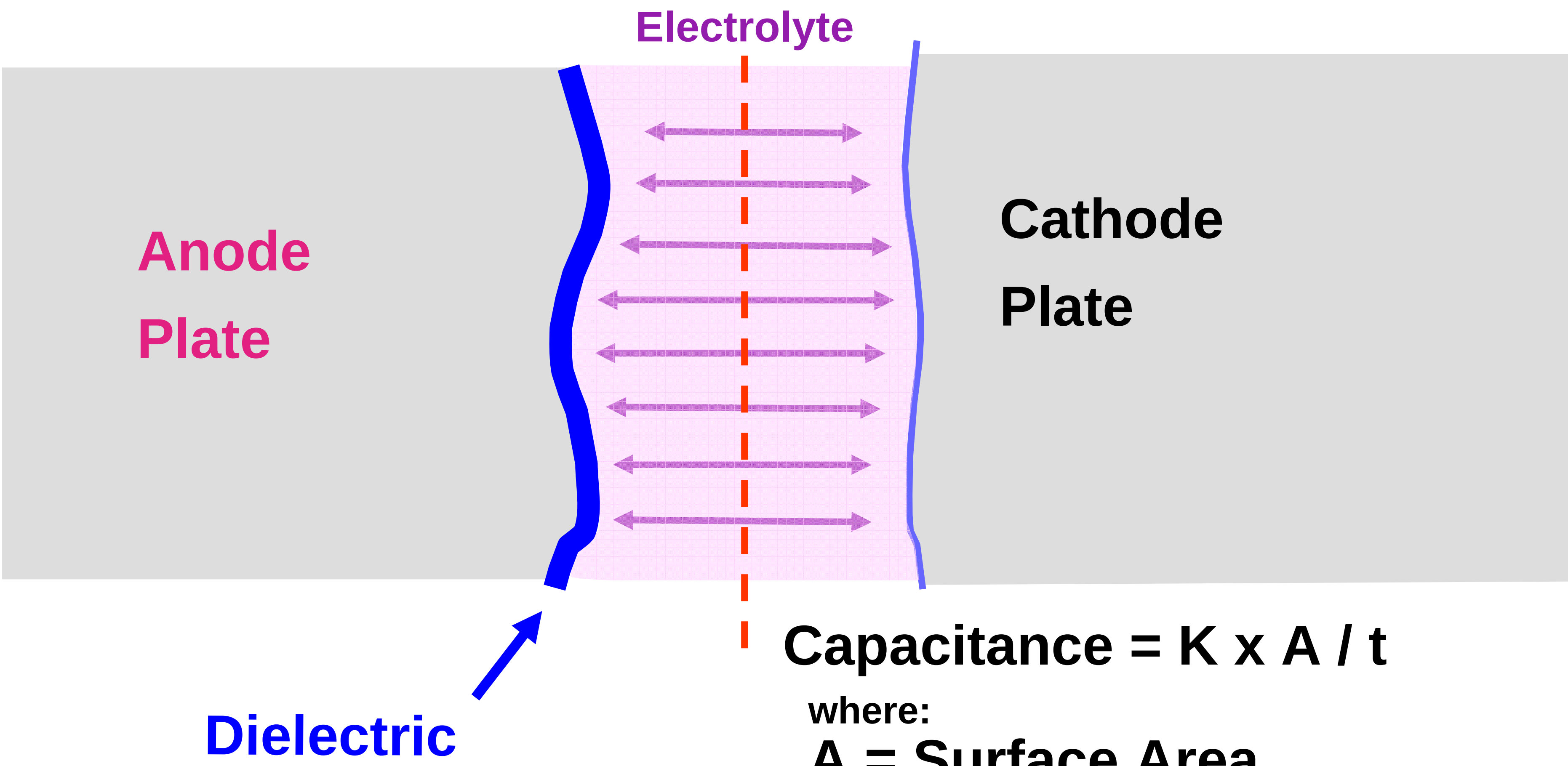
Aluminum Untreated Surface Area



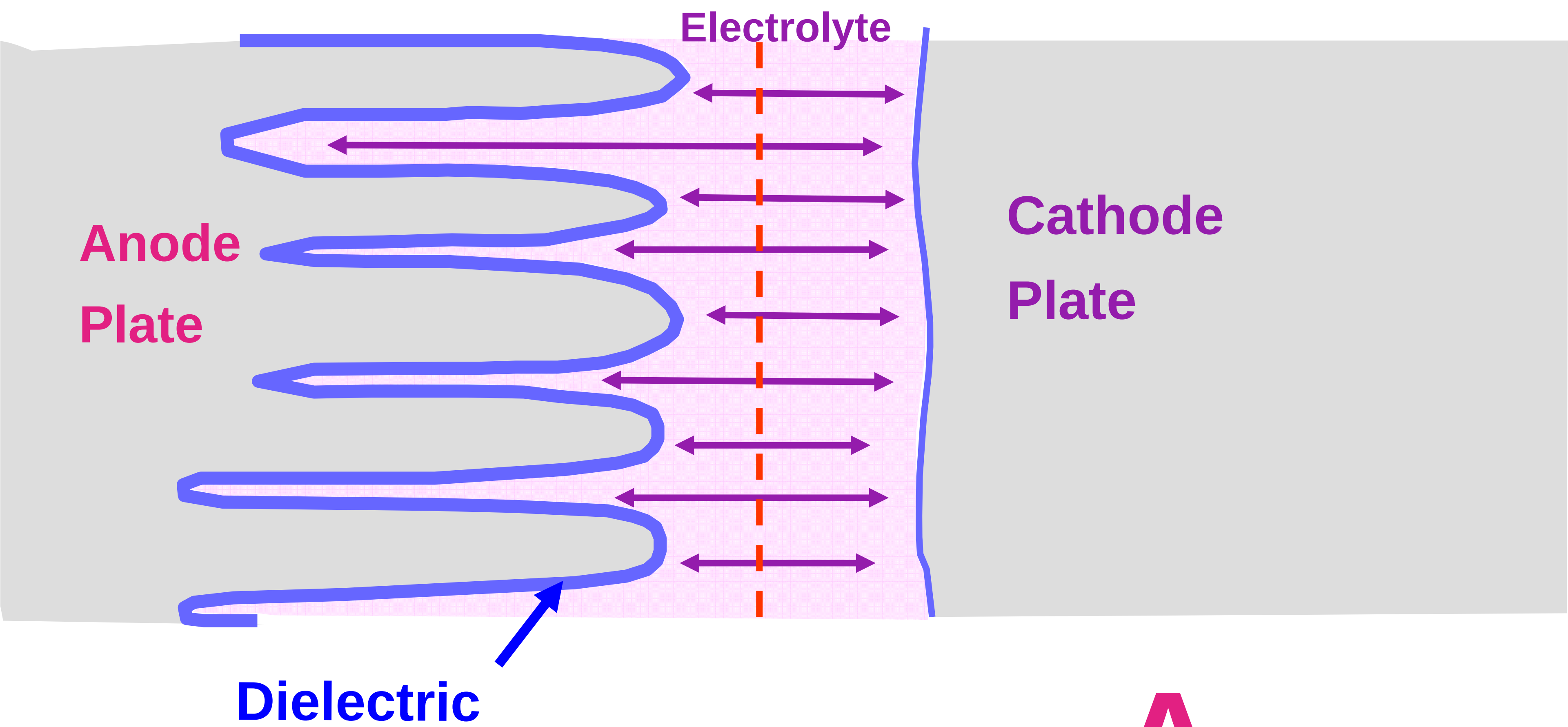
Capacitance = K x A / t

where:

A = Surface Area

t = dielectric thickness

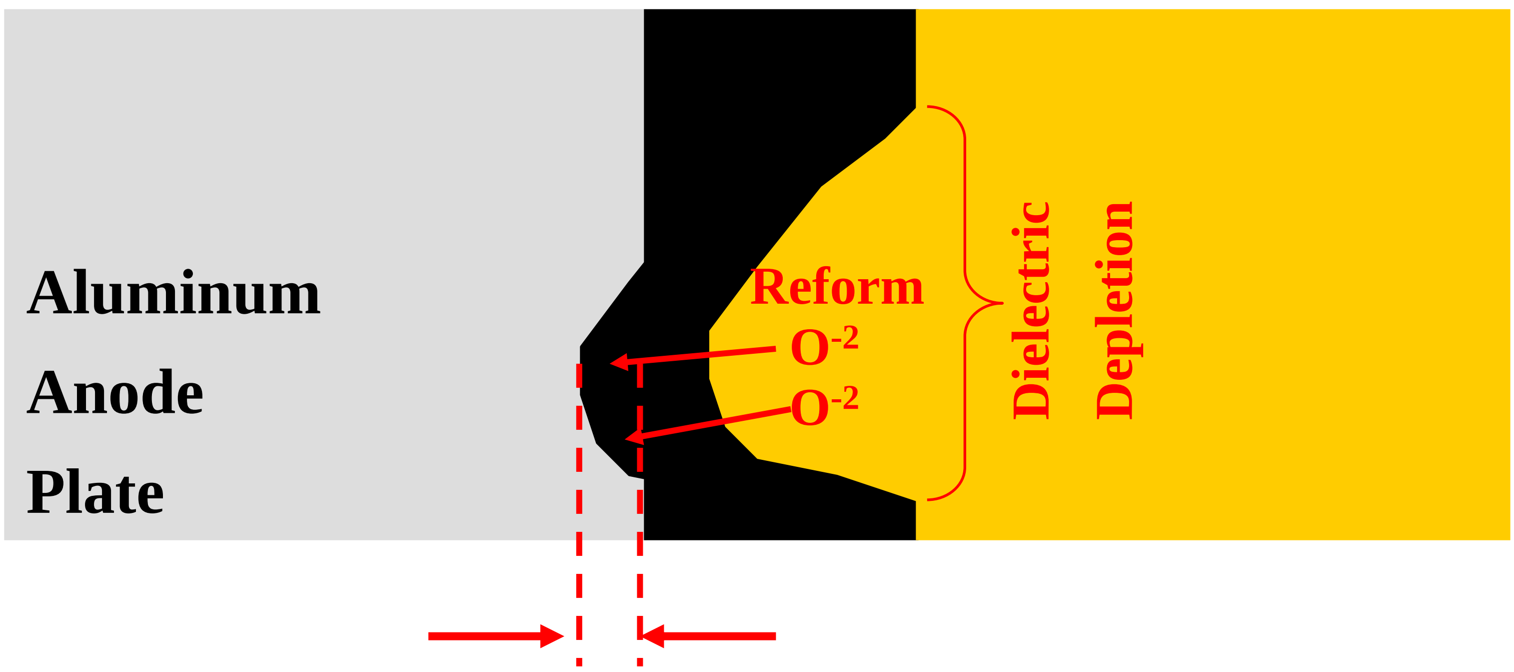
Aluminum Acid-Etched Surface Area



Capacitance = K x **A** / t

"Reform" / Self-Healing Wet Alum.

Forward bias is same as formation bias. If dielectric gets thin enough, the forward bias voltage will form new dielectric (thinner than original because $V_{Formation} > V_{Rating} > V_{Application}$).

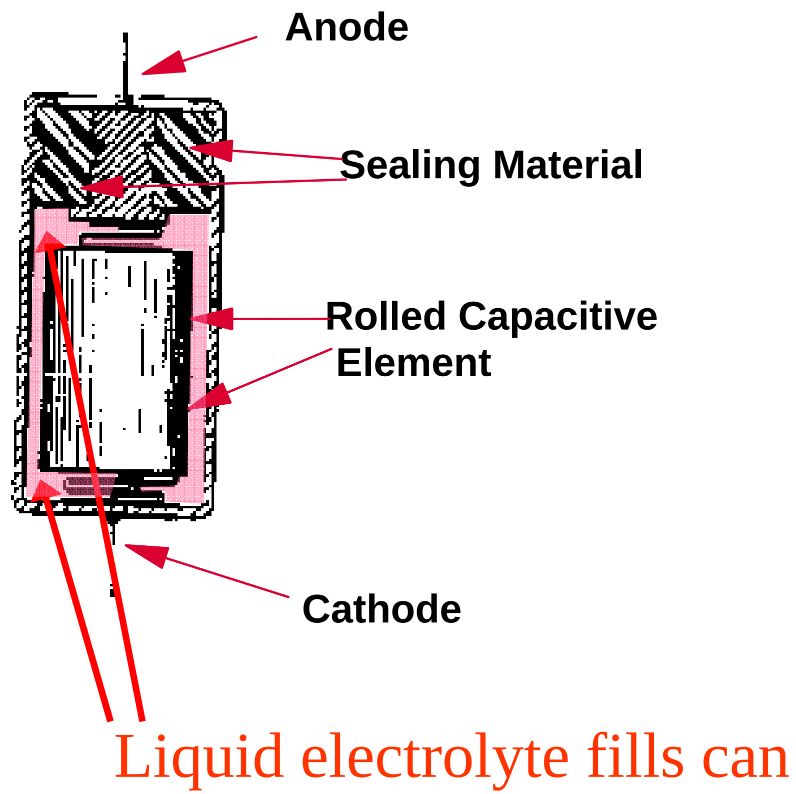


Reformed dielectric region.

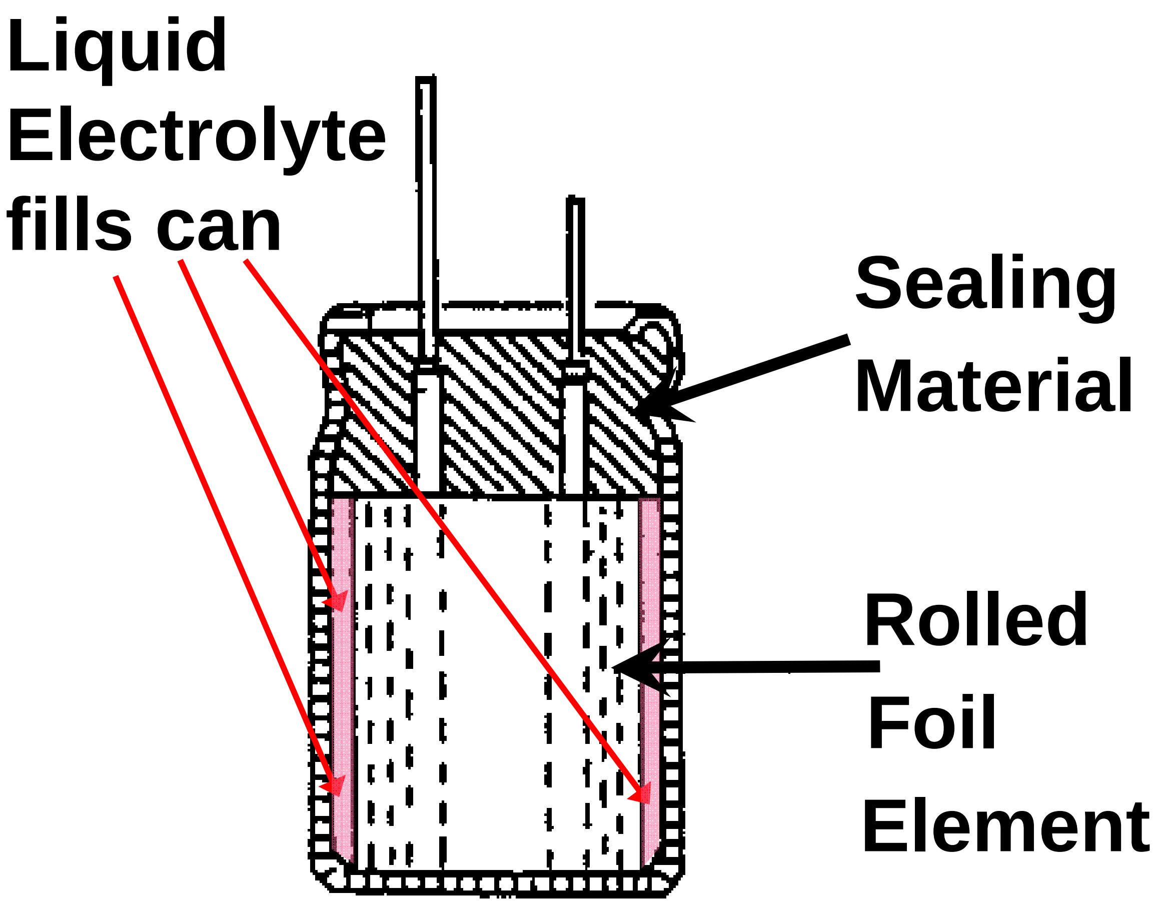
Aluminum Electrolytic Axial

Rolled foil is inserted in can, and sealed.

Lead extensions allow electrical contact to foil plates



Radial Case Aluminum



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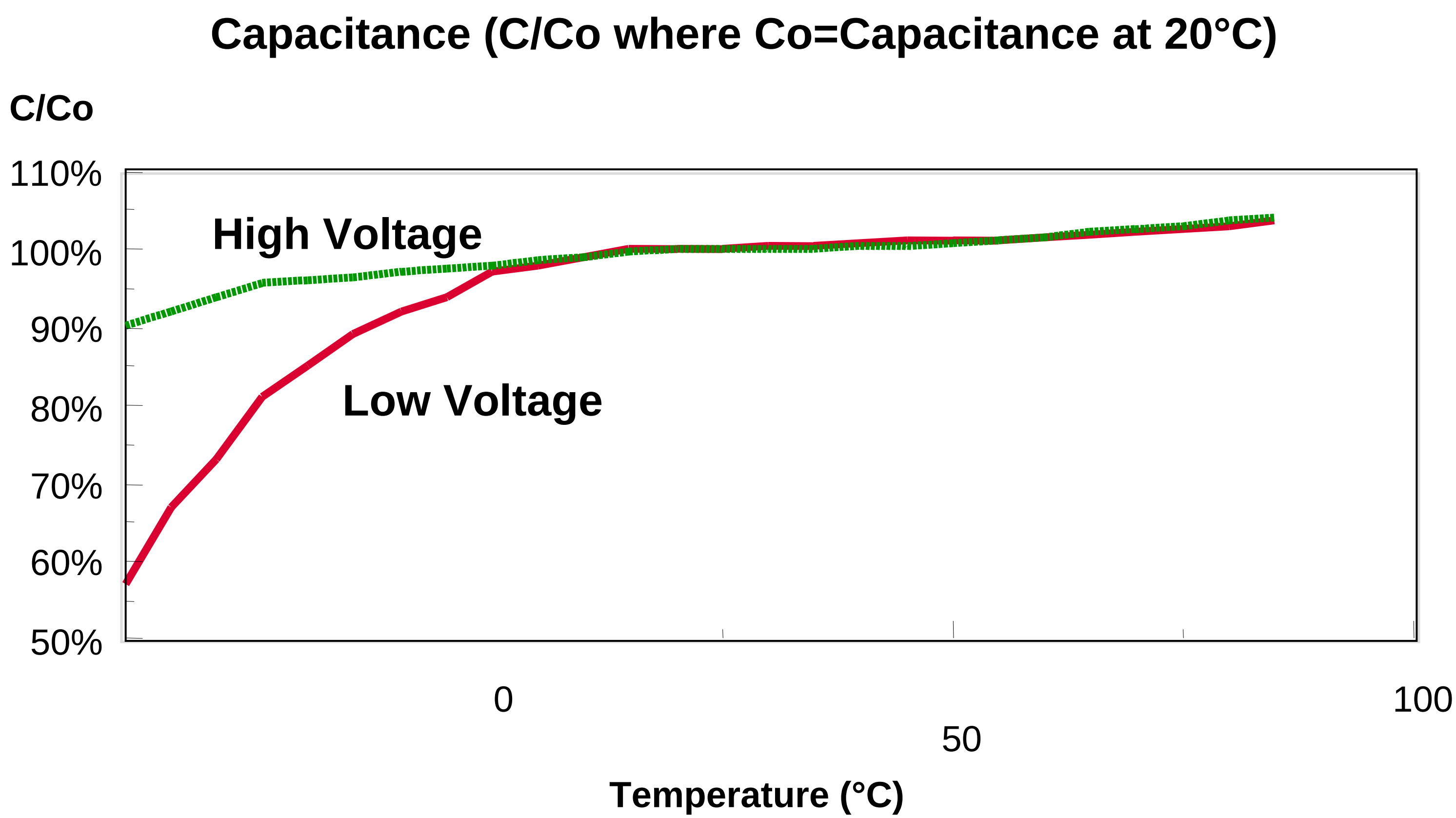
Aluminum Catalogs (Ripple/ESR):

RMS Ripple Current mA (85°C, 120 Hz)

WVDC	6.3	10	25	35	50	63	80	100	160	250
3.3 uFd					65	65	70	75	53	53
4.7 uFd			60	70	80	80	70	75	64	65
10 uFd		75	90	105	125	125	135	125	95	100

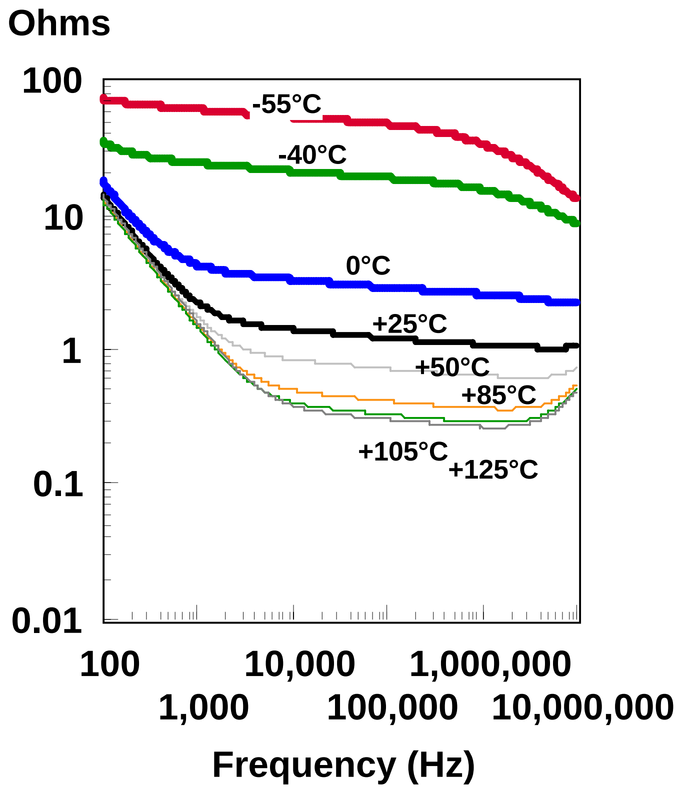
Also: Ripple Current Multipliers up to 10 KHz

Alum. Elect. Temperature Sensitivity

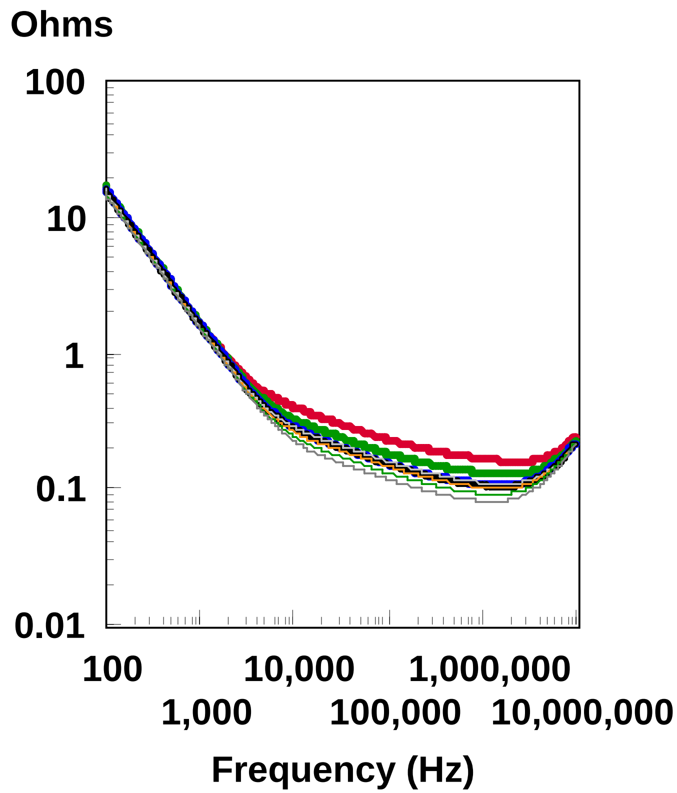


100 uF Z vs Freq vs Temp

SMT AL-Elect. 100 @ 6.3

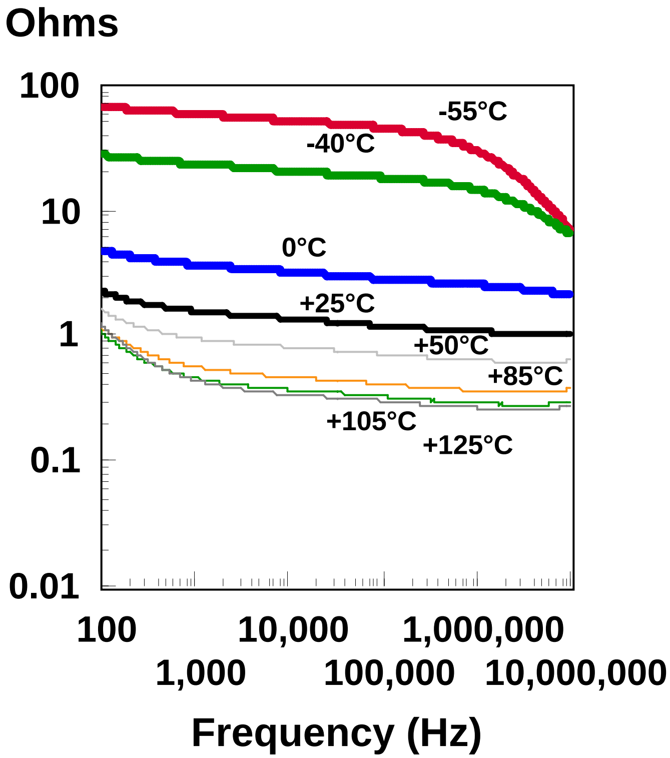


KEMET T491D107M006

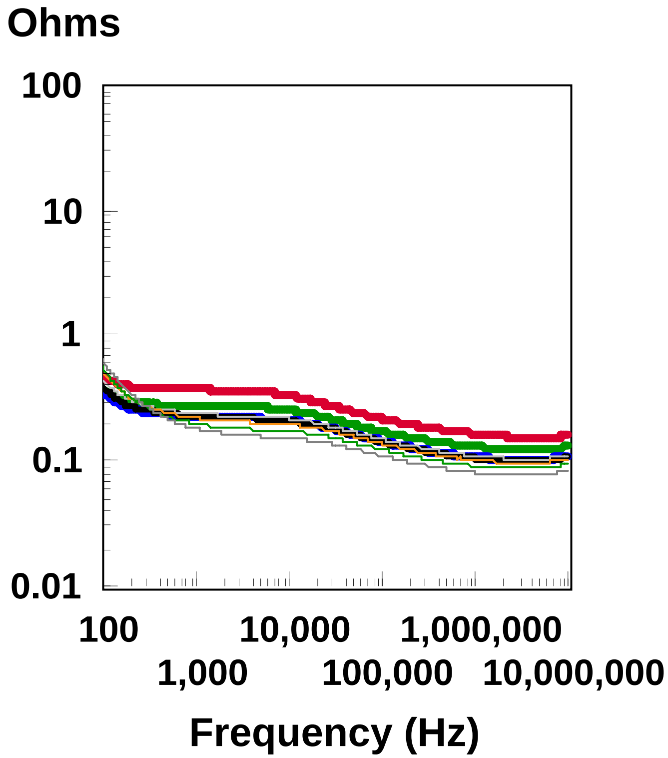


100 uF   ESR vs Freq vs Temp

SMT AL-Elect. 100 @ 6.3

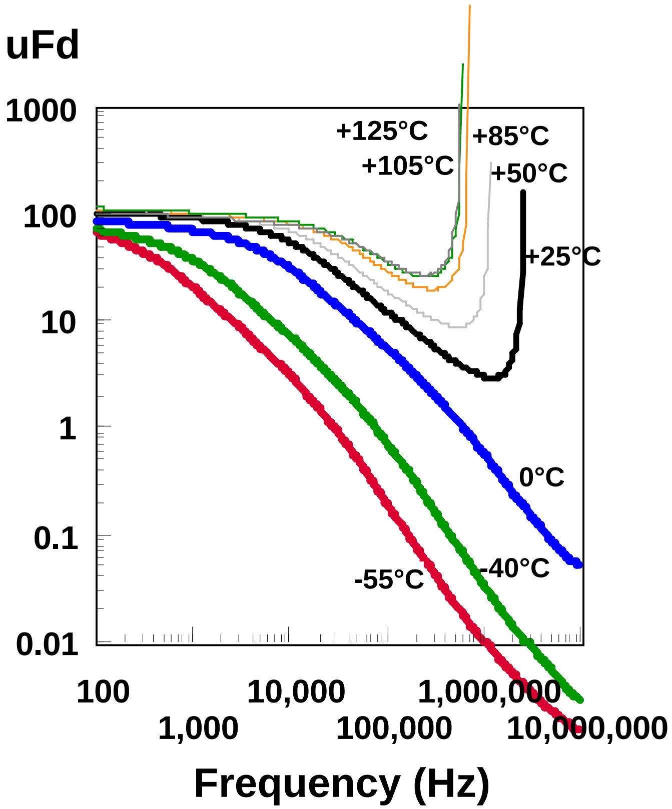


KEMET T491D107M006

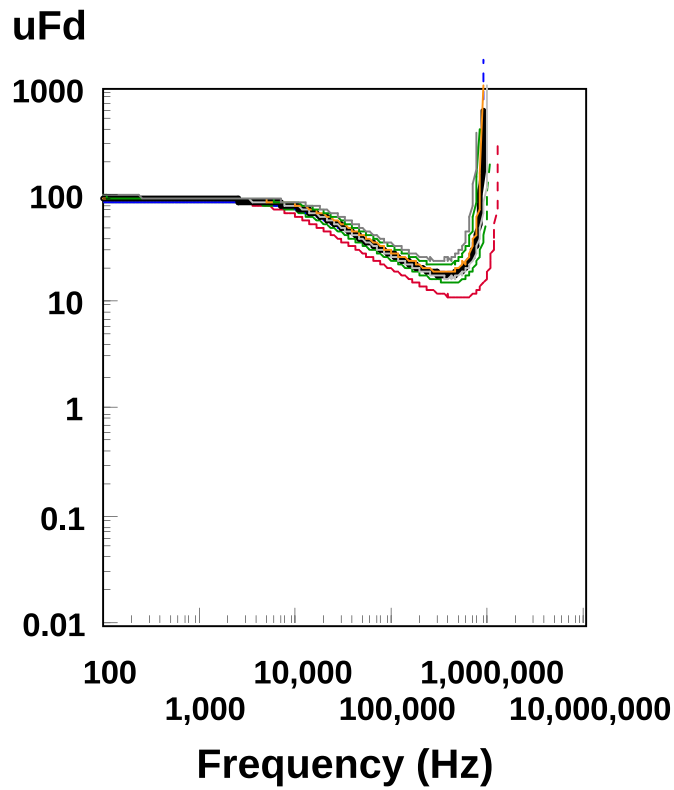


100 uF Cap vs Freq vs Temp

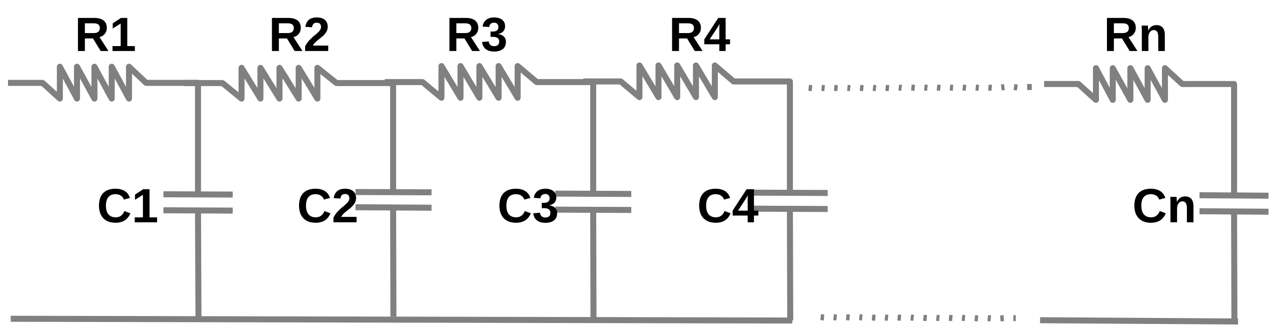
SMT AL-Elect. 100 @ 6.3



KEMET T491D107M006



RC Ladder Network



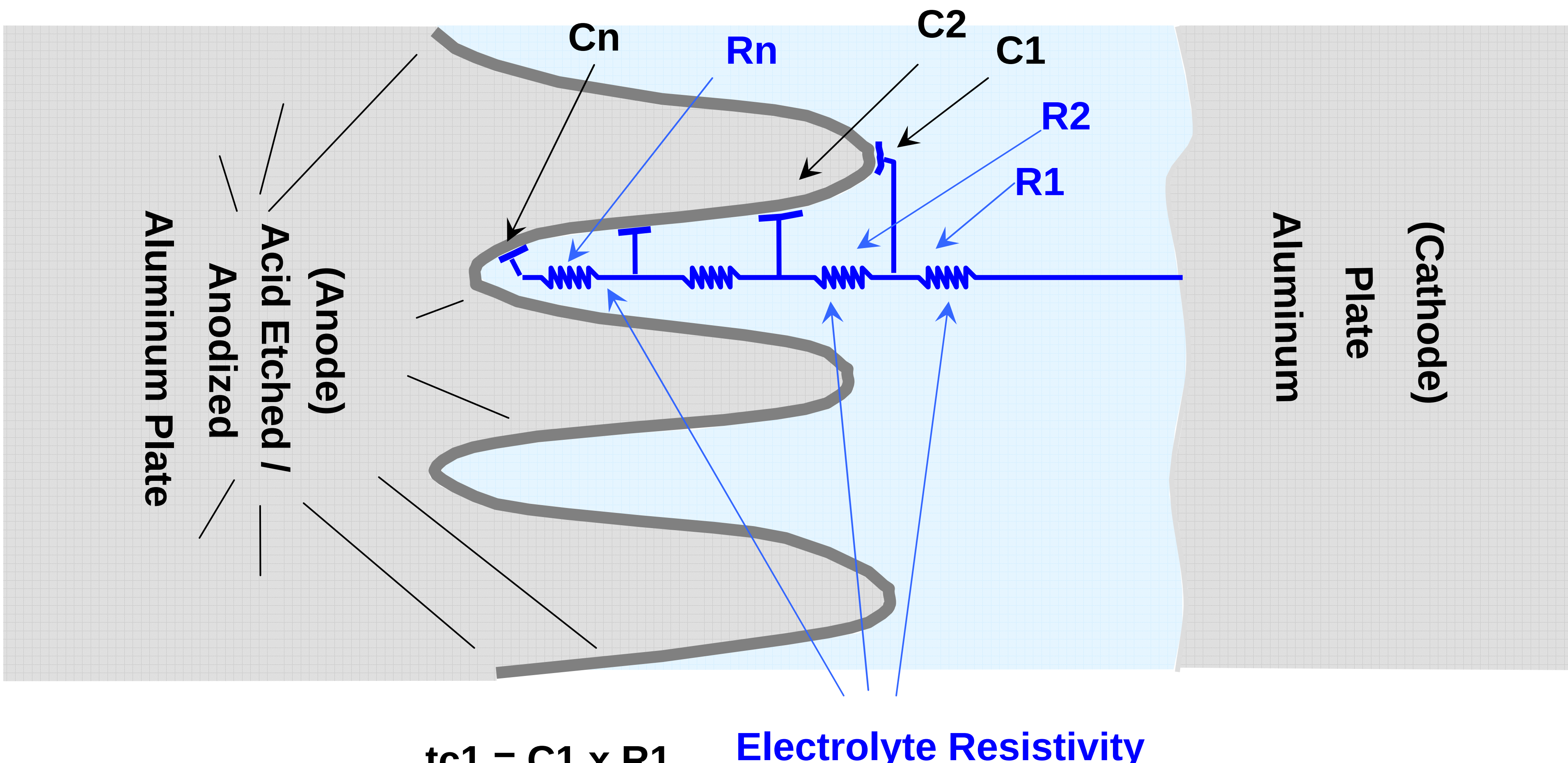
tc1 = C1 x R1

tc2= C2 x (R1+R2)

tc3= C3 x (R1+R2+R3)

tcn= Cn x (R1+R2+R3...+Rn)

RC-Ladder in Aluminum Electrolytic



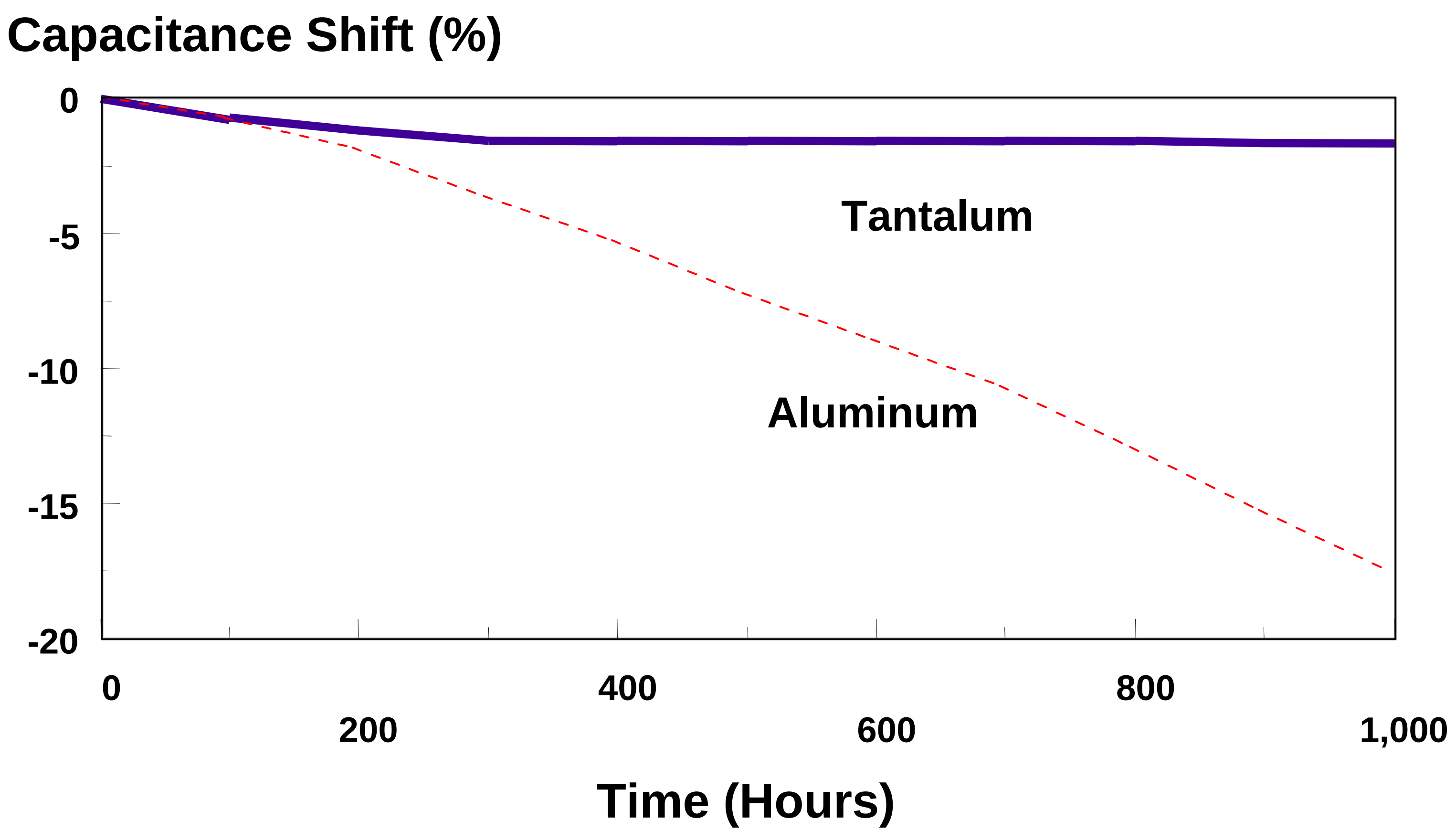
tc1 = C1 x R1

tc2 = C2 x (R1 +R2)

tcn = Cn x (R1+R2....+Rn)

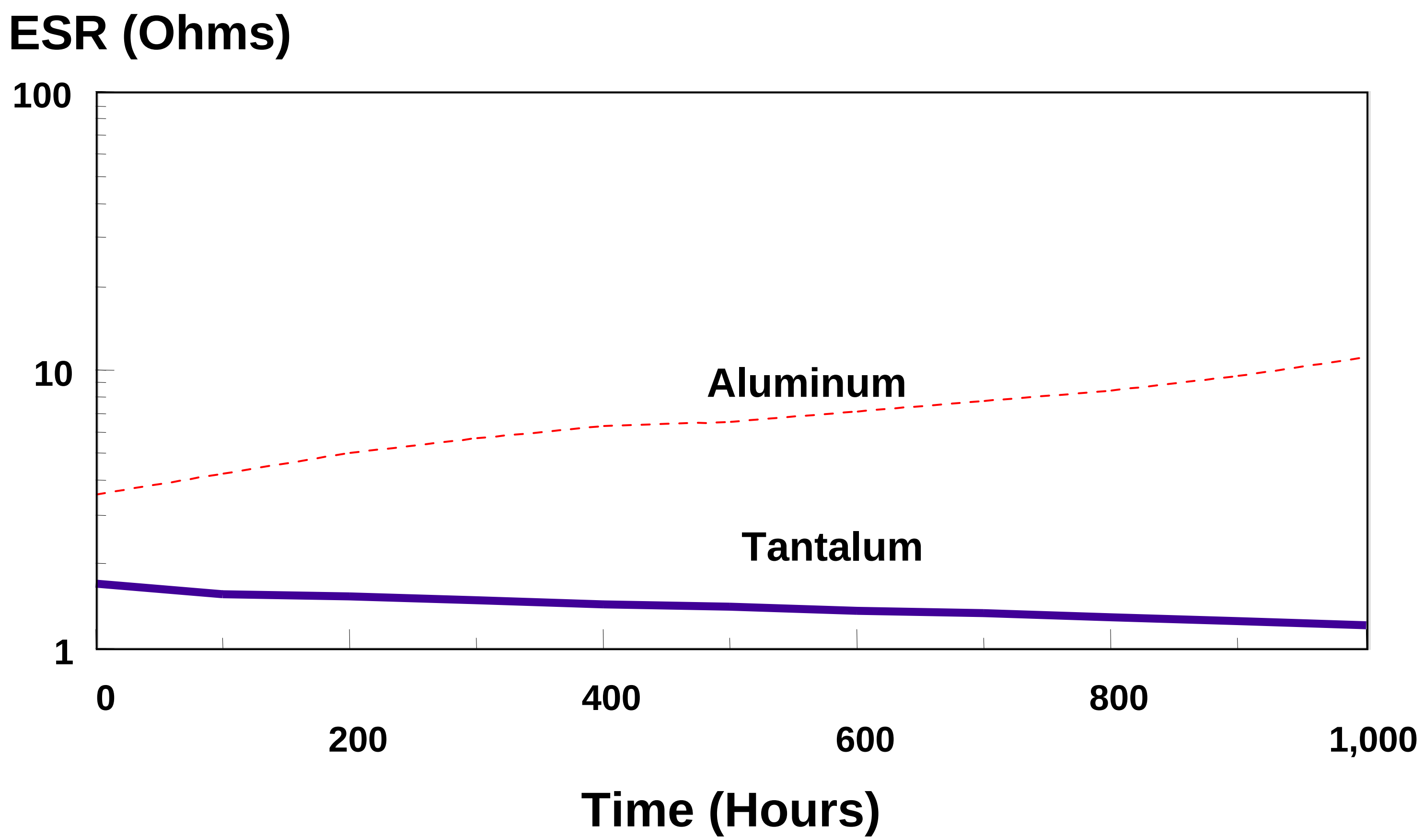
Alum. Elect. - Capacitance vs. Time

100°C Life Test 10uF @ 25VDC



Alum. Elect. - ESR vs. Time

100°C Life Test 10uF @ 25VDC



Electronic News

Monday, October 28, 2002 Volume 48, N0. 44

Got Juice?

Leaky capacitors shorting circuits; problem spreads

BY ED SPERLING

Failing capacitors are sending shock waves up the electronics food chain—literally. PCs are crashing and televisions and camcorders are going on the fritz, and the problem is becoming more widespread, according to those who replace those components.

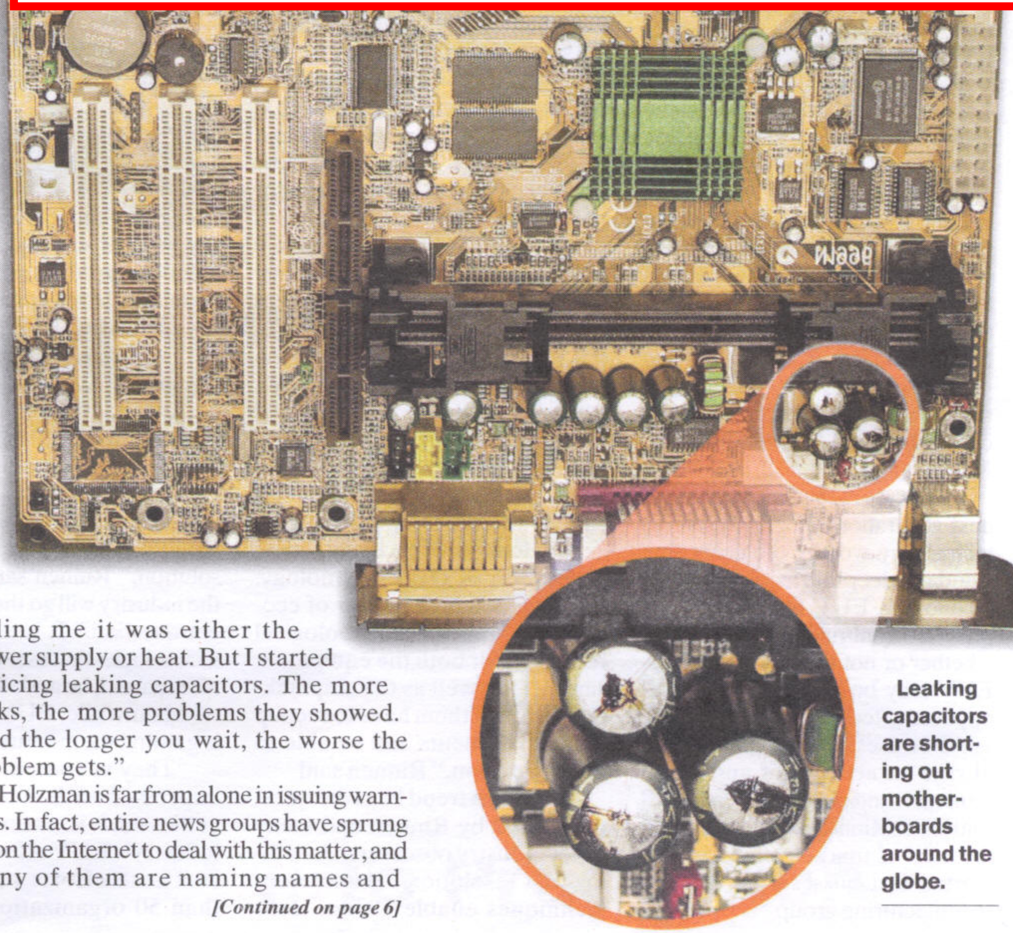
At the heart of this controversy are low-ESR aluminum electrolytic capacitors, all of which were made in Taiwan. According to systems integrators who build custom PCs and those who repair them, the capacitors start leaking electrolytic fluid within days or weeks after the computer is turned on. In most cases, the leaking fluid causes short circuits. Less commonly, they actually explode.

Carey Holzman, a private-label white-box PC builder in Glendale, Ariz., started noticing the problem about 10 months ago and has been contacting motherboard vendors to get them to acknowledge and fix the problem. So far, no one is owning up to it.

"We would get strange errors in Windows and it wouldn't reboot, or the board would lock up and reboot randomly," said Holzman, who has been building PCs for the past 12 years. "The boardmakers were telling me it was either the power supply or heat. But I started noticing leaking capacitors. The more leaks, the more problems they showed. And the longer you wait, the worse the problem gets."

Holzman is far from alone in issuing warnings. In fact, entire news groups have sprung up on the Internet to deal with this matter, and many of them are naming names and

[Continued on page 6]



Leaking capacitors are short-ing out mother-boards around the globe.

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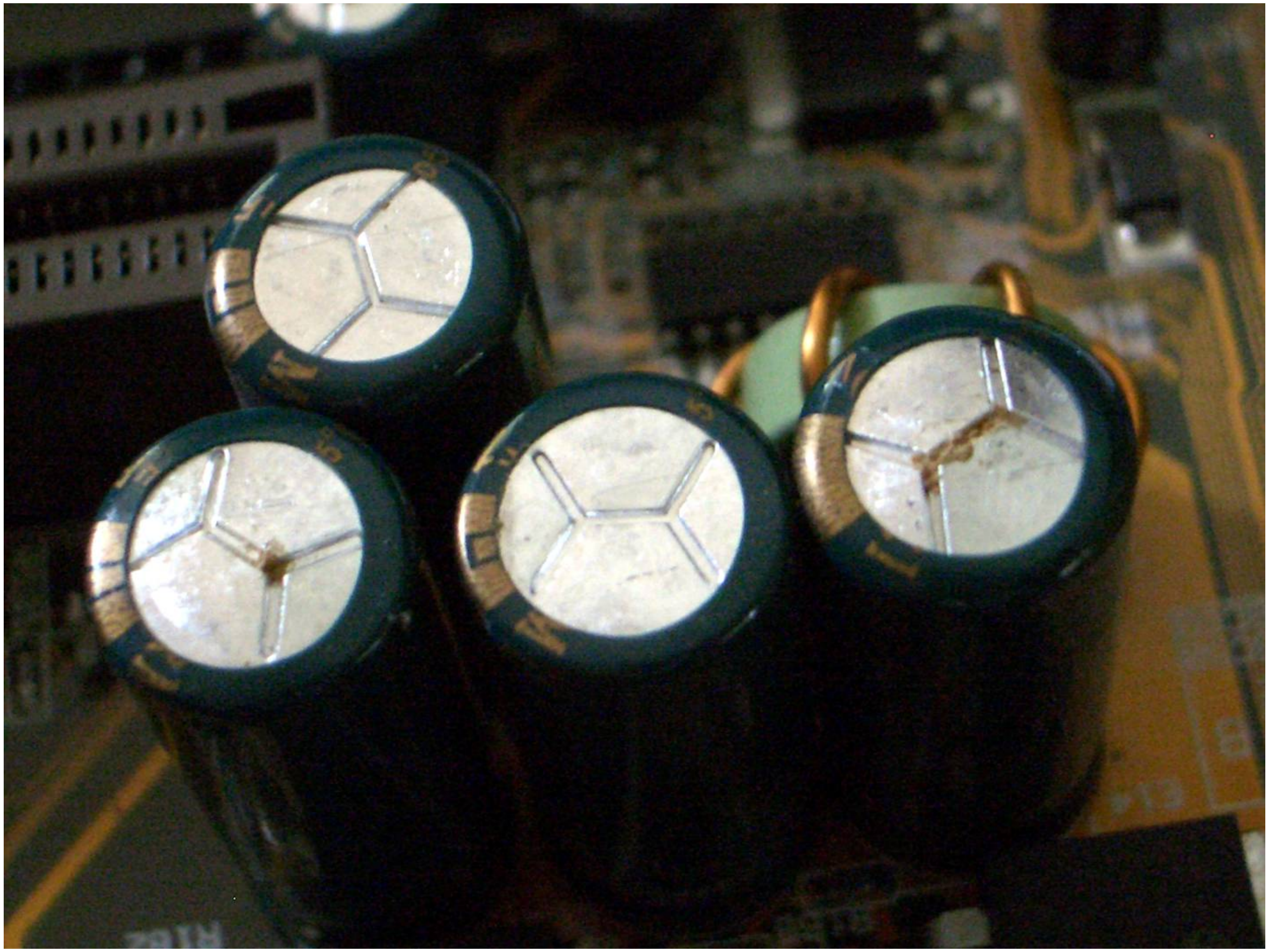
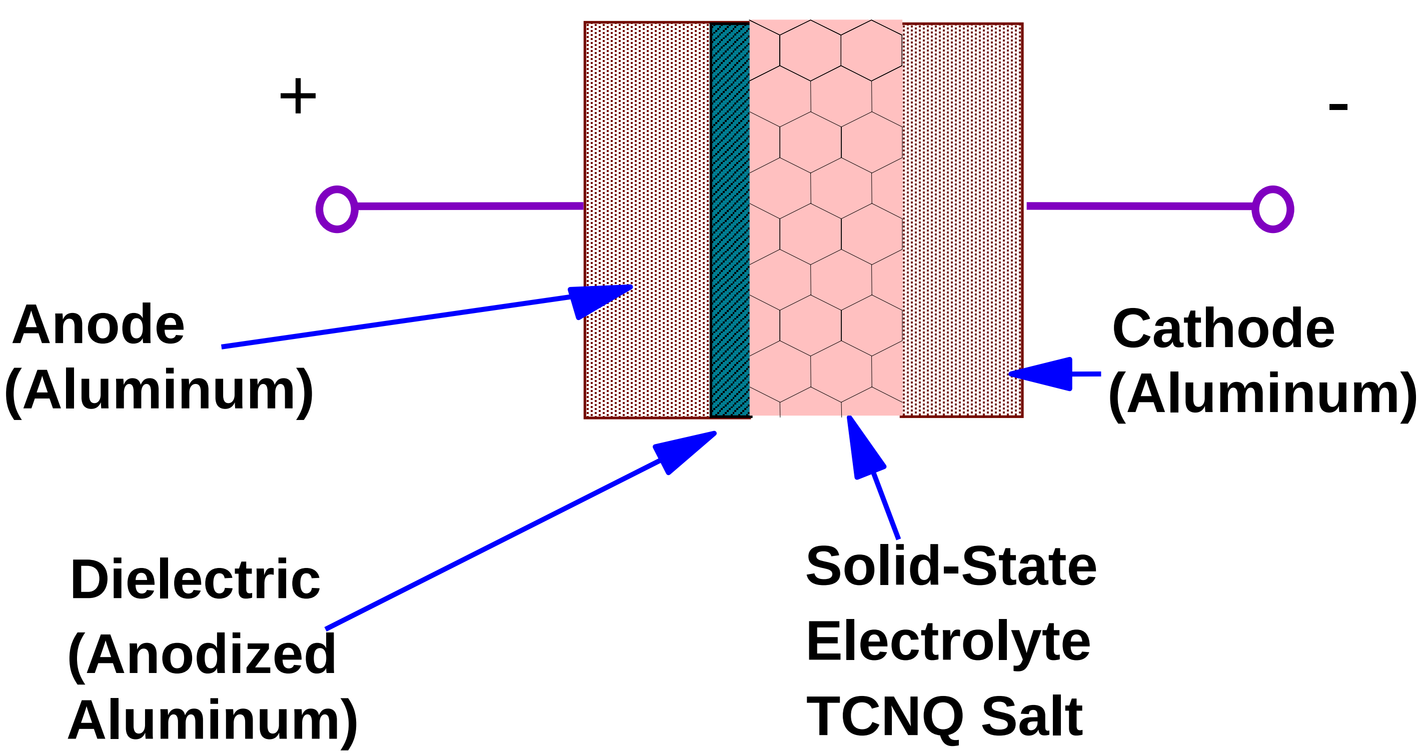
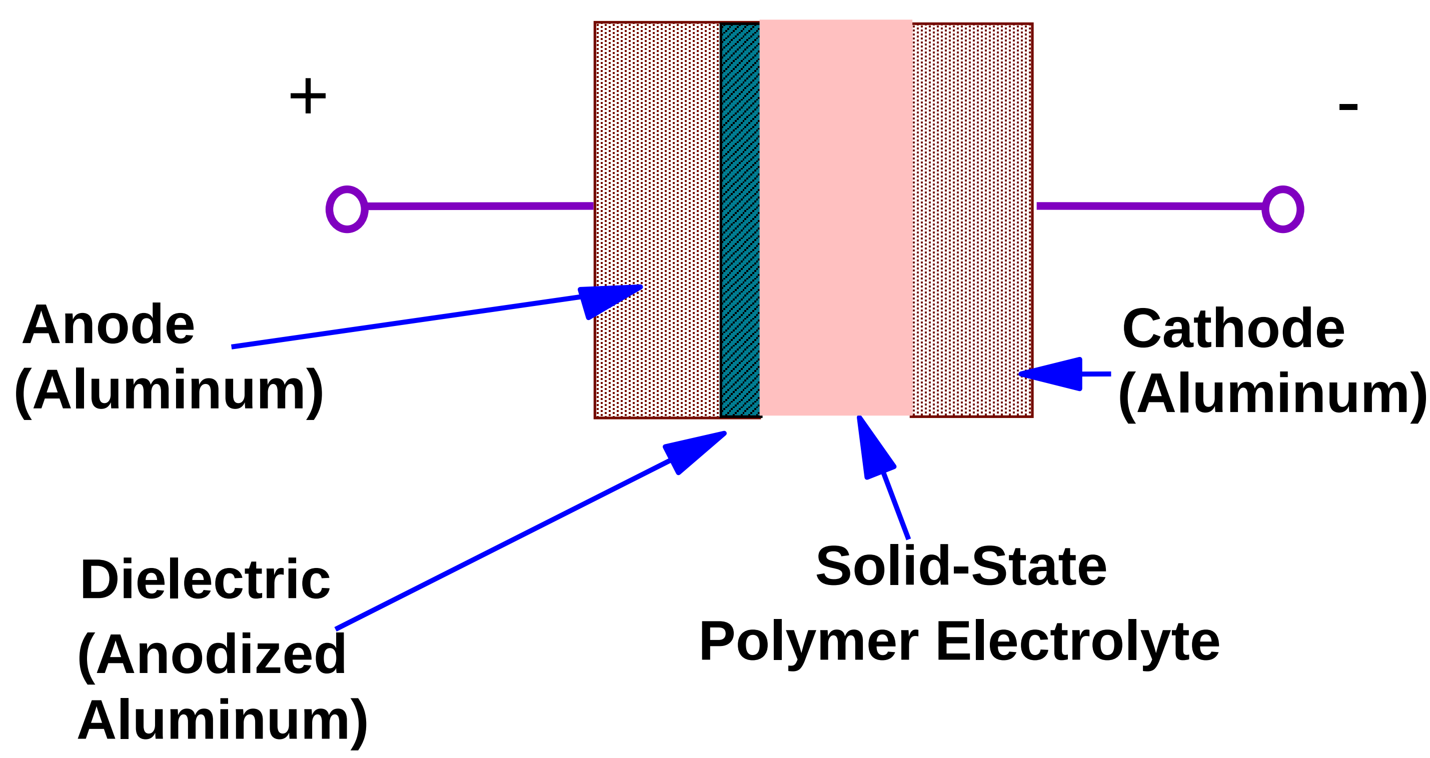
Leaky Al-Electrolytics (board Oct. 2003)



Aluminum OS-con



Aluminum “V” Chip



Film Capacitors

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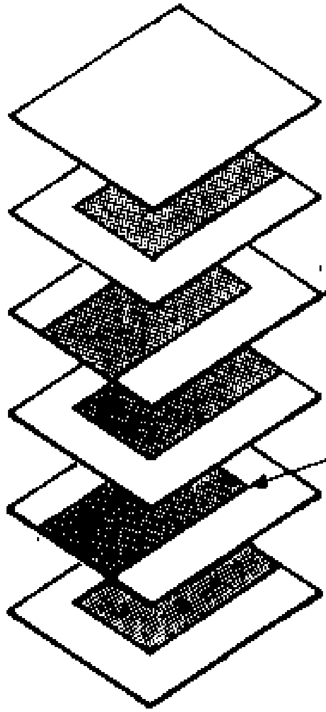
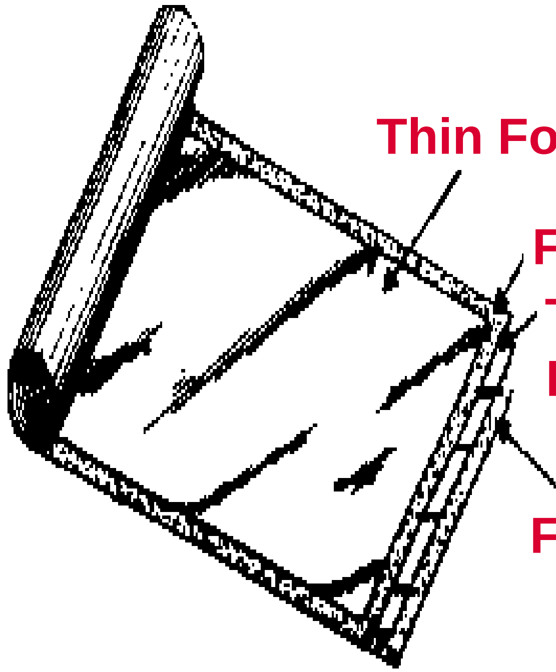
Construction and Materials

Film Capacitor Construction

Film Capacitors utilize two main constructions

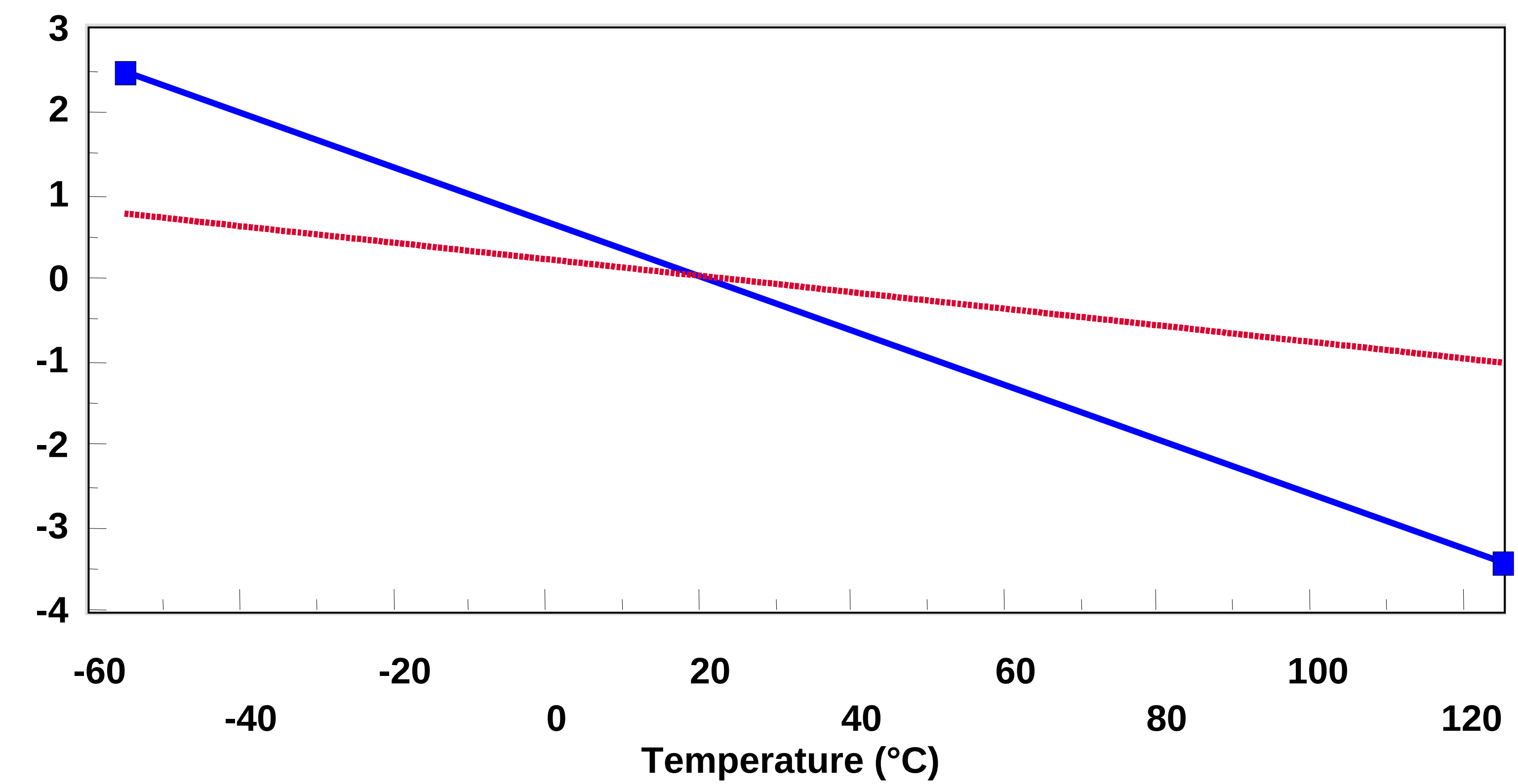


Multilayer Construction



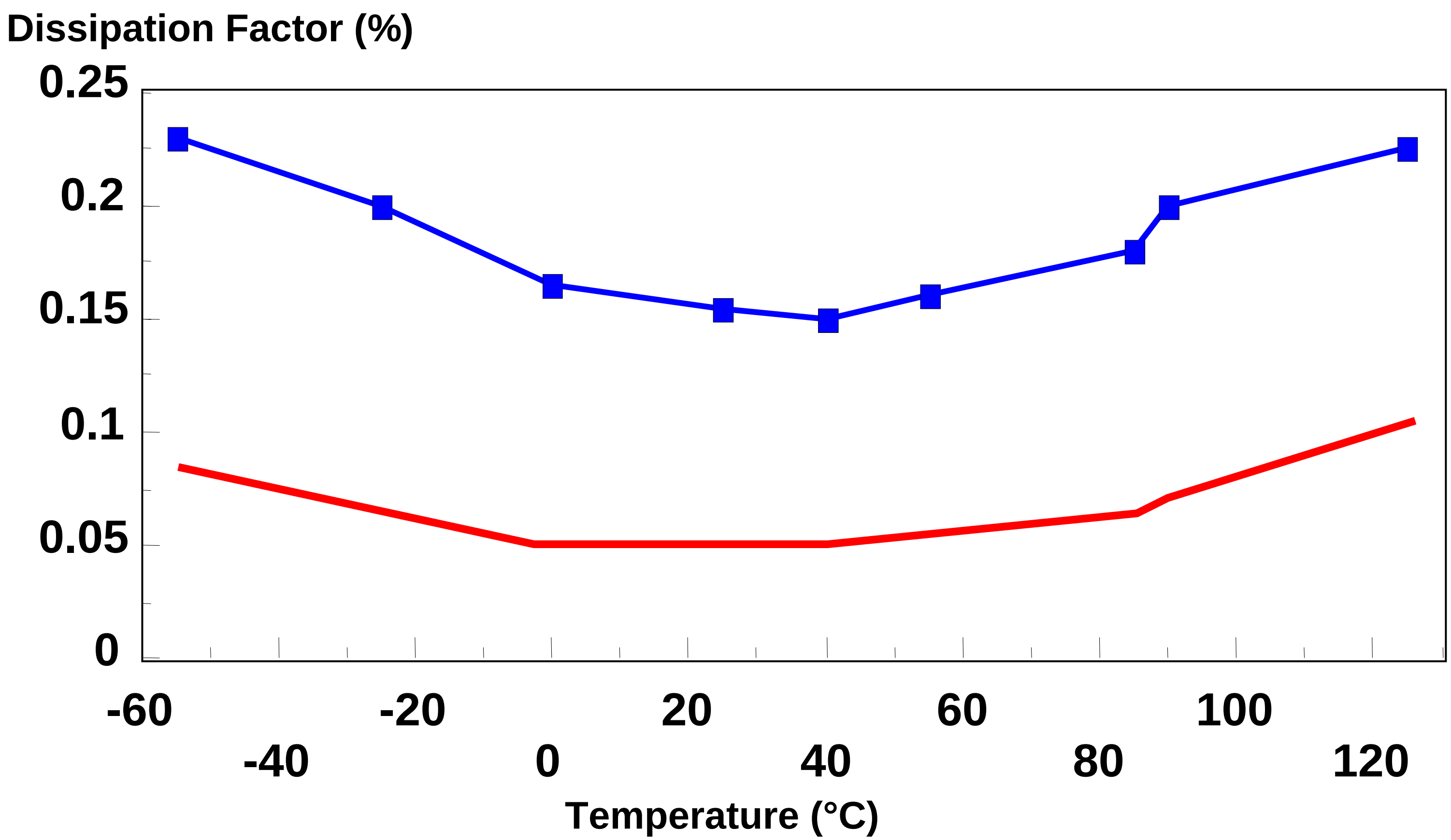
Rolled Foil Construction

Capacitance Change vs. Temperature



Film DF Temperature Dependence

%DF vs. Temperature

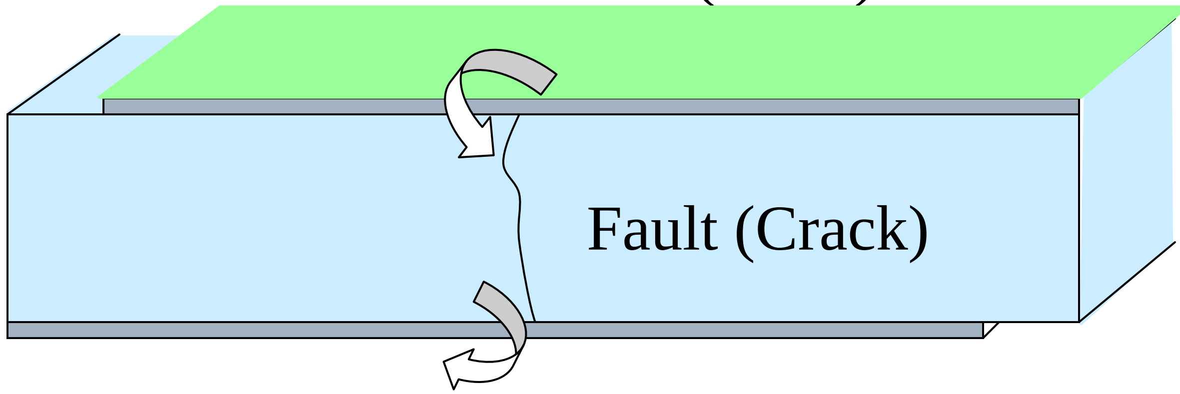


Film - Metalized vs Foil

- **Foil**
  - ►Thicker Electrode Plates
  - ► Lower ESR
  - ►Less "Self-Healing"
  - ►Easier Moisture Ingress
- **Metalized**
  - ►Sputtered Electrode on Film
  - ►Very thin electrodes
  - ►Higher ESR
  - ►Efficient "Self-Healing"
  - ►Retards moisture ingress
  - ►Low Current / Low Overvoltag e

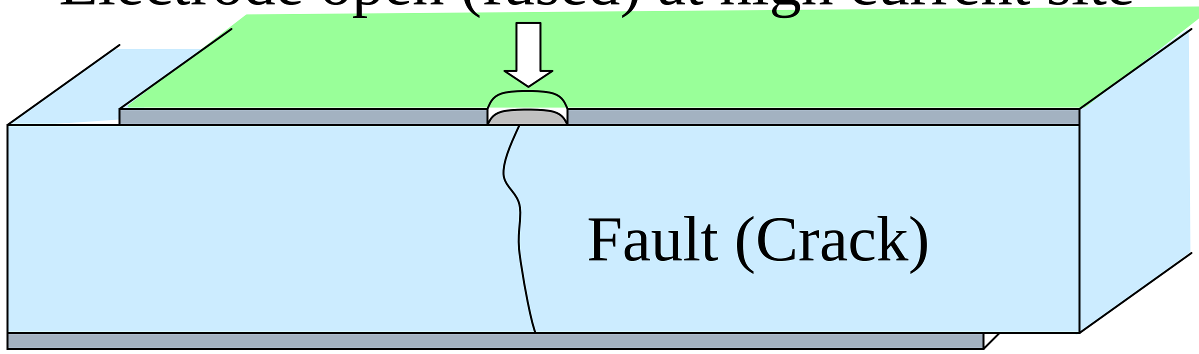
Self-healing in Films

Current into fault (crack)

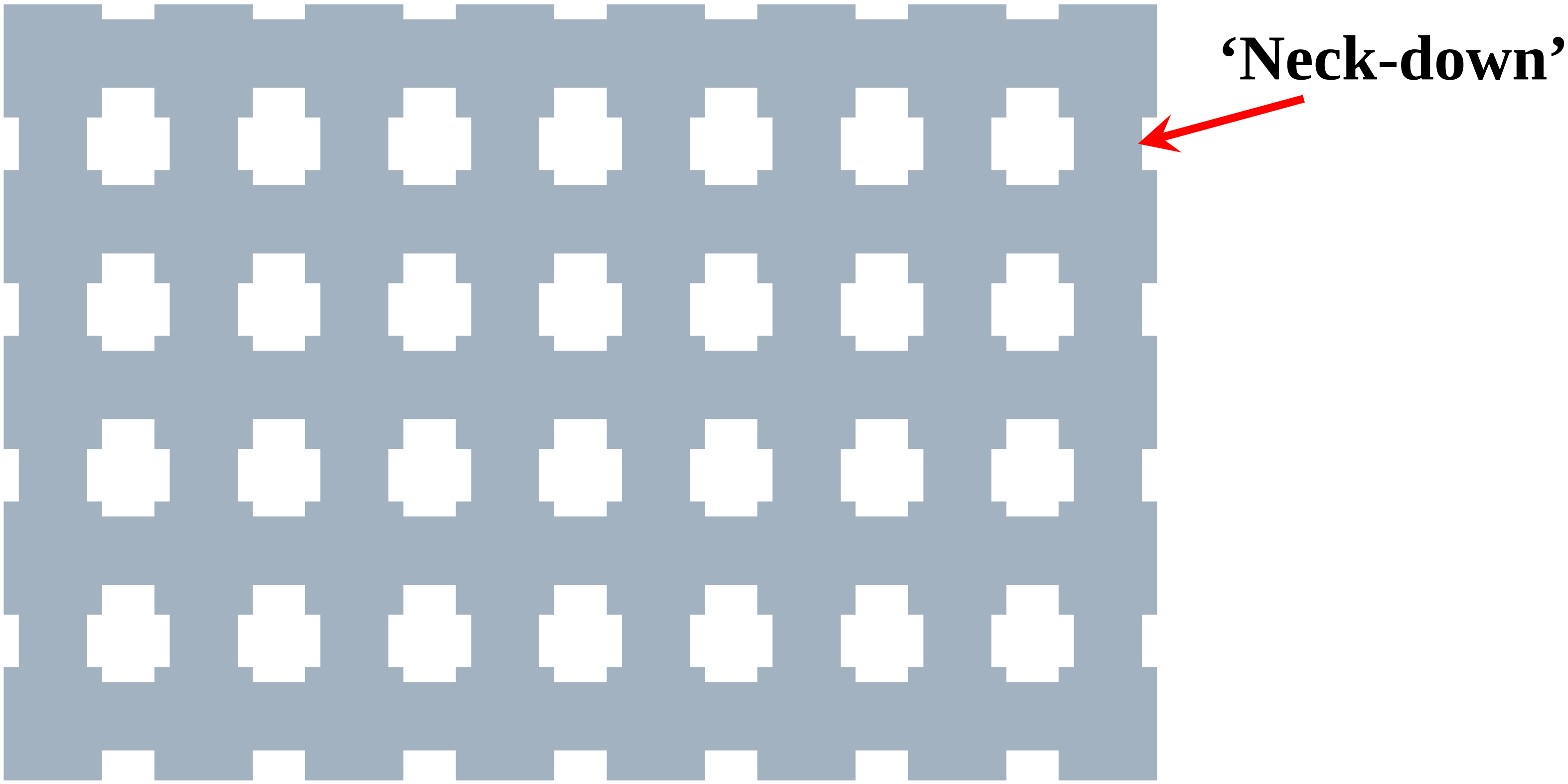


Electrodes = Sputtered (CVD) Aluminum

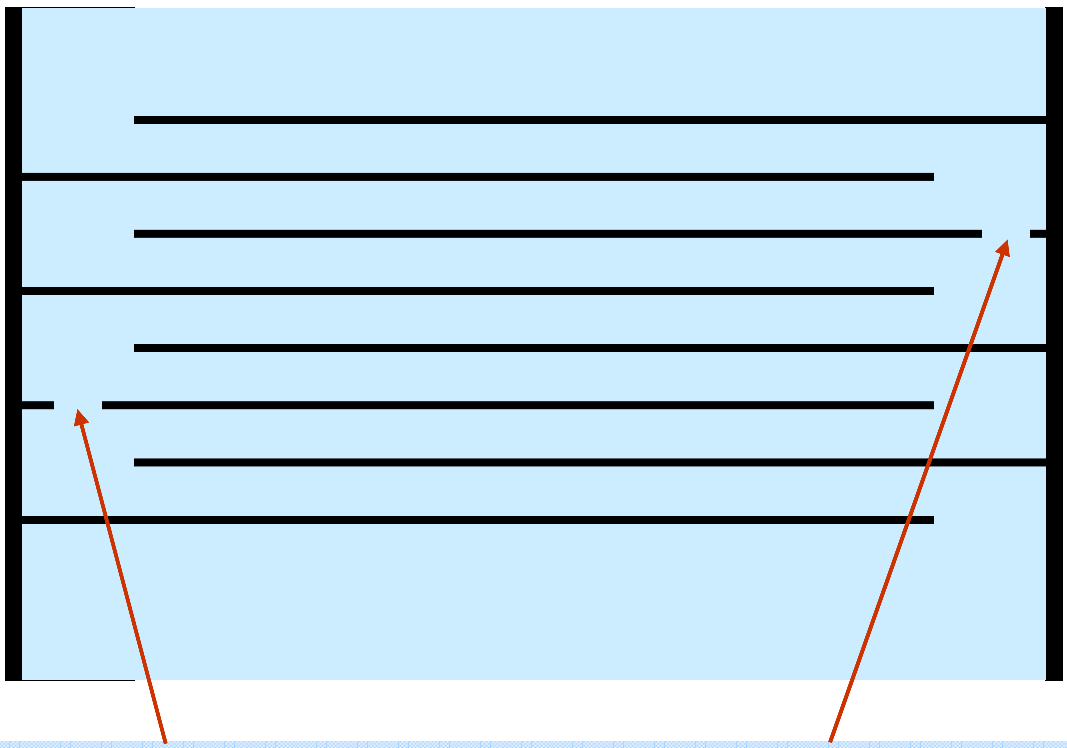
Electrode open (fused) at high current site



Web pattern to improve fusing



High Current Fault of Film



Current fuses Al plate material - capacitance loss with time

Ceramic Capacitors

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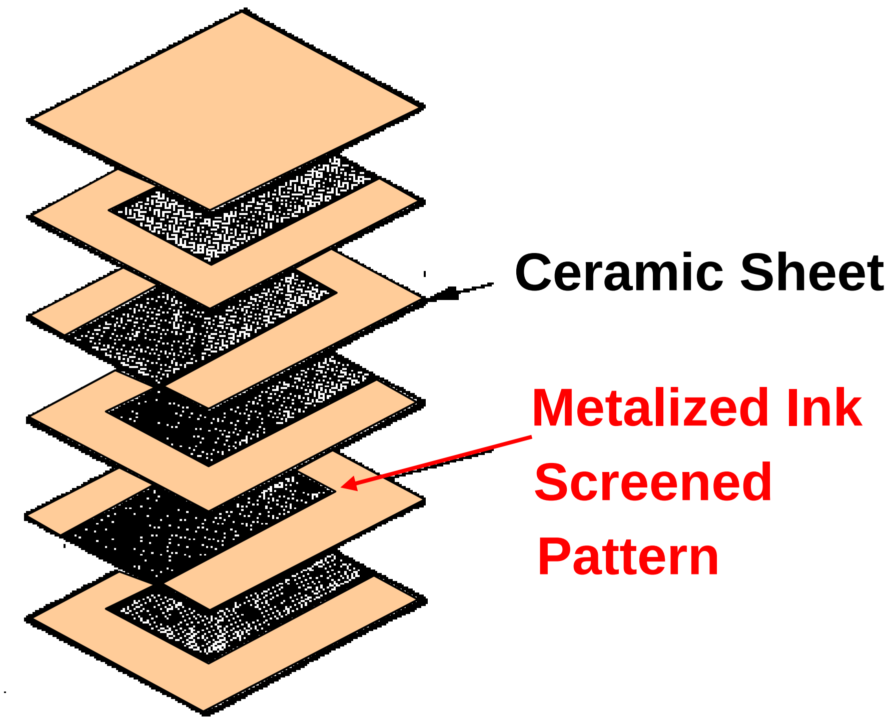
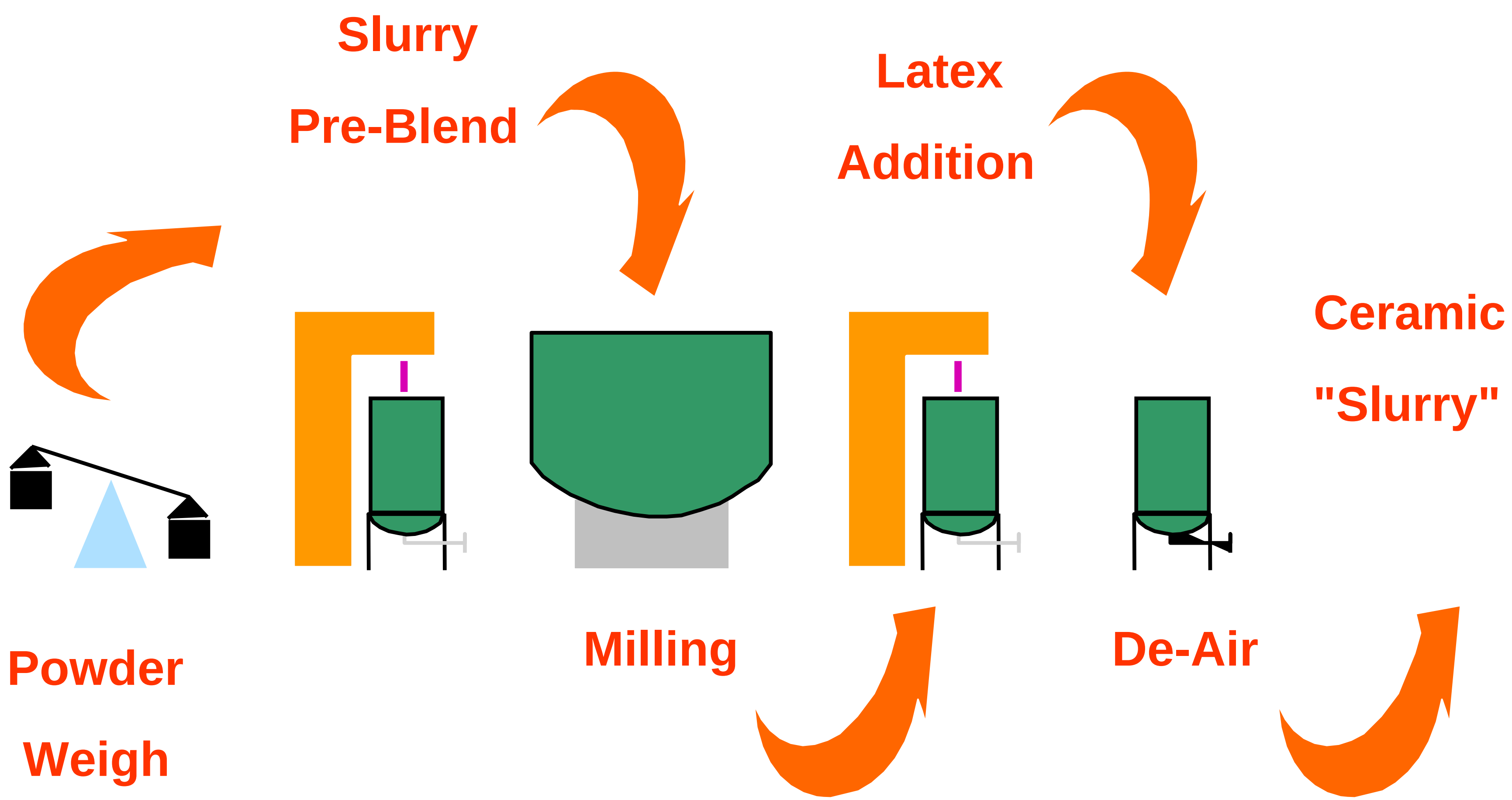
Construction and Materials

Multilayer Construction

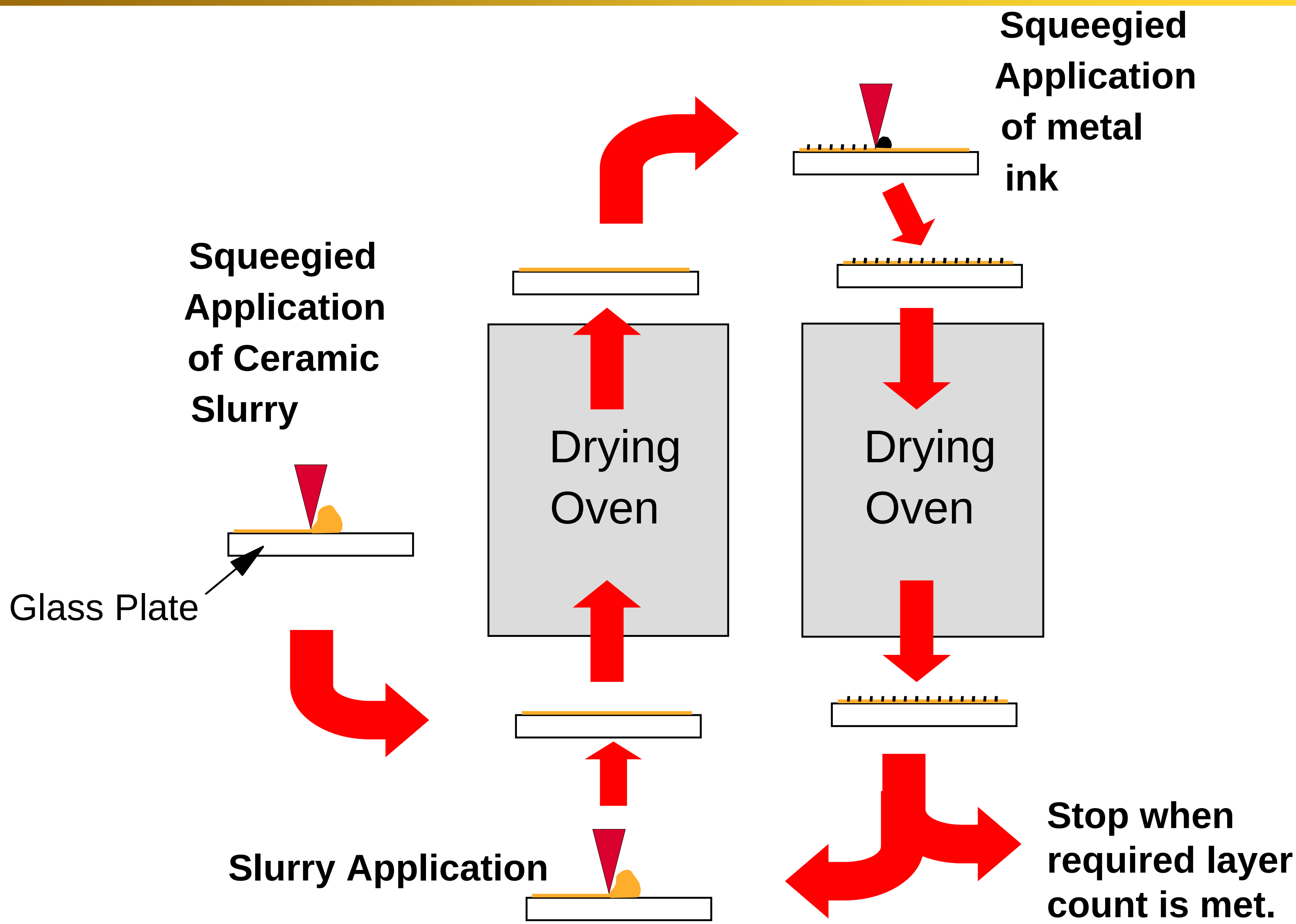


"Tape" process involves a ceramic sheet that is filled with plastic binders to allow handling

Initial Ceramic Process - Slurry

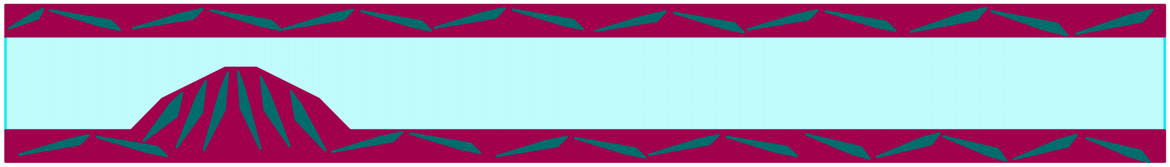


Wet process Buildup



Agglomerates

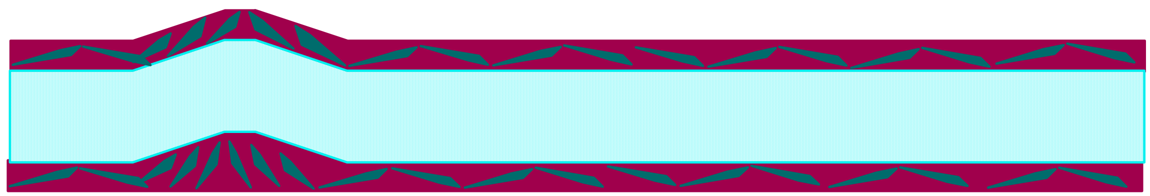
Agglomerates are lumps that form in the deposited ink as metal particles coagulate to one area, or are dropped from screen.



Agglomerates can cause shorts or lead to "weak" spots in the dielectric.

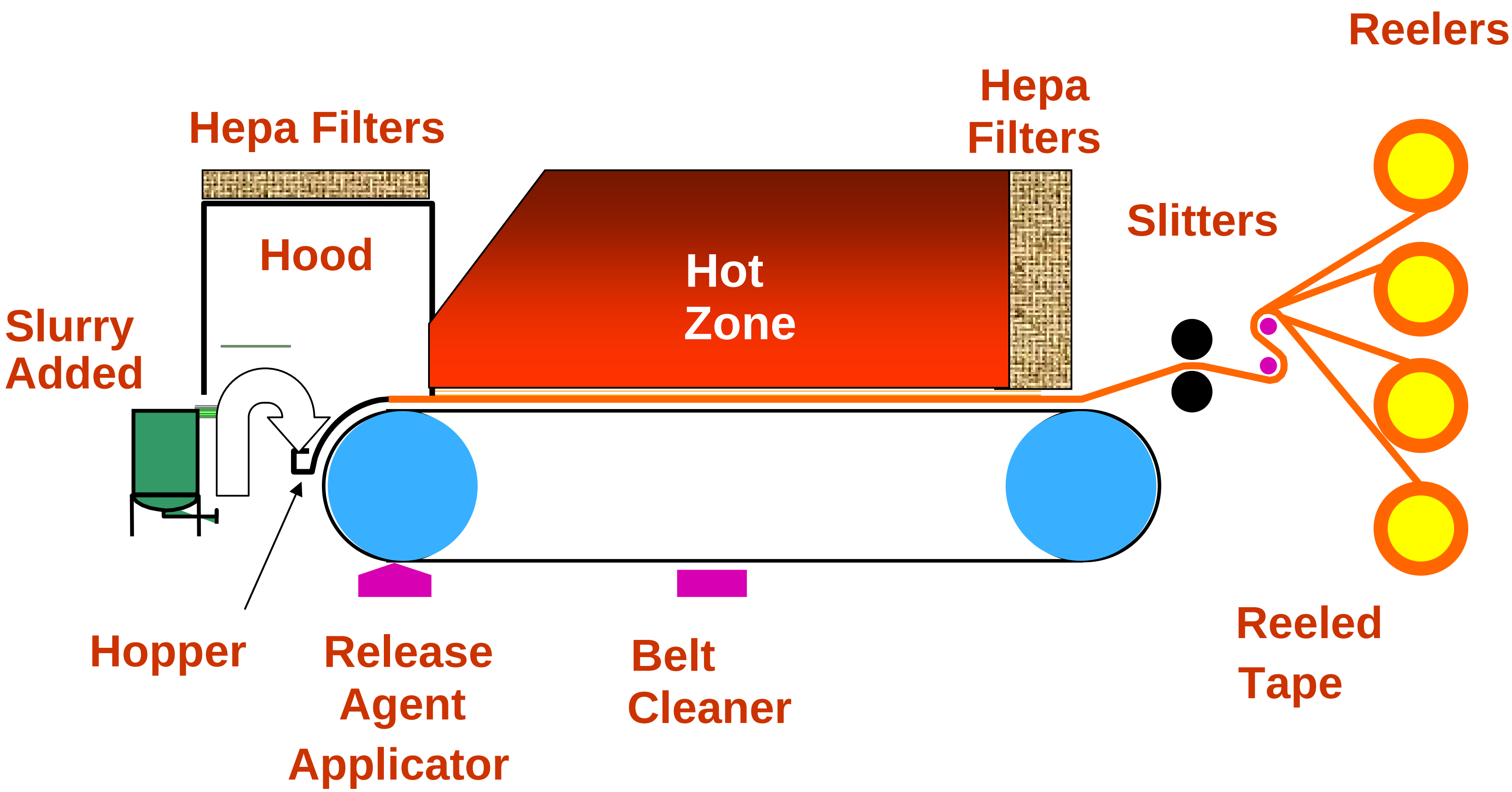
Suppressed Agglomerates in Tape Proc.

Tape process presses aggolomerates down, and tape conforms to undulation.



Agglomerate defect creation is minimized.

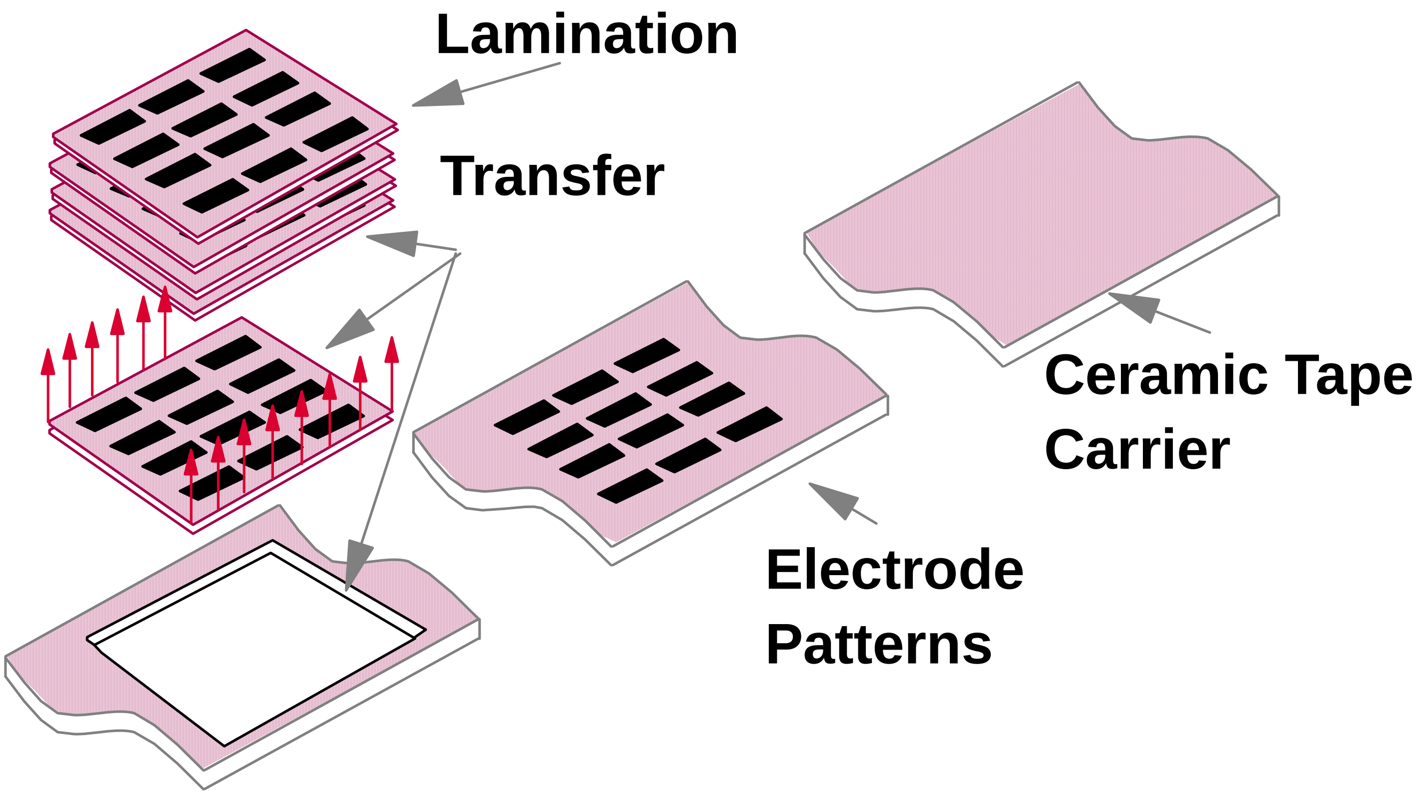
Caster in Tape Process



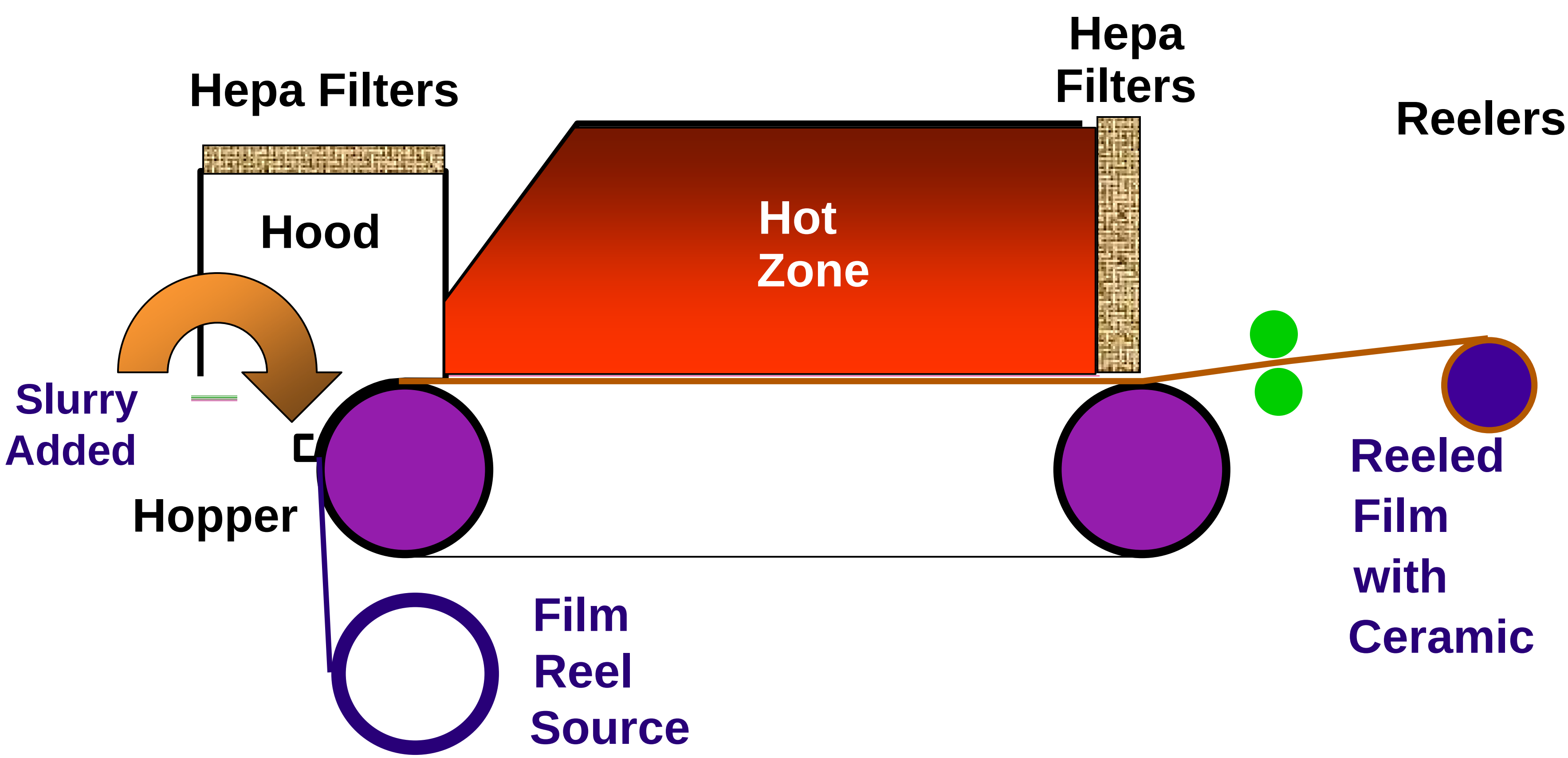
Unsupported Ceramic "Tape" 10 to 50 microns

TAPE Process (Old 'APA')

Ceramic Tape / Electrode / Transfer-Laminate



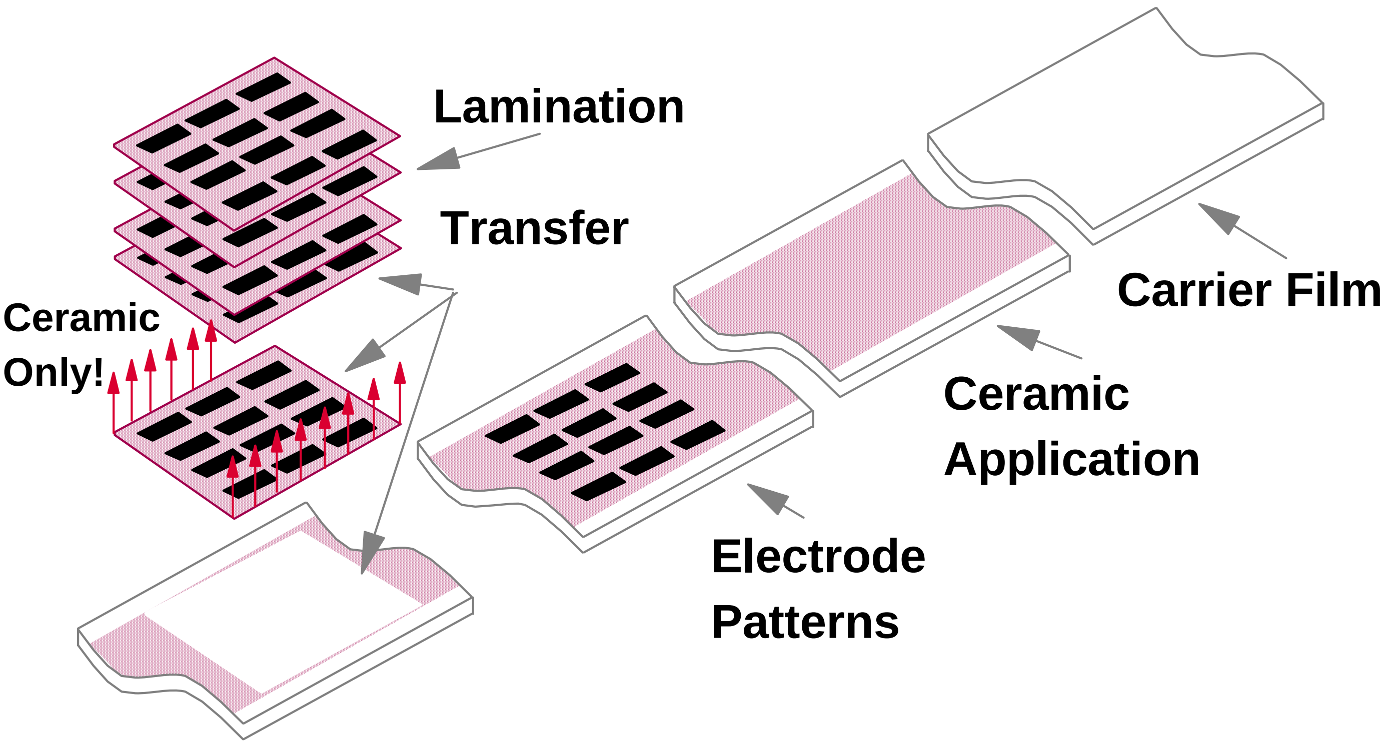
Tape & Film ('KTP' Process)



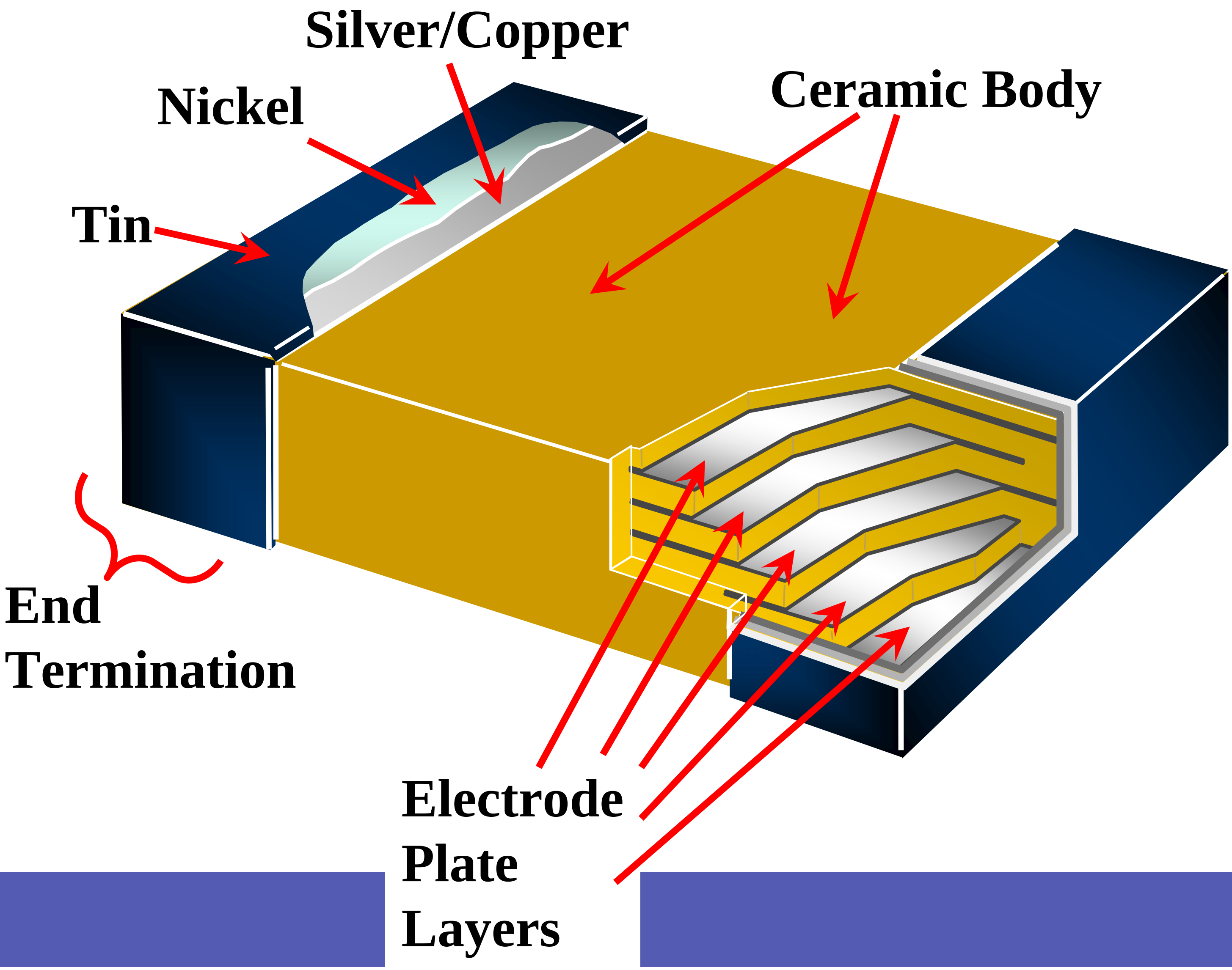
Supported Ceramic Deposit 0.5 to 5 microns

"KTP" Process

Carrier / Ceramic / Electrode / Transfer-Laminate

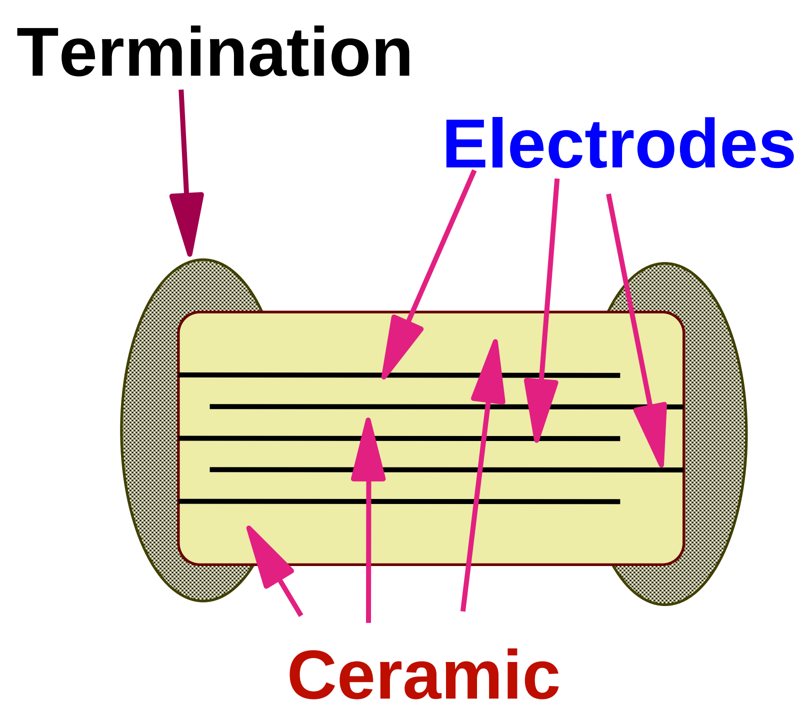


Typical Multilayer Ceramic Capacitor



Ceramic Capacitance Structure

Cut-away view



C = Design Capacitance

K = Dielectric Constant

A = Overlap Area

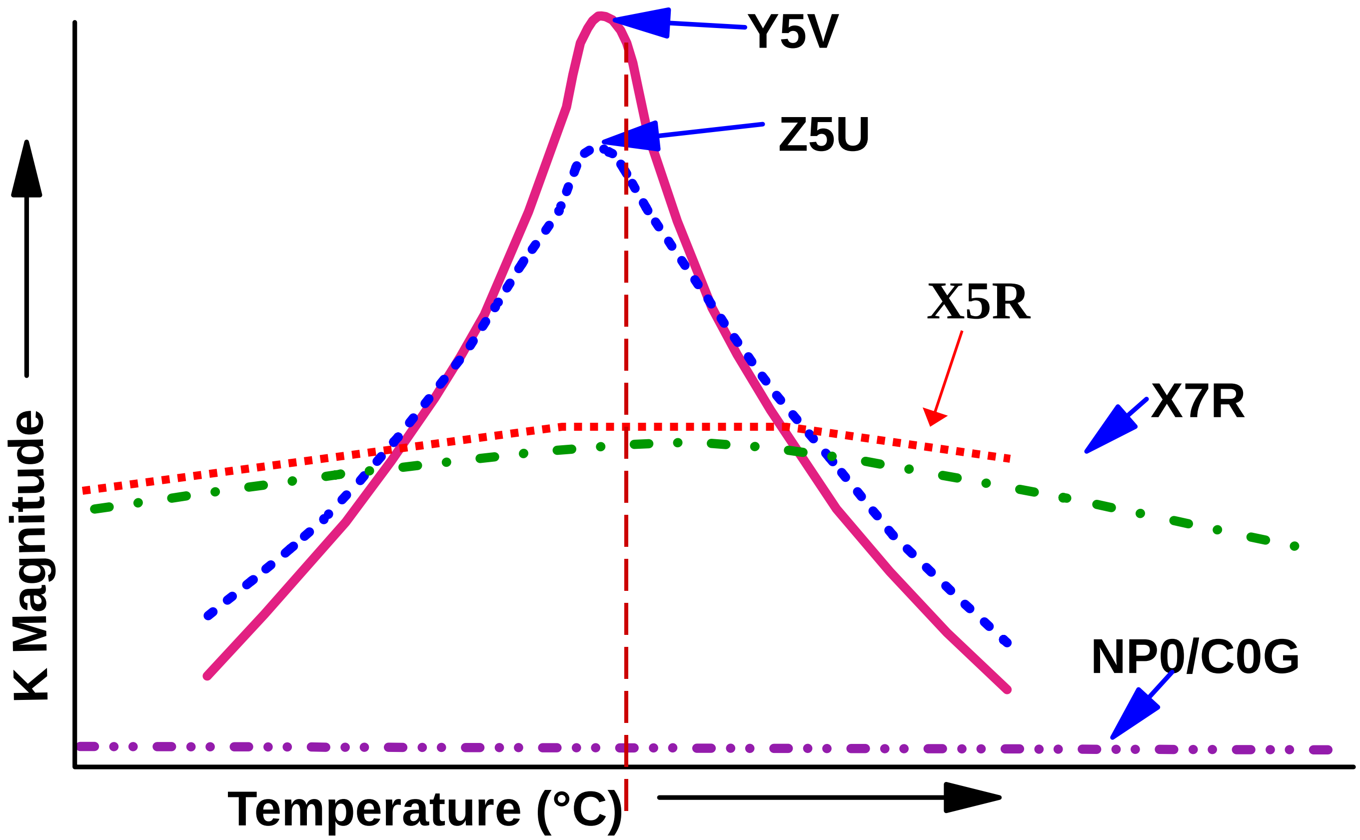
t = ceramic thickness

n = number of electrodes

Calculation of capacitance:

$$C = \frac{\{KA(n-1)\}}{\{t\}}$$

Relative Capacitance vs. Temperature



EIA Designations for Class 1

Defines Temperature Characteristics

+25°C

Significant Figure of Temperature Coefficient		Multiplier added to Temperature Coefficient		Tolerance of Temperature Coefficient	
PPM/°C	Symbol	Multiplier	Symbol	PPM/°C	Symbol
0.0	C	-1	0	± 30	G
0.3	B	-10	1	± 60	H
0.9	A	-100	2	± 120	J
1.0	M	-1,000	3	± 250	K
1.5	P	-10,000	4	± 500	L
2.2	R	+1	5	± 1000	M
3.3	S	+10	6	± 2500	N
4.7	T	+100	7		
7.5	U	+1,000	8		
		+10,000	9		

C0G?

NP0?

NP0 not shown - old designation style

R3K?

+85°C

Defines Temperature Characteristics

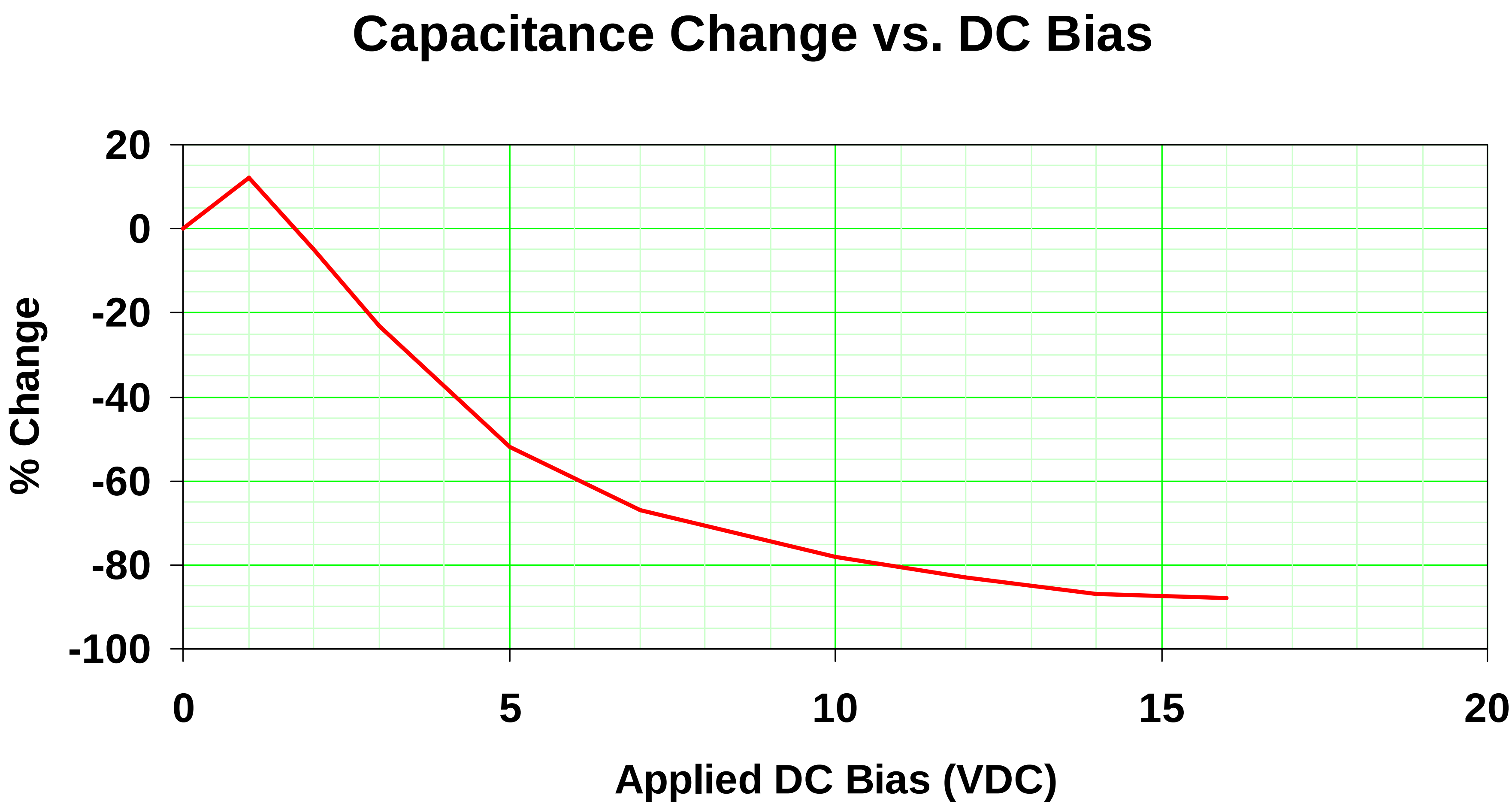
X7R? X5R?

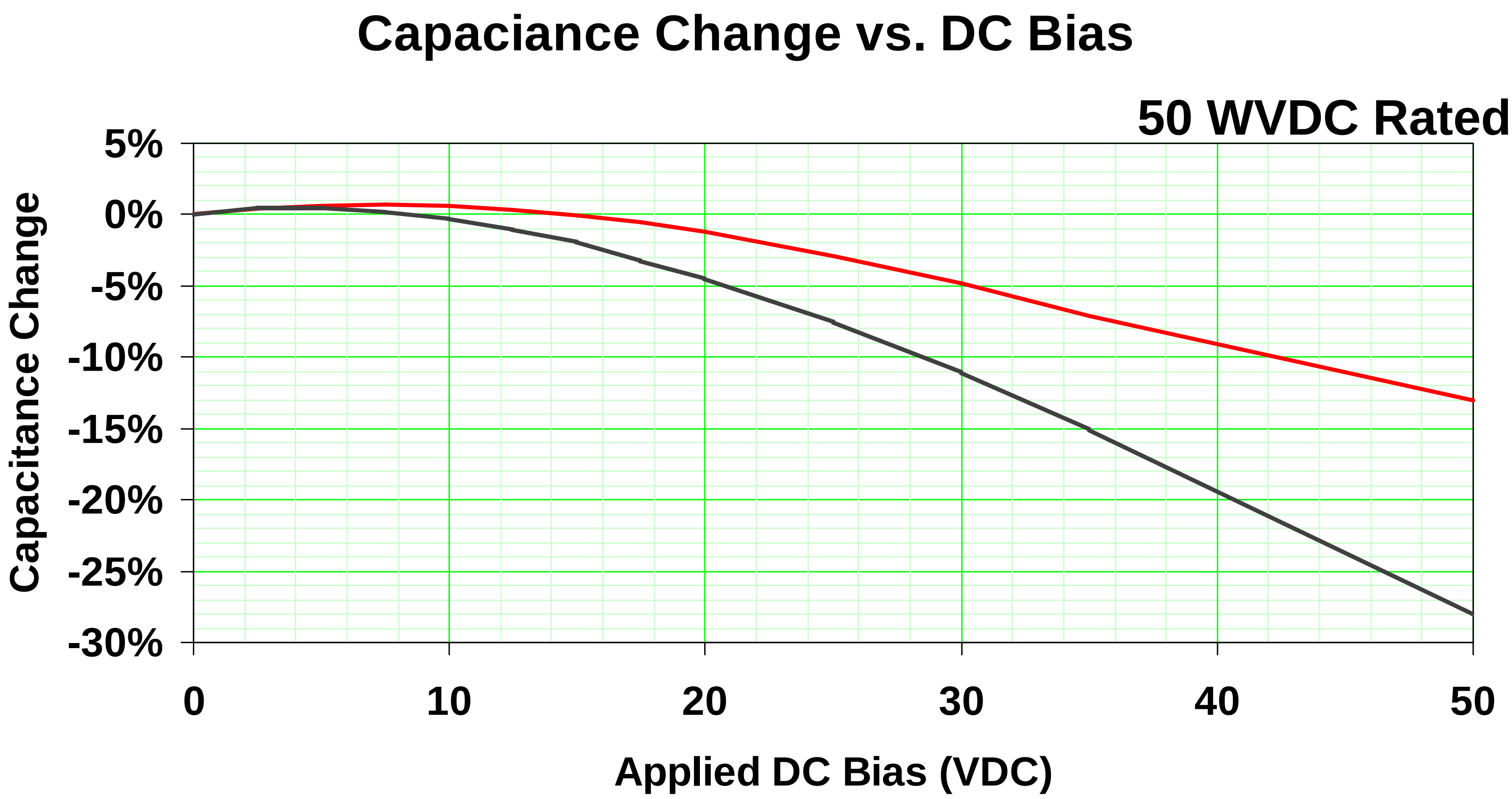
Low Temperature		High Temperature		Maximum Capacitance Change	
°C	Symbol	°C	Symbol	°C	Symbol
10	Z	45	2	±1.0%	A
-30	Y	65	4	±1.5%	B
-55	X	85	5	±2.2%	C
		105	6	±3.3%	D
		125	7	±4.7%	E
		150	8	±7.5%	F
		200	9	±10.0%	P
				±15.0%	R
				± 22.0%	*S*
				+22%,-33%	*T*
				+22%,-56%	*U*
				+22%,-82%	*V*

Class 3 (symbols S, T, U, V)

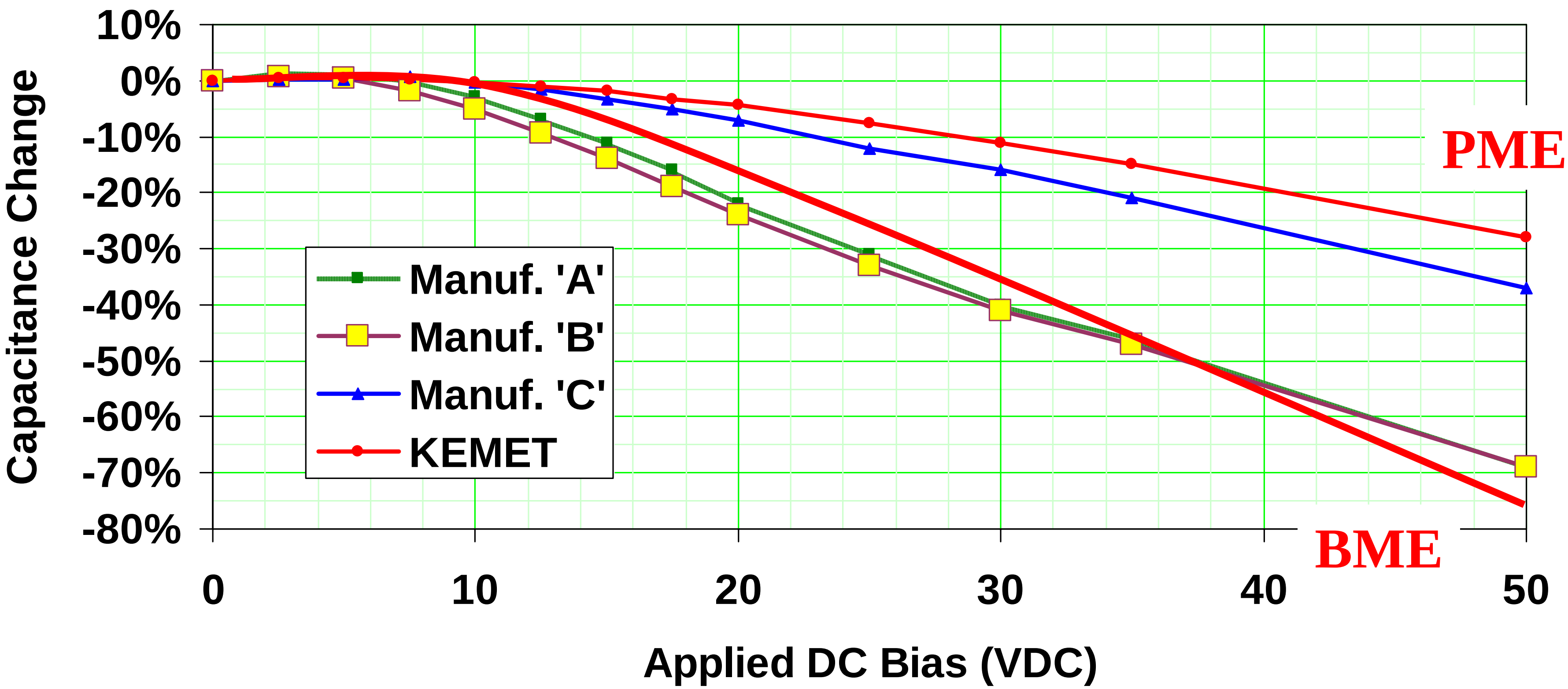
Z5U? X5P? X8R? Y5V? X8S?

Voltage Coefficient – High 'K'




Capaciance Change vs. DC Bias
50 WVDC Rated
5%
0%
-5%
-10%
-15%
-20%
-25%
-30%
Capacitance Change
0
10
20
30
40
50
Applied DC Bias (VDC)

0805 X7R 0.1 uF / 50 WVDC



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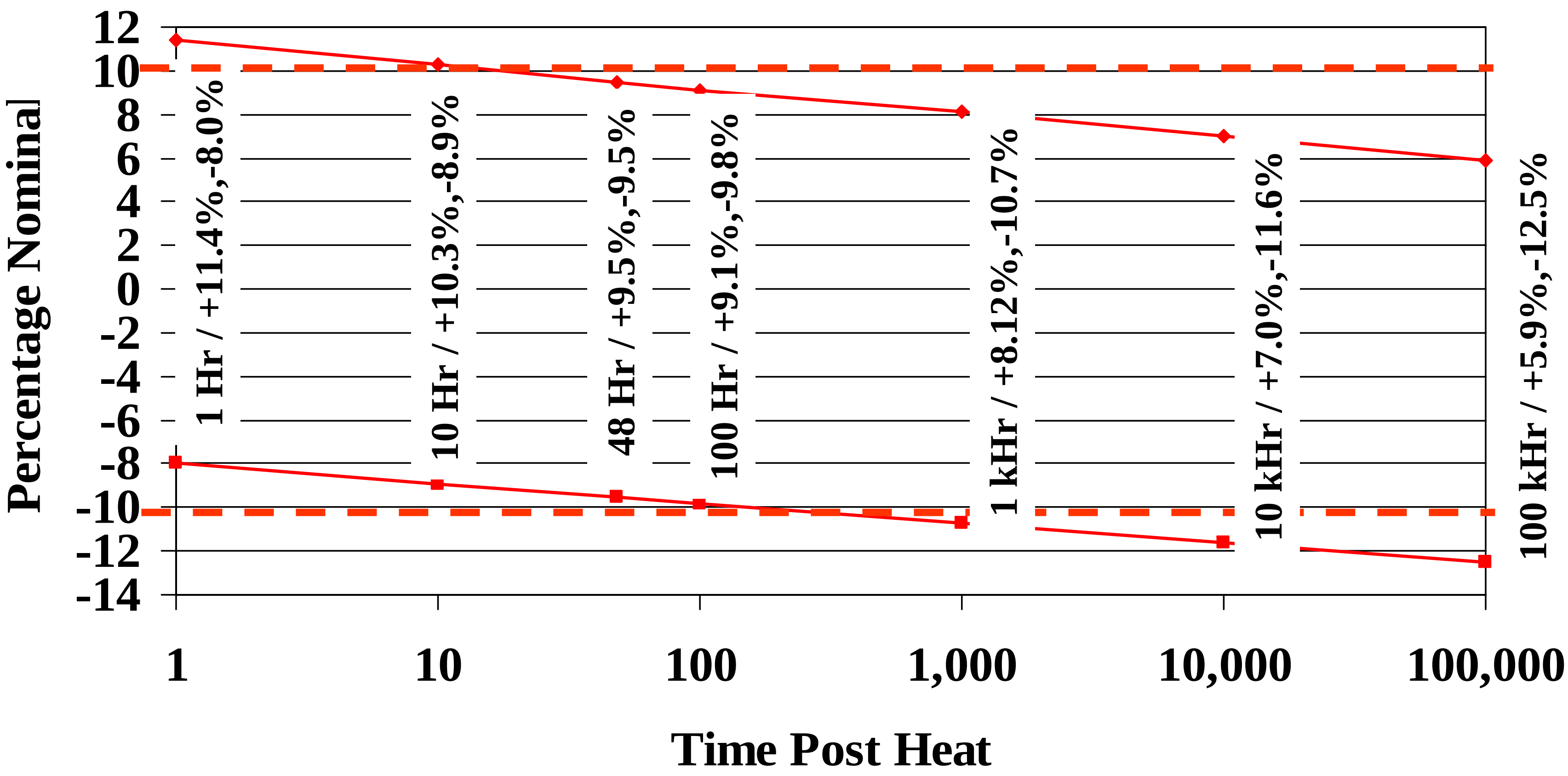
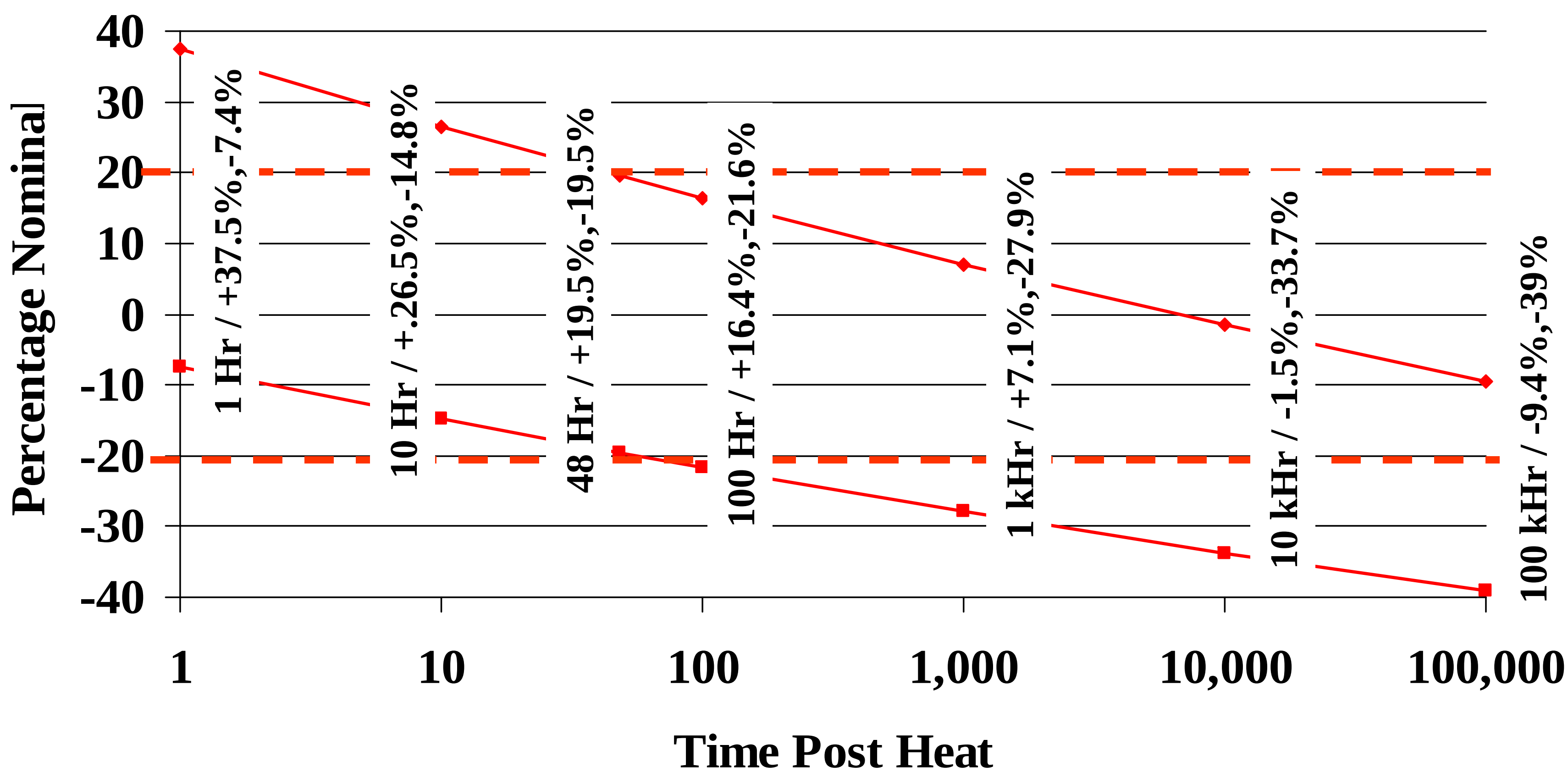
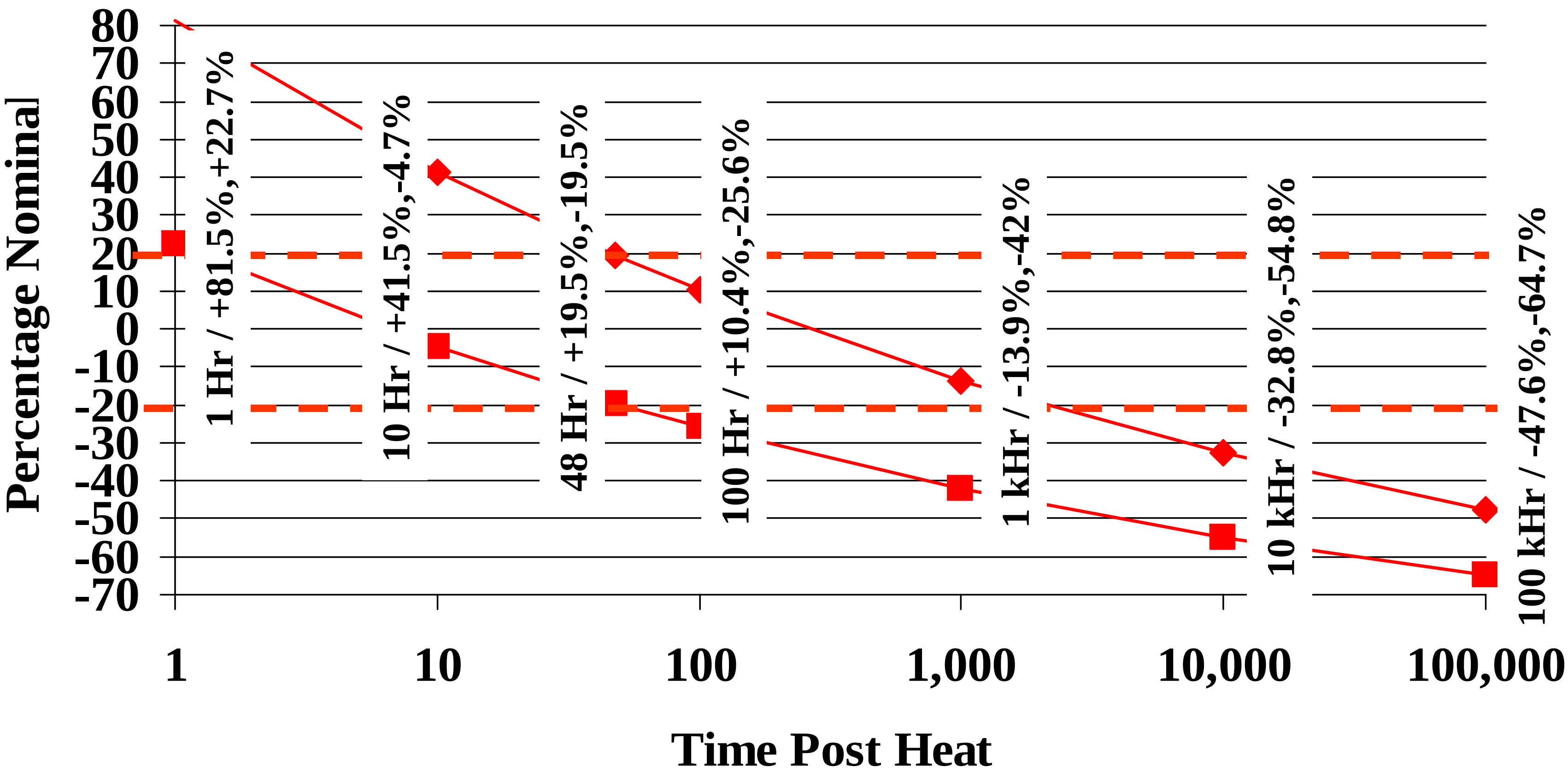
X7R Aging Rate of 1%/Dec-Hr



Y5V Aging Rate of 8%/Dec-Hr



Unk Aging Rate of 22%/Dec-Hr



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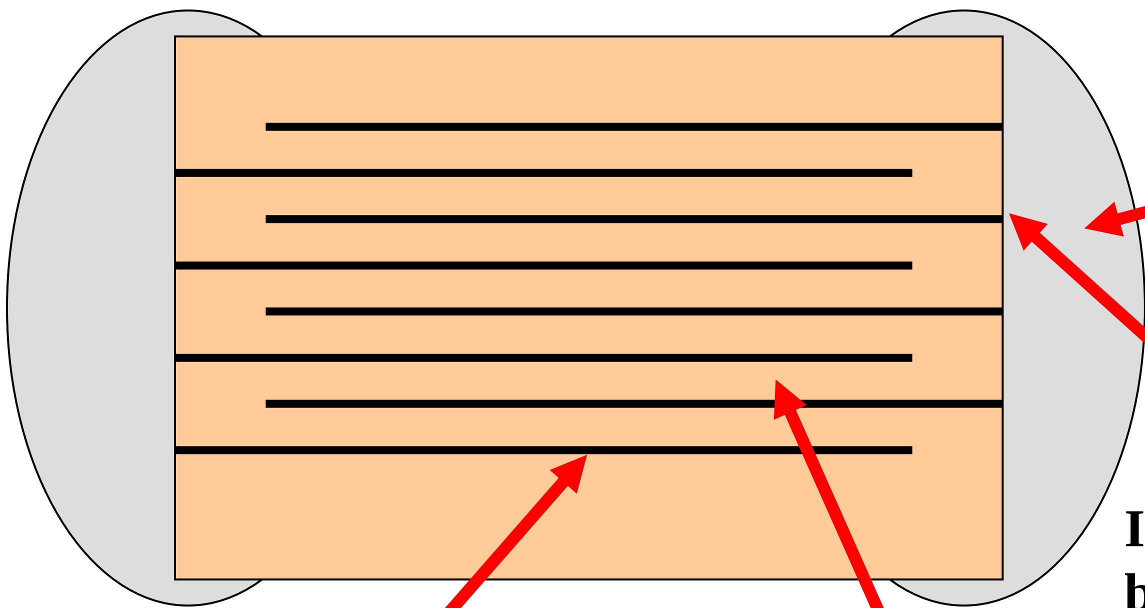
Parasitic ESR in Ceramic

Termination
Thick/Height/Width
Material Resistivity



Interconnect
between electrode
and termination

Electrode Plate
Length/Width/Thick
Material Resistivity

Dielectric Resistance
Energy lost in aligning
polarization to conform
to field.

ESR Elements of MLC

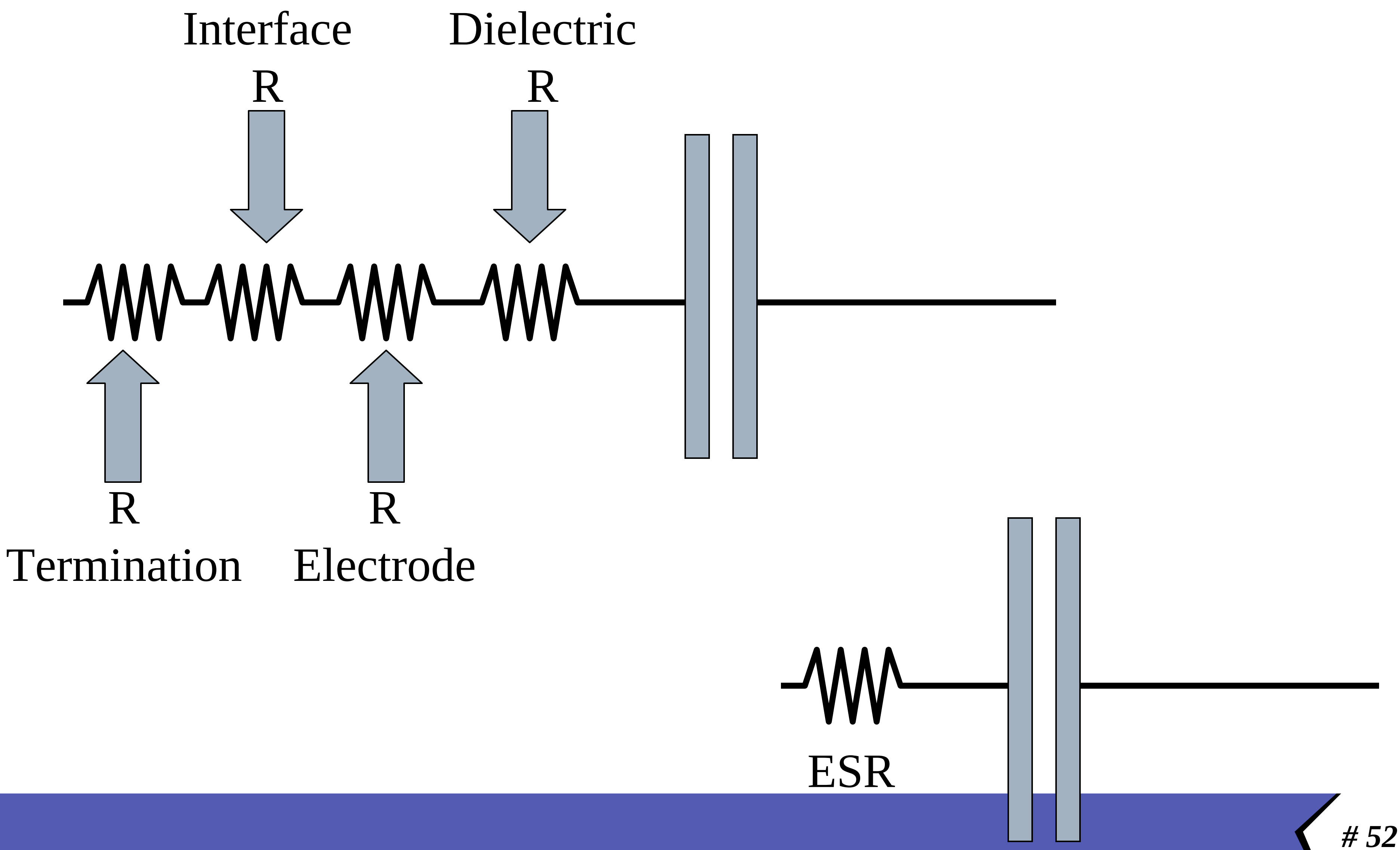
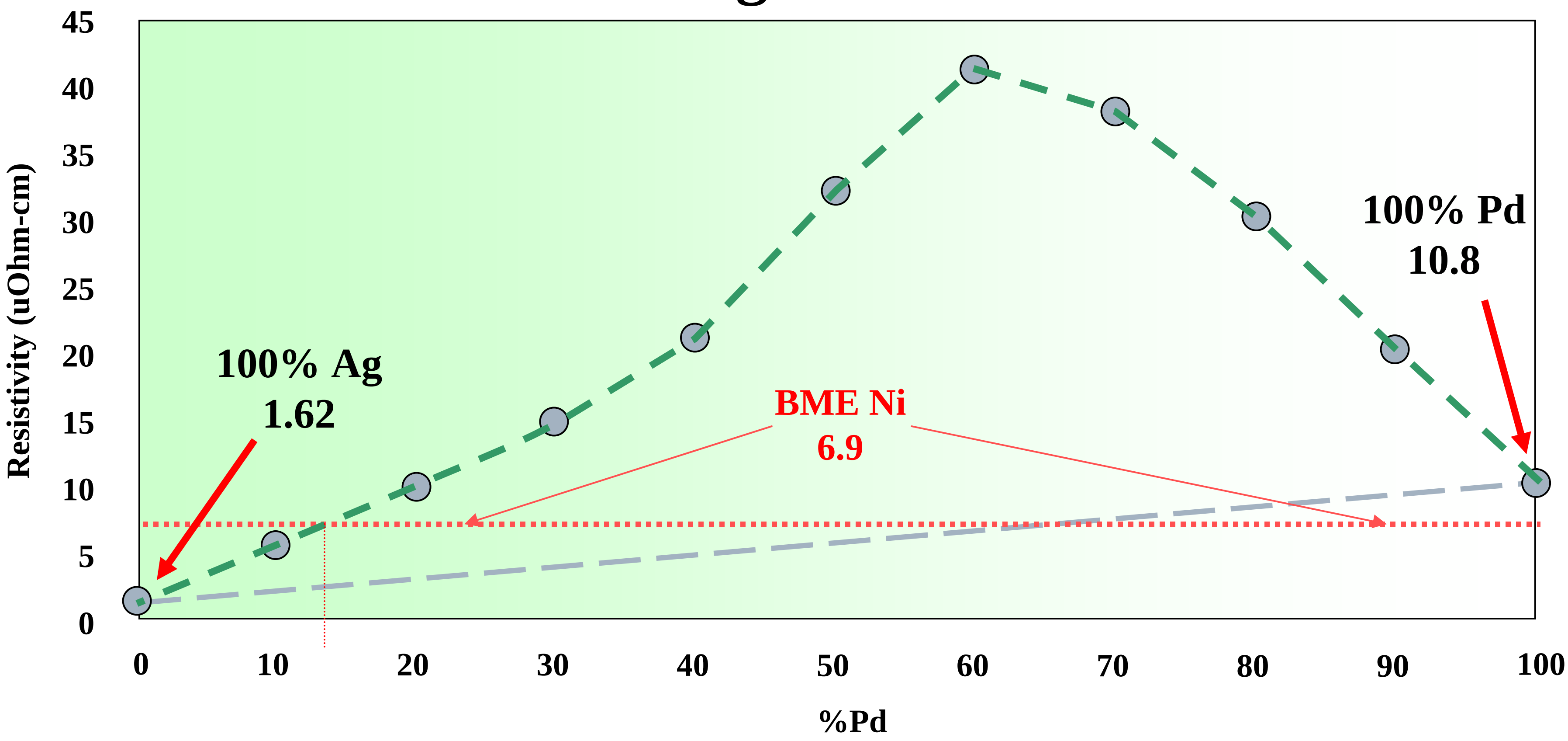


Plate-Material Resistivity

Pd-Ag Electrodes

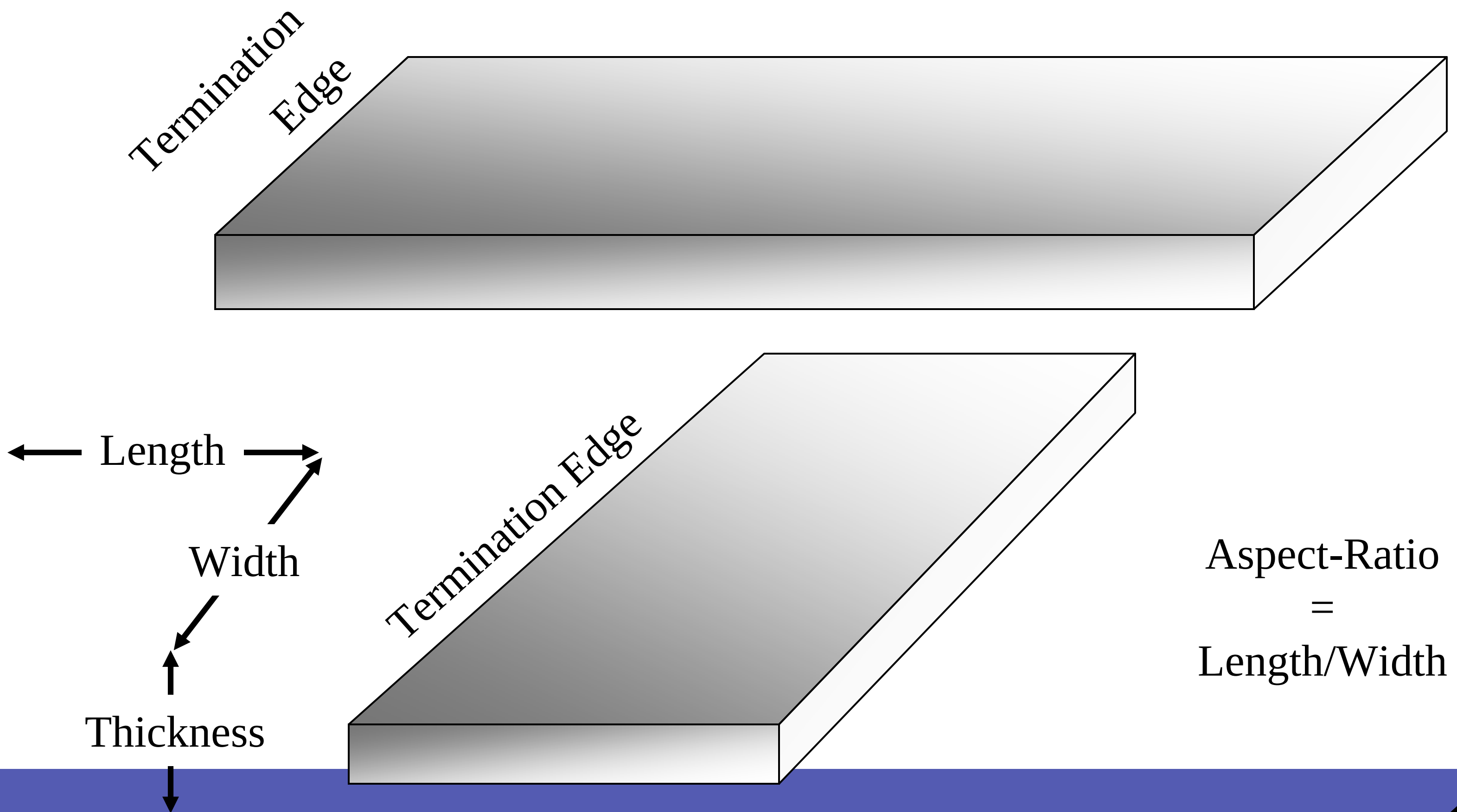


Reference

Schröder, Claus, Handbook of Electrical Resistivities of Binary Metallic Alloys, CRC Press Incorporated, 1983

Resistance vs. Aspect-Ratio

$$R = \theta \times Length / (Width \times Thickness)$$



Aspect-Ratio
=
Length/Width

Plate Inductance

$$L(nH) = 5l\,[\ln(2l/(W+T)+1/2]$$

Where:

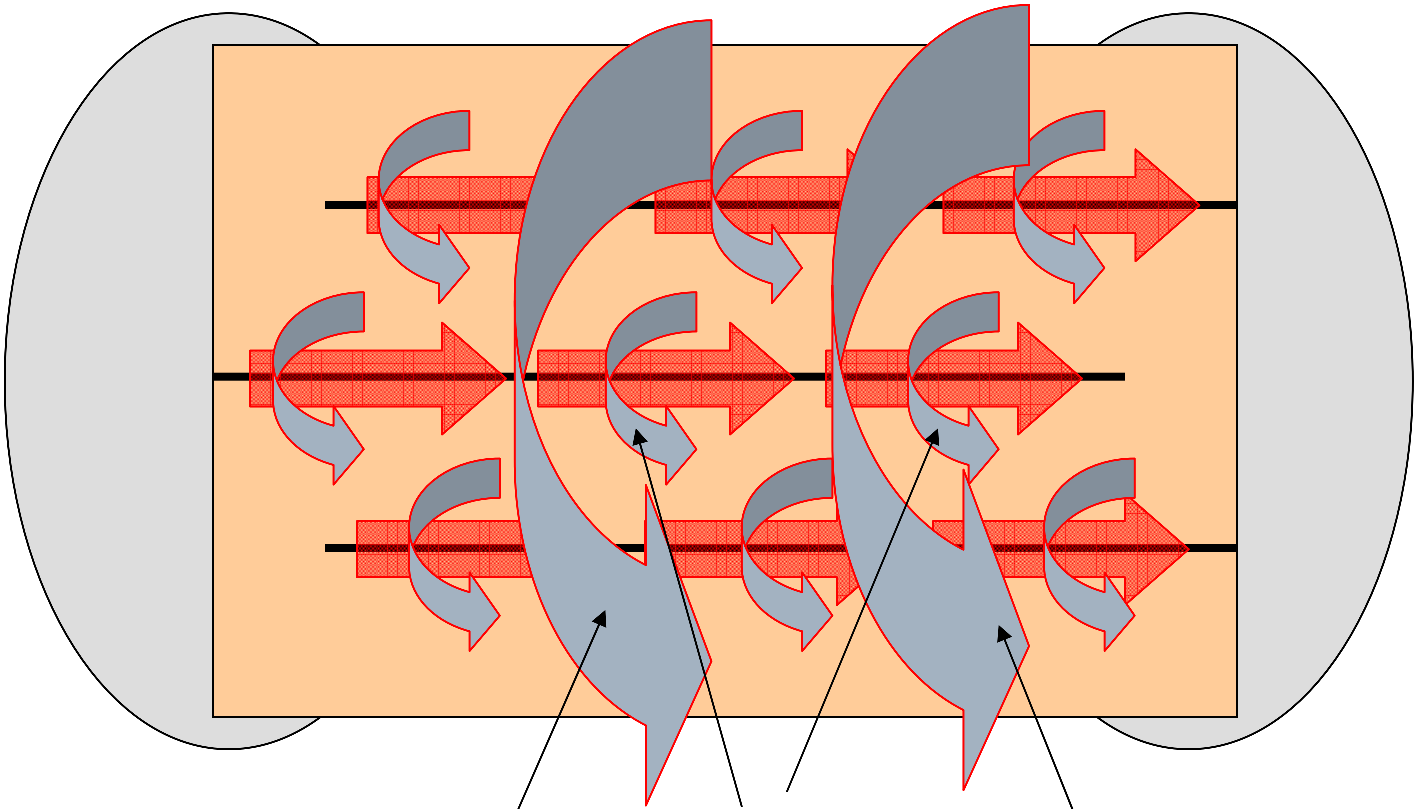
l = length in inches

W,T = width & thickness (inches)

Aspect Ratio is controlling factor

1206 has higher ESL than 0612

Mutual Inductance



Mutual-Inductance controlling factors = Diel. Thickness & Plate Count

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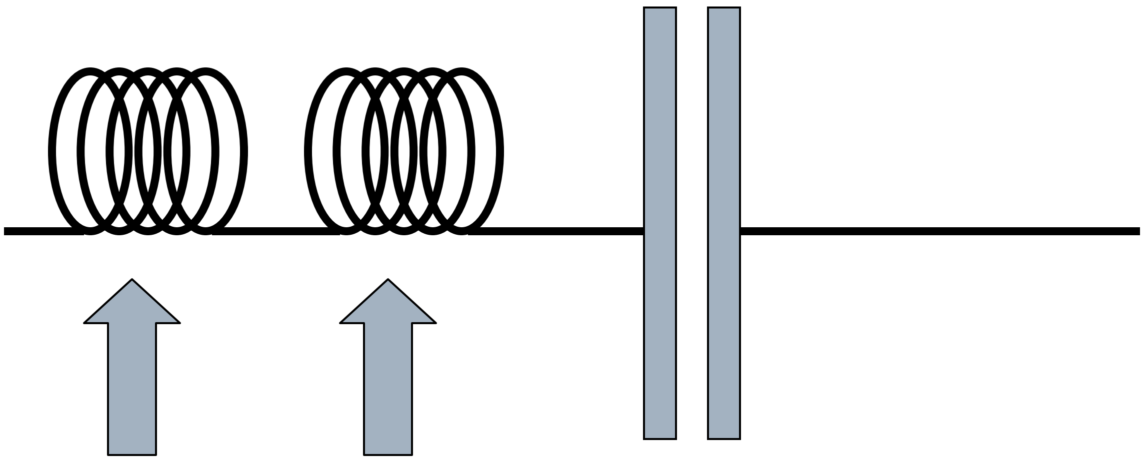
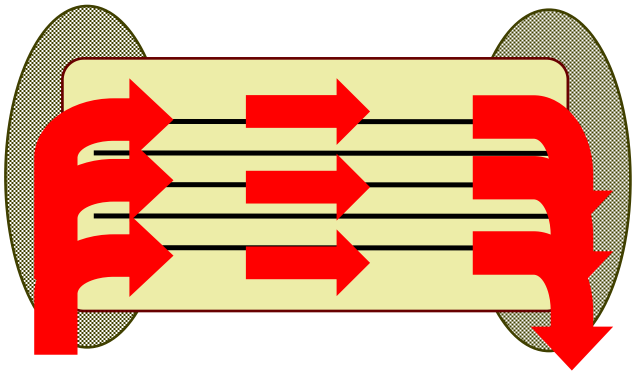
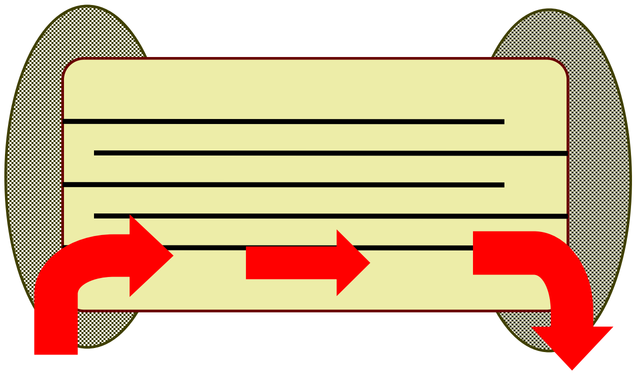
ESL Elements of MLC



Lm
Mutual-
Inductance

Ls
Self-
Inductance





Lower Frequencies

All plates active

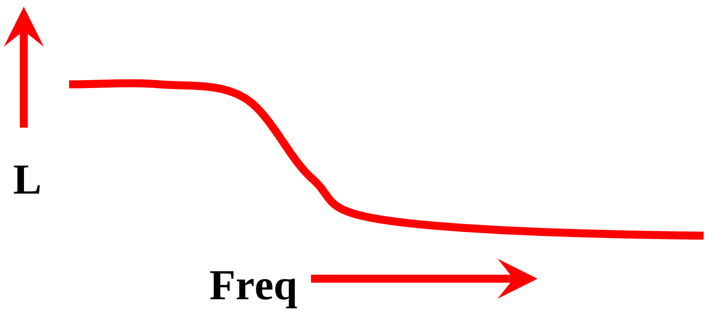
Inductance - Cumulative

Higher Frequencies

Lower plates Active

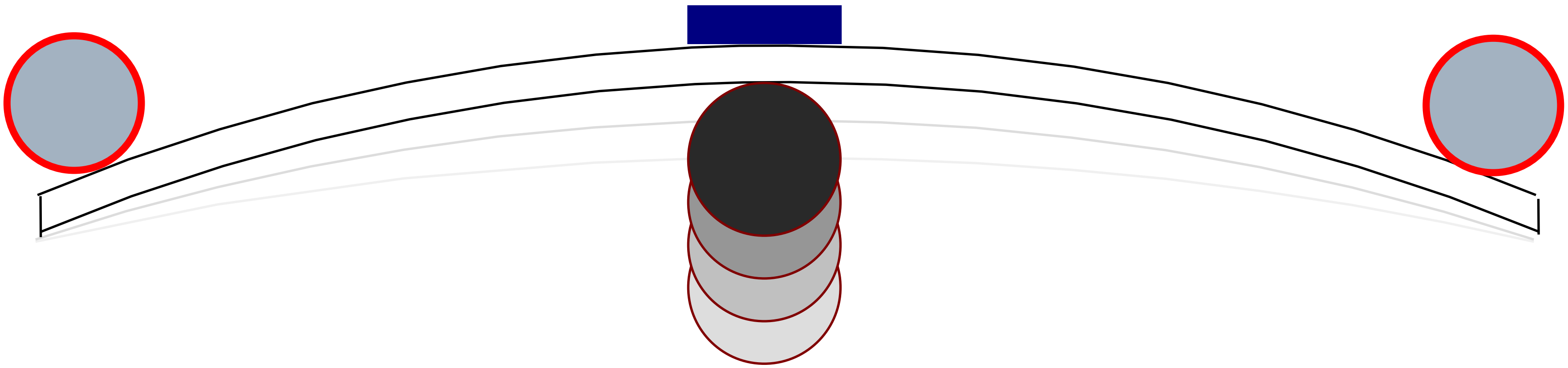
Upper plates inactive

Inductance – minimum loop

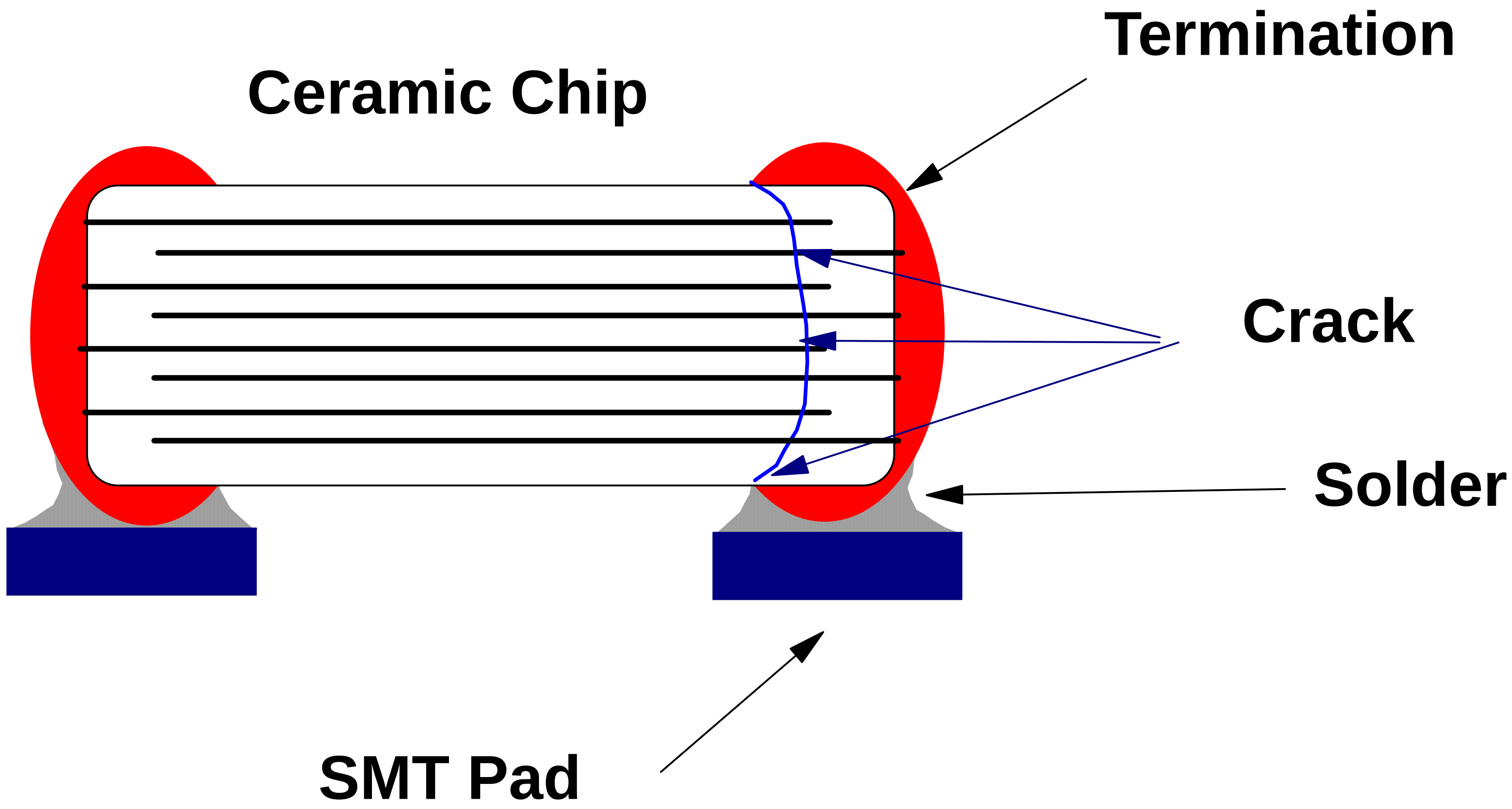


with
Capacitance Monitoring

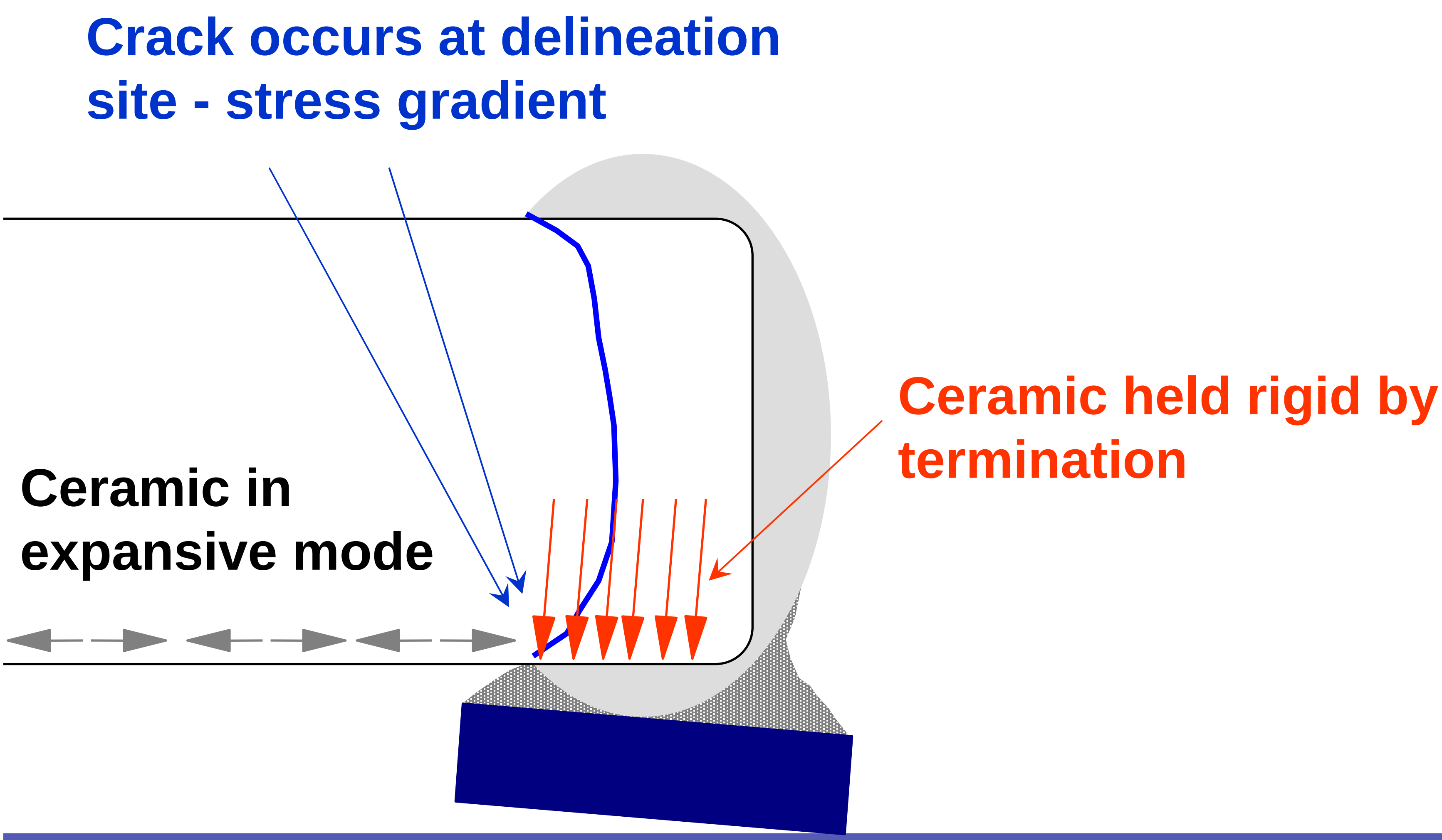
KEMET Electronics Corp.



What is a "Flex Crack?"



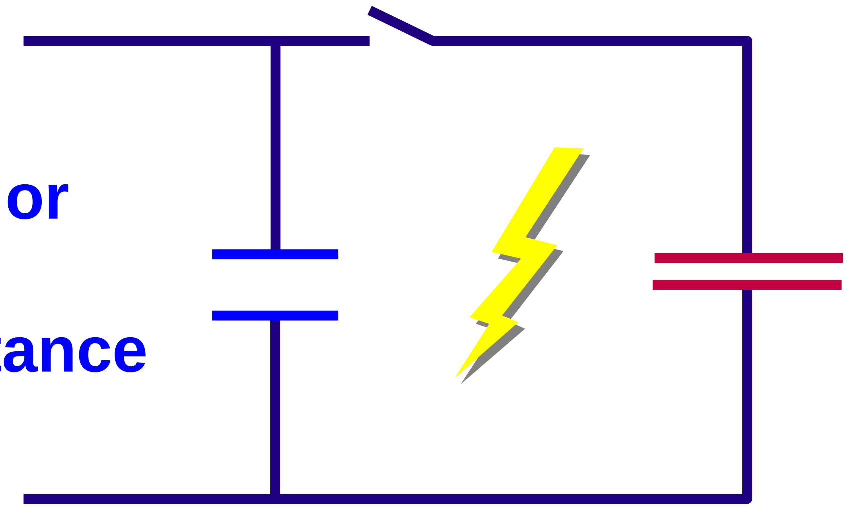
Crack Sheer Force



Determined by Test

Reference Capacitor Charged
Reference Capacitor Discharges into Test Capacitor

Source or Initial Capacitance



CUT (Capacitor Under Test)

Pass / Fail determined by Capacitance and Insulation Resistance Tests

Conservation of Charge

$$Q_{Initial} = Cap_{Source} \text{ x } Voltage_{Initial}$$

$Q = 150\ pF \times 8\ kV = 1.2 \times 10^{-6}$ Coulombs

$$Q_{Final} = Q_{Iniital} \text{ or simply } Q$$

1.2×10^{-6} Coulombs $= 1.2 \times 10^{-6}$ Coulombs

$$Voltage_{Final} = Q / (Cap_{Source} + Cap_{CUT})$$

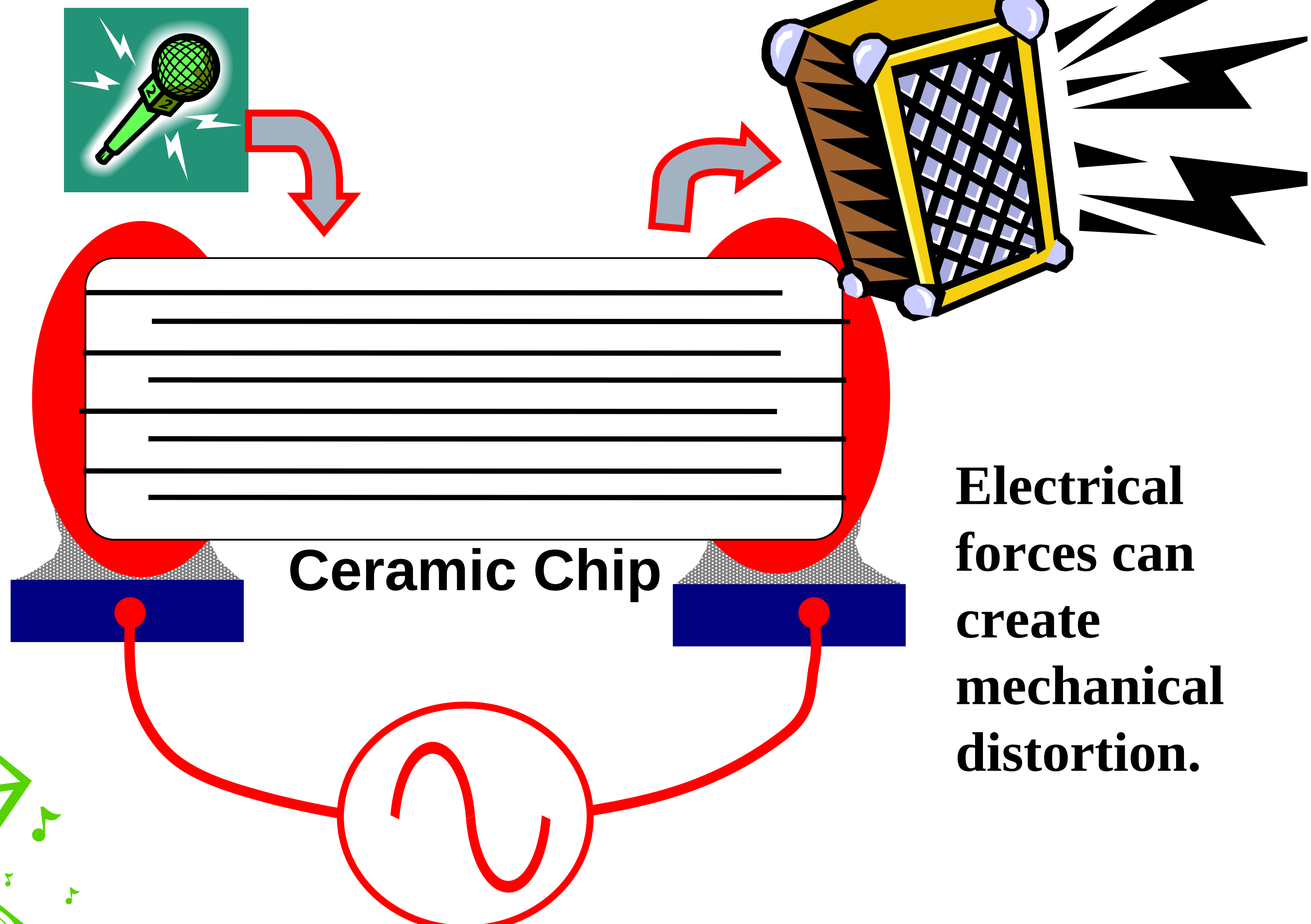
$V = 1.2 \times 10^{-6} / (150\ pF + 1000\ pF) * 10^{-6} = 1043\ V$

Why MLCs are susceptible

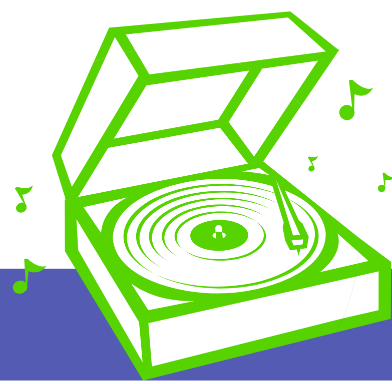
- Charge transfer is only significant for lower capacitance values (<0.01uF)
- This capacitance range is dominated by ceramics
- Downsizing (0603,0402,0201) requires thinner dielectric
  - Lower breakdown voltages
  - Higher voltage coefficients/lowers capacitance

Piezoelectric Noise

Mechanical forces can create electrical signals.



Electrical forces can create mechanical distortion.



Barium Titanate crystal cartridges

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Piezoelectric Dos and Don’ts

- **Do Not**
  - Use in audio circuits where signal levels are high (final stages).
  - Use in high-gain circuits where mechanical shock or vibration can create noise.
  - Use in audio front end where mechanical shock or vibration can create noise.
  - Use in bus applications that are being cycled on and off in a ‘sleep’ mode.

- **Do use**
  - In high frequency circuits where response of ceramic is too slow for matching electrical stress with mechanical response (>40 kHz)
  - Use leaded (or leadframe) ceramics to allow mechanical isolation between chip and board.
  - Use higher voltage rating, or lower dielectric constant to diminish response (both of these could lead to larger chips).

Tantalum Capacitors

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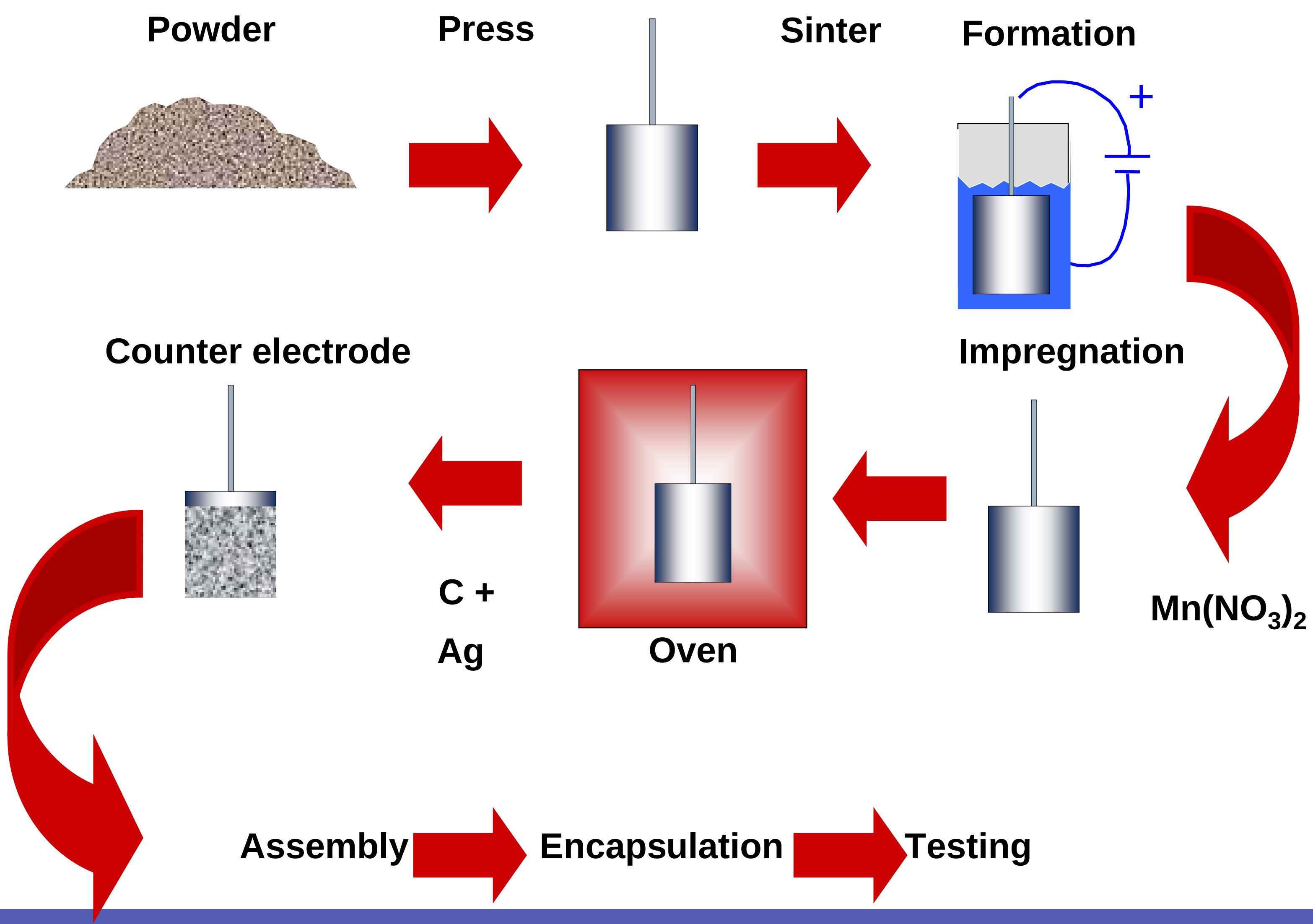
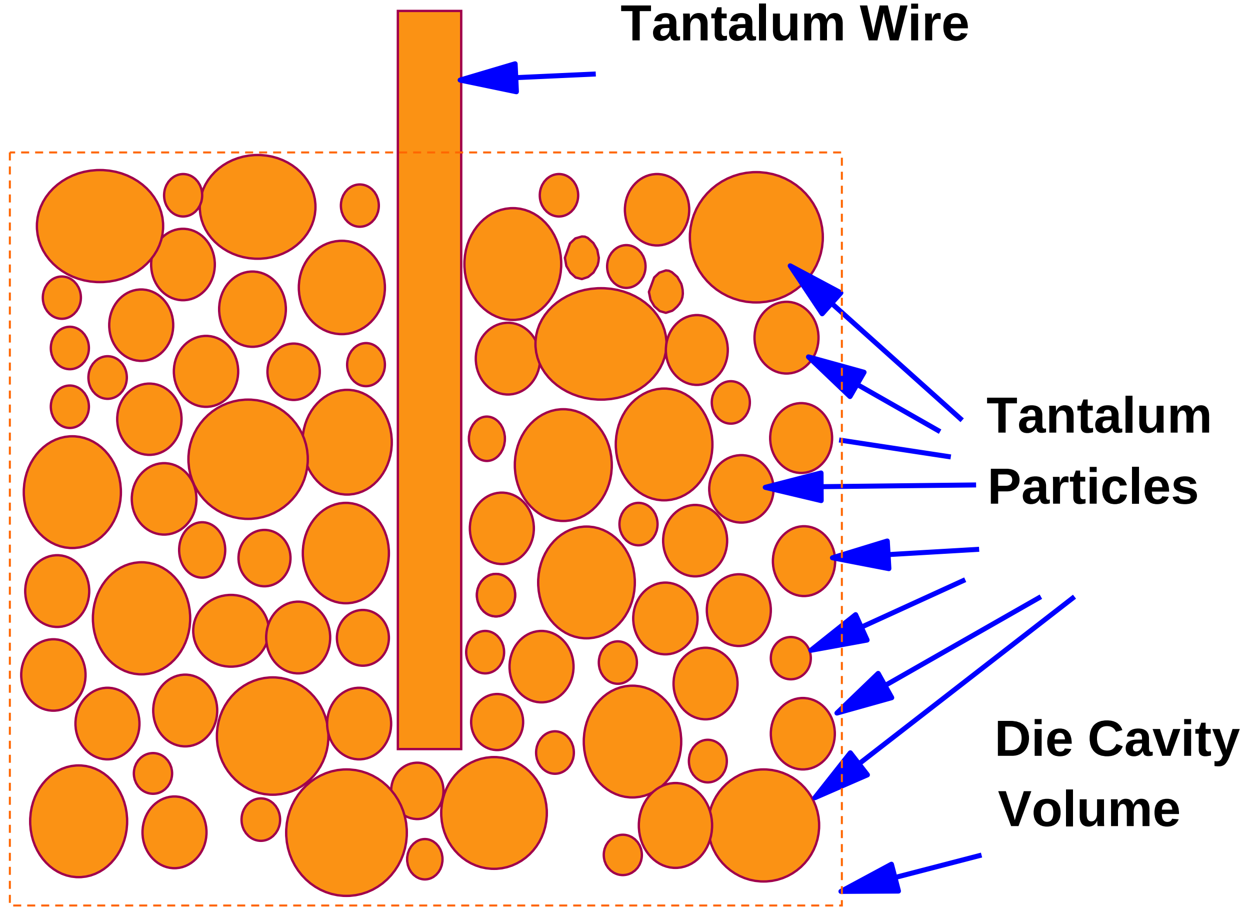
Construction and Materials

Tantalum Process

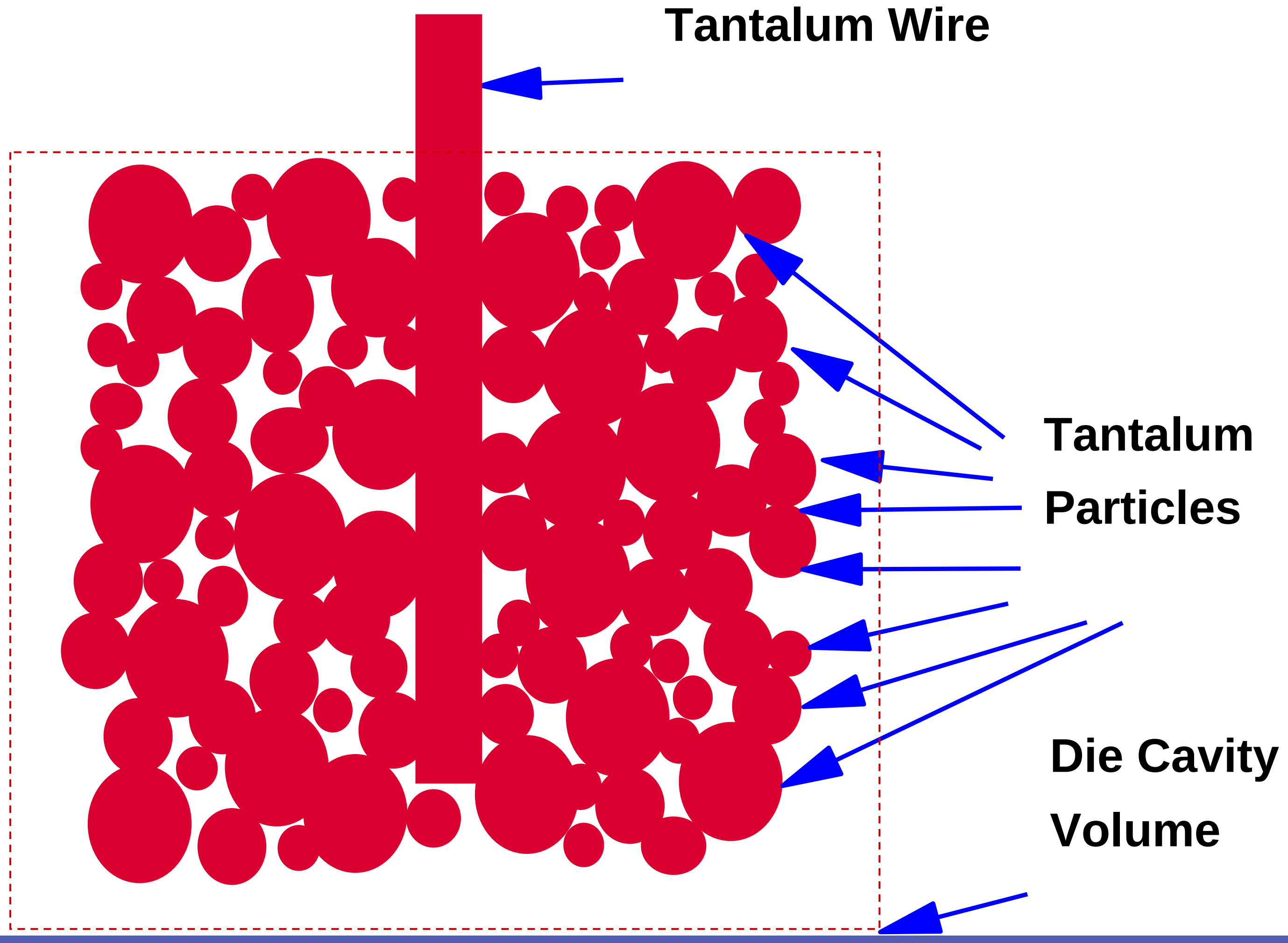


Pressed Pellet -
tantalum in chance contact, most not in contact

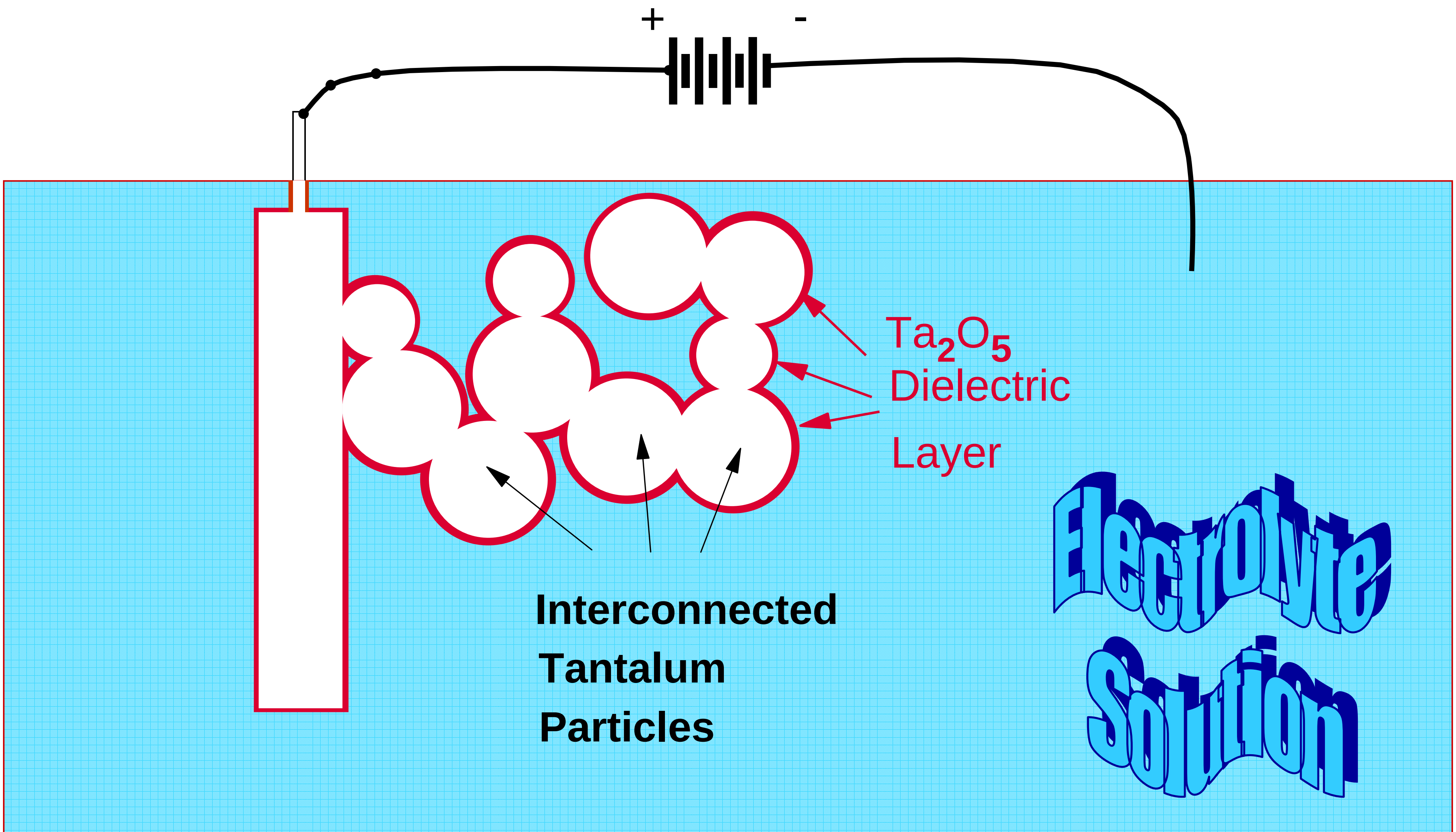


Tantalum Construction - Sintering

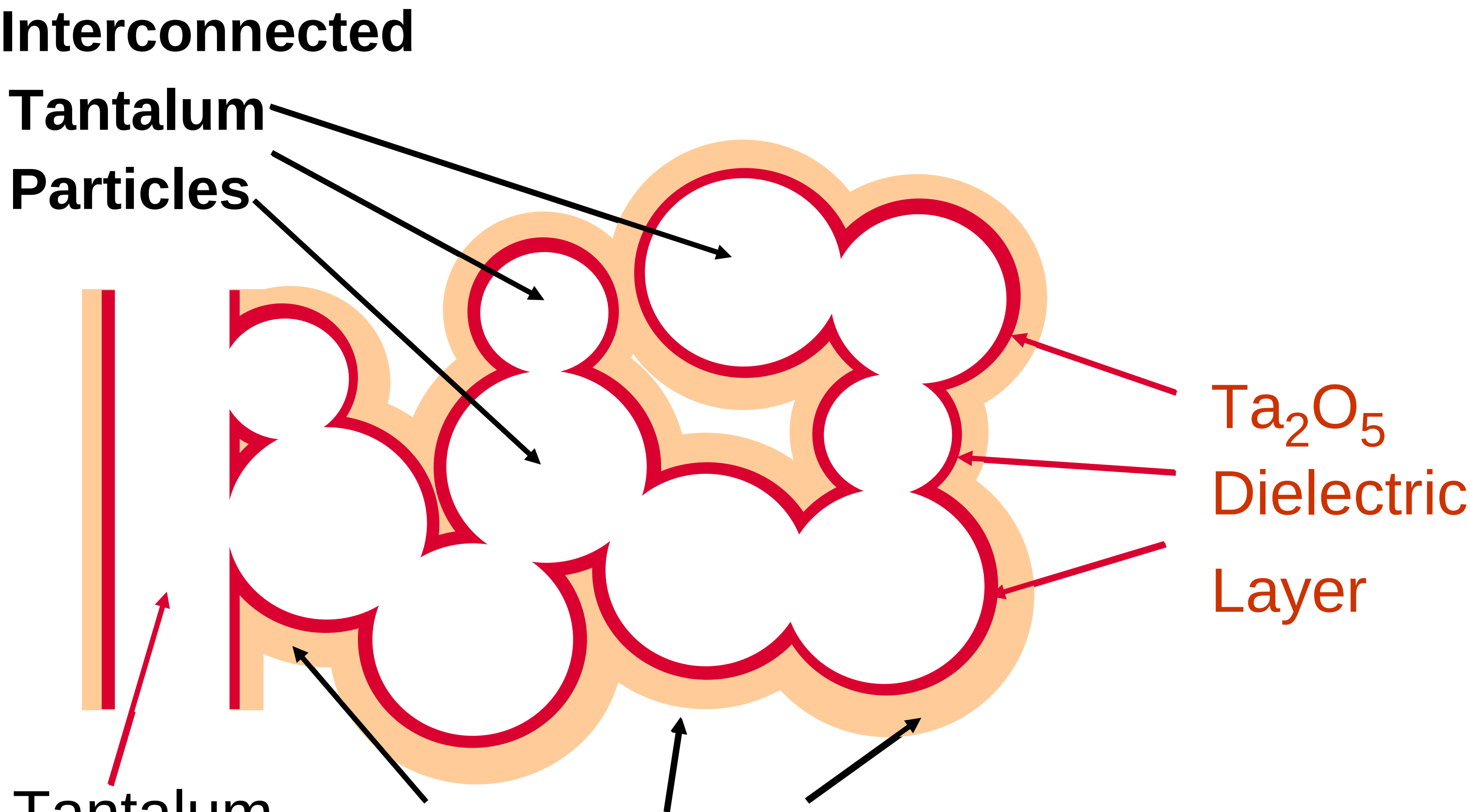
Sintered Pellet - All tantalum in electrical contact



Dielectric Formation

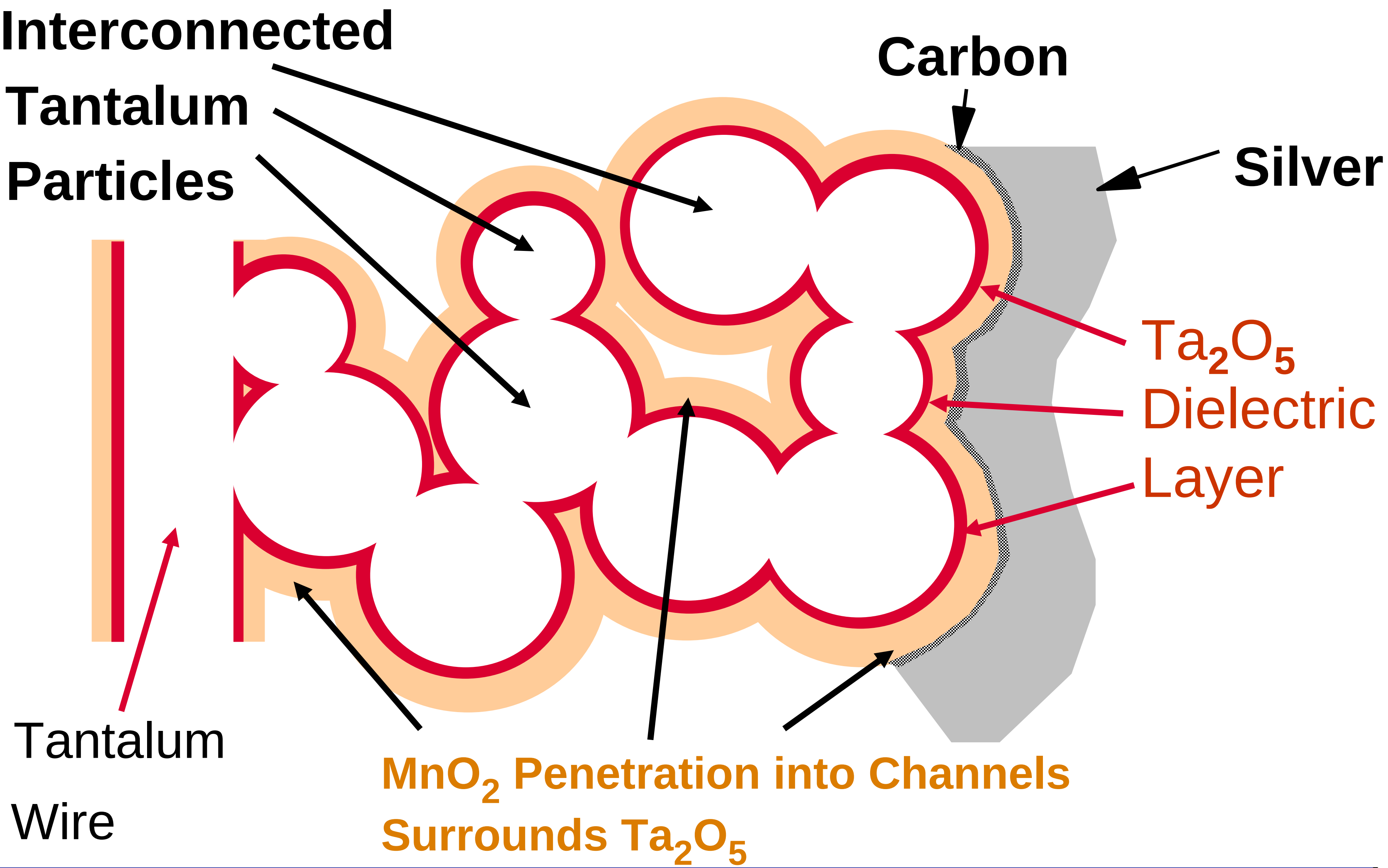


MnO_2 Impregnation

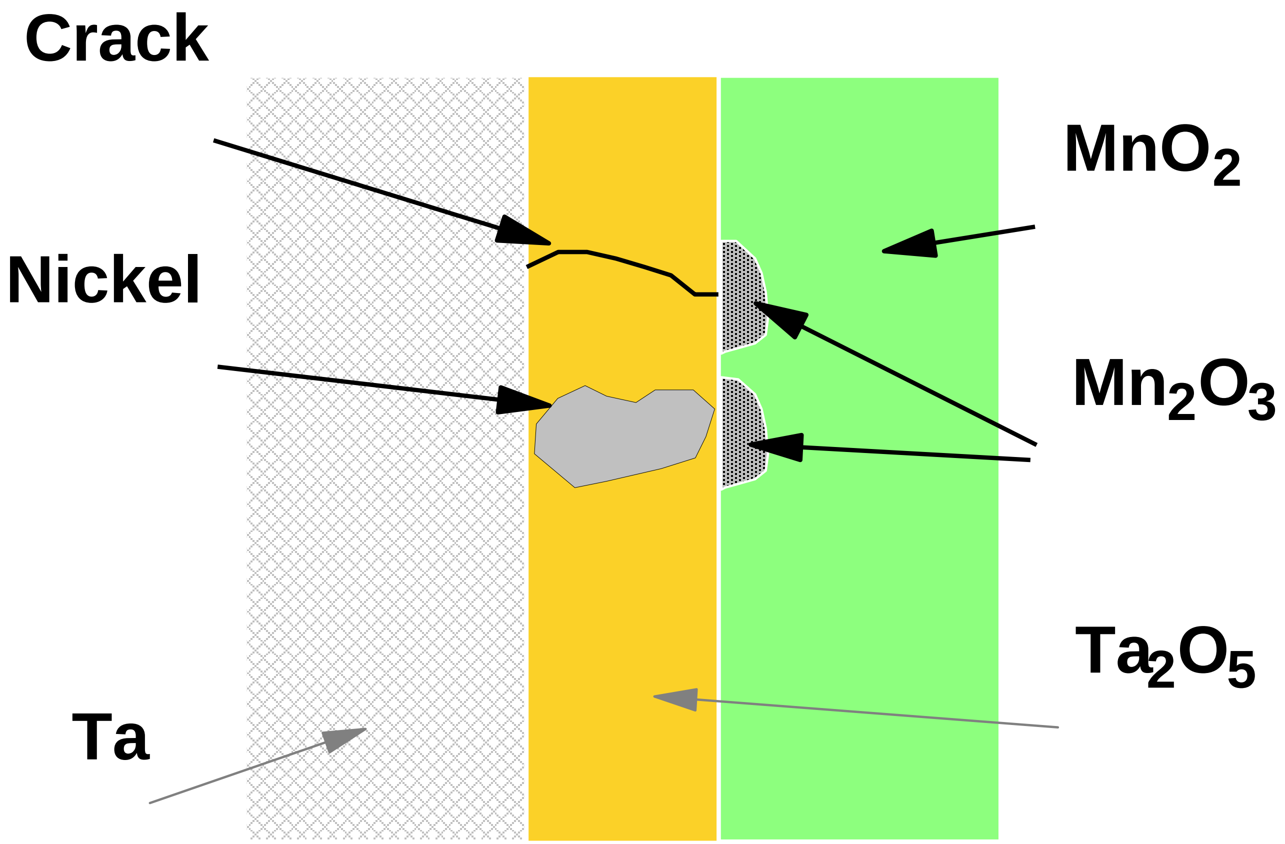


MnO_2 Penetration into Channels Surrounds Ta_2O_5

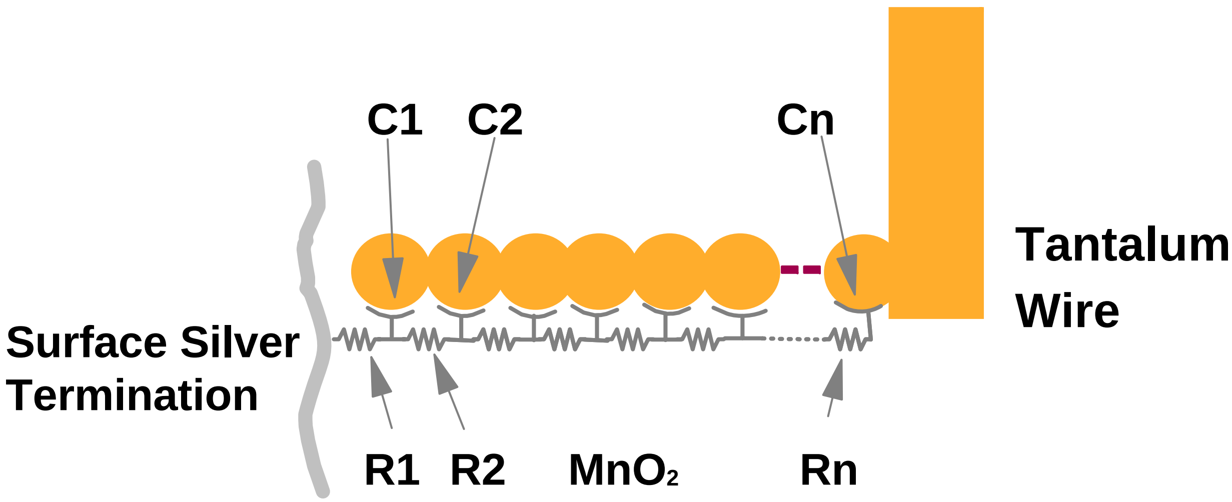
Tantalum Construction



Healing Effect of MnO_2 Layer



Tantalum RC-Ladder

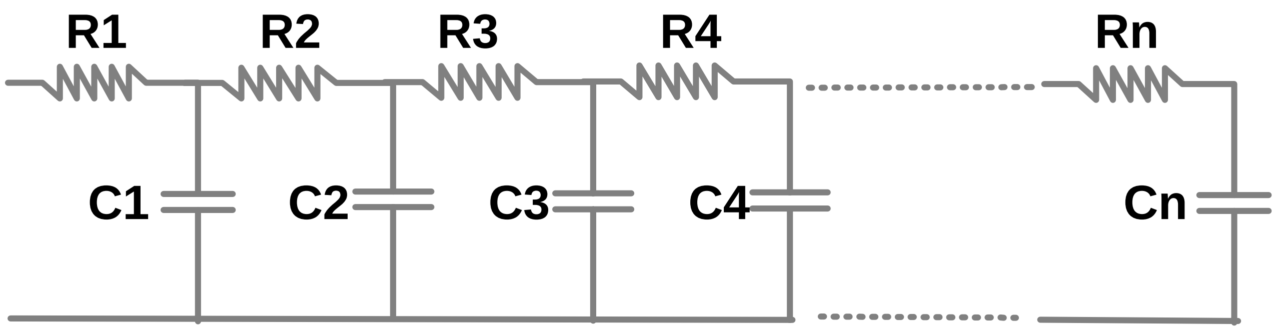


tc1 = C1 x R1

tc2 = C2 x (R1+R2)

tcn = Cn x (R1+R2...+Rn)

RC Ladder Network



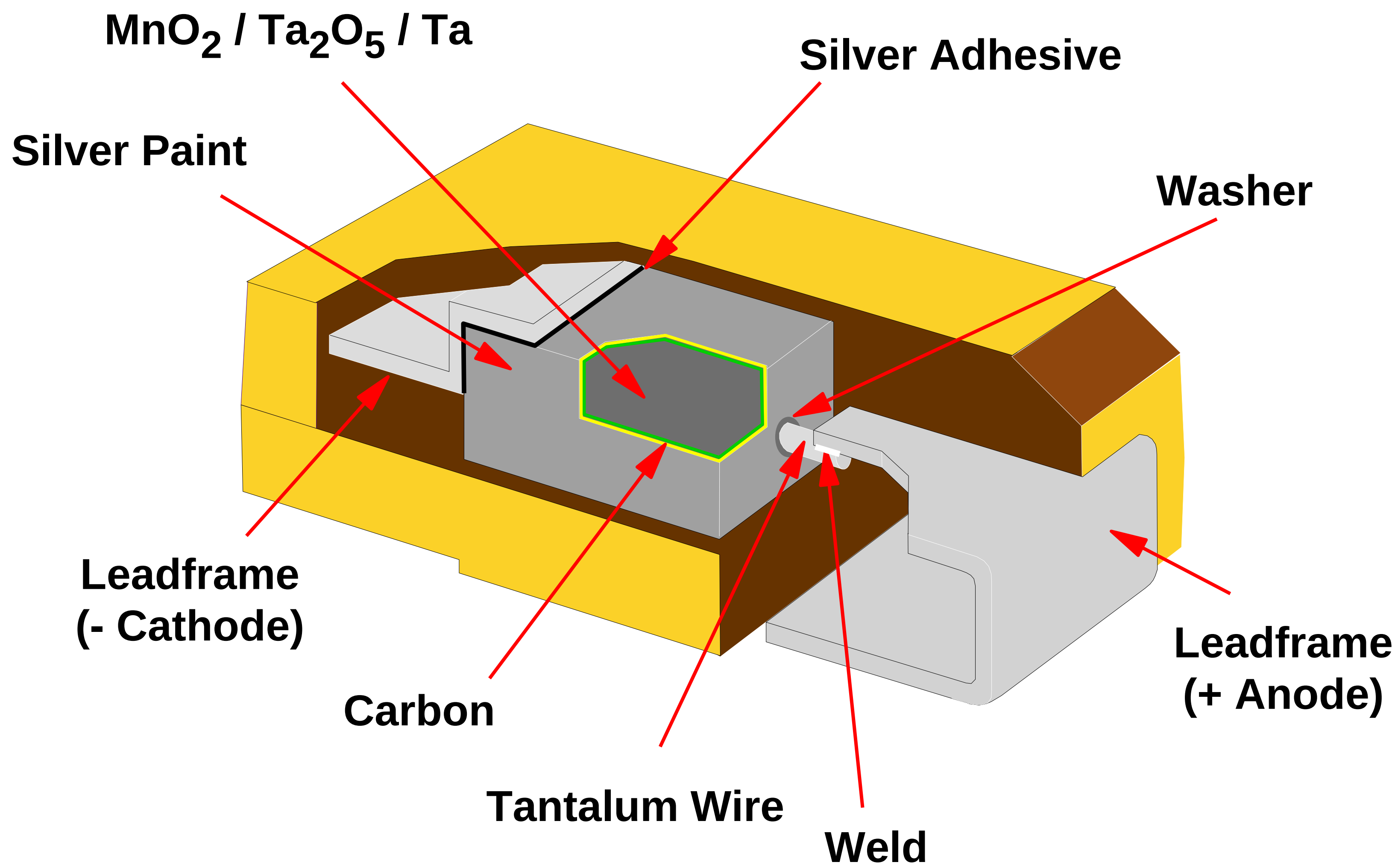
tc1 = C1 x R1

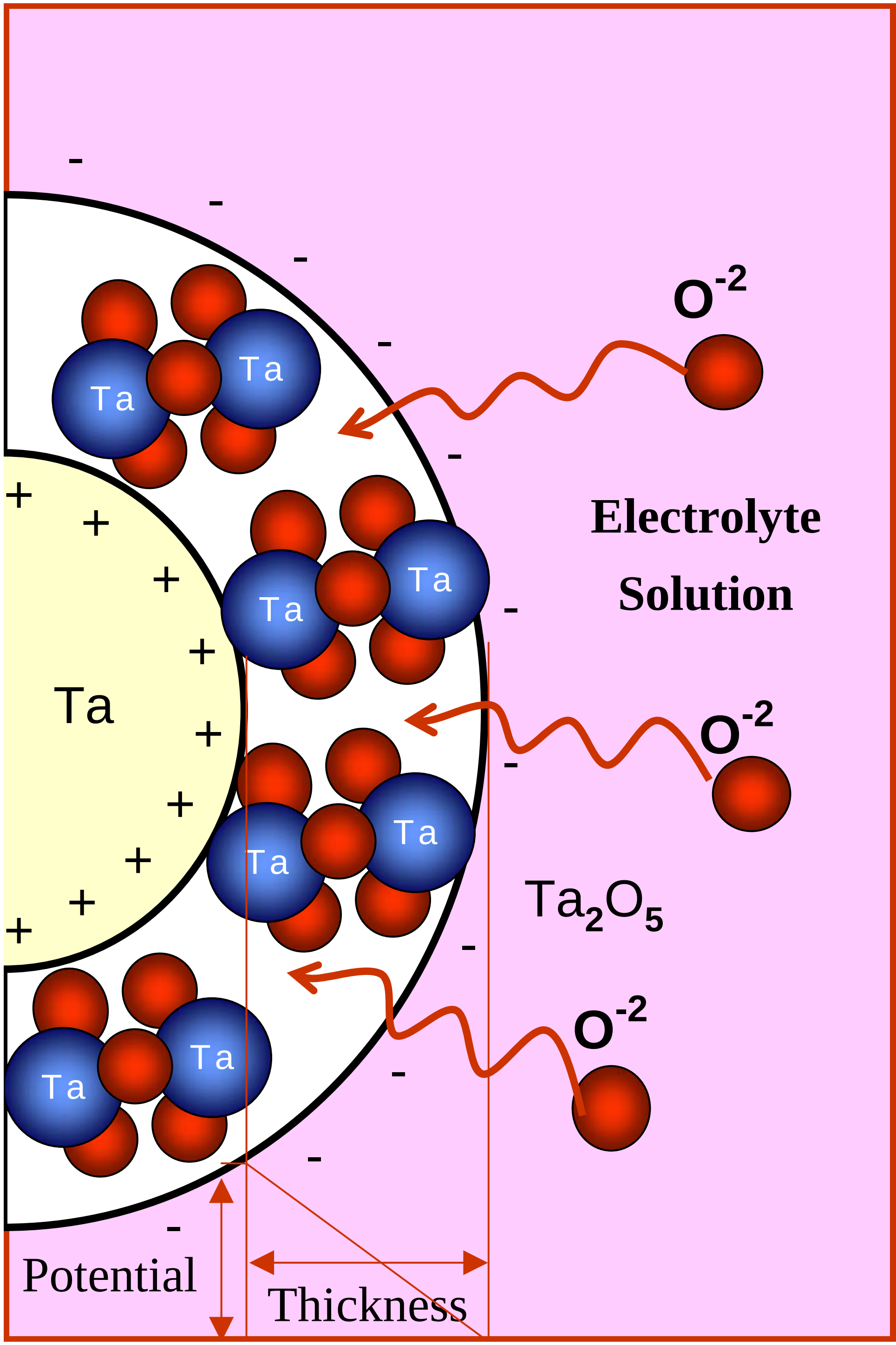
tc2= C2 x (R1+R2)

tc3= C3 x (R1+R2+R3)

tcn= Cn x (R1+R2+R3...+Rn)

Solid Tantalum Surface-Mount Capacitor





Dielectric Formation

Oxygen, pulled into Ta by applied voltage, combines with tantalum to form Ta_2O_5

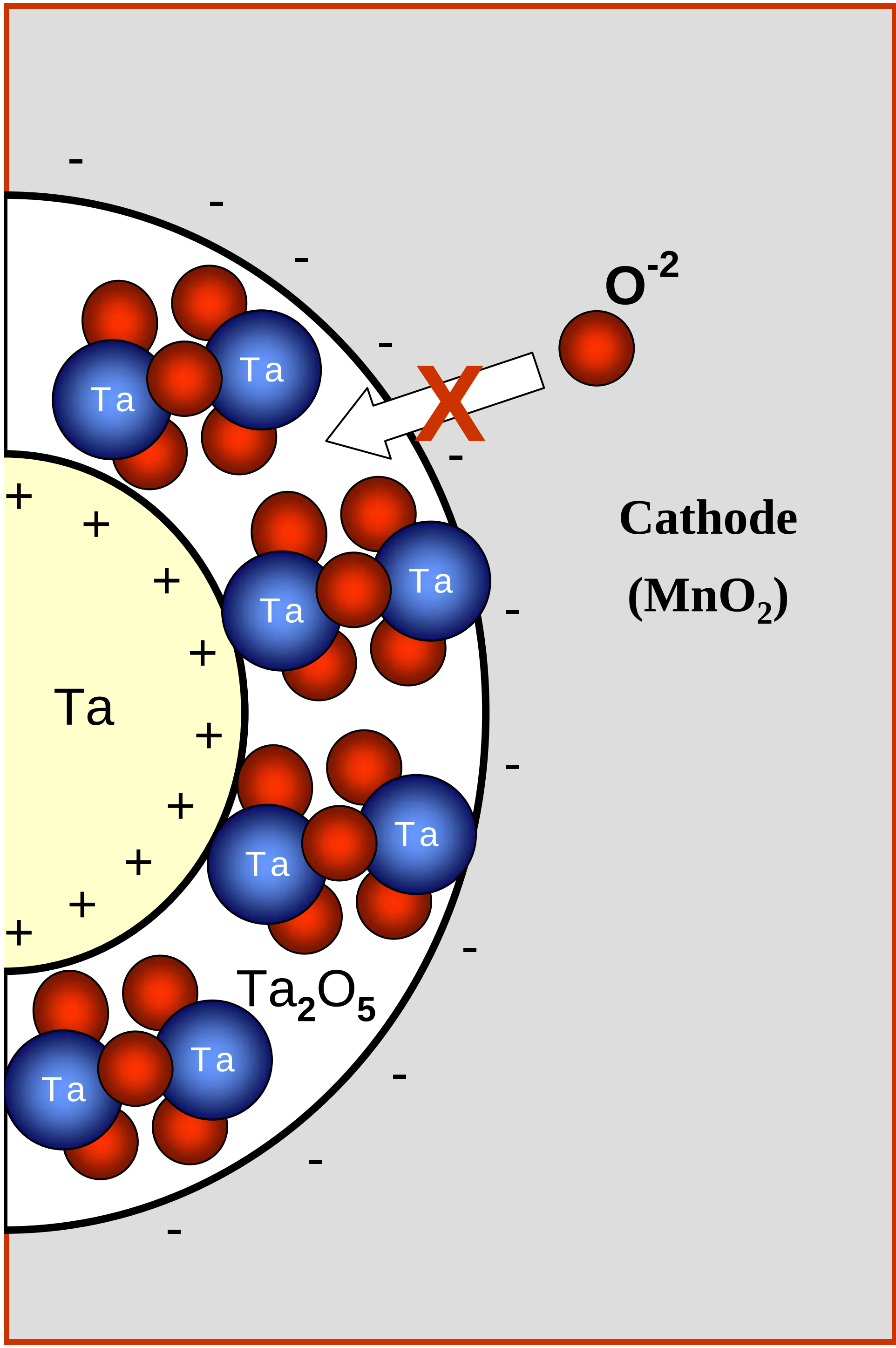
Thickness determined by the formation voltage.

~20Å per Volt

Formation Voltage

=

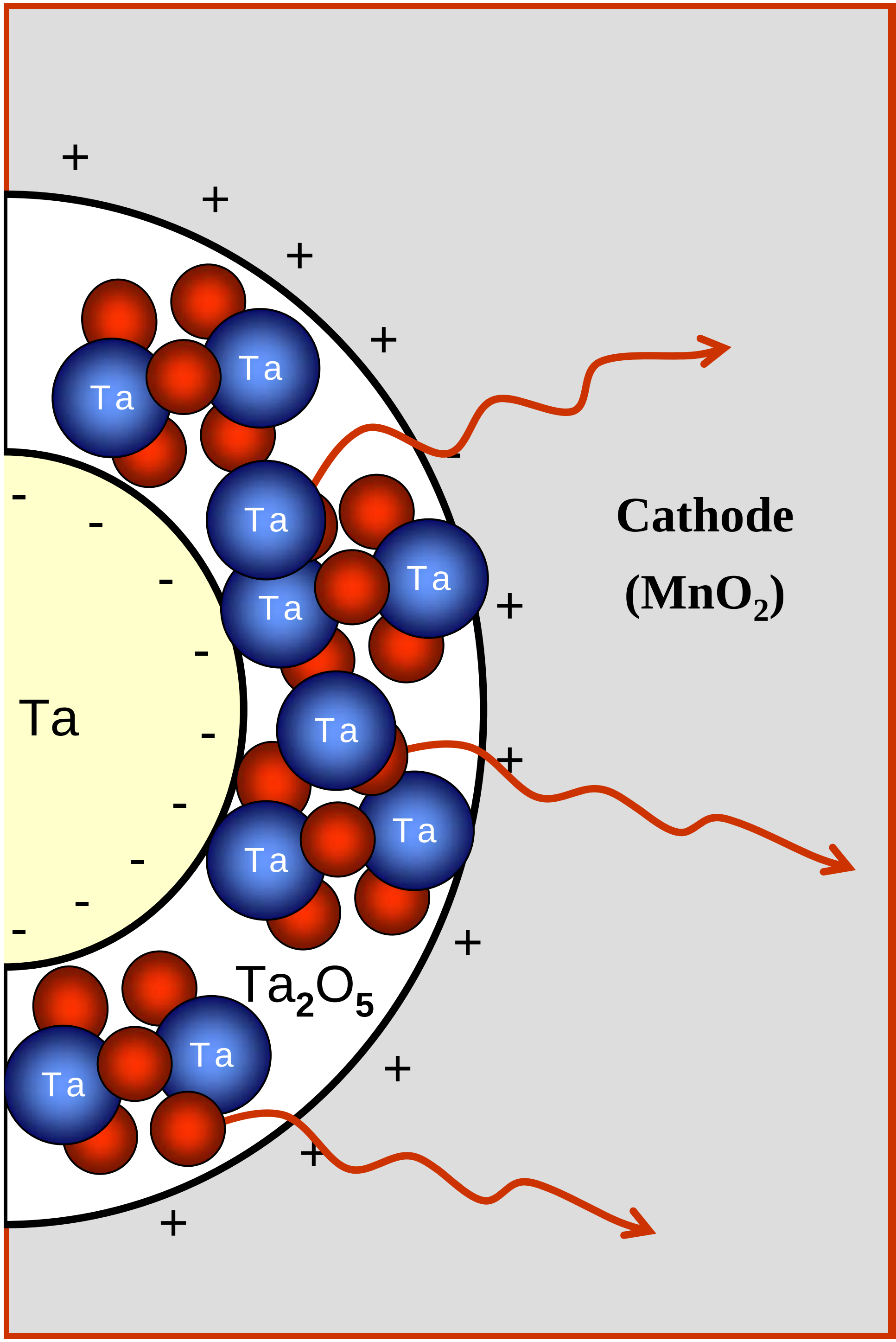
3x to 4x Rated Voltage



Forward Biased

Although polarity is the same as in formation, the voltage is much less and although no additional oxygen transfer takes place,

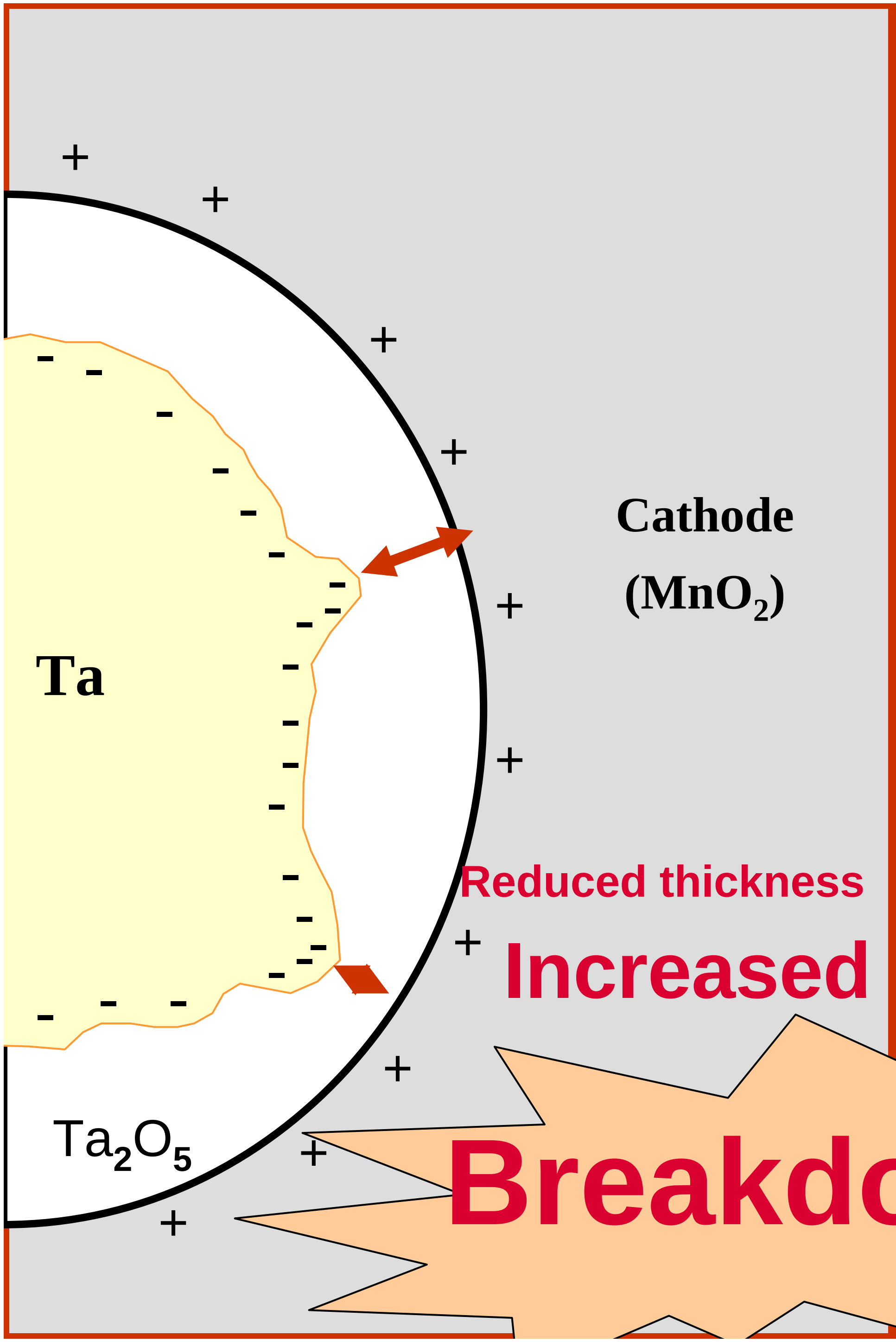
the oxygen continues to be locked into the Ta_2O_5 bond.



Reversed Biased

When force (voltage) is reversed & high enough (*knee* voltage), oxygen displacement begins, leaving tantalum behind.

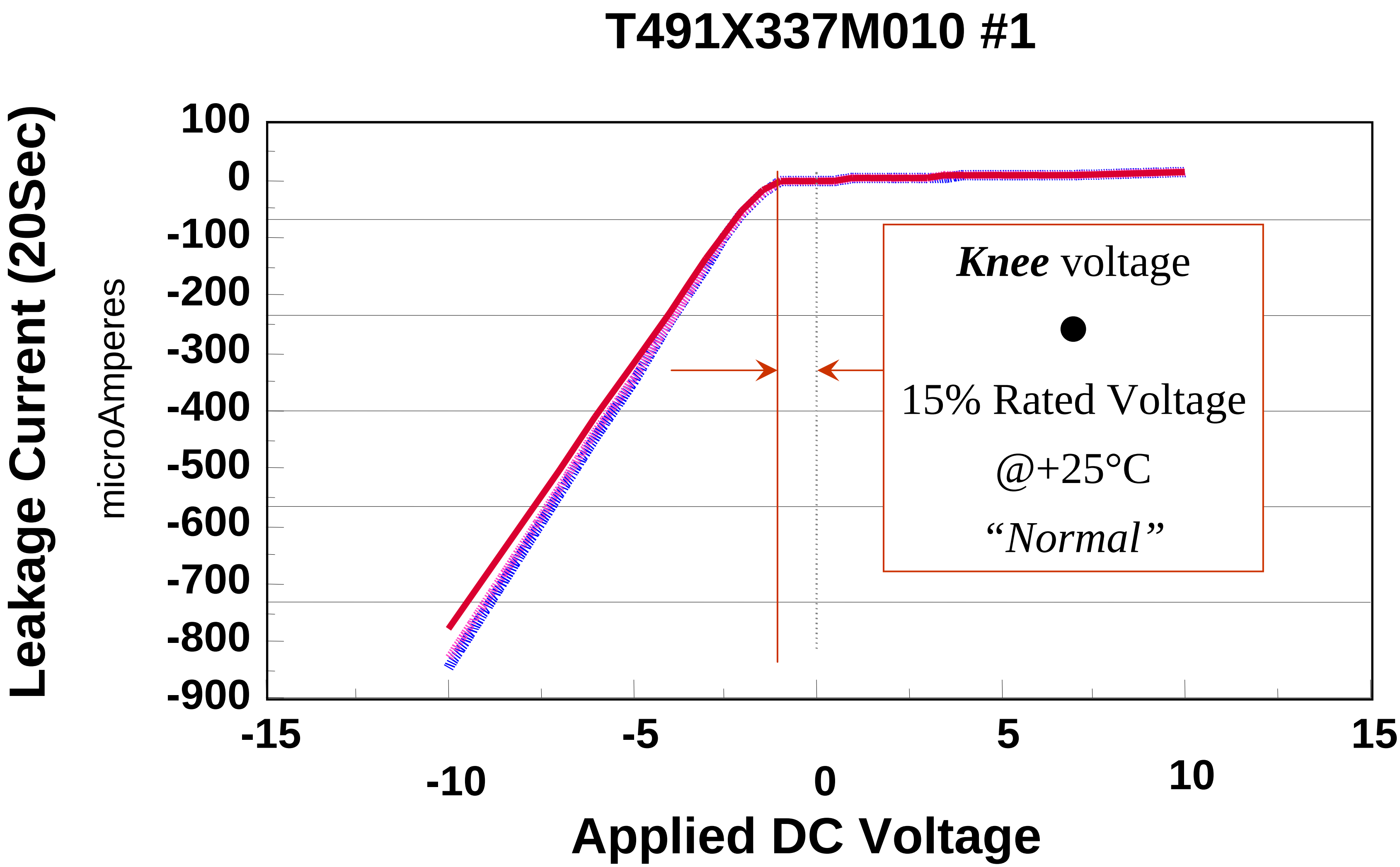
Reverse Biased - Failure



Although polarity is the same as in formation, the voltage is much less and although no additional oxygen transfer takes place, the oxygen continues to be locked into the Ta_2O_5 bond.

Increased Leakage - Breakdown!!

Knee Voltage Determination

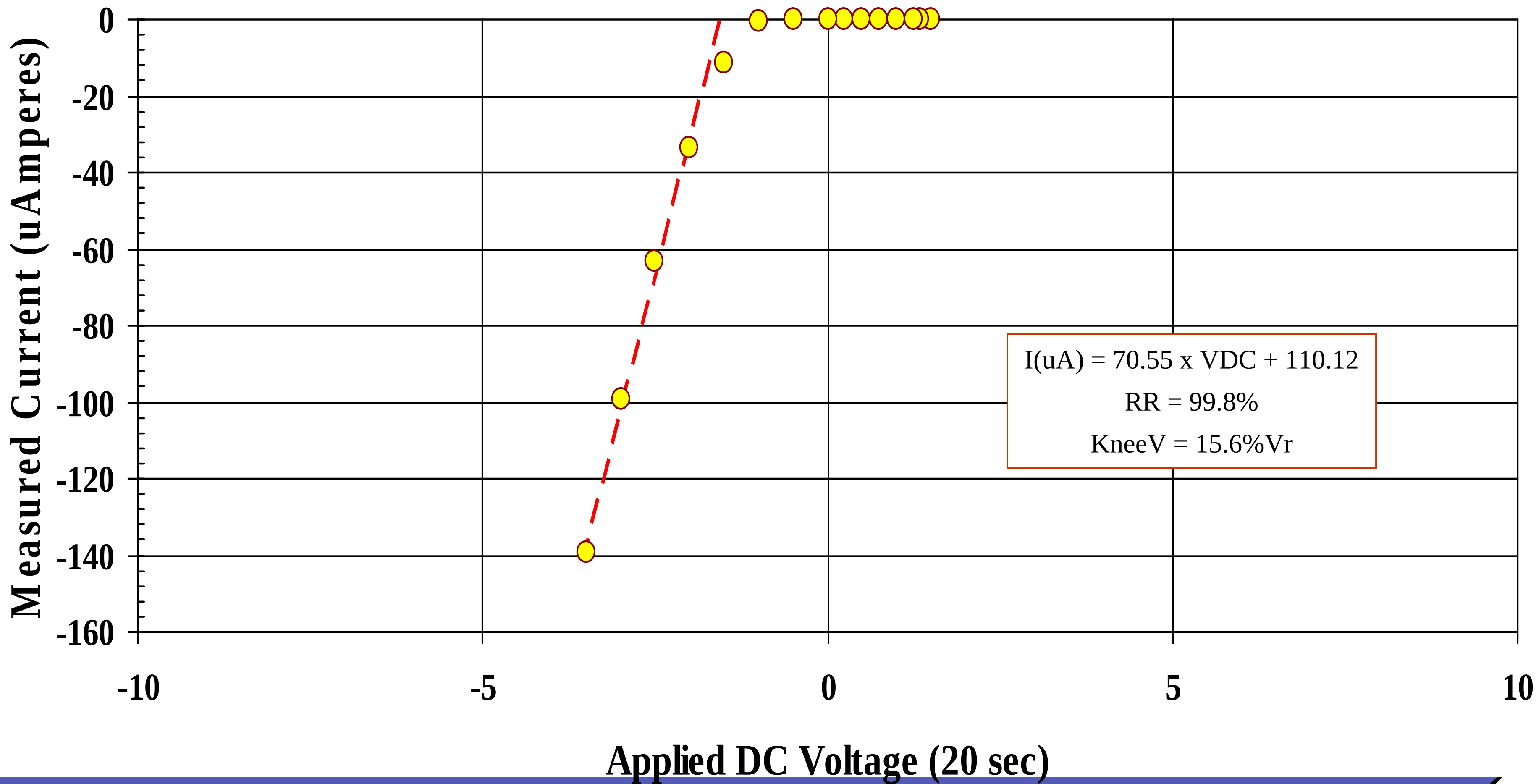


Catalog Table

Temperature	Maximum Reverse Voltage
25°C	15%
85°C	5%
125°C	1%

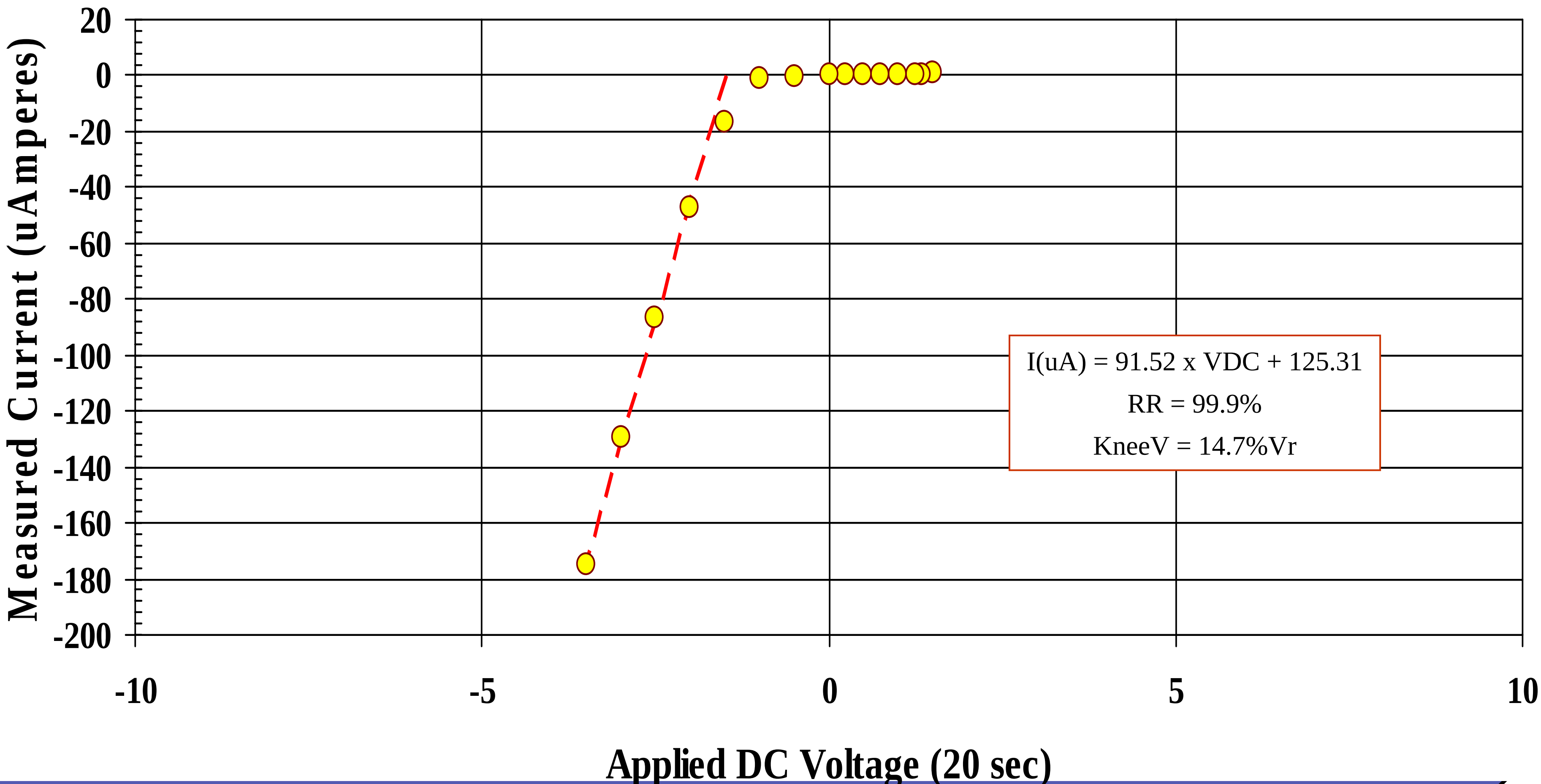
Knee Voltage Determination +25C

T520V686M006 @ 25°C

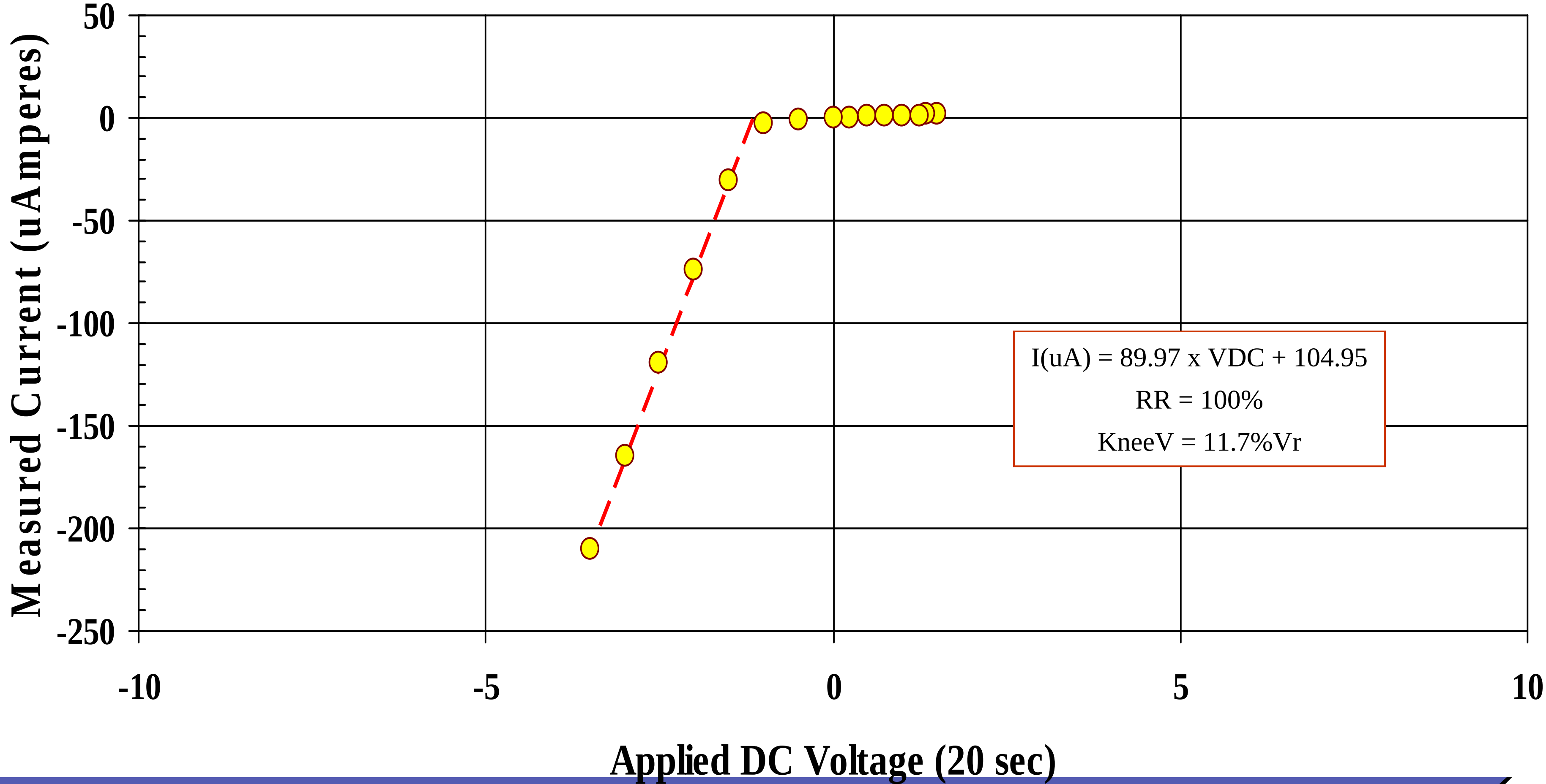


Knee Voltage Determination +85C

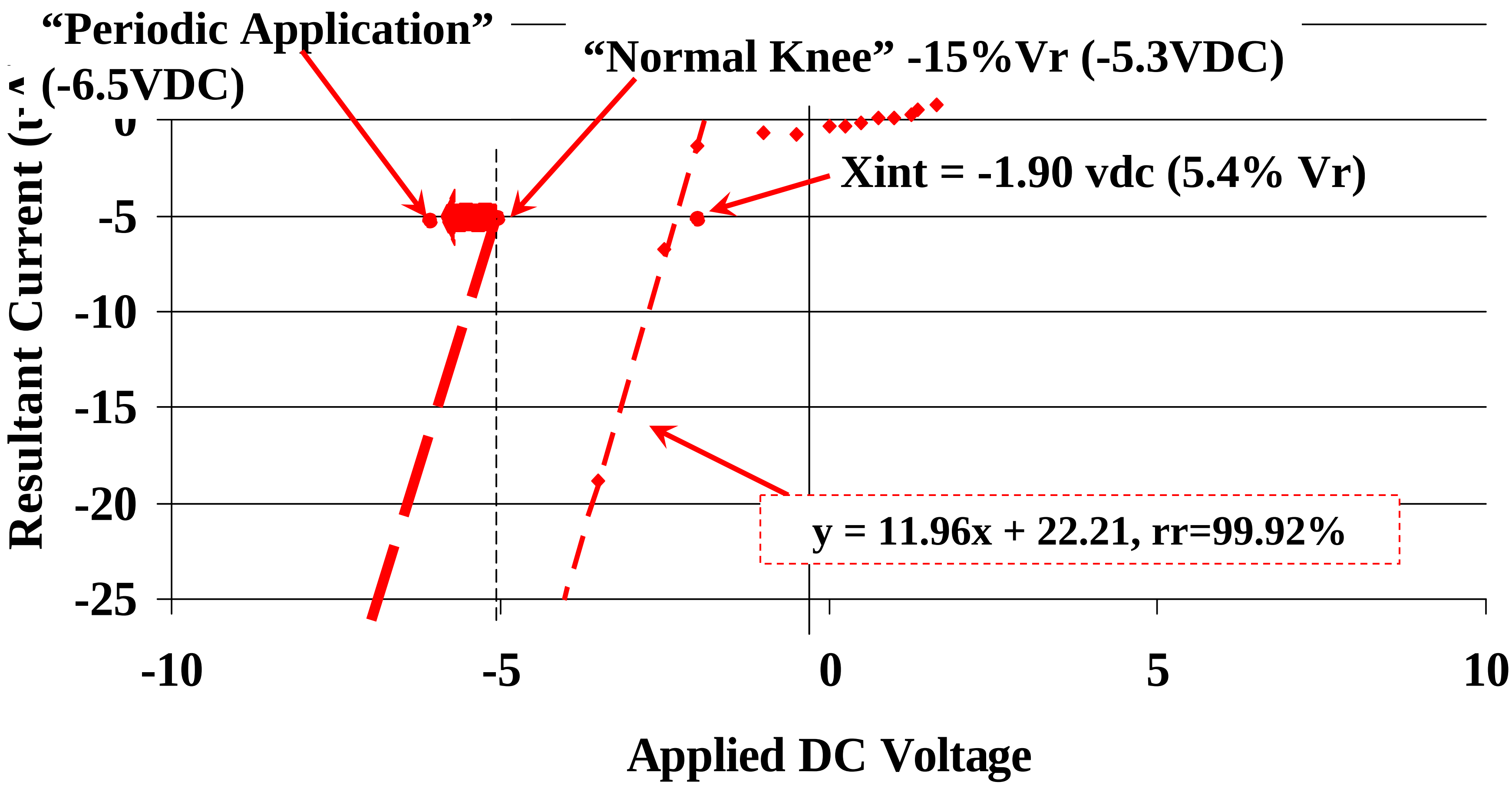
T520V686M006 @ 85°C



T520V686M006 @ 125°C



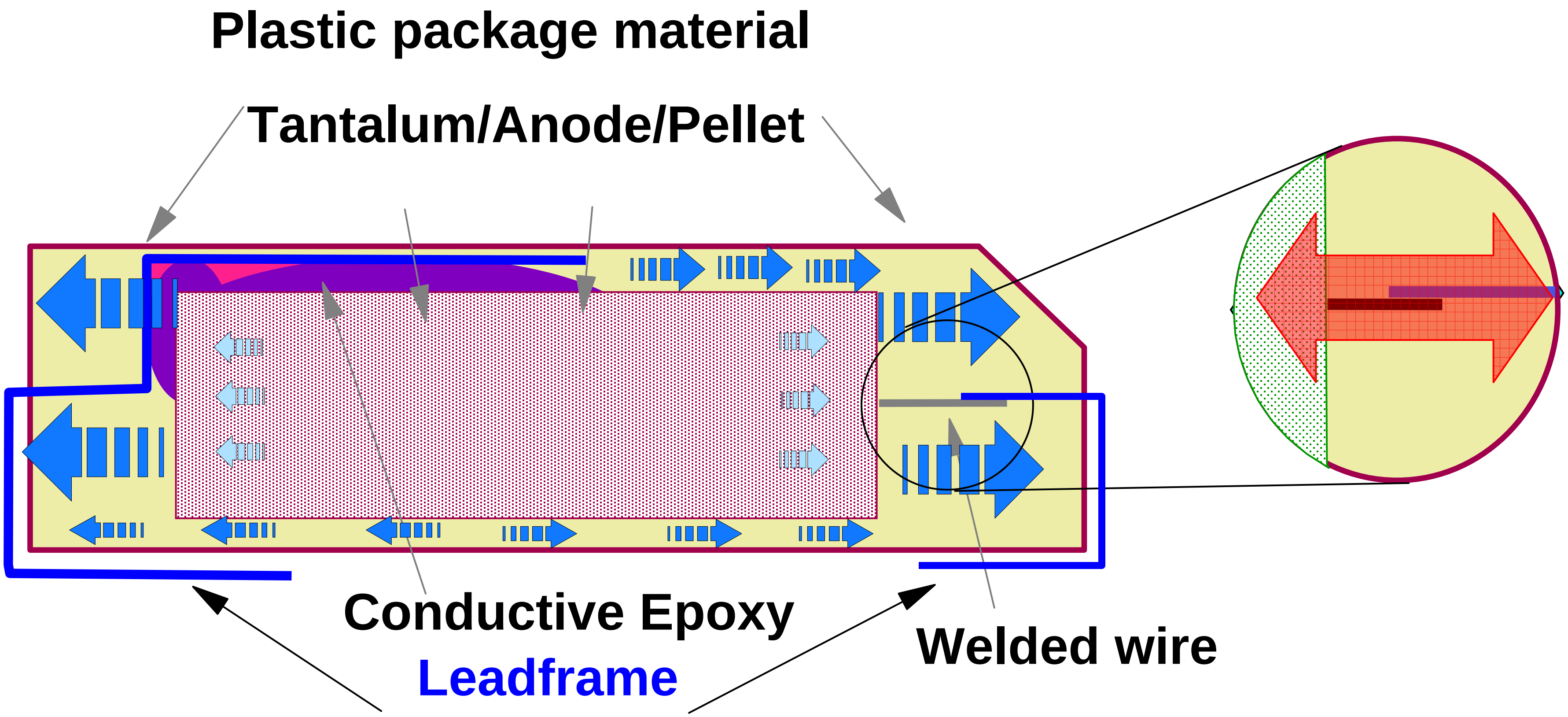
"Bad Unit" #4 - T491B474M035



Breakdown Mechanism

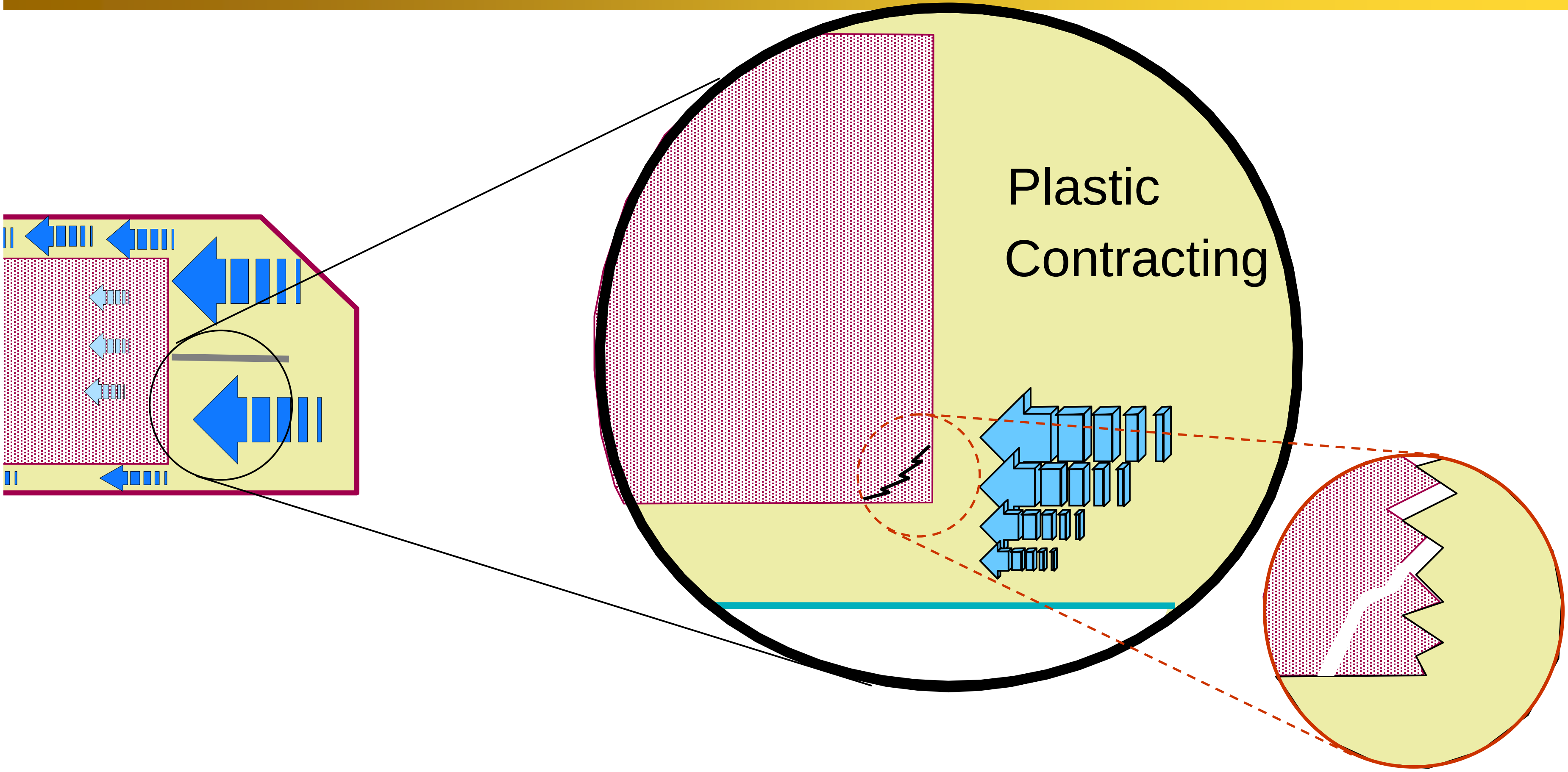
Power-On Failures

Solder Heat Expansion



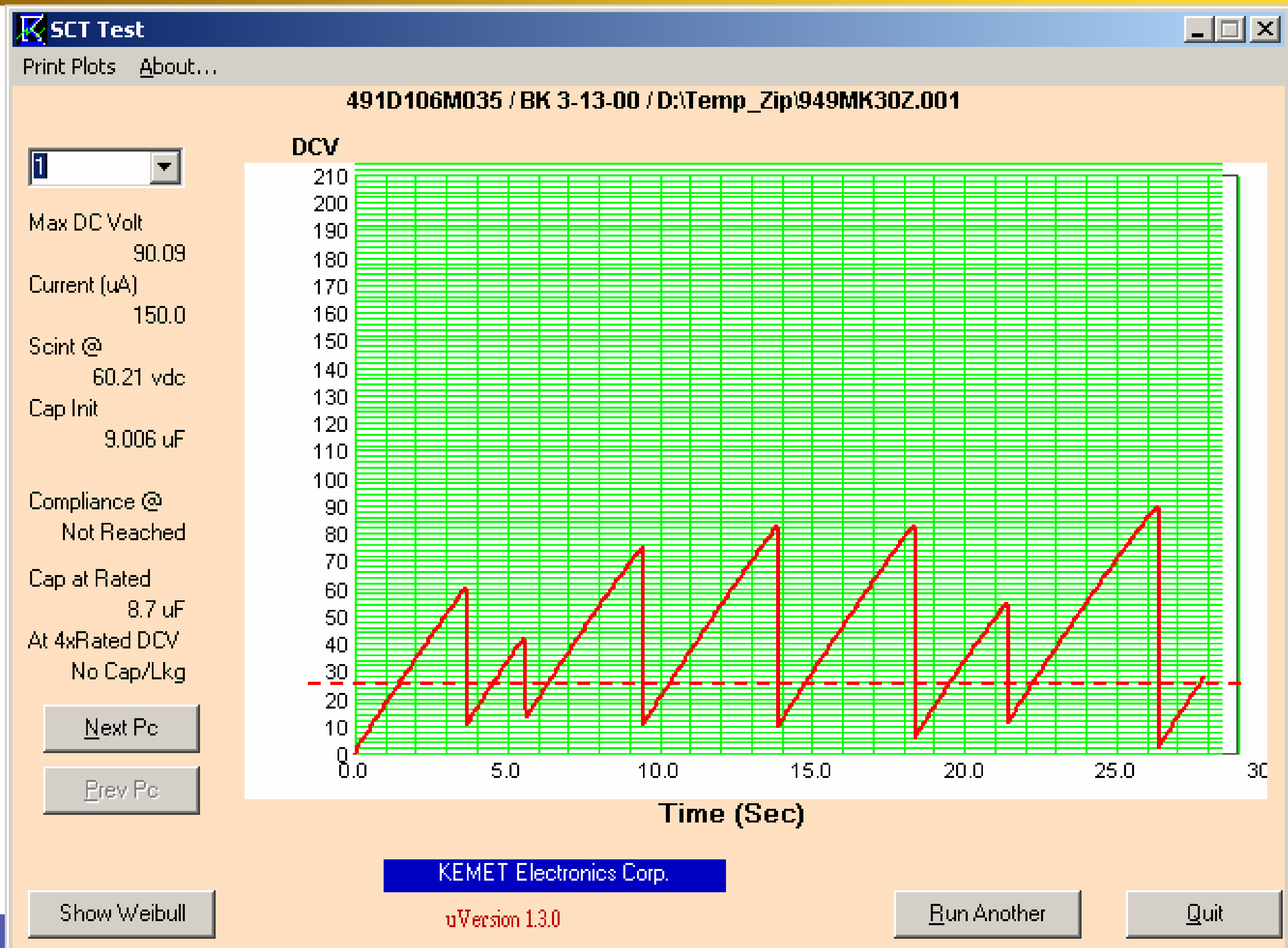
Differences in coefficients of thermal expansion cause stresses to build up within the structure, the mold compound tries to pull (shear) the capacitor apart!

Cooling and Contraction



Edges and corners are focal points of shrinkage forces. Crack can develop in pellet that fractures Ta_2O_5 dielectric sites. Full power application results in ignition - not self-healing.

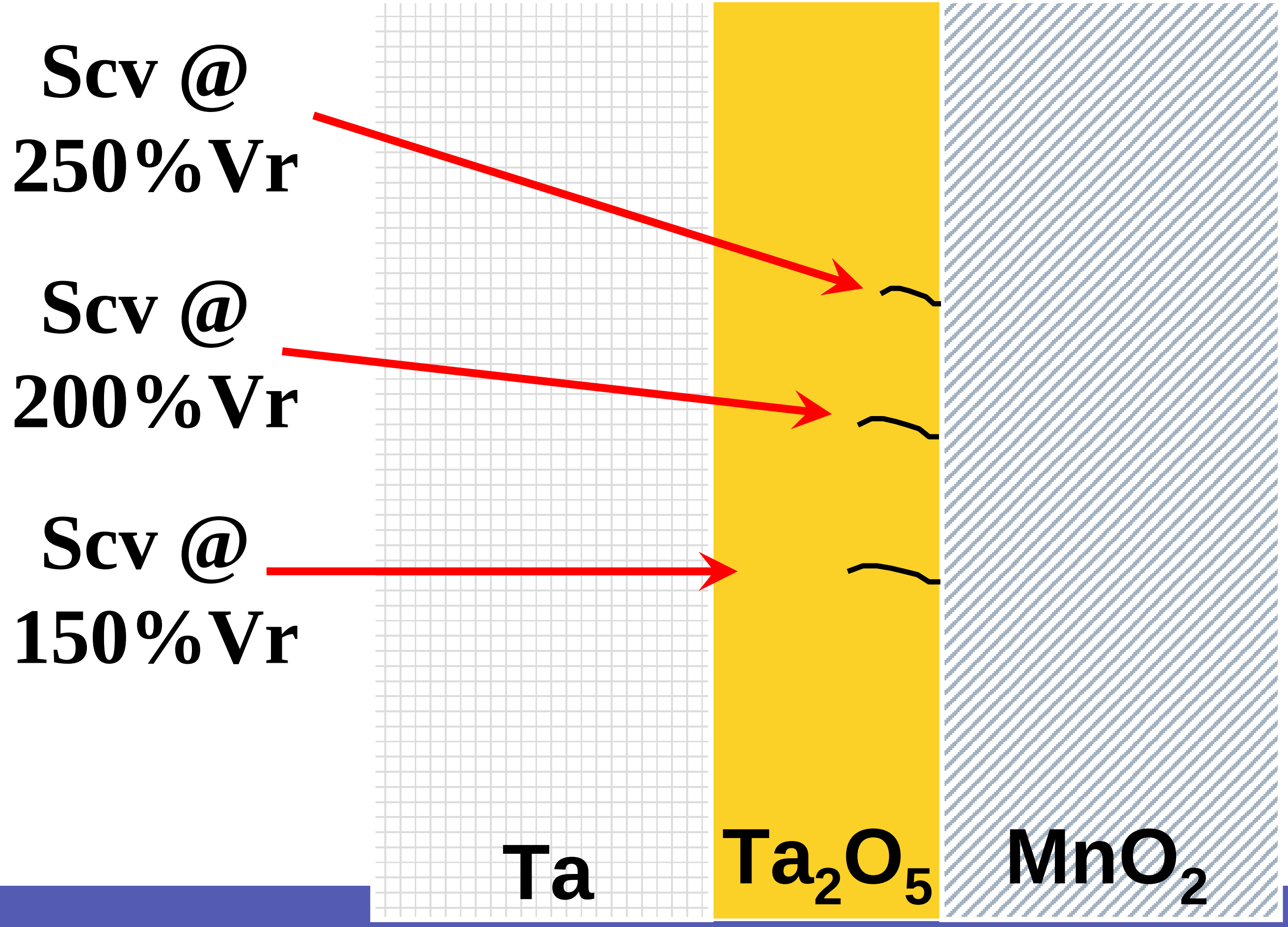
Scintillations



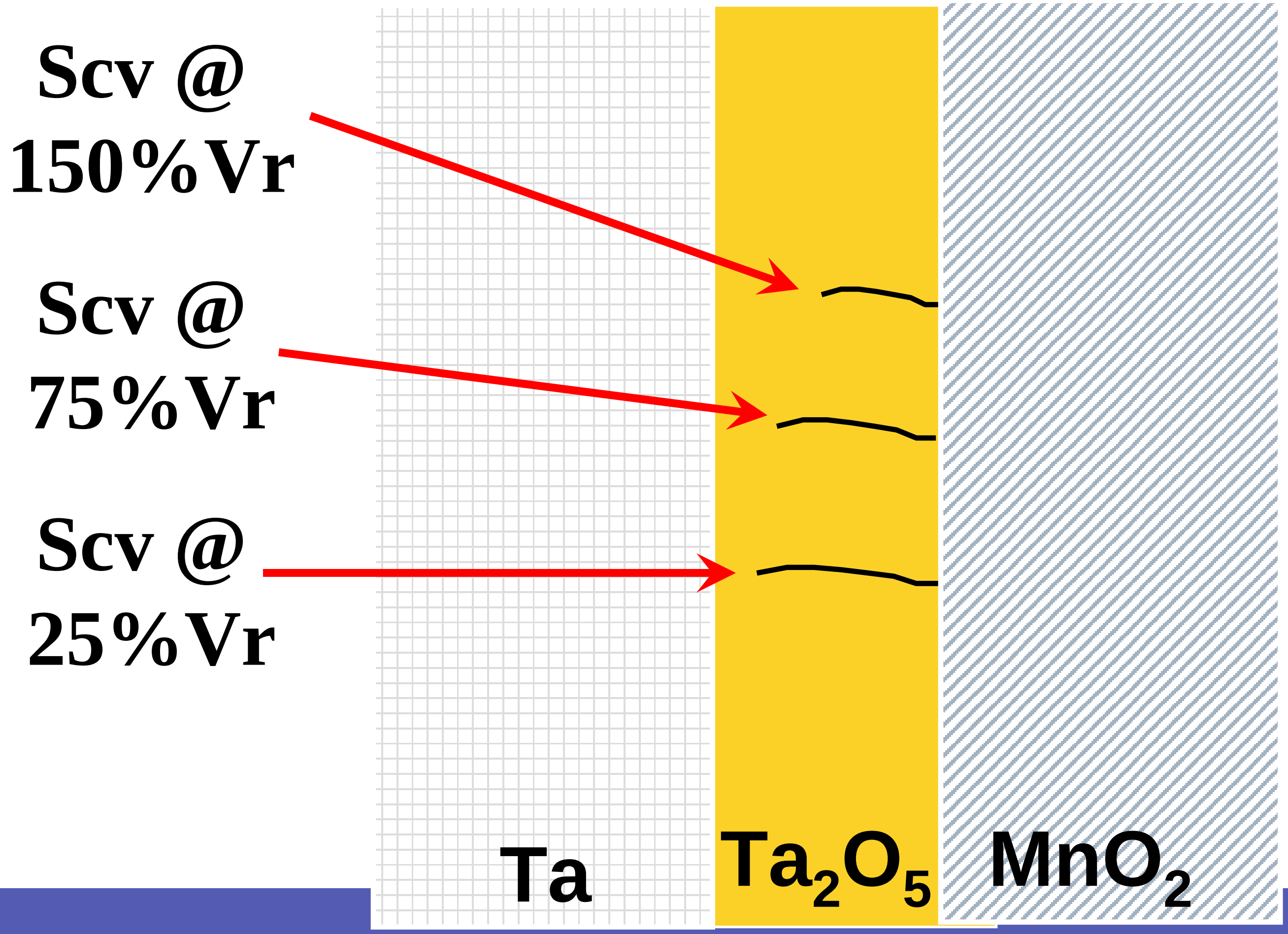
Initial Variable Breakdown Levels

Post 100% Electrical Test

Breakdown Relationship to Crack Severity

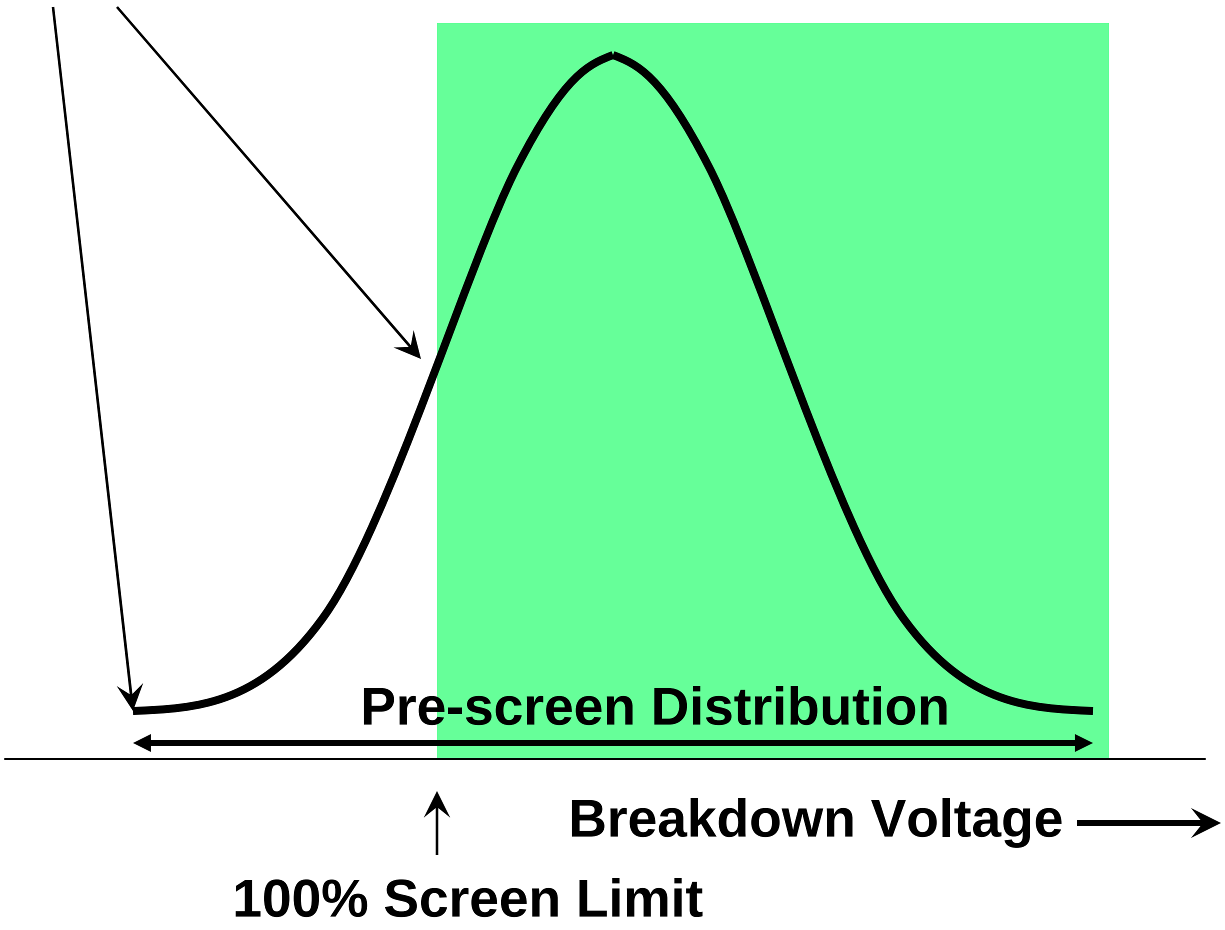


NEW Breakdown Relationship to Crack Growth

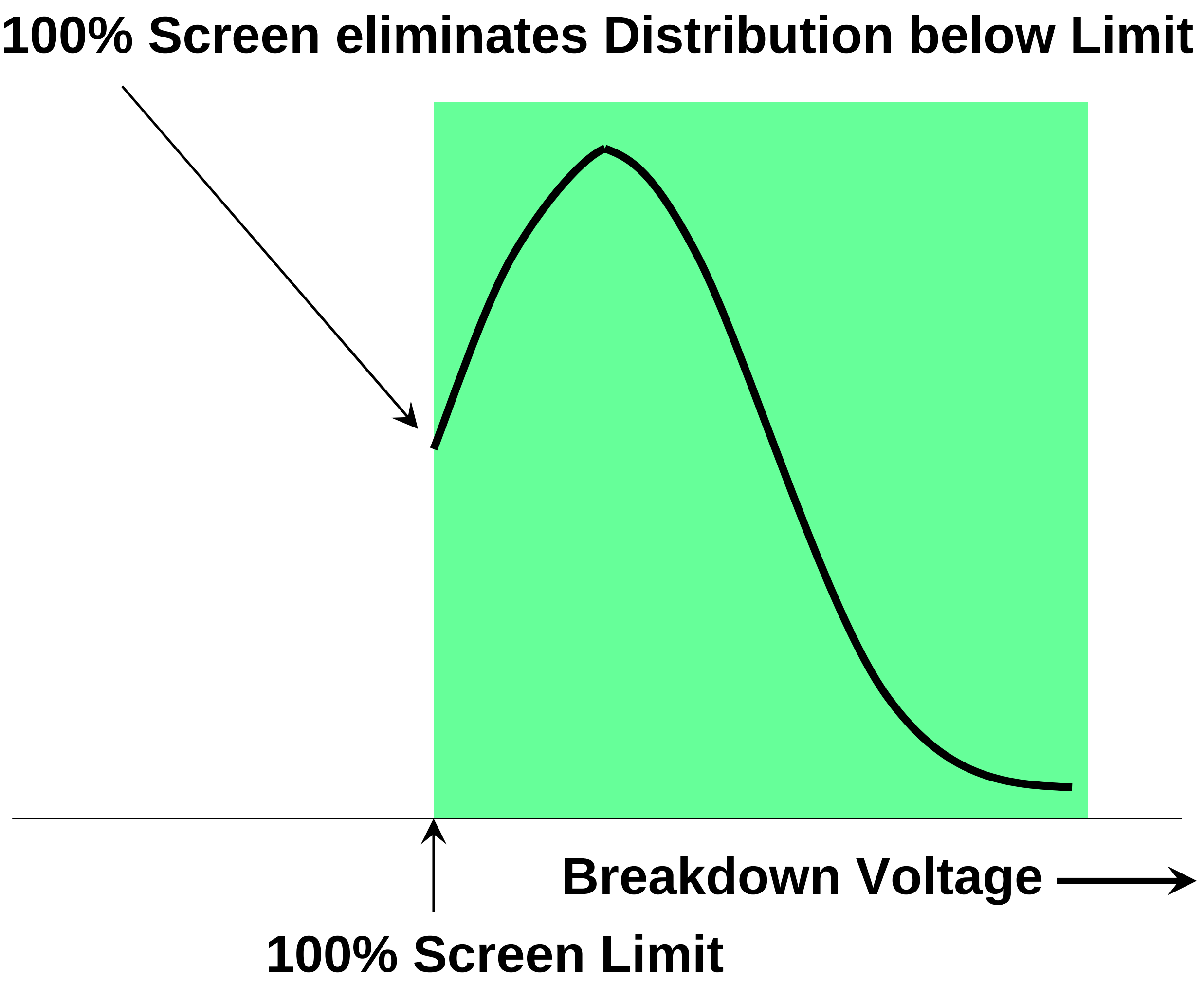


Screening Clips Distribution Tail

Raw Distribution includes pieces below Screen Limit

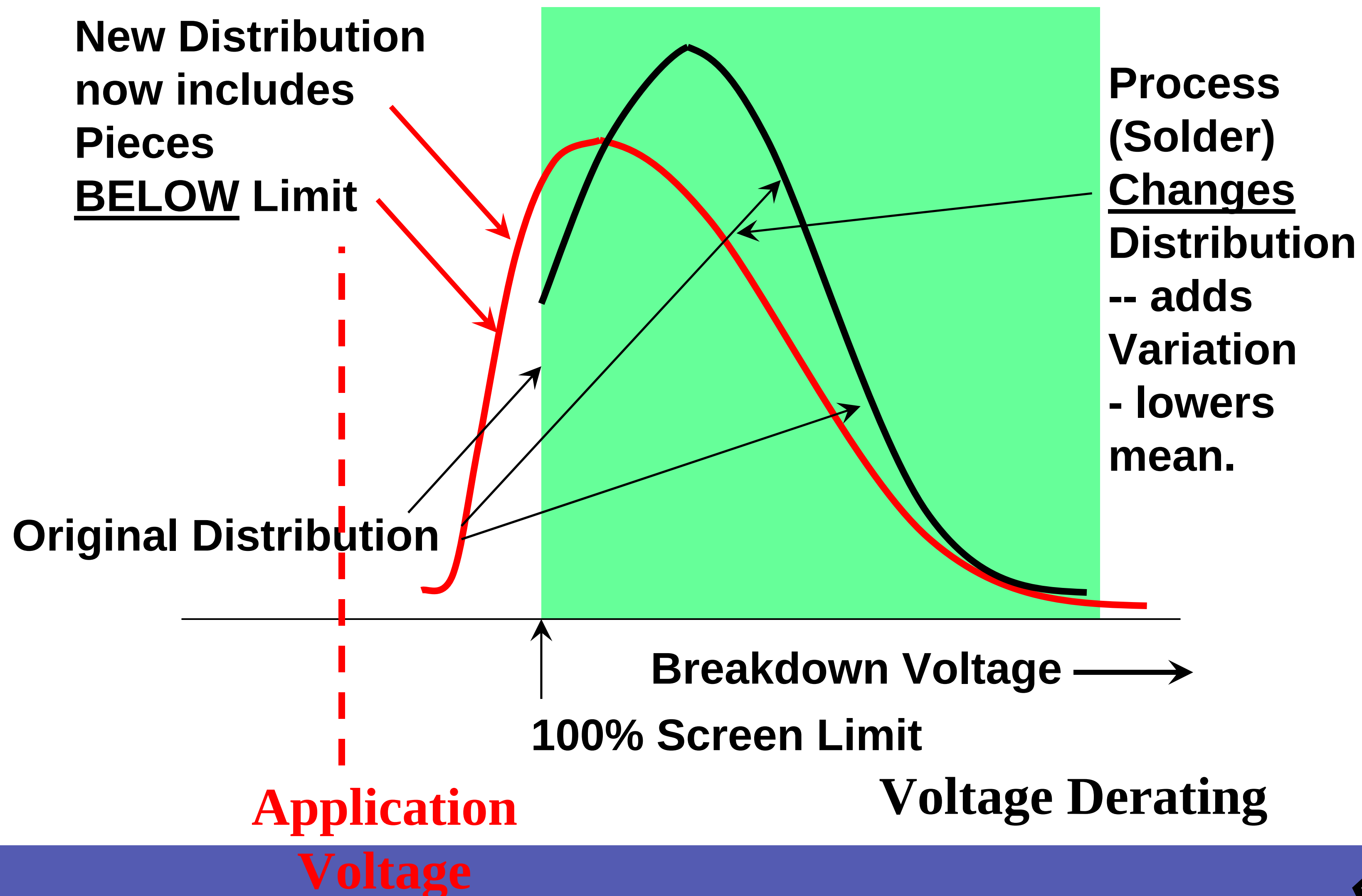


As Packaged Distribution

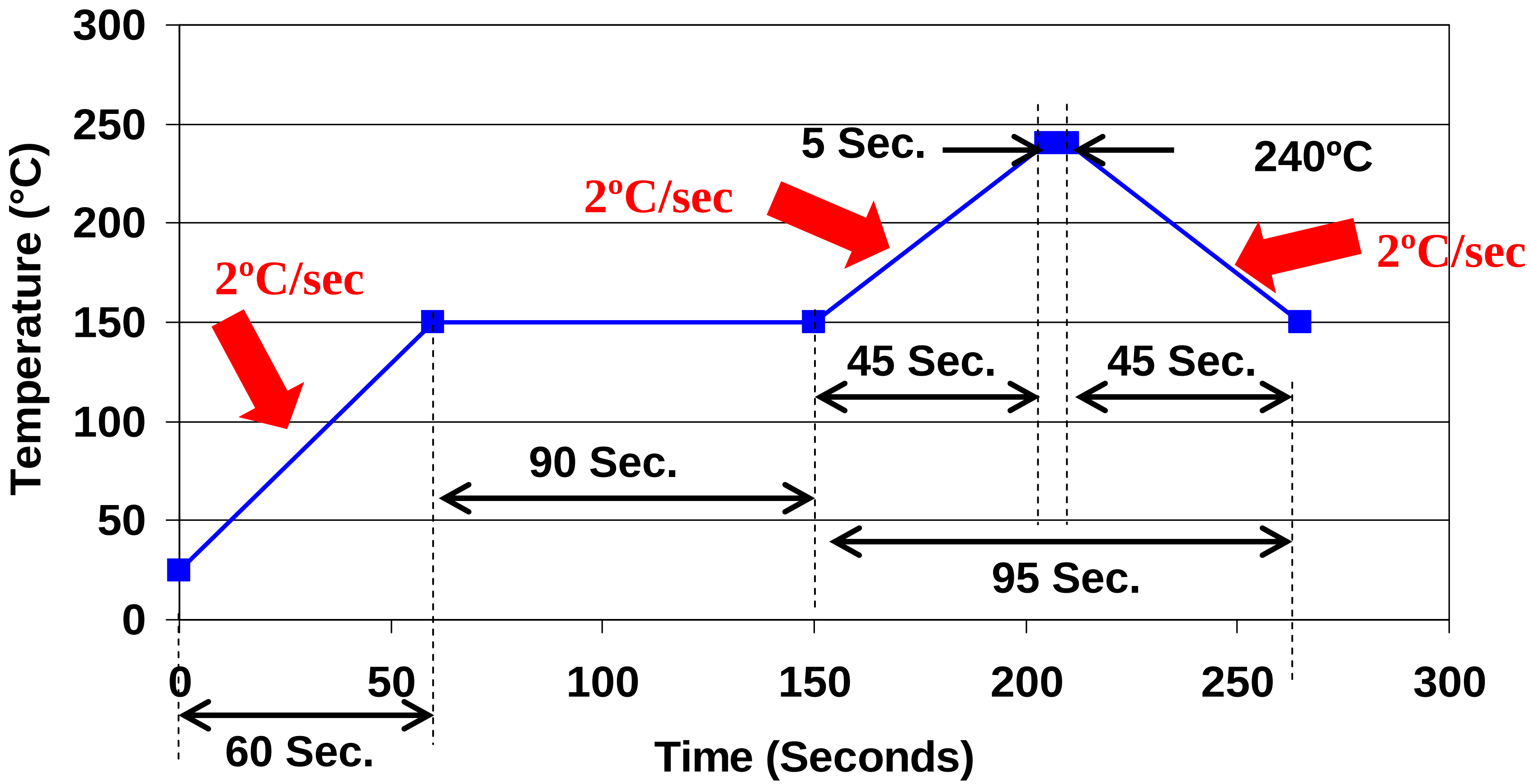


Post Solder Redistribution

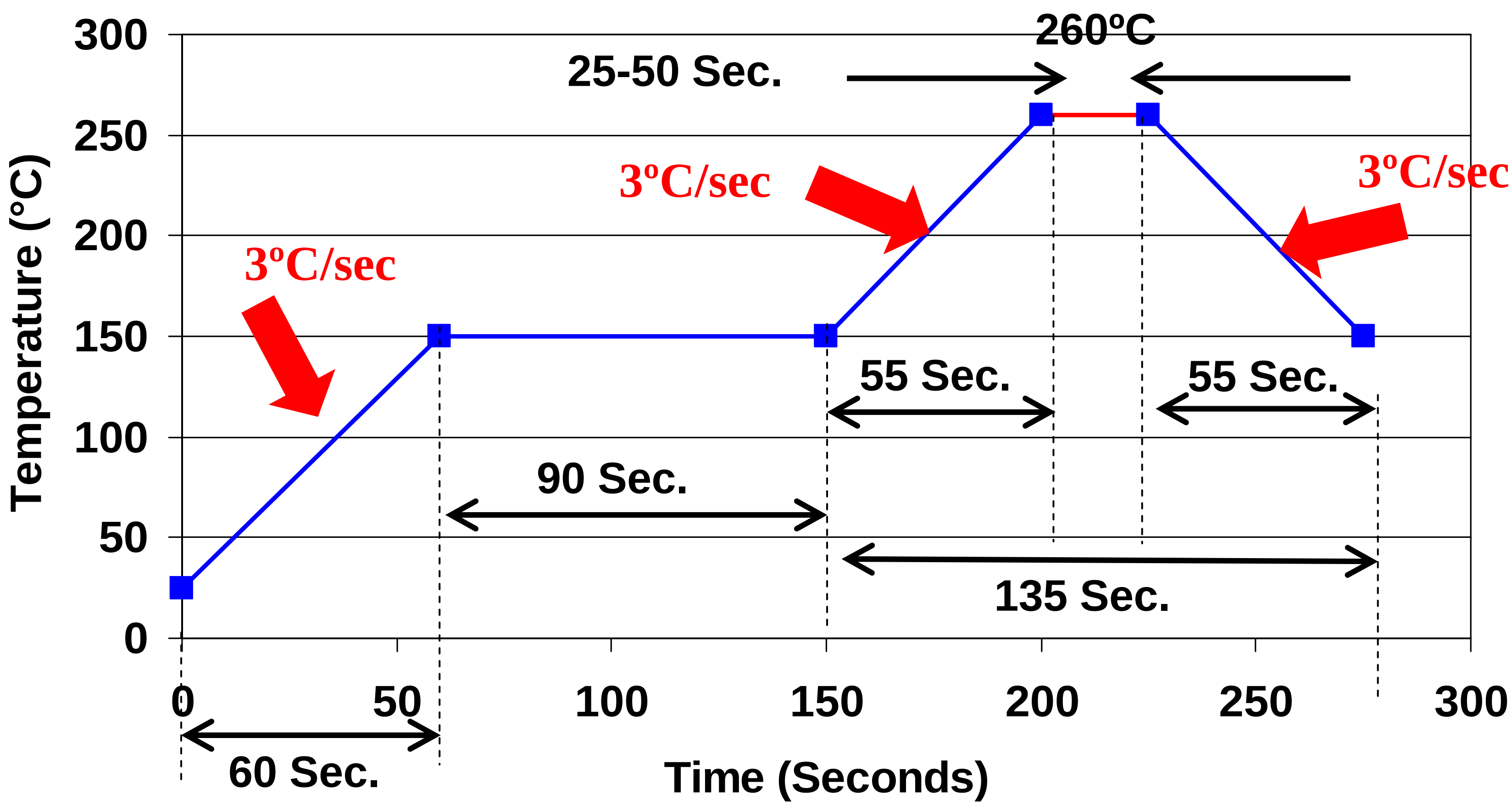
Forces create new, altered distribution after solder.



Recommended IR Reflow Profile (with Pb)



Recommended Pb-Free IR Reflow



In-line IR Reflow

An attempt to exercise the package expansion/contraction prior to customers solder process.

Assembly → In-line IR-Reflow → Final Electrical Test

Proofing Procedure

- Establish a voltage capability of the capacitor through a high resistance.
  - 1 kOhm resistor most common
  - Apply highest voltage that capacitor will ever see.
  - Verify voltage at capacitor.
  - Remove the voltage.
- Remove the resistance - no longer necessary.
- Capacitor has been “proofed.”

Conclusions

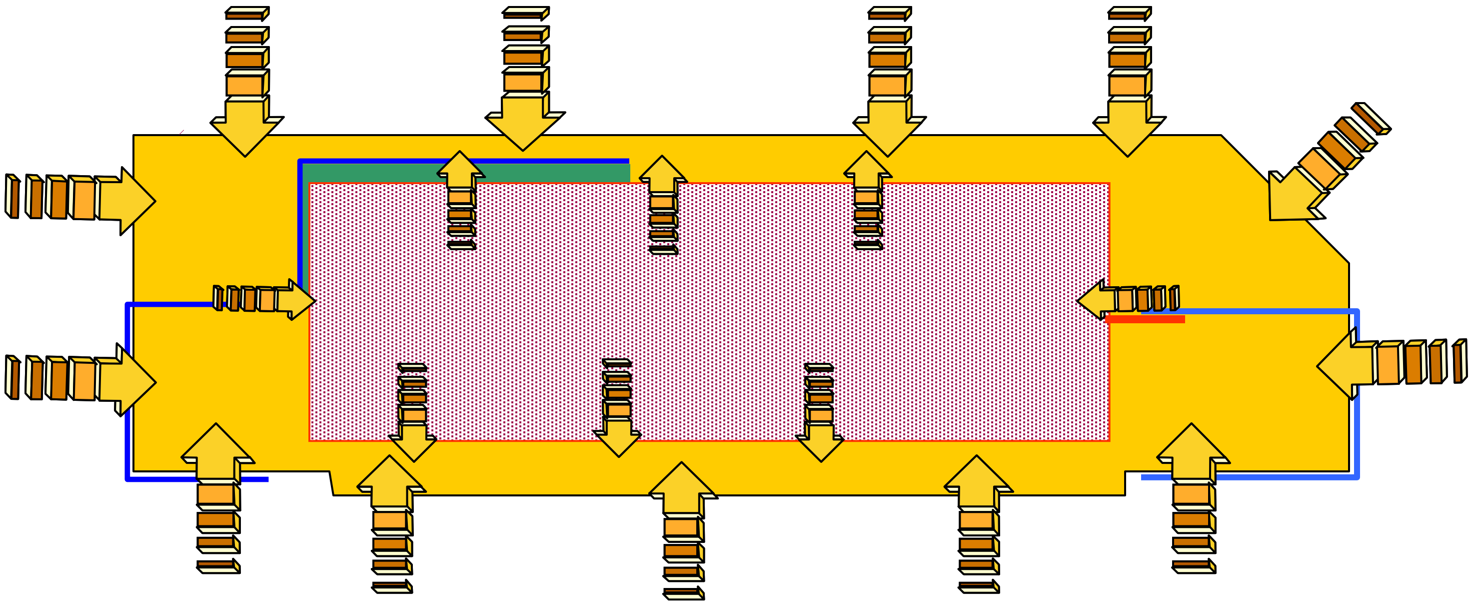
- The 100% electrical testing of these devices does not preclude faults from developing within the device.
- The mismatch of CTEs for the materials used in these devices can create forces large enough to create new cracks or extend existing cracks during the solder process.
- The severity of the solder process will have a direct impact to the magnitude of power-on failures.
- The voltage capability of the device is defined by the level of stress applied to the part after mounting (proof).
- The closer the peak application voltage is to the rated voltage of the part, the greater the number of turn-on failures.

Moisture Problems

Case Absorption

Ionic Penetration

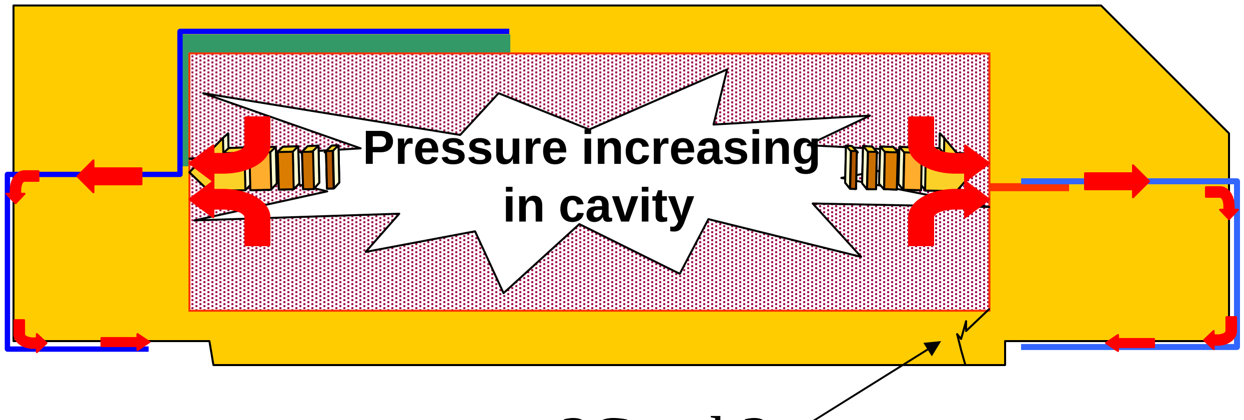
Plastic moisture absorption



Moisture absorbed into plastic material over long time periods.

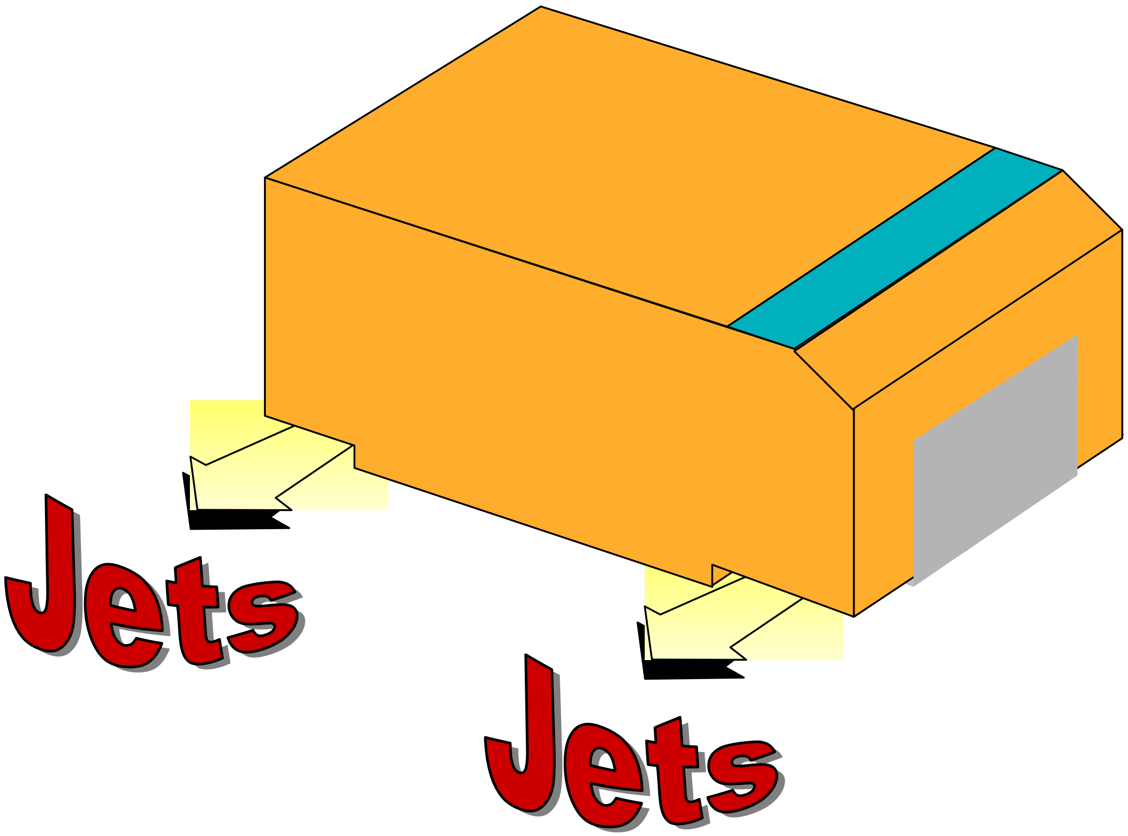
Plastic is <u>hydroscopic.</u>

Pressure venting at egress



Pressure builds and may create crack.
Pressure vents along lead egress.
Jet is deflected down, then into glue-pad at bottom of chip.
Jet turns outward to sides of chip.

Gas jets at sides



Jets of gas emanate from beneath chip and can displace small component or solder balls if close enough.

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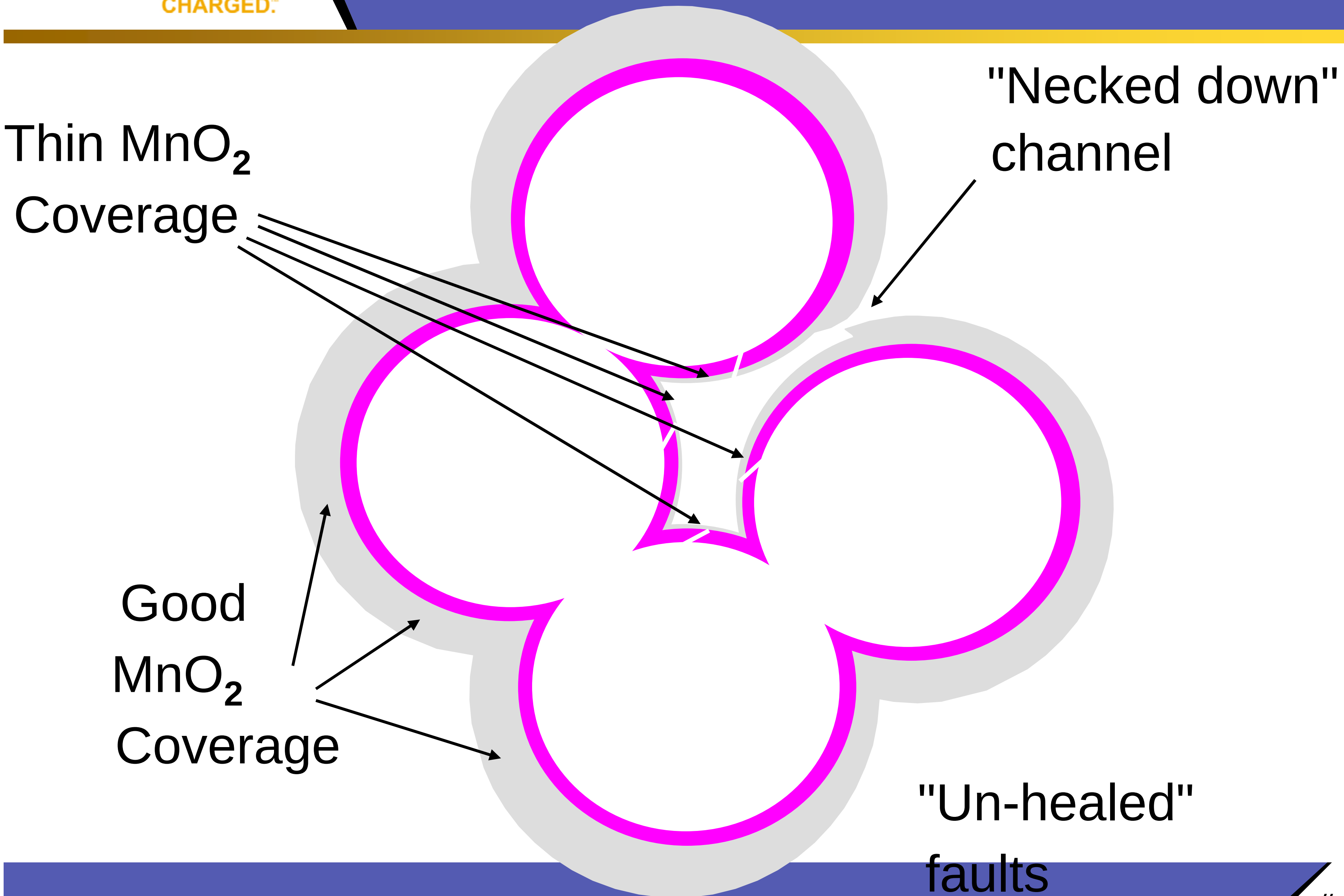
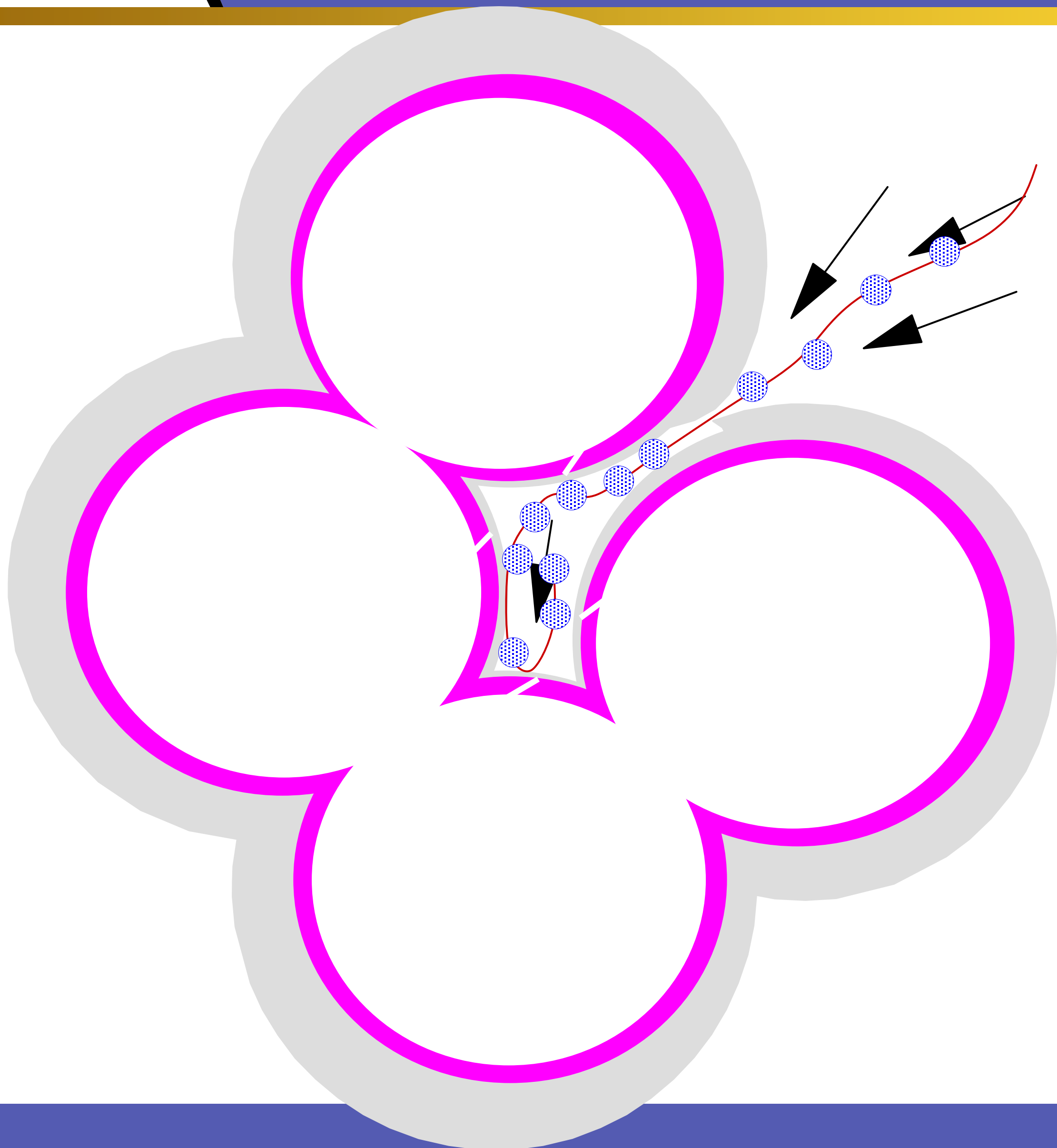
Moisture Fault Potential



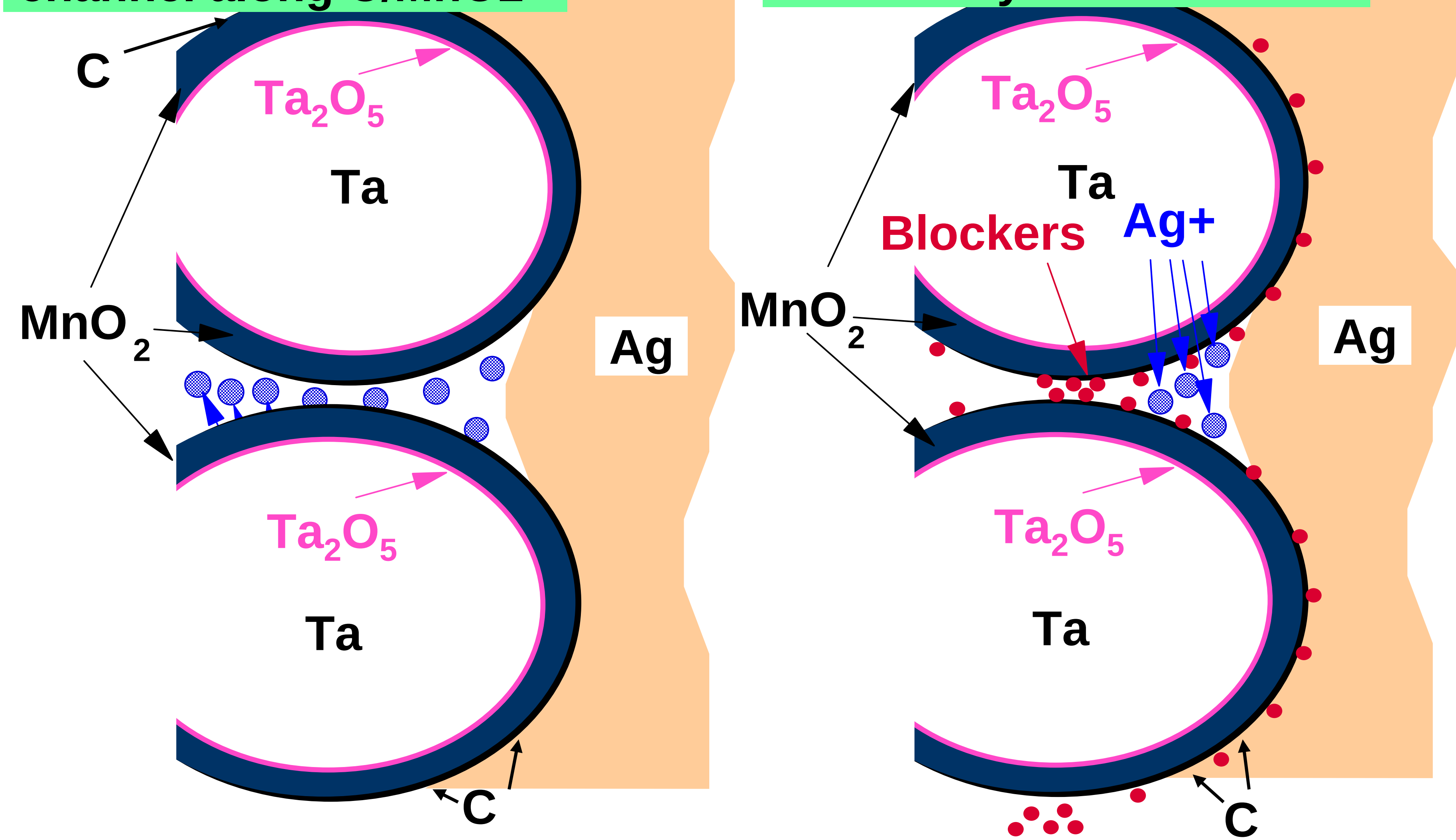
Moisture Fault Activation



Ionic laden moisture establishes contact to fault -- No MnO_2 healing mechanism!

Ag+ ions move freely into channel along C/MnO2

Ag+ ions restricted from channel by "Blockers"



Aluminum (WET) Failure Modes

- Reverse polarity damage
- Solder heat evaporation of electrolyte (wet)
- Cleaning solvent susceptability
- Leakage increase
  - Outgassing
  - Loss of electrolyte
  - Drying
- Early Catastrophic Failures
- Increasing DF, ESR, Z
- Shelf Life loss of memory
  - Requires "Refresh"
  - Low voltage applications create "shelf life"

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Film Failure Modes

- **Sensitive to mild overstress (surge voltage)**
- **Foil type**
  - Short Circuits
  - Increasing ESR with temp/time
- **Metalized Electrodes**
  - Self-healing / noise generation
  - Loss of cap / open circuits
  - Parametric degredation with life
  - Surge susceptability
  - Aluminum attacked by moisture

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Ceramic Failure Modes

- **No wear-out mechanisms of undamaged part**
- **Sensitive to mechanical damage**
- **Crack induced failures**
  - ✓ Short Circuits / Catastrophic
  - ✓ Increasing Leakage / degradation of IR
  - ✓ Increasing ESR / DF

Tantalum (Poly-Al) Failure Modes

- **Sensitive to mild overstress (surge), reverse polarity**
- **No wear-out mechanisms / self-healing**
- **Stress induced failures**
  - ✓ Short Circuits / Catastrophic
  - ✓ Increasing Leakage / degradataion of IR
  - ✓ Increasing ESR / DF
  - ✓ Capacitance decay
- **Plastic package hydroscopic venting during reflow disturbing smaller adjacent components (0603 chips)**