POLYCHARGE

High Energy Density Solid Stare Polymer Capacitors for Space Applications

By

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Power Systems for Deep Space Exploration

Deep space missions to planetary bodies require electrical components with both low an d high temperature survivability Missions to the surface of Europa, permanently shadow ed craters on the Moon, small bodies, and comets will be exposed to temperature s below -180 °C.

Cryogenic environments, combined with high temperature, cosmic radiation and spacecraft generated radiation when using Dynamic Radioisotope Power Systems (DRPS) such as Stirling Engines, impose significant limitations on the choice of electrical components

One of the largest components in Power Processing Units (PPUs) are Energy Buffer and DC-link capacitors that used to minimize ripple current, voltage fluctuations and transient suppression.

In addition to operating in extreme temperature and radiation environments, long life, high reliability, high energy density and specific energy to reduce size and weight, are desirable capacitor properties

Commercially Available Capacitor Technologies For Energy Buffer, DC-link, and Pulse Power Applications

Polymer Film Capacitors
Chosen for their high stability of dielectric properties with temperature and voltage,
Large and heavy especially for lower voltage applications
Temperature range 105C-125C
Degrade in the presence of radiation

Ceramic Capacitors
High operating temperature
High voltage and high microfarad parts are large and heavy
Poor capacitance stability with temperature especially at cryogenic temperatures
Large drop of capacitance with applied voltage
Large ceramic capacitors can microcrack and short in DC-link and Pulse Power applications

Tantalum Capacitors
High operating temperature
Not available in high voltages
About 10X increase in ESR at cryogenic temperatures

NanoLam™ : A Disruptive Polymer Capacitor Technology

Conventional Polymer Capacitor Supply Chain

Three Different Independent Industries are involved

Film Extrusion

A Handful of OEMs Worldwide

Electrode Metallization

A Small Number OEMs Worldwide

Capacitor OEMs

100s of capacitor manufacturers worldwide utilize the same polymer films, thus limiting the ability to differentiate and innovate

NanoLam™ Capacitor Manufacturing Process

Single Step Process Using two Materials to Produce 70sq.ft. of Nanolaminate Composite that is Processed into Capacitors

Aluminum Wire

\+

Monomer Liquid

Complete Control of all Key Capacitor Properties

- Polymer Chemistry
  - High Temperature Polymers
  - Energy Storage (dielectric constant)
  - Self-healing Properties
  - Operating Temperature
  - Glass Transition Temperature
- Dielectric Thickness (100nm and higher)
- Electrode Design and Metal Thickness

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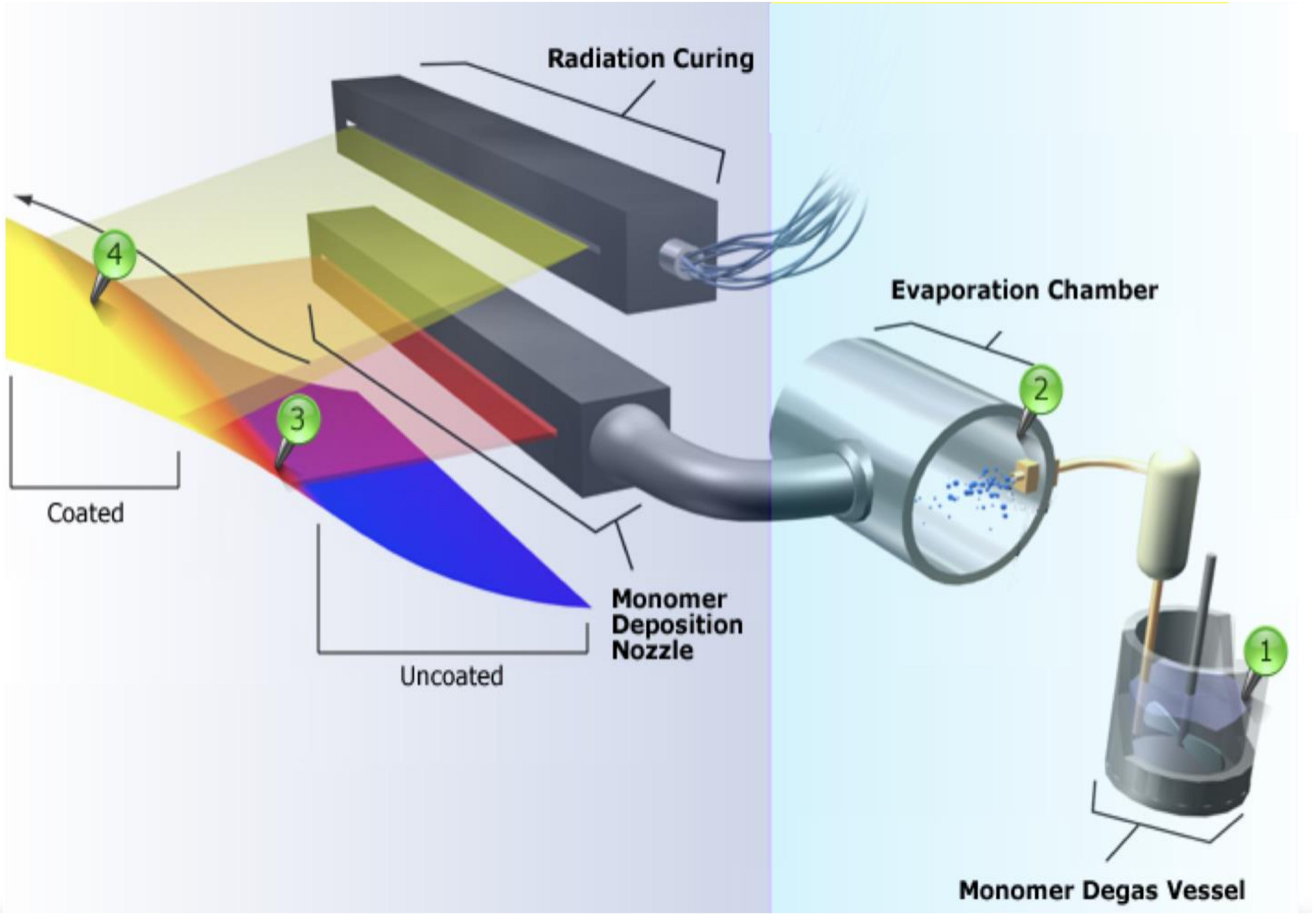
A Unique and Novel Element of the NanoLam Technology is the Ability to Form 1000s of Highly Uniform Nanothick Polymer Dielectric Layers in the Vacuum on a Web or a Rotating Process Drum at speeds of 100s ft/min



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Products Developed By Sigma Technologies Based on NanoLam™ Technology Prior to Spinning Off Polycharge America Inc.

Developed low voltage SMD solid state polymer multilayer (PML) capacitors that were licensed to Panasonic and Rubycon

Size/w.v.	25V.DC	50V.DC	100V.DC
1608 inch code 0603	0.033 μF	0.001→0.01 μF	
2012 inch code 0805	0.047→0.15 μF	0.015→0.047 μF	
3216 inch code 1206	0.22→1.0 μF	0.068→0.33 μF	0.001→0.047 μF
3225 inch code 1210	1.5→2.2 μF	0.47→0.68 μF	0.068→0.1 μF
4532 inch code 1812	3.3→6.8 μF	1.0→2.2 μF	
5750 inch code 2220	10→15 μF	3.3→4.7 μF	

RUBYCON CORPORATION

Functionalized textiles for heat management with superhydrophobic properties

Developed color shifting pigments for currency security applications

Heat Management Applications

Nanoflake aluminum pigment used in inks and paints.

Air and Moisture Barrier Applications

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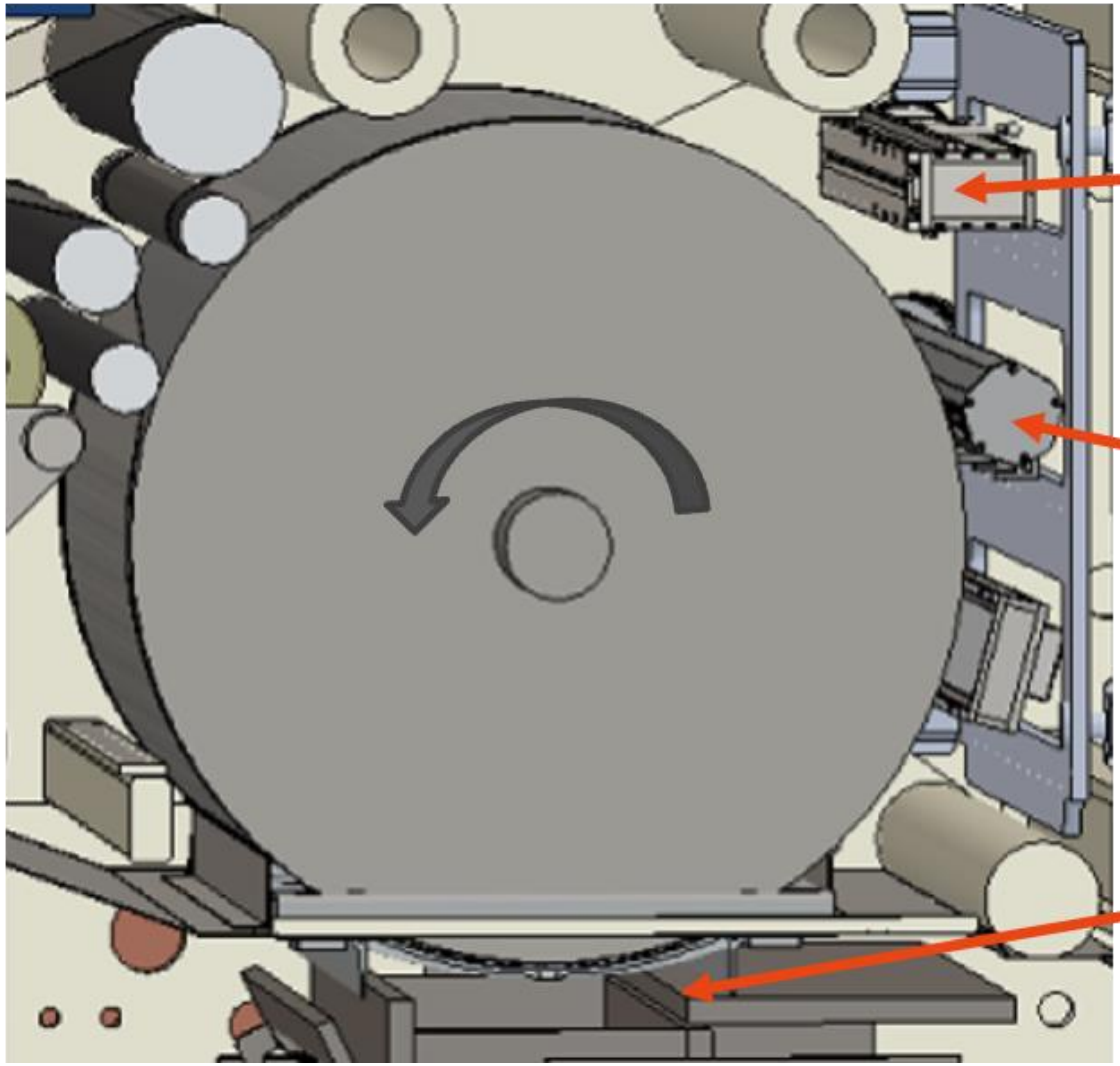
NanoLam™ Production Process

Bulk NanoLam™ Material Production in a single chamber.



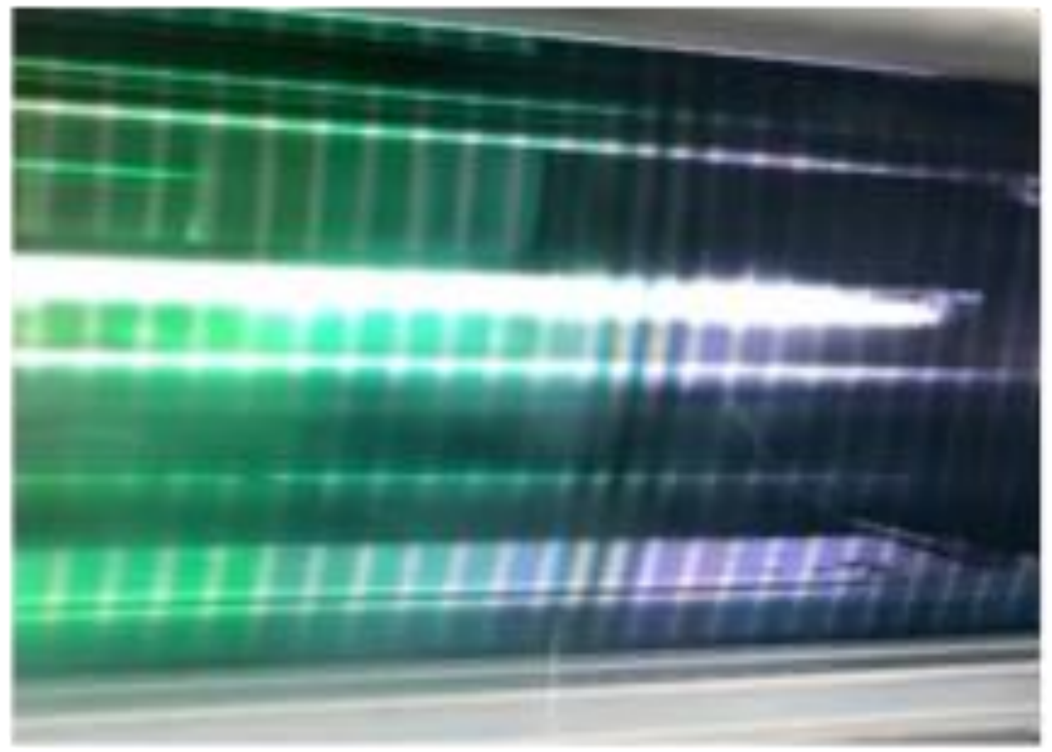
NanoLam™ Dielectric Curing
Monomer is cross-linked using an electron beam curtain

NanoLam™ Dielectric Deposition
Formulated acrylate monomer are vapor deposited onto the metallized electrode.

Electrode Metallization

Nanolam™ Capacitor Process

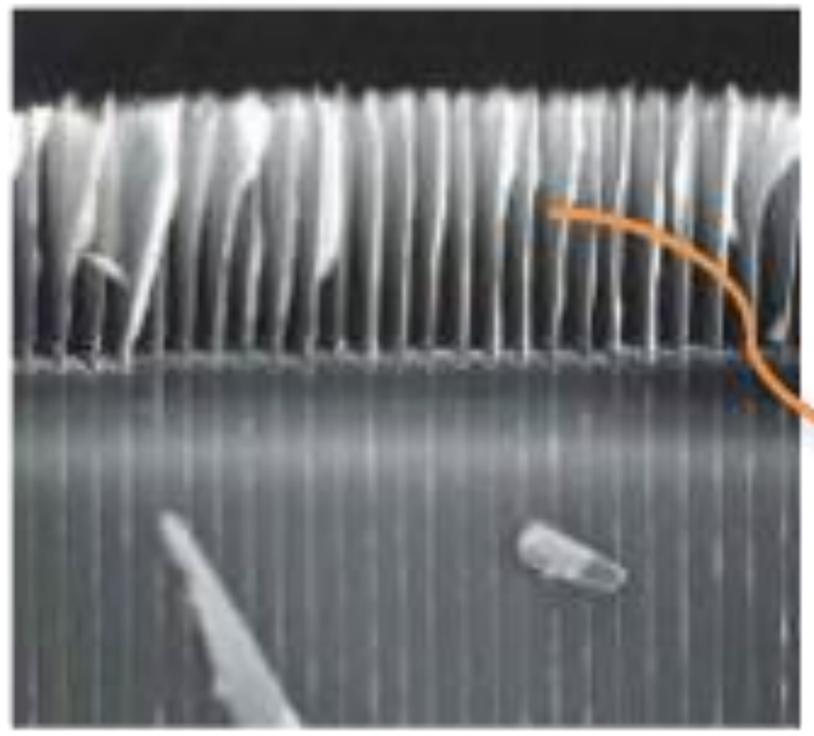
Mother Capacitor Material Produced on a Rotating Drum



Mother Capacitor Material Segmented into Cards

Cards Segmented into Capacitor Elements

Removal of Polymer to Expose the Electrodes

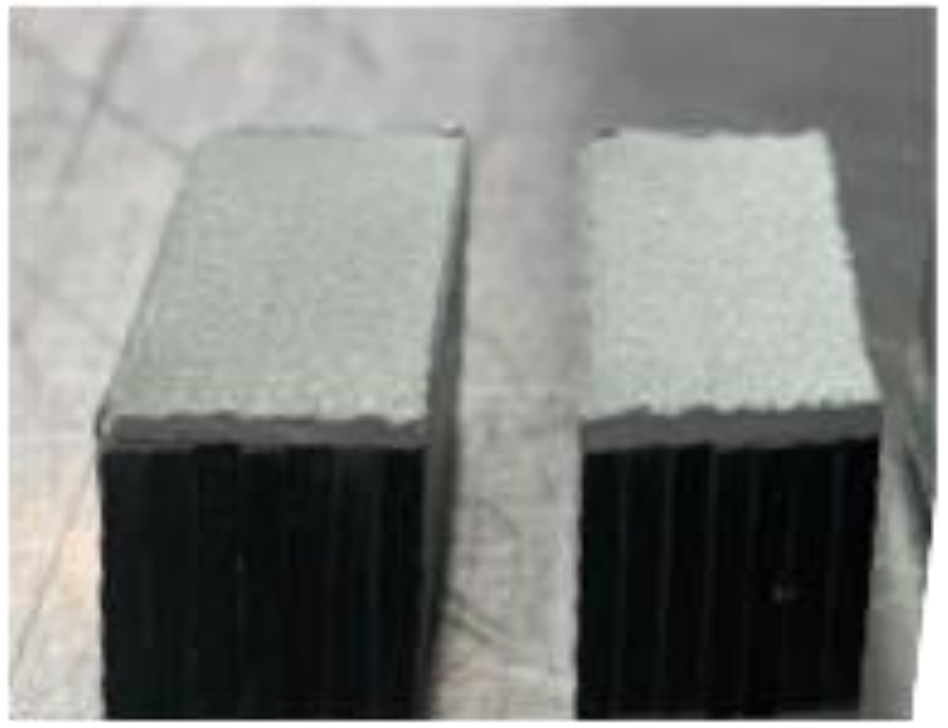


Arc Spraying To Connect Electrodes in Parallel

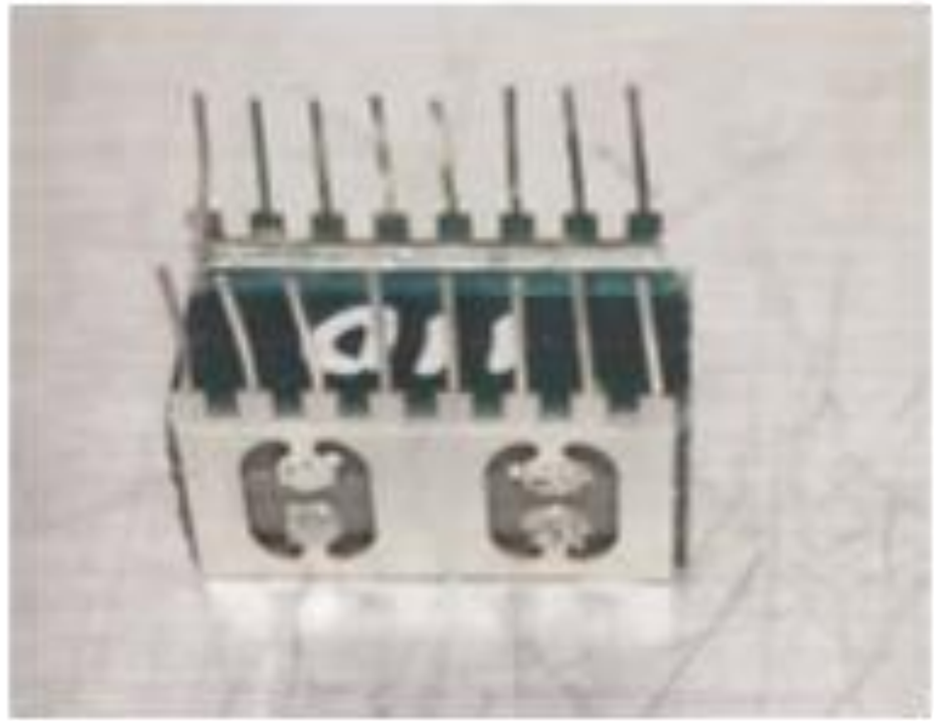
Process Flow

Fully Tested Capacitor Elements

Capacitor Block Formed by Stacked Elements



Block with Attached Bus Bar



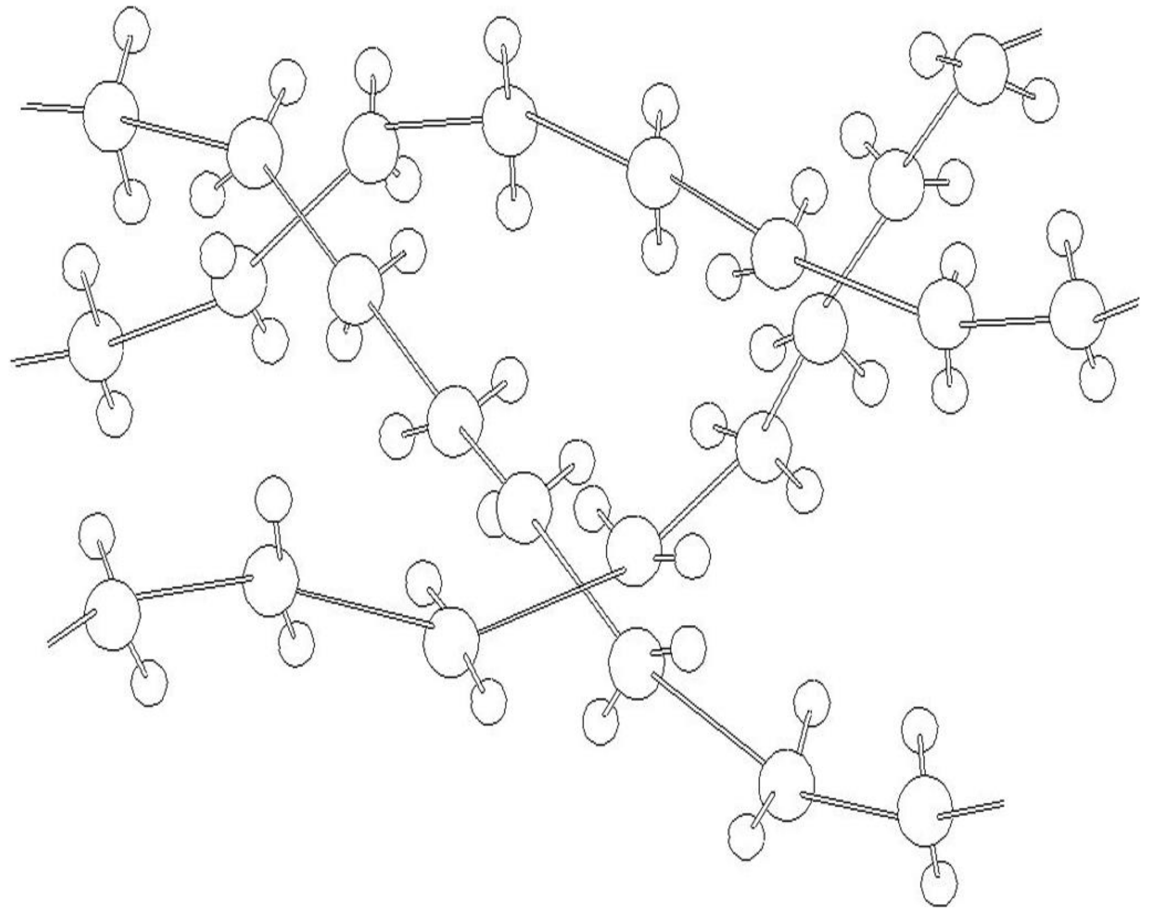
Packaged Capacitor

High Temperature Polymer Dielectric Materials
Wide Range of Chemistries

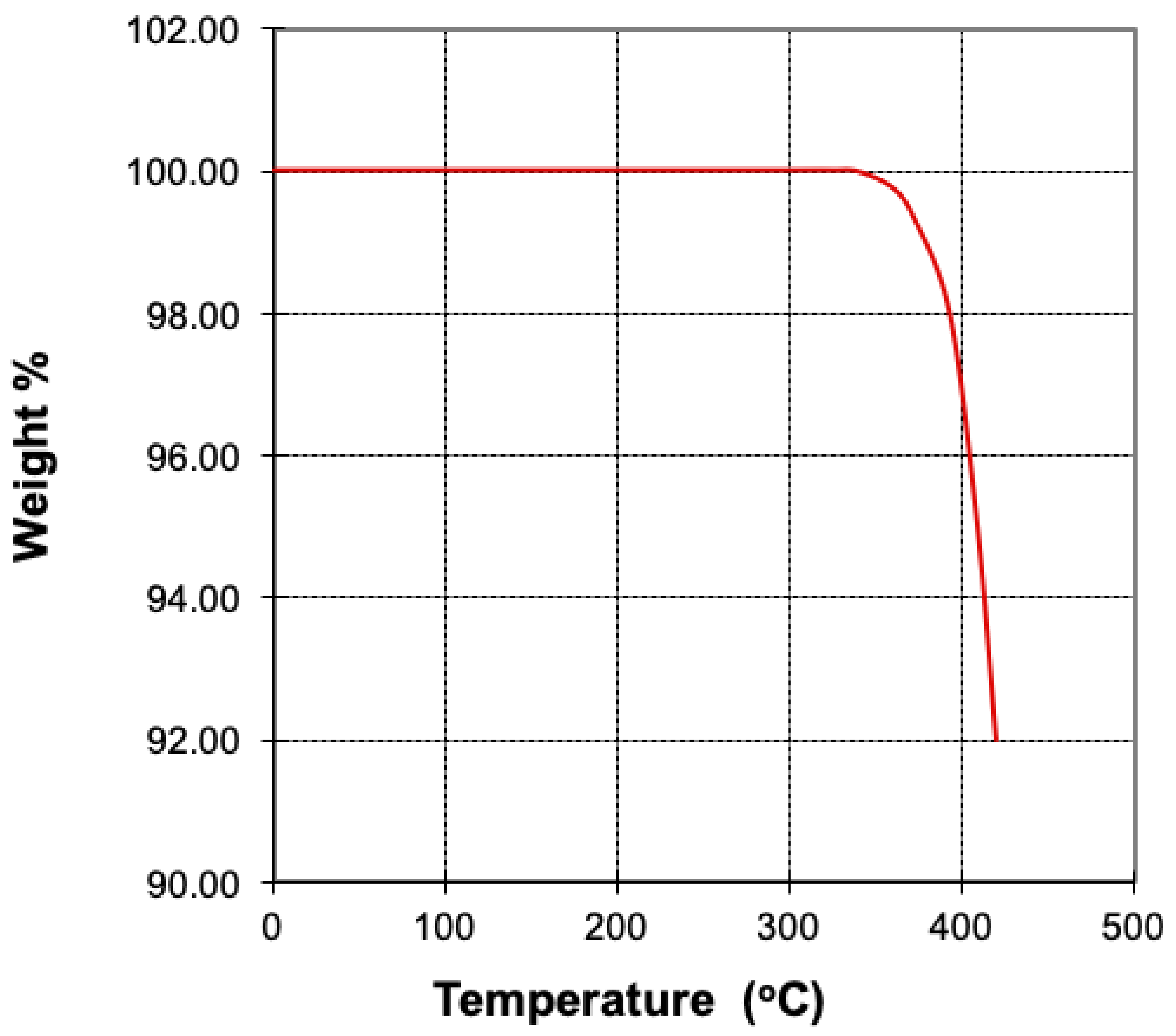
The Polymer Dielectric is Formed Using
Electron Beam Crosslinked Acrylate Monomers
(Beta Radiation)

$H_2C{=}CHC(O)O\ \ R(X)\ \ OC(O)CH{=}CH_2$

R = aliphatic, aromatic, cycloaliphatic, etc



Thermal Stability (TGA)



Dielectric Constants 2.7<k<9

Current NanoLam Polymer k=3.2

Dielectric constant of PP k=2.2

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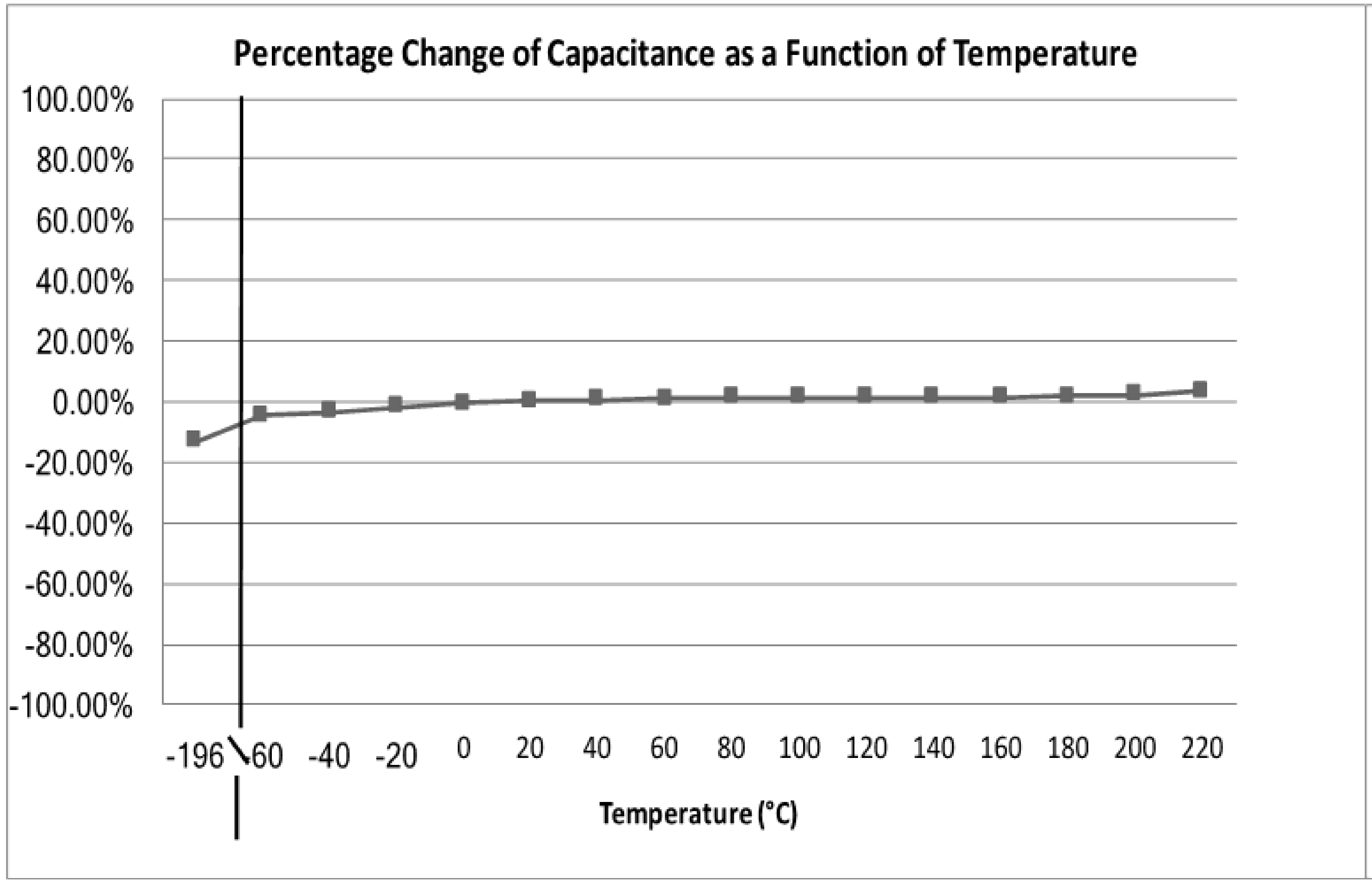
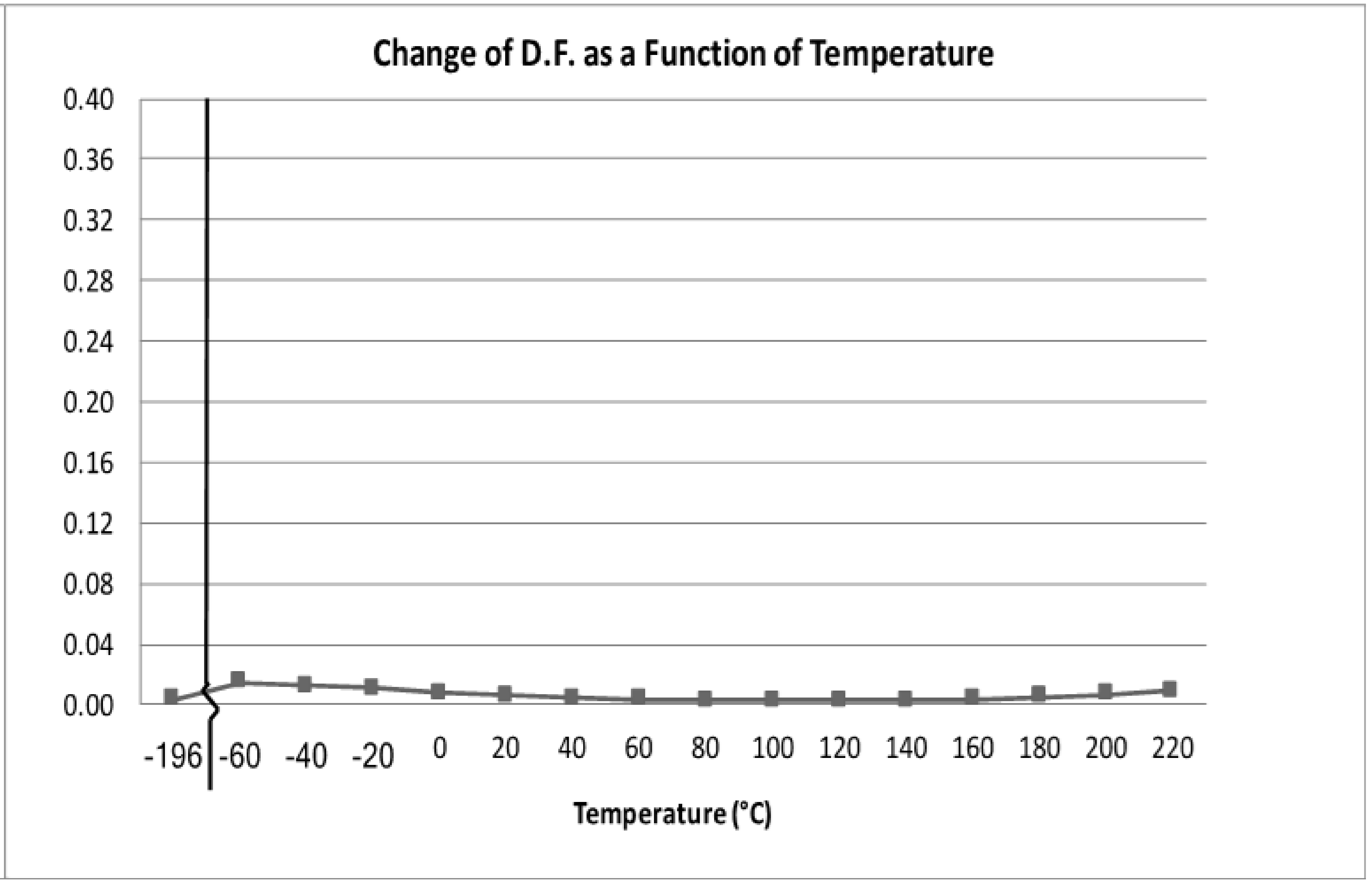
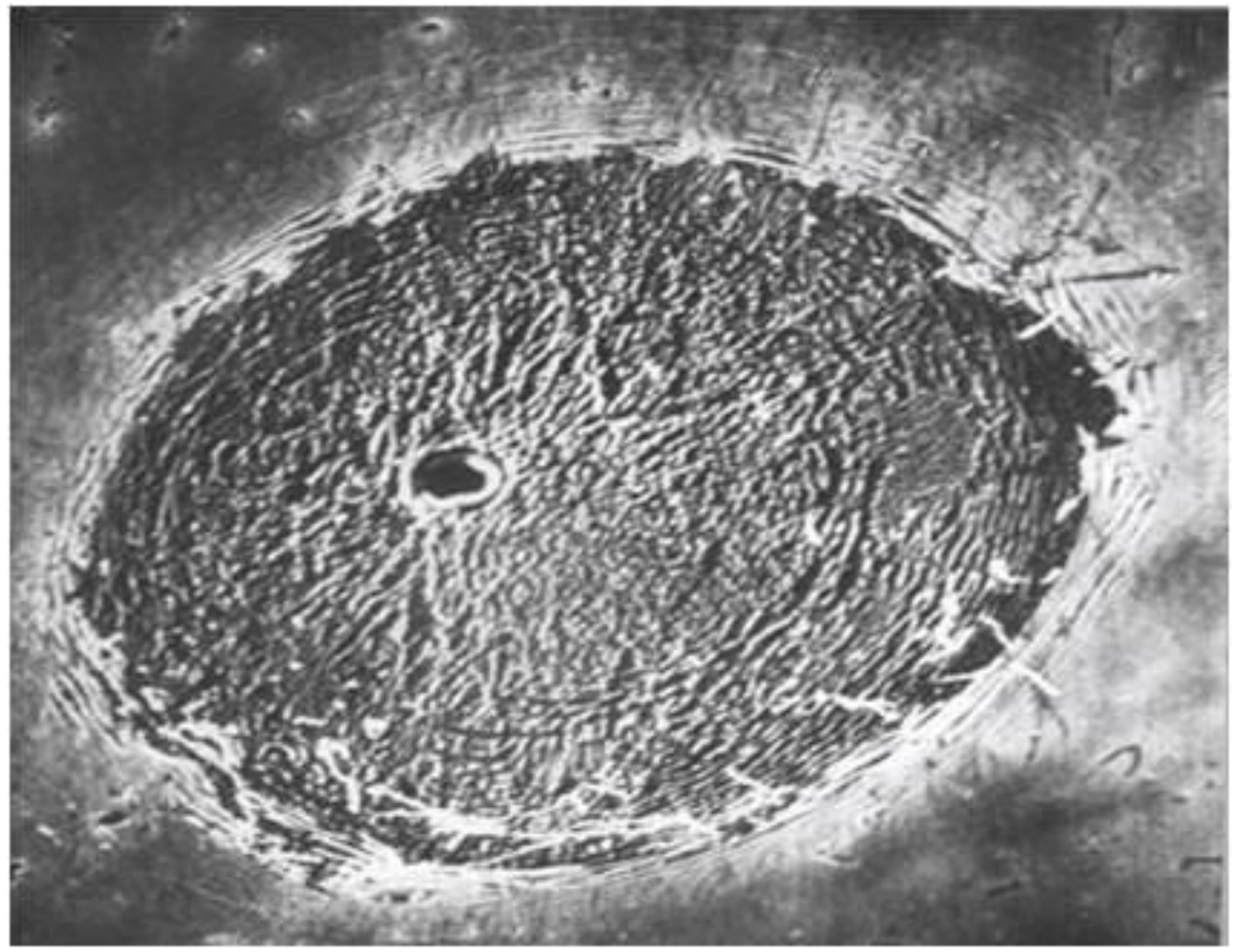
Capacitance and Dissipation Factor Are Stable Over a Wide Temperature Range





Controlled the Self Healing Process by Polymer Dielectric Design



Metallized Electrodes
Electrodes with a thick (heavy) edge are used that allow a much thinner electrode in the active capacitor electrode area to facilitate the self healing process

Polymer Dielectric:
NanoLam capacitor dielectrics are formulated with chemistry that has specific O:C and H:C ratios. This parameter along with the electrode thickness dictates the capacitor In the active capacitor area dictate the self-healing properties

Carbon and aluminum from the breakdown site are removed by conversion to Al_2O_3, CO, CO_2, CH_3, CH_4, and other hydrocarbon gases.

The Dielectric Breakdown Strength Increases as the Dielectric Thickness Decreases

The Breakdown Field is Inversely Pr oportional to the Dielectric Thic kness

$$E_b = \frac{P_c}{J} \propto e^{-kx}$$

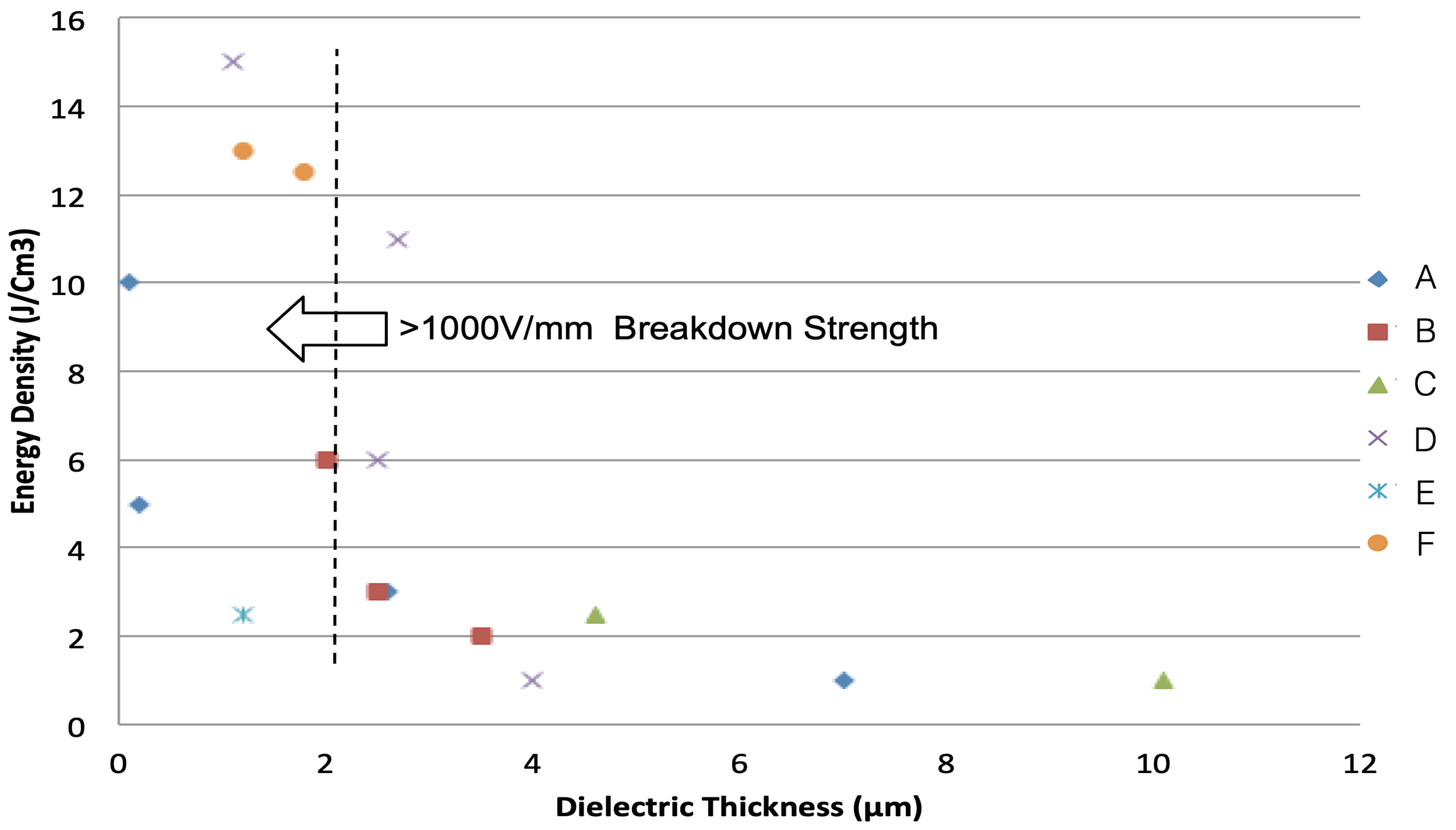
P_c Critical power density at which gaseous combustion products form

J = Current

k = Constant

x = Electrode Distance

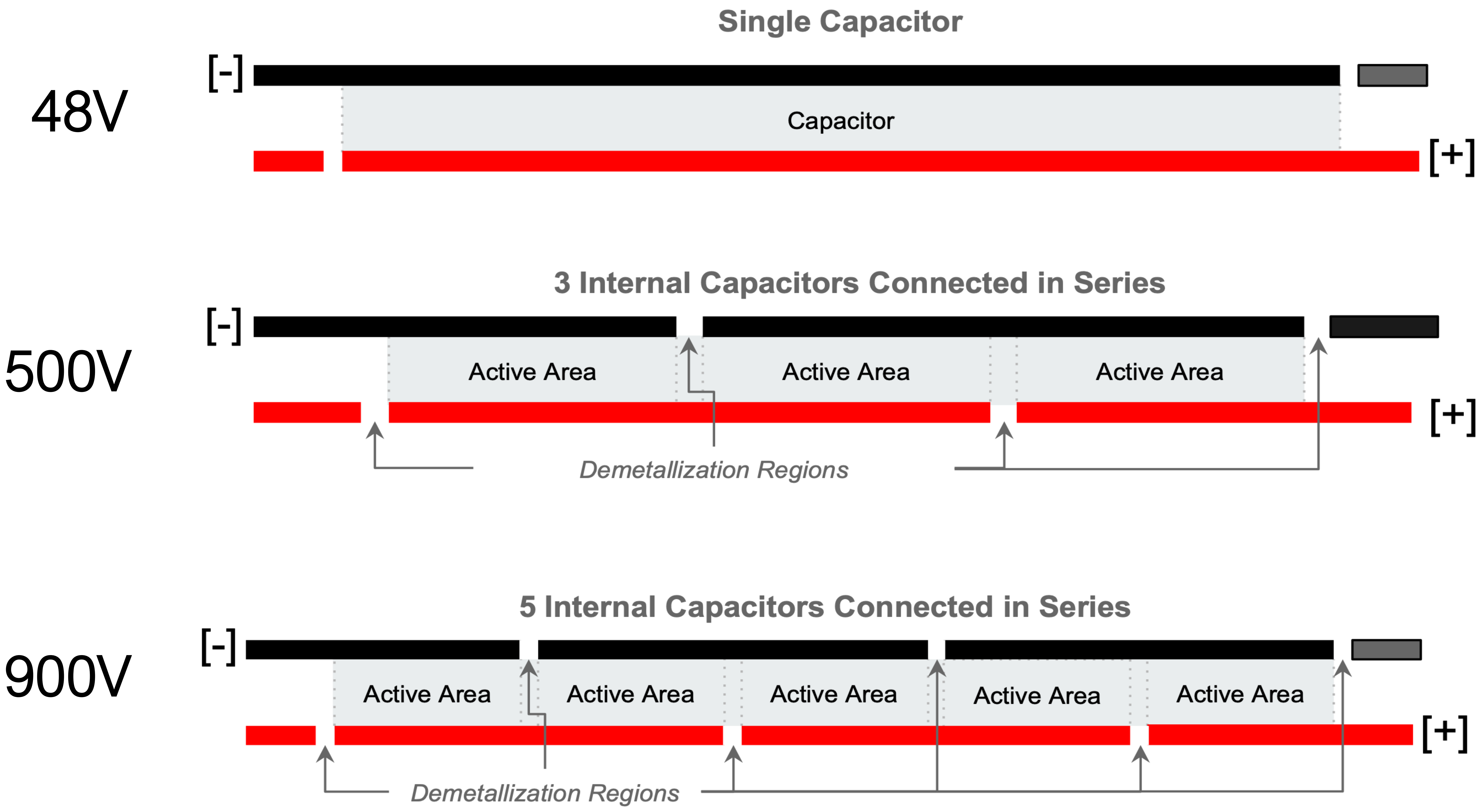
Polymers A to F Have Dielectric Constants k in the range 3>k<9



In order to Take Advantage of the High Breakdown Strength of the Nanothick Dielectric Layers Higher Voltage Capacitors are made with Internal Series Sections

<u>Capacitors are routinely produced with voltages in the range of 48V to 5000V</u>

Common DC-Link capacitor Designs



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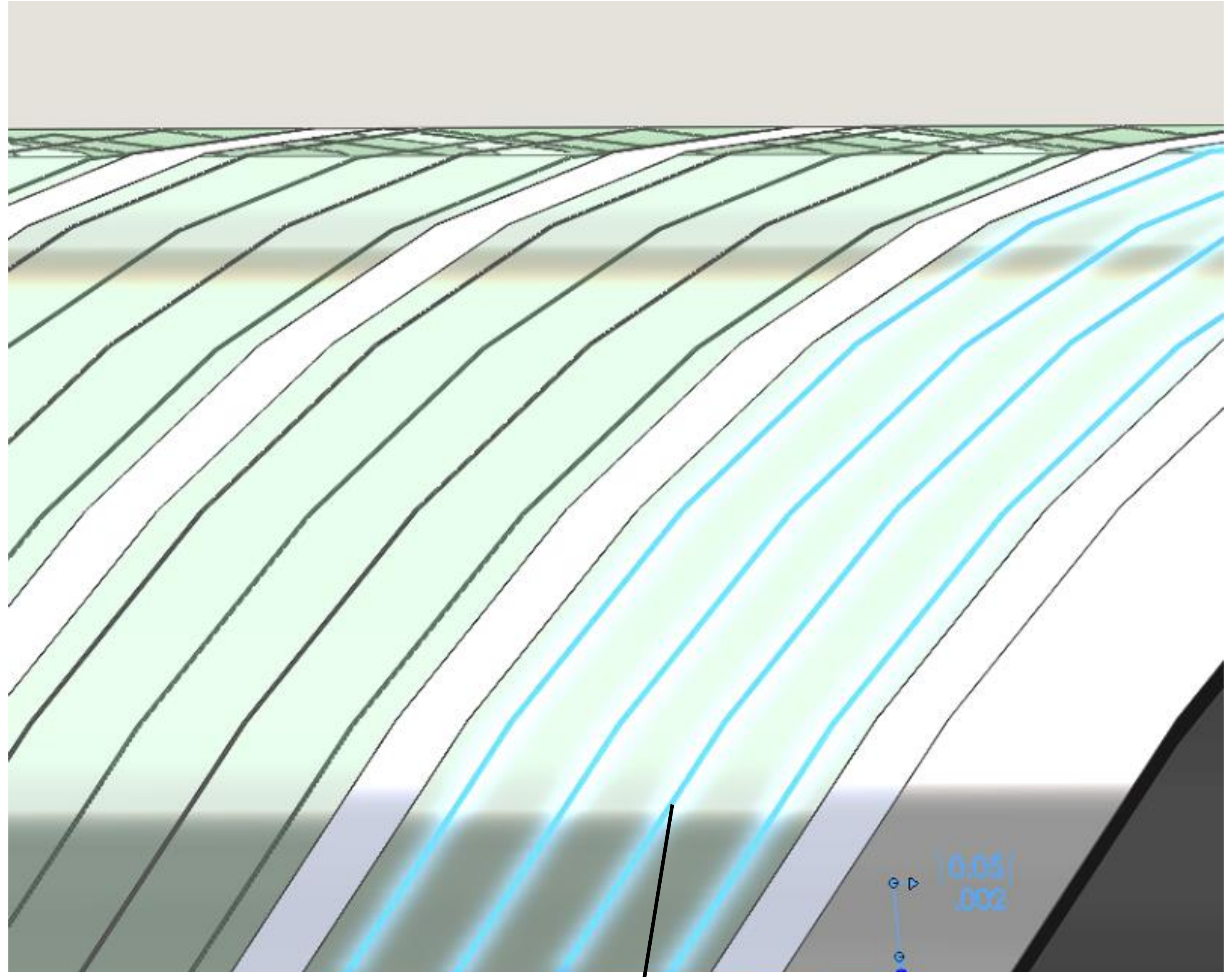
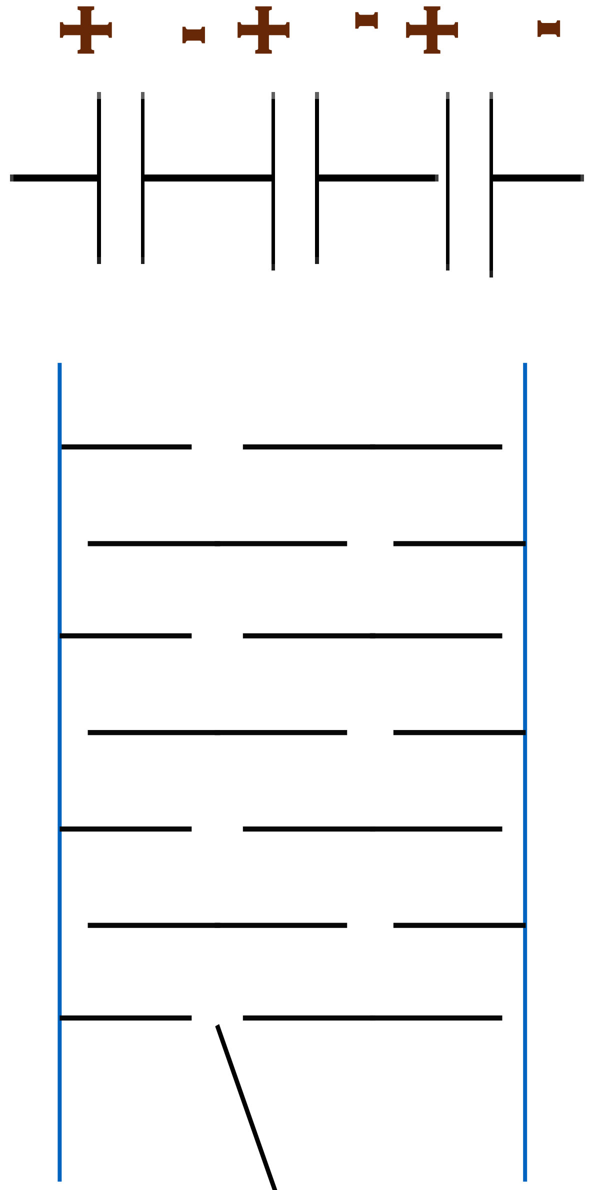
Higher Voltage Capacitors with Multiple Internal Series Sections are Produced In-situ in the Vacuum Chamber on the Process Drum





Oil Generated Demetallization Areas to Form Series Capacitors

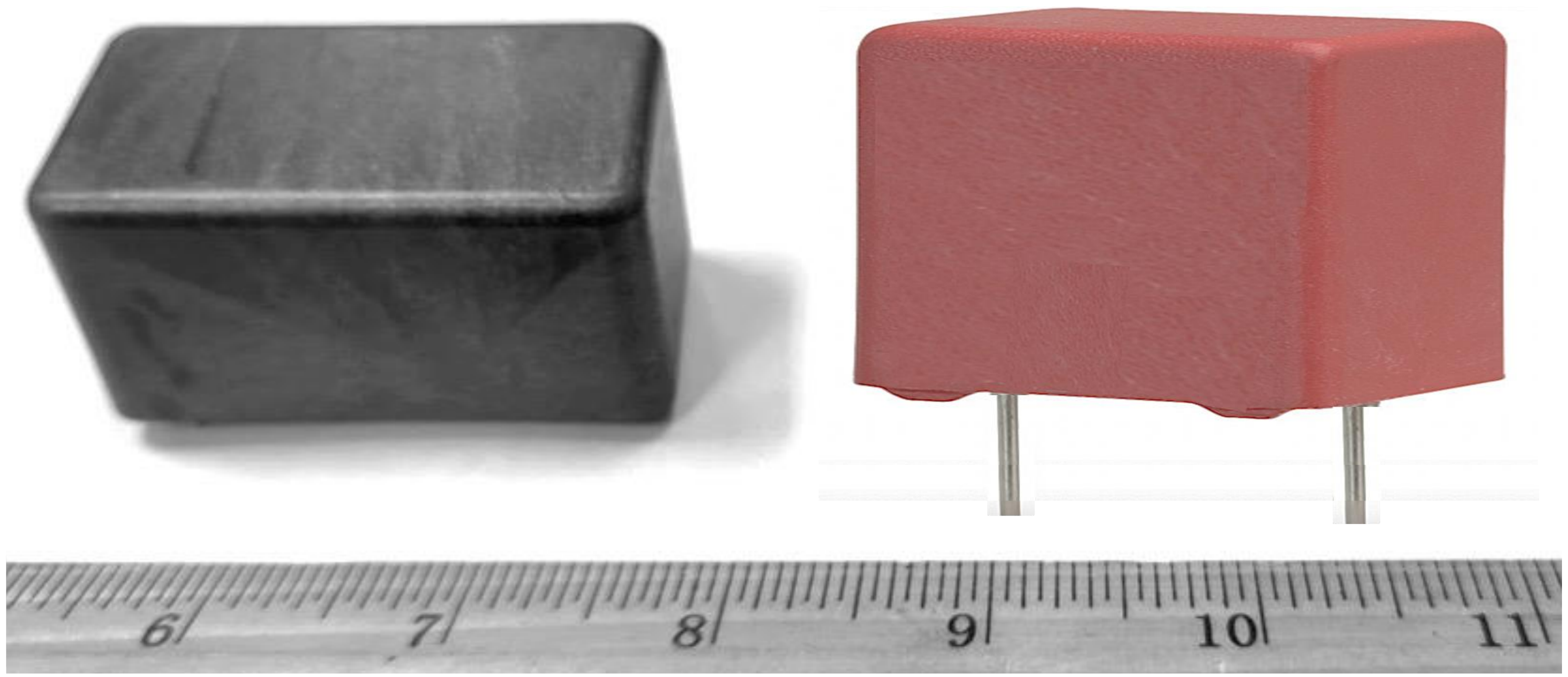
Energy Buffer 4400μF NanoLam Capacitors Produced for a NASA Dynamic Radioisotope Power System (DRPS)

Solid State Polymer
NanoLam™ Capacitor
50V/4400μF,
-55°C to +125°C
Energy Density = 0.1J/cc

W:28mm H:33mm L:61mm

State of the Art
Wound Film Capacitor
50V/680μF,
-55°C to +105°C
Energy Density = 0.006J/cc

W:45mm H:55mm L:57mm



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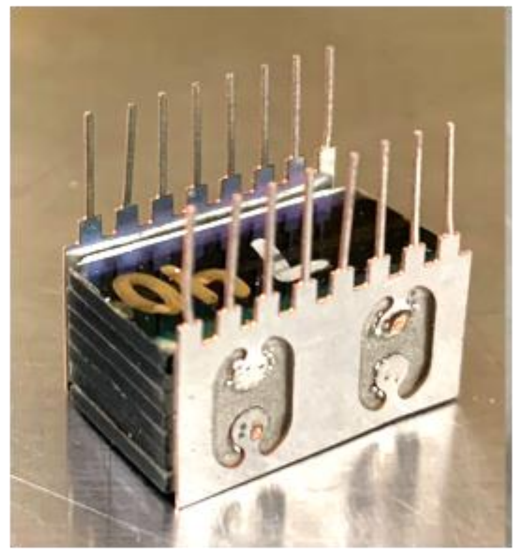
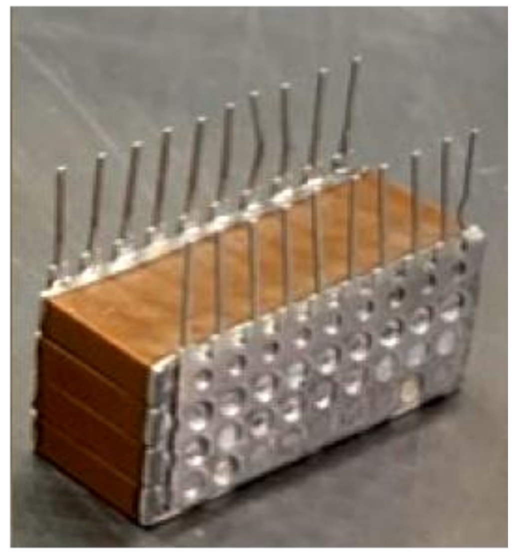
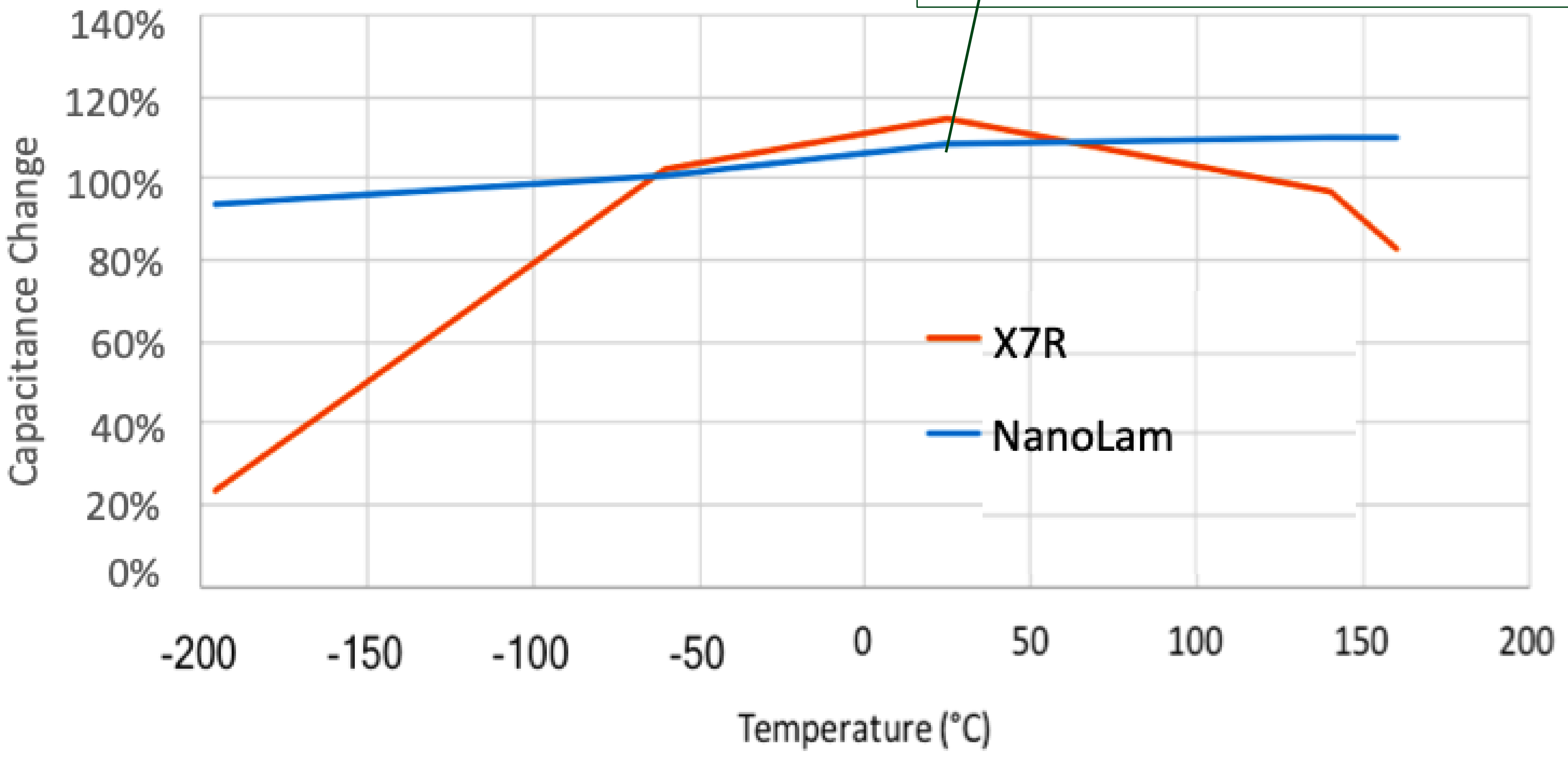
DC-link 500V NanoLam Capacitors Developed for a NASA Ion Thruster PPU to Replace 500V X7R Capacitors that Were Microcracking and Shorting

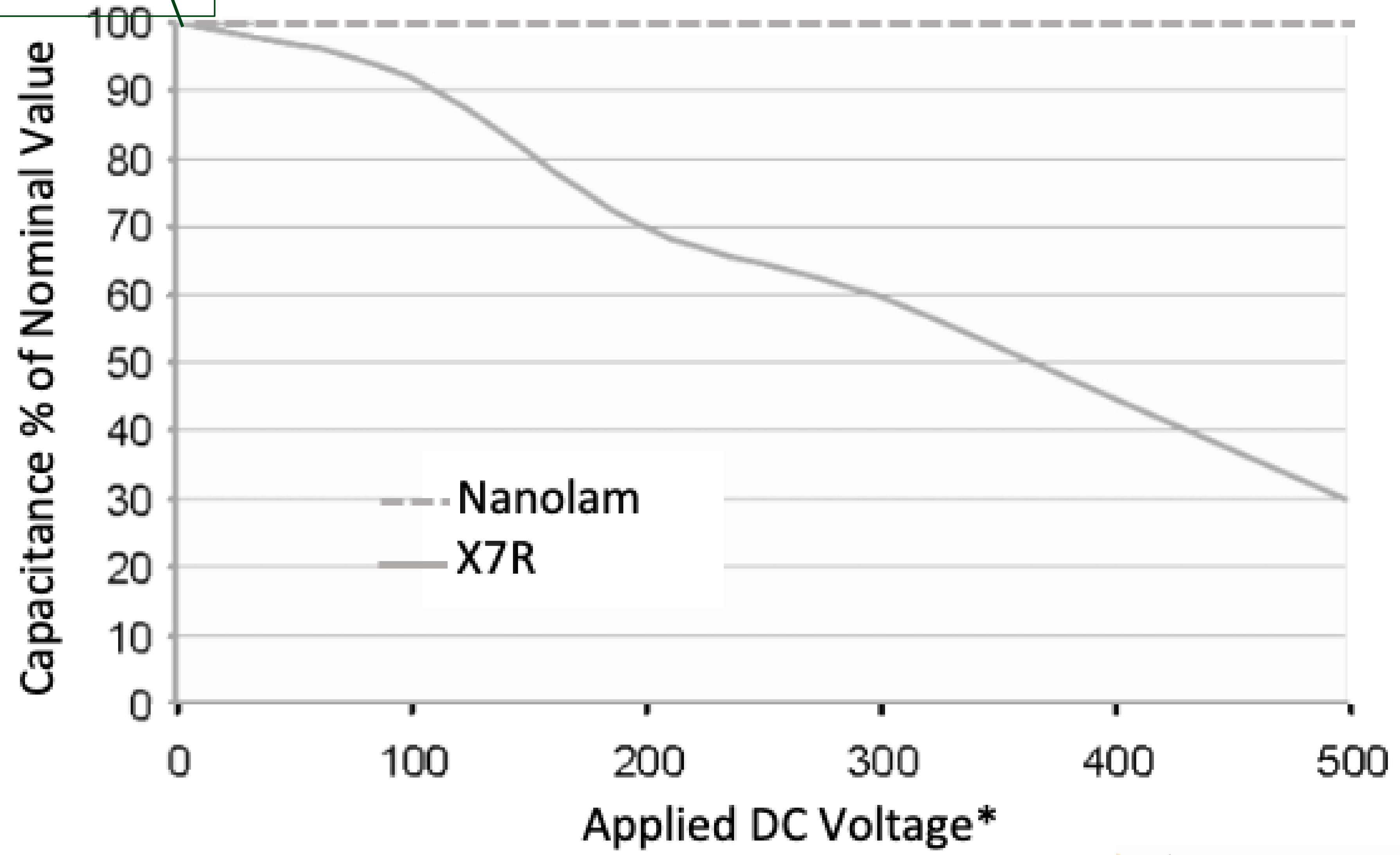
Property	NanoLam	X7R
Capacitance µF	15.2	5.7
Volume cc	2.0	2.86
Weight gr	3.8	20.6
Energy Density J/cc	0.95 (3.8X)	0.25
Specific Energy J/gr	0.50 (16X)	0.03





Temperature and Voltage Used in the Above Comparison



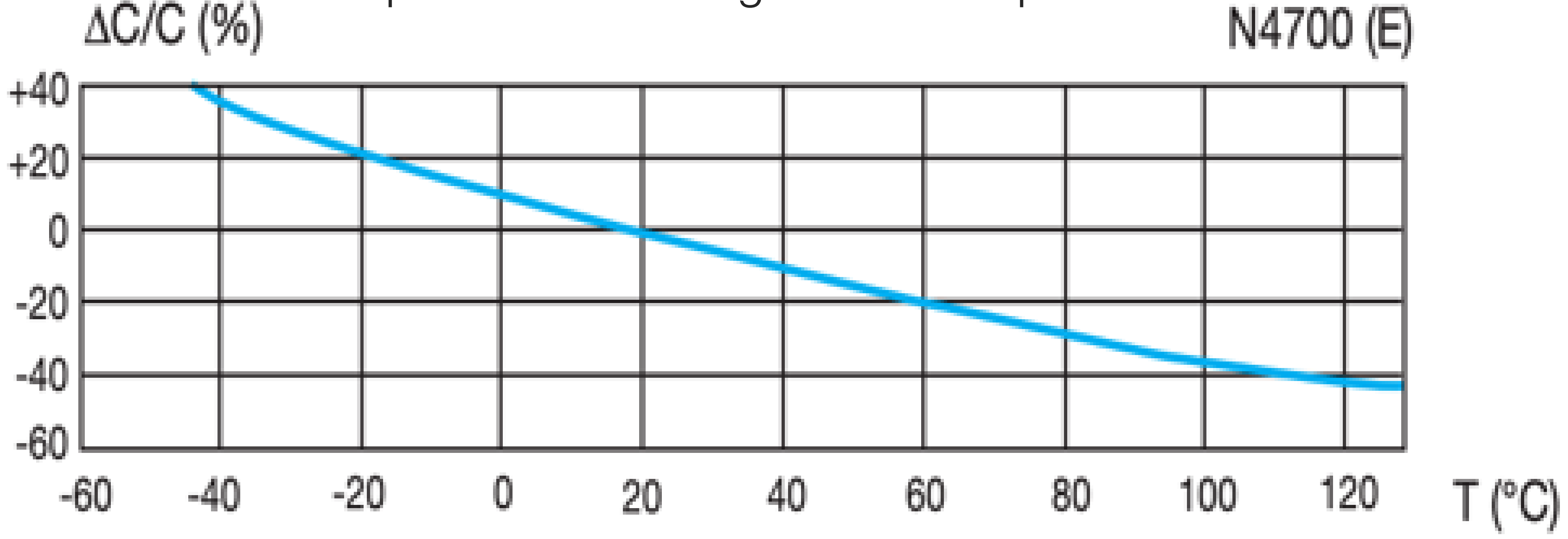


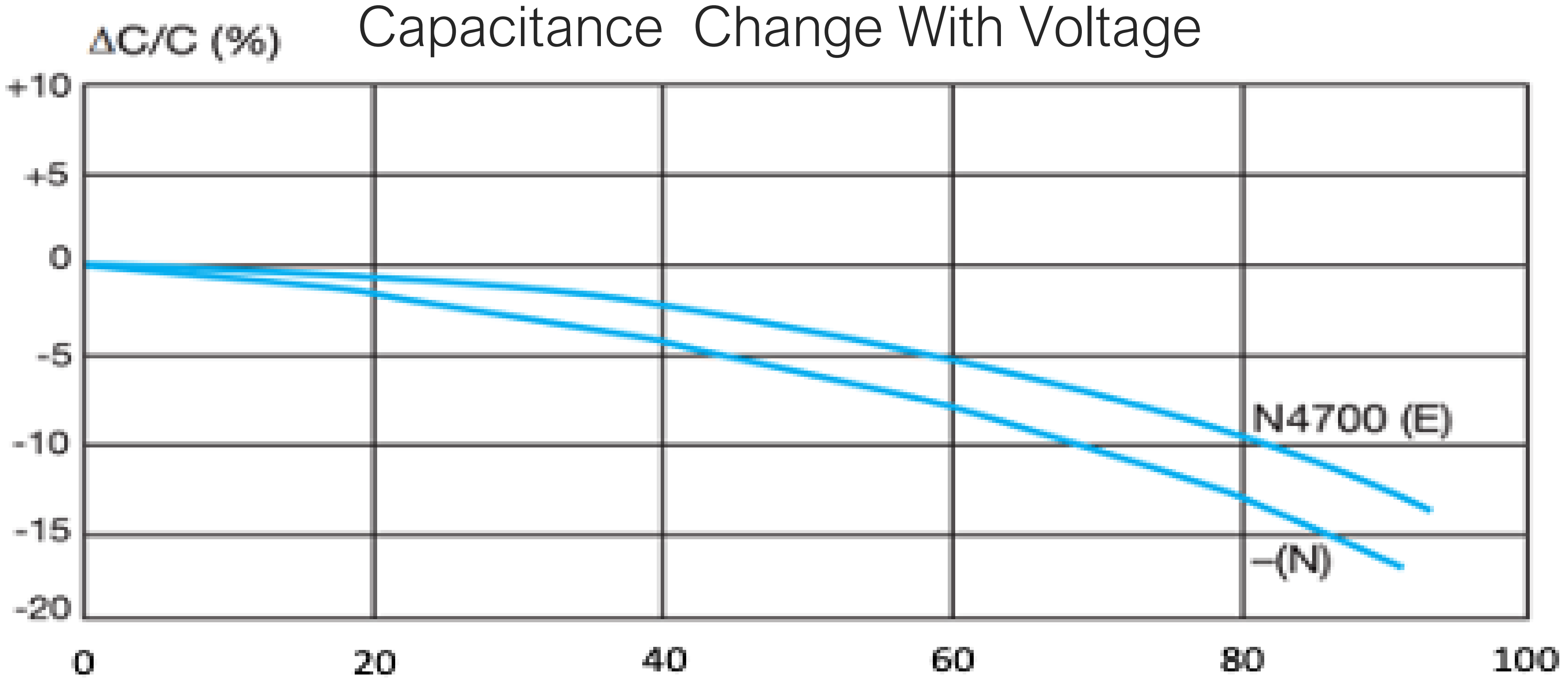
* This property can vary somewhat from OEM to OEM

HV Pulse Power Capacitors

Ceramic Capacitor Banks used for HV Pulse Power Applications

Ceramic Capacitance Change with Temperature and Bias
Operating temperature -30C to +85^{o}C



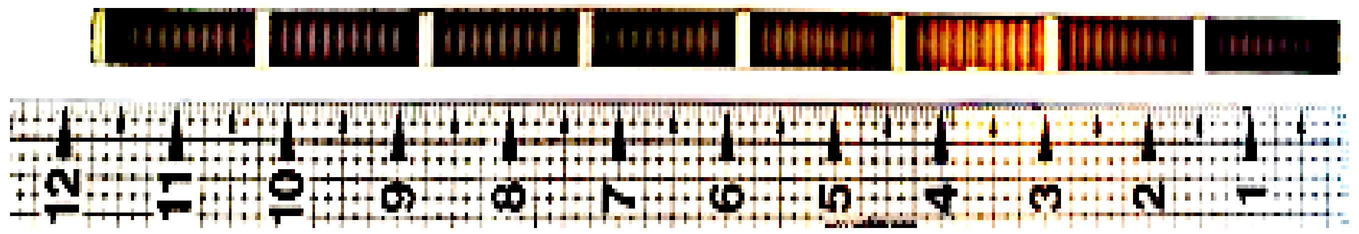


Typical State of the Art Ceramic Capacitor
40KV/C=1.3nF
D=45mm, H =25mm
W-175gr

Energy Density
0.023 J/cc

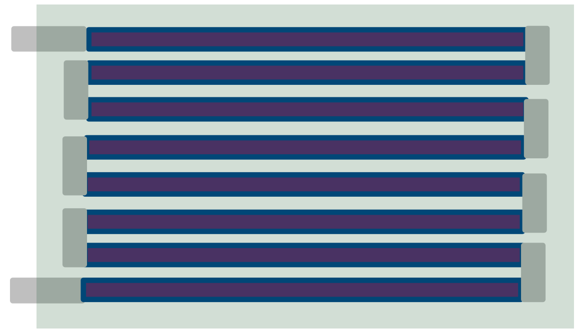
Specific Energy
0.006 J/gr

5KV/40nF
L=37mm x H-1.6mm W=10mm



40KV/5nF
W=10mm, H=1.6mm, L=298mm
Weight: 4gr

40KV



0V

Packaged Design
5KV/40nF capacitor
20gr

Energy Density
0.48 J/cc

Specific Energy
0.20 J/gr

> 20X Energy Density
> 25X Specific Energy
Not Including Capacitance Loss
Due to Temperature and Voltage

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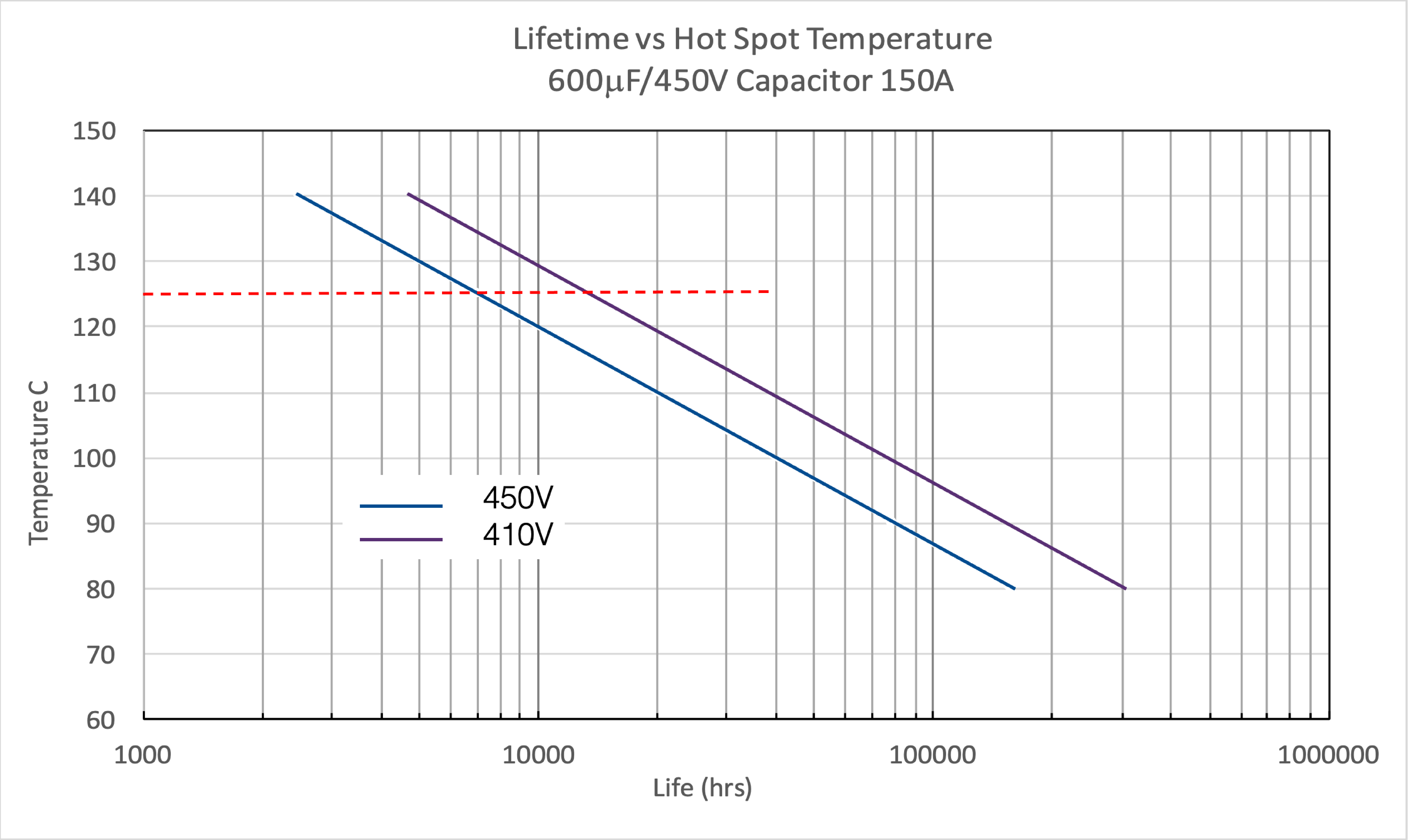
Given That We Control All Material and Process Parameters NanoLam Capacitors Can be Customized for a Variety of Applications

Pulse Capacitor for a Medical Application
140μF/2200
Energy Density: 6.3 J/cc

Example of Life Of High Current 450V DC-link NanoLam Capacitors
End of Life = 5% Capacitance Loss



CONCLUSIONS

When compared to polymer film and Ceramic Multilayer capacitors

- High temperature polymer dielectric
- High Breakdown strength dielectric layers
- Optimized O:C and H:C chemistry to maximize self-healing performance
- High thermal conductivity
- High energy density and Specific Energy
- High RMS ripple current capacity and and excellent dV/dt performance
- Manufactured using a single step process allowing control most key capacitor parameters including:
  - Dielectric thickness
  - Dielectric constant
  - Glass transition temperature
  - Self-healing properties
  - Electrode metallization