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Solid-State Polymer Dielectric Capacitors as an Alternative to Aluminum Electrolytics for 48V–120V Power Electronics

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NanoLam™ Capacitors - Automotive, Medical, Aerospace and other Applications that Require High Energy Density, High Temperature, and Resistance to Radiation Exposure



48V Automotive Applications

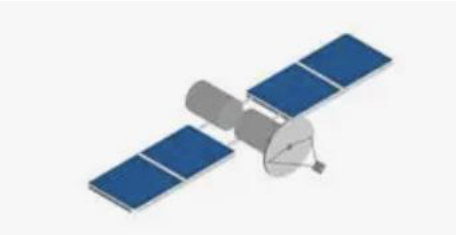


	Mild-hybrids - 48V	Zonal/auxiliary 48V
Applies to	ICE and hybrid vehicles	Every vehicle type
What it powers	Drivetrain, starter motor; e-turbos; e-compressor; pumps: water, oil, power steering; active suspension; other	The entire vehicle's low-voltage backbone — replacing 12V outright
Status	Mature, ~24% Growth - as long as ICE/hybrid architectures persist	Early but accelerating
Driver	Emissions /fuel economy and regulations*	Increasing electrical load requires heavy duty 12V harnesses

*Regulations: Automotive regulations require costly shielded, galvanically-isolated high-voltage cabling above roughly 60V



Aerospace and Space Applications



System	Voltage
Commercial and Military Aircraft	270V as primary power, with 28V among other supporting buses.
Satellites - Primary DC Bus (legacy and still standard)	28V - As satellite power demand has grown, 50V, 70V, and increasingly 120V buses have become common for higher-power platforms.
Lunar Surface Stations and Mobility	At 270V/50V

Current Default Technologies for Use in 48V Power Electronics

Hybrid Polymer Aluminum Electrolytic capacitors are the default choice for DC-link service,

Where they win

- High energy-density advantage — often several times higher than film or multilayer-ceramic capacitors
- Lower cost per unit of stored energy.

Limitations

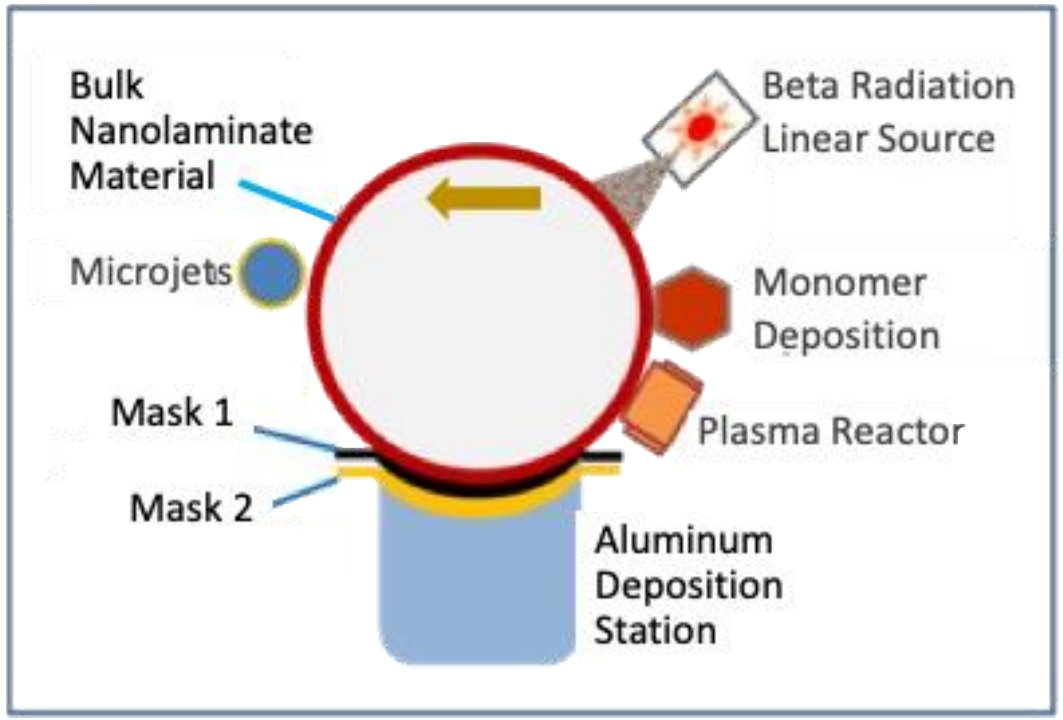
- High ESR, requiring multiple parts for high power applications
- The technology tops out and about 100V
- Poor stability when long life is required

Above 100V Wet Aluminum Electrolytics Are Used

- Energy Density and Cost leader up to about 400V for power electronics
- Parametric performance lower than that of hybrid electrolytics
- At > 150V polymer films are preferred for long life and higher reliability applications

NanoLam™ Capacitors are Produced Using a One Step Manufacturing Process

1000s of Polymer Dielectric and Aluminum Electrode Layers are Deposited on a Process Drum that is Rotating at High Speed in a Vacuum Environment





Only Two Materials Used



Aluminum Wire



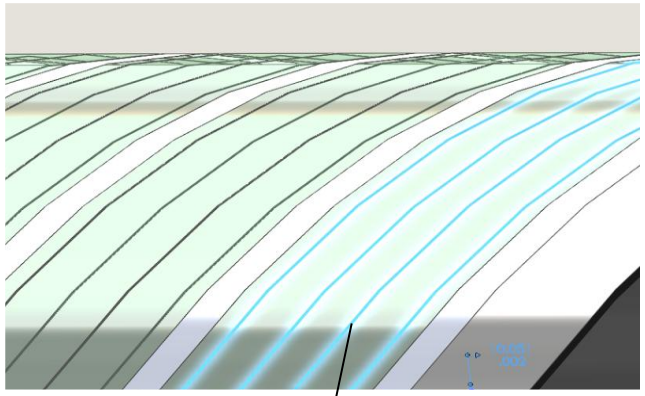
Monomer Liquid

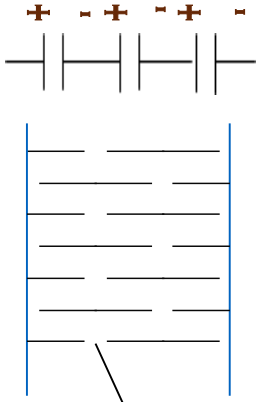
Several Square Meters of a Nanolaminate Composite is Produced that is Processed into Capacitor Elements

All NanoLam™ Capacitors are Produced with Submicron Dielectric Layers

Internal Series Sections are Used to Produce Capacitors Up to 10,000VDC





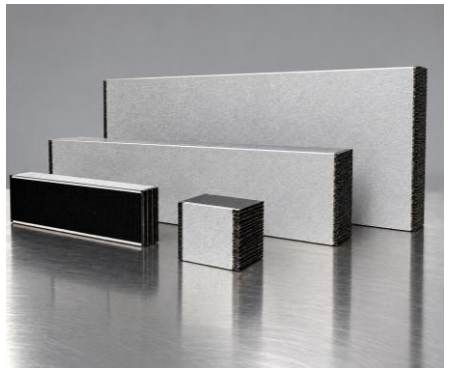


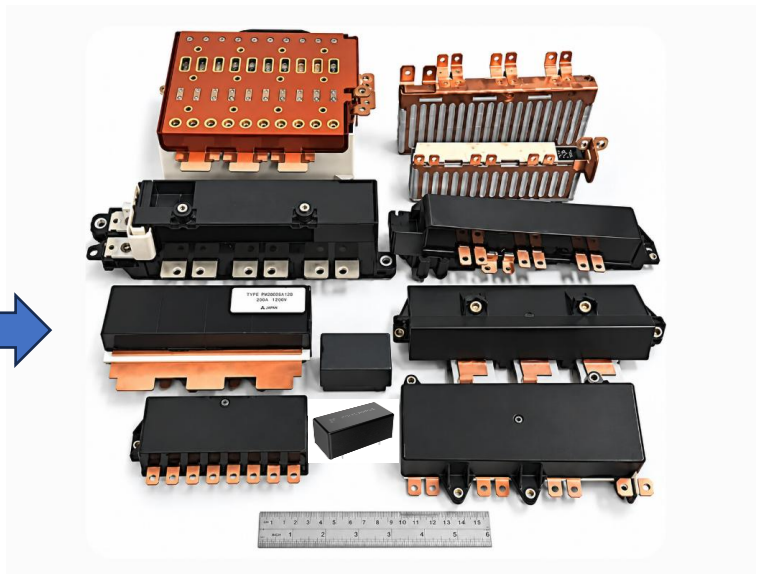
Oil Generated Demetallization Areas to Form Series Capacitors

Capacitor Element XY Dimensions
10s of mm to 10s of cm

Element Thickness 0.5 - 2mm
4000-6000 Layers



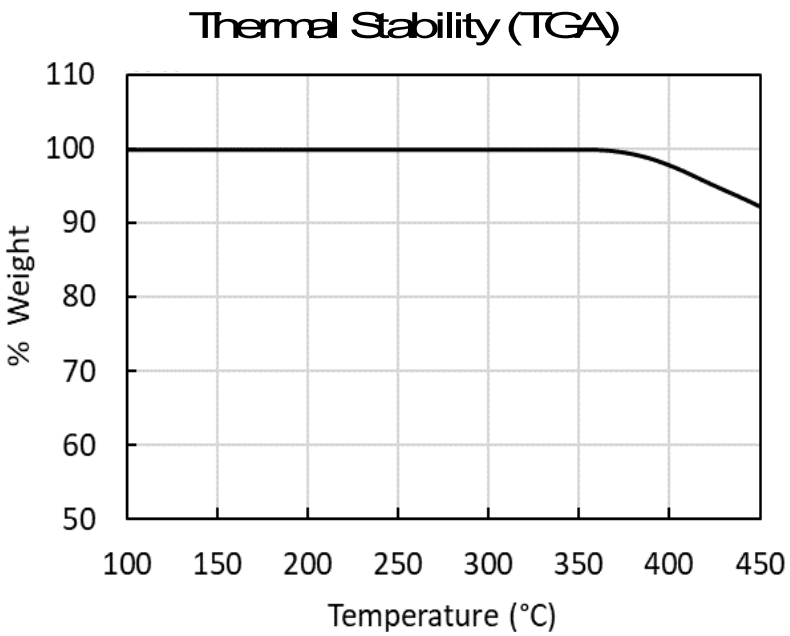




What Makes The NanoLam™ Polymer Dielectric Unique

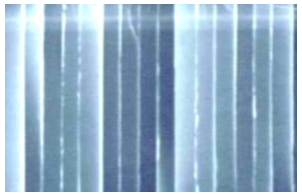
- Dielectric Thickness as Low as 100nm
- Highly Cross-linked High Temperature Acrylate Dielectric
- Stable Capacitance in the Temperature Range: -200°C to + 200°C
- Glass Transition Temperature: 200°C
- Dielectric constant: 3 to 4+
- Excellent Self-healing Properties
- High Resistance to Radiation Exposure

Highly Cross-linked
High Temperature Polymer

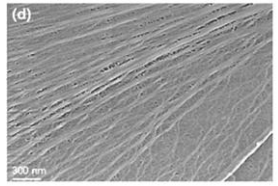


What Makes The NanoLam™ Polymer Dielectric Unique

Highly Uniform Polymer Layers at a Nanoscale Level

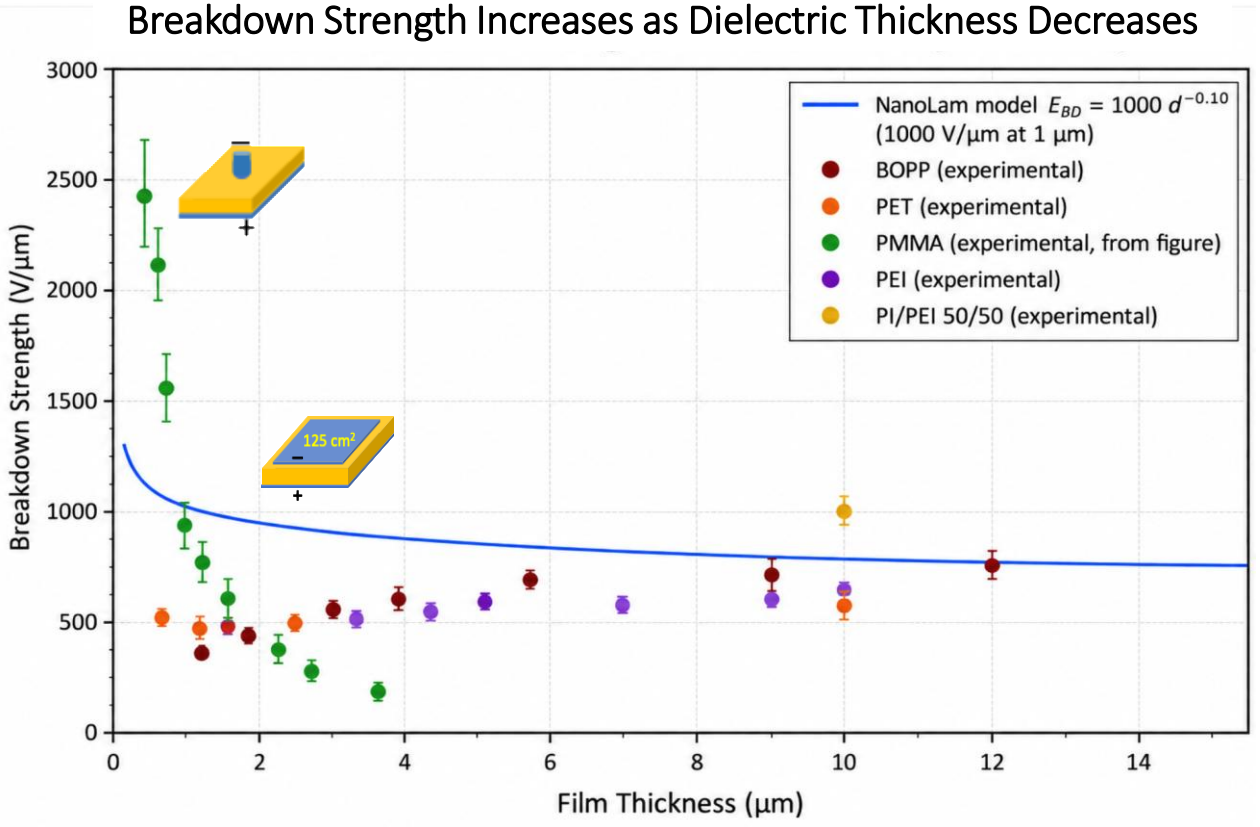


0.65µm NanoLam

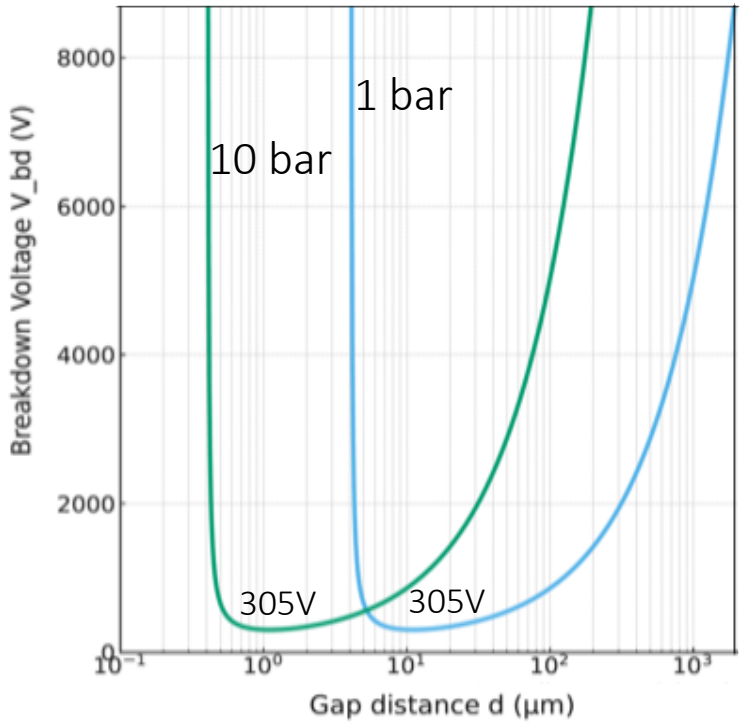


1.3µm PP Film

Breakdown Strength Increases as Dielectric Thickness Decreases



Paschen's Law
Breakdown of Air In a Uniform Field



Breakdown Strength - Inverse Power Law

$$E_b = E_o\left(\frac{1\ \mu m}{d}\right)^n$$

E_b = Breakdown strength (V/µm)
E_o= Breakdown at 1µm
d = Dielectric thickness
n = Exponent - Typically 0.1-0.3 for polymers)

800µF0/60V NanoLam™ Capacitor Construction



(a) Capacitor elements 60µF : X=10mm, Y=55mm Z: <1mm
(b) Capacitor Block : 800µF
(c) Packaged in a High Temperature Case

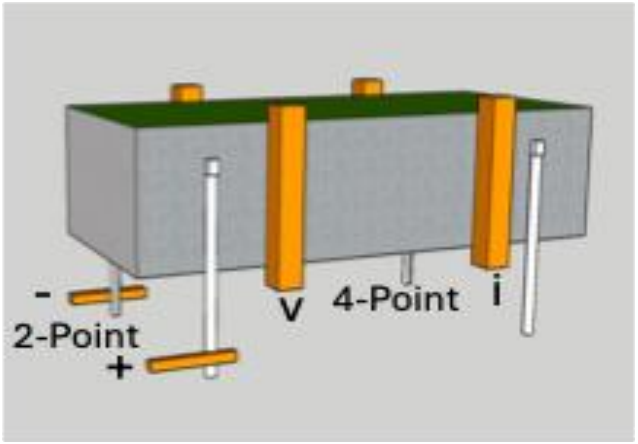
60V/800µF NanoLam Capacitor Elements, Blocks and Packaged Parts Dielectric Parameters



a) 4-Point Capacitor Element Measurements

Cap 1kHz (µF)	DF 1kHz	ESR 10kHz (mohm)	ESR 20kHz (mohm)
59.375	0.007	8.0	7.0
59.944	0.0071	8.2	7.2
60.362	0.0072	8.2	7.2
60.817	0.0071	8.2	7.2
60.952	0.0072	8.2	7.2
59.486	0.0071	8.2	7.3
60.093	0.0071	8.3	7.3

b) Capacitor Block Unpackaged





c) 4-Point Capacitor Block Measurements (13 capacitor elements per block)

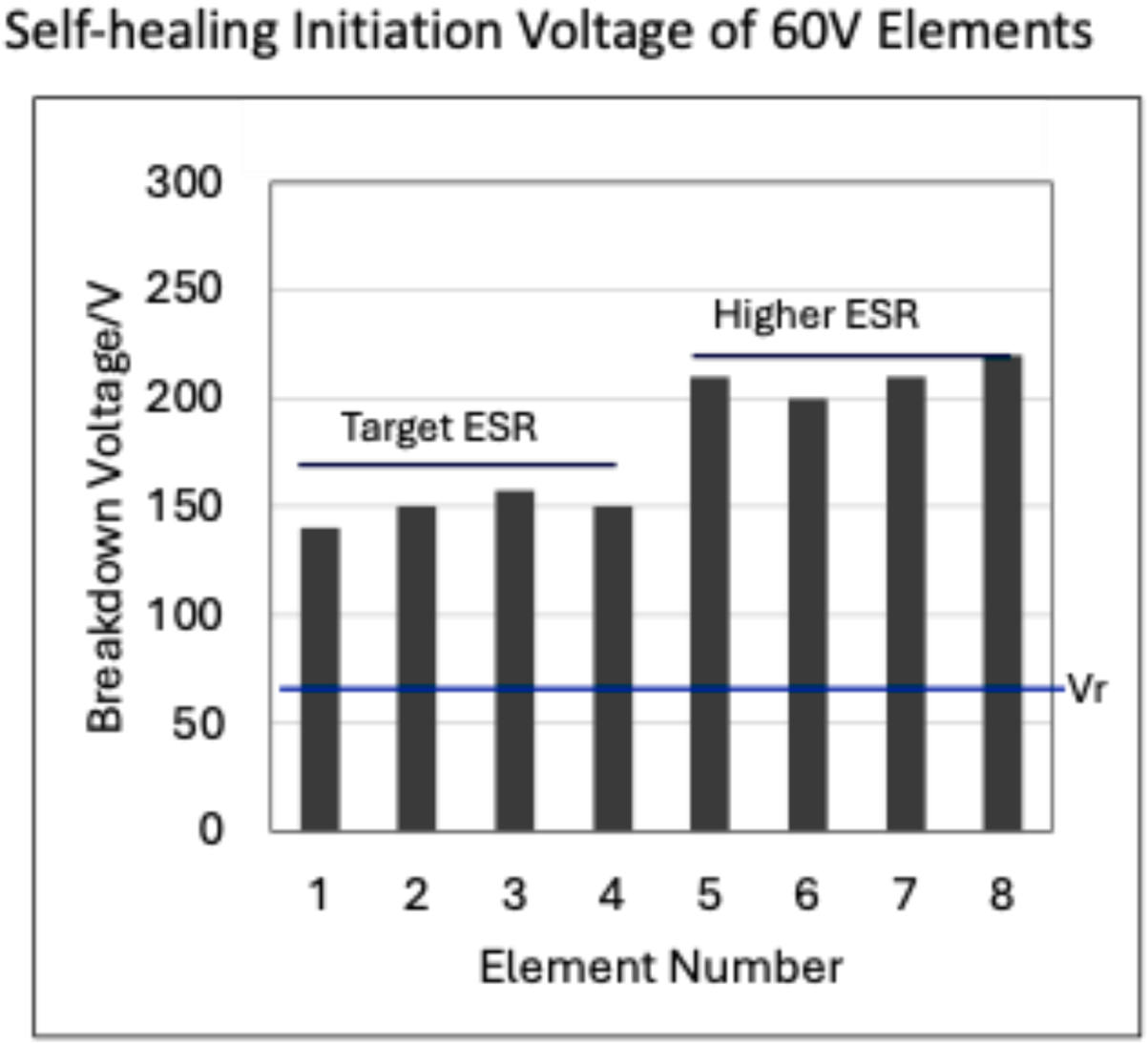
CAP 1kHz (µF)	DF 1kHz	ESR 10kHz (mohm)	ESR 20kHz (mohm)
799.739	0.0077	0.6	0.6
814.185	0.0081	0.7	0.7
809.384	0.0088	0.9	0.8
799.845	0.0076	0.6	0.5
809.56	0.0078	0.7	0.6
815.619	0.0082	0.7	0.7
806.51	0.0089	0.9	0.8

d) 2-Point DF and ESR of Packaged Parts

DF 1kHz	ESR 10kHz (mohm)	ESR 20kHz (mohm)
0.0114	1.5	1.4
0.0125	1.6	1.6
0.0128	1.7	1.6
0.0114	1.4	1.4
0.0117	1.5	1.5
0.0126	1.6	1.6
0.0128	1.7	1.7



60V / 800µF Nanolam™ Capacitor Elements "Breakdown Voltage"



60V / 800µF Nanolam™ Capacitor
Target Ripple Current Capacity: 40 Arms at 125°C
<10% loss in Capacitance at 10,000-Hour

How the test is run

1. A thermocouple is inserted through a hole drilled at the center of the packaged part to capture hot-spot temperature; a second thermocouple monitors the top surface.

2. The capacitor is soldered to a PCB with high-current terminals bolted directly to the PCB.

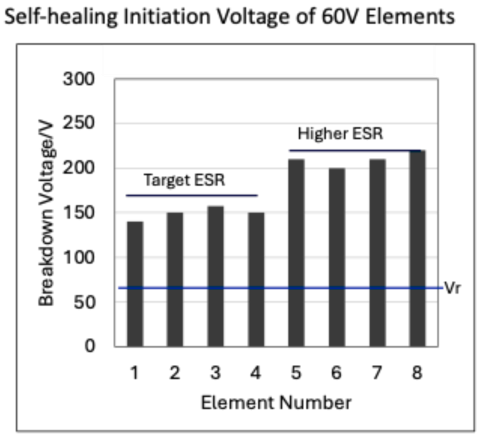
3. The assembly sits in an oven with minimal air movement.



800µF/60V NanoLam™ Capacitor Ripple Current Capacity Test

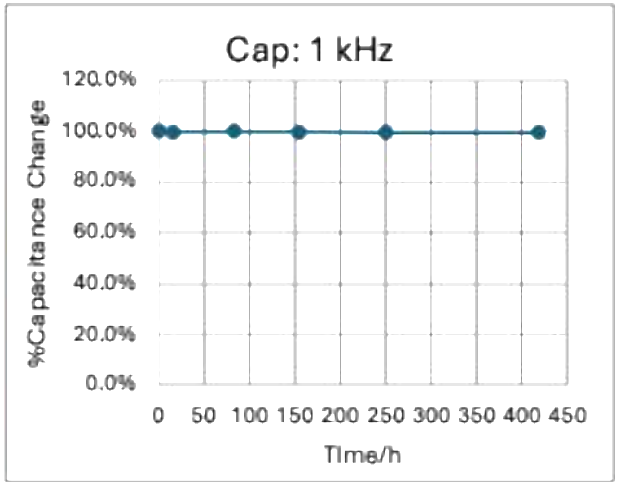
Ripple Current Heating at Different Ambient Temperatures

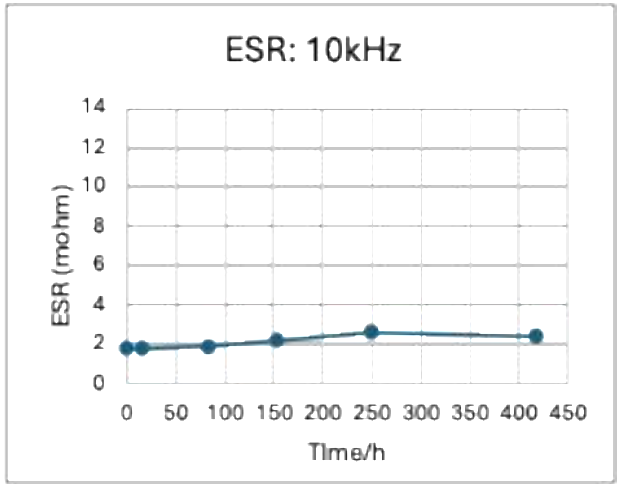
Ambient Temperature °C	Test Frequency kHz	Ripple Current Arms	Surface Temperature °C	Hot-Spot Temperature °C
85	10	60	116	135
125	10	40	137	145



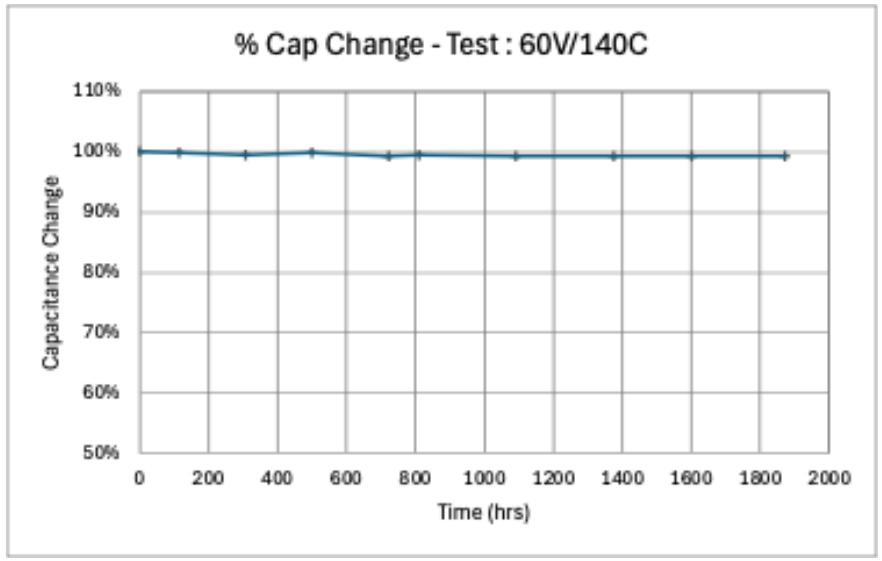
800µF/60V Capacitor Tested at 140°C Ambient After Ripple Current Test

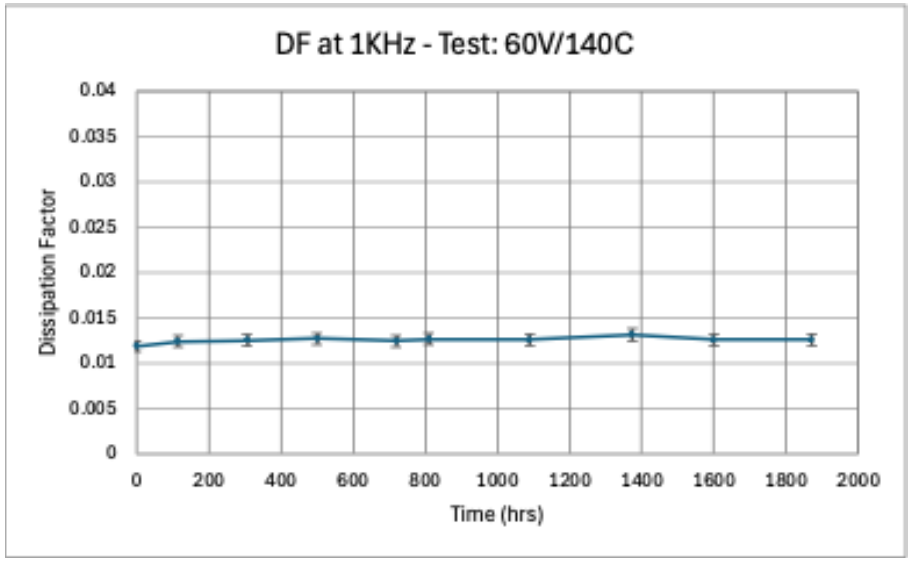


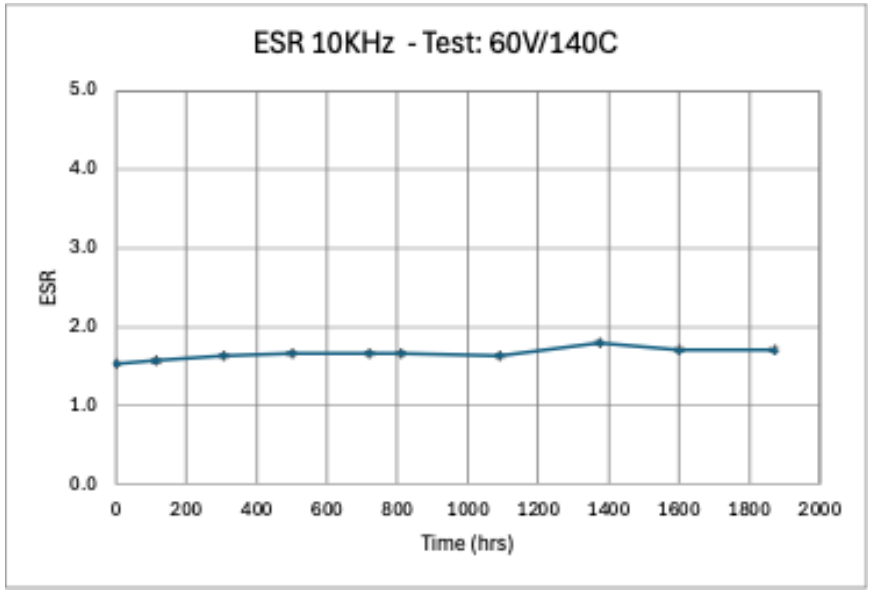


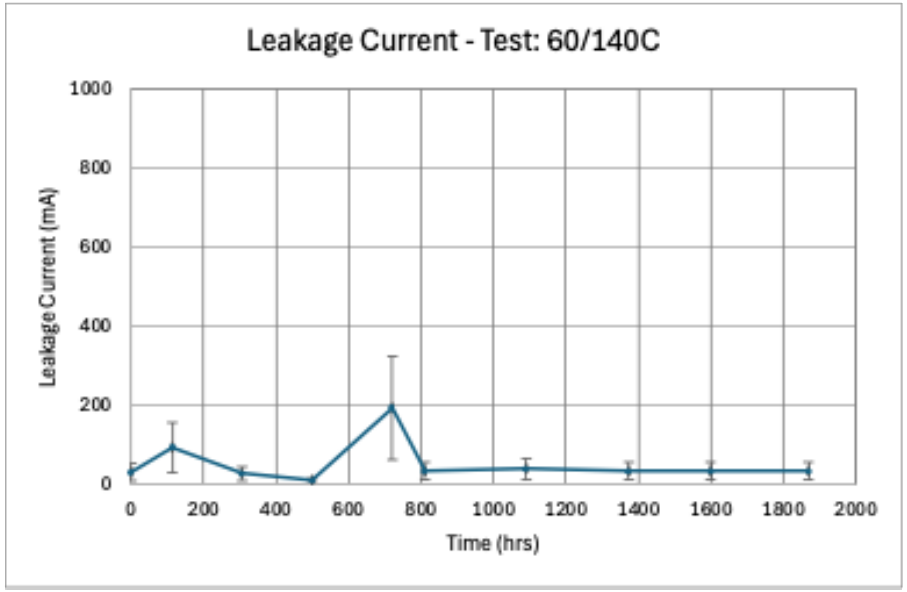


800µF/60V NanoLam™ Capacitor Life Test at 60V/140°C







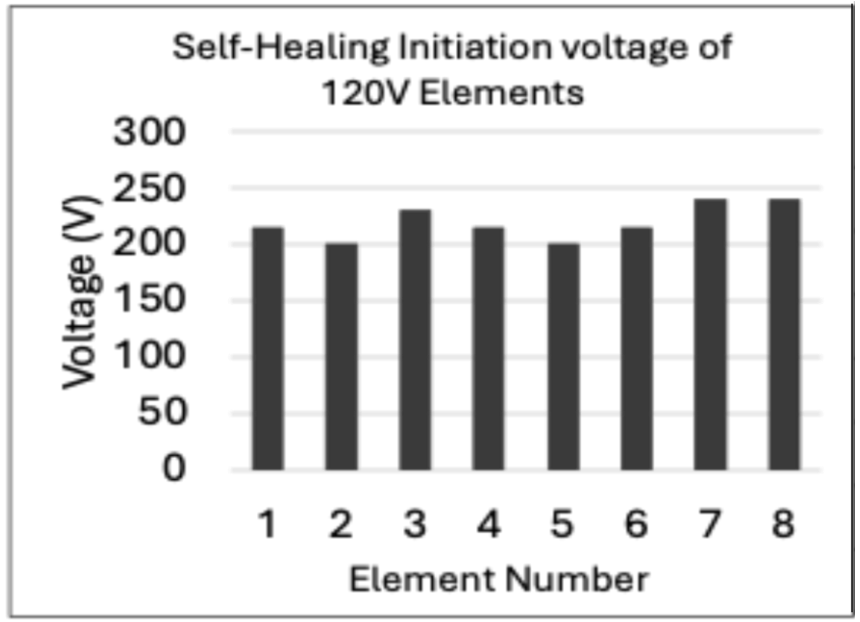


400µF/120V NanolamTM Capacitor Elements "Breakdown Voltage"

400µF/120V
Same Size as the
800µF/60V Capacitor



Cap 1kHz (µF)	DF 1kHz	ESR 10kHz (mohm)	ESR 100kHz (mohm)	Leakage Current (µA)
41.016	0.0062	8.2	5.1	4.1
38.124	0.0063	9	5.7	2.2
39.82	0.0063	9	5.9	3.5
39.911	0.0064	9.2	6	3.8
39.135	0.0063	9.3	6.2	3
39.702	0.0065	9.5	6.1	1.9
39.187	0.0069	11	7.8	3.7



400µF/120V Nanolam™ Capacitors - Basic Parameters



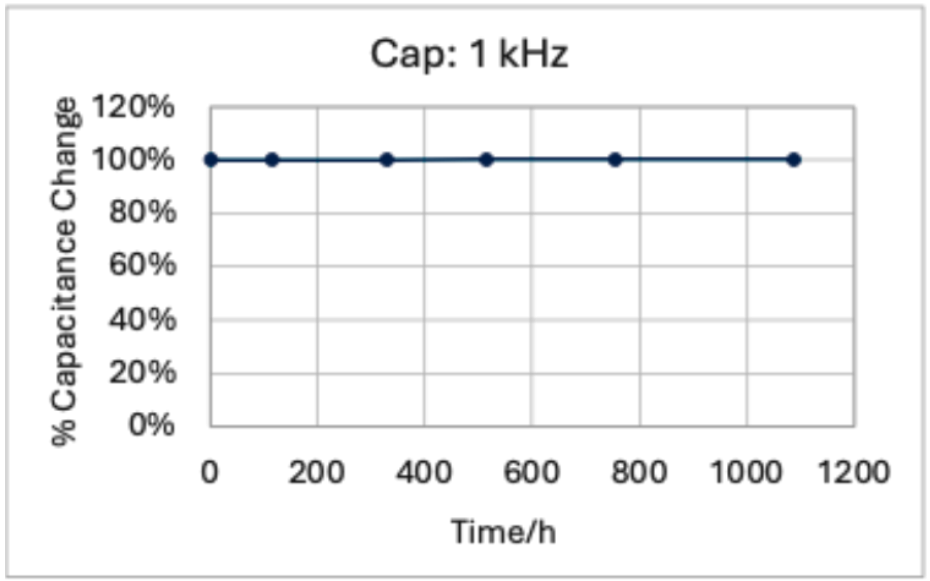
Block #	Cap 120Hz (uF)	Cap 1kHz (uF)	DF 1kHz	ESR 1kHz (mOhm)	ESR 10kHz (mOhm)	ESR 20kHz (mOhm)	ESR 100kHz (mOhm)
1	404.6	402.5	0.01	3.3	1.7	1.7	2.9
2	402.7	400.7	0.01	3.4	1.8	1.8	3.0
3	401.4	399.3	0.01	4.3	2.6	2.4	3.1
4	407.7	405.7	0.01	3.5	1.9	1.9	3.2
5	405.2	403.0	0.01	5.0	3.1	2.6	3.3
6	404.7	402.5	0.01	4.6	2.6	2.3	3.3
7	407.9	405.7	0.01	3.6	1.9	1.9	3.3
8	405.9	403.8	0.01	3.6	1.9	1.8	3.1
9	405.9	403.7	0.01	3.5	1.9	1.8	3.1
AVERAGE	**405.0**	**402.9**	**0.01**	**3.9**	**2.2**	**2.1**	**3.2**

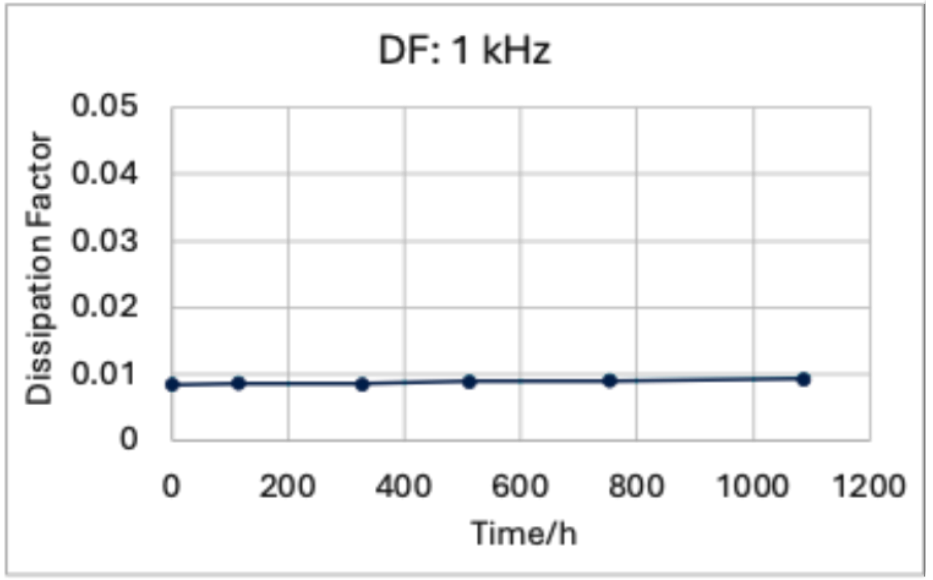
400µF/120V NanoLam™ Capacitor Ripple Current Capacity

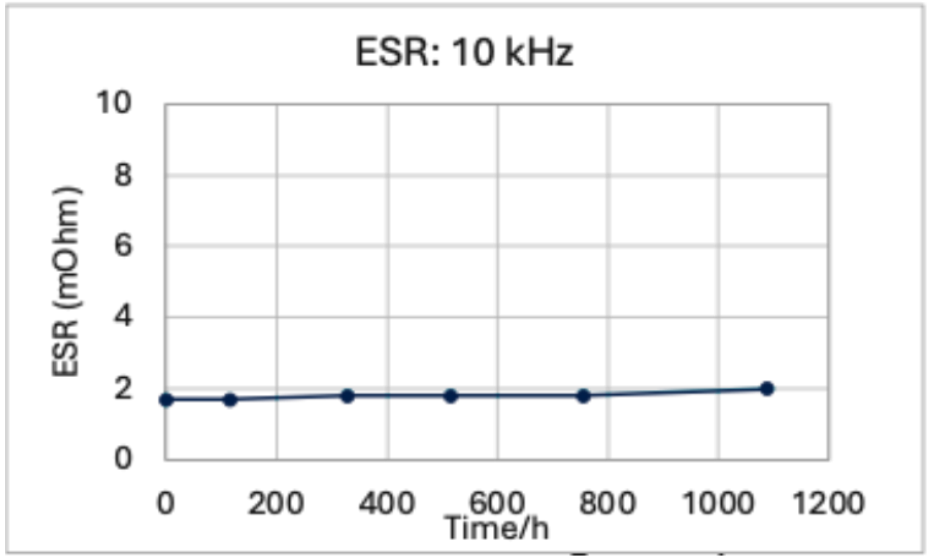
Ambient Temperature °C	Test Frequency kHz	Ripple Current Arms	Surface Temperature °C	Hot-Spot Temperature °C
85	20	40	107	116
105	20	40	128	136
125	20	30	137	142
140	20	20	145	147

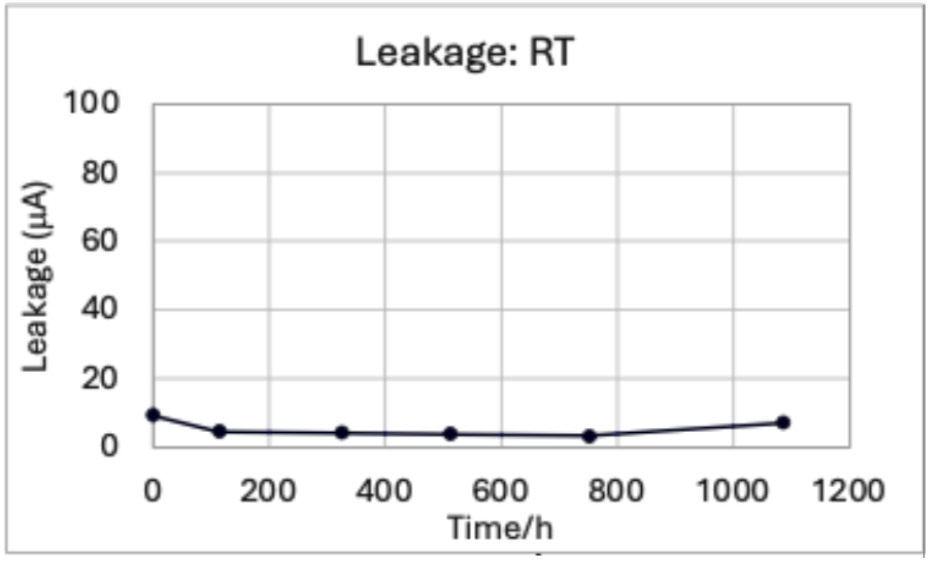


120V/400µF NanoLam™ Capacitor Life Test at 120V/140°C









Comparison with State-of-the-Art Aluminum Electrolytic capacitors

Technology	C / V rating	ESR	Ripple current 10KHz – 20Kz	Leakage	Capacitance Life at 125°C
NanoLam (this work)	800 µF / 60V	< 1 mΩ at 10KHz	40 Arms @125°C	< 50 µA	10,000 hr, <10% loss
Panasonic ZL-hybrid, 4 x 220µF capacitors	880 µF / 63V	3 mΩ @100kHz	15Arms -20 Arms @125°C	<550 µA	4,000 hr, <30% loss, ESR≤200%
NanoLam (this work)	400 µF / 120V	2 mΩ at 10KHz	30 Arms @125°C	< 50 µA	10,000 hr, <10% loss
Panasonic SVX (solid Al)	39 µF / 100V	30 mΩ @100kHz	2.1Arms	< 195 µA	1,000 hr @125°C, 20% loss
Nichicon PVC (poly-electrolytic)	15 µF / 125V	48 mΩ @100kHz	2 A @100kHz	<375 µA	3000 hr, at 105°C 20% loss
TDK B43693 (wet electrolytic)	650 µF / 125V	79 mΩ	7.5 A @125°C	—	2,500 hr, <30% loss, ESR ≤3×

Other Parametric Advantages:
10X lower Dissipation Factor which is important when switching at lower than 100KHz frequencies
Prismatic construction – Lower Inductance

Summary

The initial experimental results demonstrate that NanoLam™ capacitors can play a significant role in 48–120 V Power Electronic applications

NanoLam™ Capacitors Combine:

- Low dissipation factor - greater performance at lower frequency applications
- Lower Inductance – prismatic structure
- Low leakage current
- High ripple current capacity
- Overvoltage capability > 2Vr
- High parametric stability for longer life applications
- High resistance to radiation exposure

Acknowledgements

The authors gratefully acknowledge NASA - JPL for support in the capacitor development presented in this work.