EESTOR CORPORATION
ENERGY EVERYWHERE

EEStor Poised to Disrupt the Multi-Billion Dollar Aluminum Electrolytic Capacitor Market

Company Develops Longer Lasting, More Cost-Effective Solutions

Ready to Disrupt the Multi-Billion Dollar Aluminum Electrolytic Capacitor Market

EEStor Provides Longer Lasting, More Cost-Effective Solutions

EEStor Corporation (TSXV:ESU) has disclosed the development of a hybrid capacitor dielectric material with significantly higher permittivity than traditional capacitor materials. As a capacitor, the material would compete effectively against the existing $4.6 billion (USD) global aluminum electrolytic capacitor market[1], enabling licensees of EEStor to price disrupt a key segment of the power capacitor market.

Additionally, the ceramic-based dielectric material offered for global license by EEStor allows its licensees to build capacitors that dramatically extend the 1,000 to 10,000-hour life expectancy usually offered by aluminum electrolytic capacitor technology which, in turn, further increases the pricing advantage of the EEStor capacitor replacement.

AECs at a Glance

Aluminum electrolytic capacitors (AECs) represent a $4.6 billion (USD) global market in 2018. AECs are used in alternative energy, lighting, industrial, telecommunications, automotive, military, medical and consumer electronics applications worldwide.

> *The global market for aluminum electrolytic capacitors is projected to reach $5.5 billion U.S. by 2022.*
>
> – *Global Industry Analysts, Inc.*

EEStor, developers of high energy density solid-state capacitors, has developed a significant higher permittivity ceramic dielectric material that can be liquid-phase sintered at low temperatures to utilize lower cost base metal electrodes (BME).

EEStor's capacitors are therefore significantly smaller than aluminum electrolytic capacitors for the same capacitance and have a much longer expected lifetime. This makes the EEStor capacitors much more cost effective per farad per year for the design engineer than aluminum electrolytic capacitors serving the same application. Due to this reduced cost and extended lifetime, EEStor expects its licensees to gain a significant portion of the estimated $5.5 billion (USD) global market for AECs by 2022.

Third Party Testing and Validation

EEStor's Composition Modified Barium Titanate (CMBT) is the basis for significantly higher permittivity dielectric materials, both polymer-based and glass-based. These dielectrics have been tested extensively over a 3-month period by three independent laboratories - Intertek, Radiant Technologies and MRA Laboratories. To learn more about test results, visit https://www.eestorcorp.com/.

Aluminum electrolytic capacitors are known for high capacitance values but, unfortunately, possess a limited operational lifetime as the oxide layer degrades with time and temperature. "Aluminum electrolytic capacitor load life ratings are generally expressed between 1,000 and 10,000 hours at their rated voltage, maximum temperature rating and with maximum ripple current applied to the capacitor," [2]

Longer Life

Aluminum electrolytic capacitors can achieve longer life than they are rated for by a method called "derating," or operating the capacitor at less than max temperature and max ripple current. The expected life of an aluminum electrolytic capacitor in any particular application is dependent on the environment for that application. In an LED lighting circuit for instance, AECs have an estimated life of 20,000 hours or a little less than 3 years.[3] Capacitors made from EEStor's ceramic dielectric have no such life limitations from environmental conditions. EEStor's capacitor dielectric is a cubic, paraelectric, electrostatic solid-state material. This means capacitors made with EEStor technology have no electrolytes to evaporate and do not suffer loss of capacitance due to aging under field-like ferroelectric ceramic capacitors. In addition, highly accelerated life testing performed by MRA Laboratories showed the leakage current stabilizing at high heat and voltage conditions implying a long expected lifetime. These characteristics enable EEStor capacitors to enjoy an expected lifetime measured in decades. In the same multi-decade lifetime expected for one EEStor based ceramic capacitor, several AEC replacements would have to be purchased and installed or entire sub-assemblies replaced. Thus, one EEStor capacitor can last as long as several AECs and this reduction of "waste" in both material and labor to replace failed AECs represents a large increase in efficiency in favor of EEStor technology, translatable in further pricing advantages.

Less Expensive Dielectric Materials

The raw materials that are used in the construction of EEStor's ceramic capacitors cost less gram-for-gram than materials used in the construction of AEC capacitors.

"Aluminum capacitors differ from other capacitors with respect to cost structure because of the number of raw material types consumed per capacitor, i.e. foil and paper, liquid or solid electrolyte, tab, can, leads, stoppers and end seals. None of the other dielectrics, other than perhaps OPP (biaxially-oriented polypropylene) film capacitors, have so many different raw materials and required disciplines to produce the finished capacitor. In terms of raw material feedstocks, aluminum is more cost effective when compared to tantalum and plastic film, but not as cost effective as ceramics, which have lower cost feedstocks in barium carbonate and titanium dioxide." [4]

Less Material Consumed

Since capacitors contain little or no empty space, the volume of the final part is directly related to the volume of material needed for its construction. The table compares the volume of three commercial aluminum electrolytic capacitors and one commercial MLCC. In all cases, EEStor has a volume/price advantage.

Capacitor - voltage, size	40V, 33 µF	450V, 10 µF	450V, 470 µF	500V, 2.9 µF
Type	AEC	AEC	AEC	MLCC
Kemet Volume	1.57 cm^3	5.83 cm^3	-	2.46 cm^3
United Chemi-Con Volume	-	-	43.3 cm^3	-
EEStor Volume	0.874 cm^3	0.811cm^3	38 cm^3	0.33 cm^3
% larger than EEStor	80%	618%	14%	645%

Calculation details in Appendix.

EEStor's capacitors are thus more cost effective per farad to manufacture. When this "low cost to manufacture" is added to the additional longer expected lifetime of the EEStor licensed solution, the cost per farad per year shows a significant technological advantage that favors the hybrid EEStor capacitor solution.

Promising Markets

Long-term markets for aluminum electrolytic capacitors that EEStor's licensees could displace include power supplies and inverters, medical defibrillators, downhole logging tools, DC link circuits, renewable energy systems, traction and electric rail, pulsed energy networks, phased array radar, laboratory test and measurement equipment, and related devices.

Aluminum electrolytic capacitors account for 6% of the global capacitor market by volume or 22% of the market in U.S. dollar value.[4] This market is currently supplied primarily by Nippon Chemicon, (TYO6997) Nichicon (TYO6996) (both with about 20% of the market) followed by Rubycon (RUBI) (10%), TDK/EPCOS (TDK) (8%), Kemet (6%),(KEM), Panasonic,(TYO6752) Cornell Dubilier, Vishay (VSH) and others that have less than 5% each.[5] Due to EEStor's advantages in lifetime and performance, and the ability to address both the high and low voltage aluminum electrolytic capacitor market segments, EEStor AEC replacement capacitor solutions are likely to gain a significant portion of the estimated $5.5 billion (USD) global market for AECs by 2022.

About EEStor

EEStor is a developer of high energy density solid-state capacitor technology utilizing the company's patented Composition Modified Barium Titanate (CMBT) material. The company is focused on licensing opportunities for its technology across a broad spectrum of industries and applications.

The Company's success depends on the commercialization of its technology. There is no assurance that EEStor will be successful in the completion of the various enhancement phases underway to warrant the anticipated licensing opportunities in the technology. Readers are directed to the "Risk Factors" disclosed in the Company's public filings.

Bibliography

1. Dennis M. Zogbi, Paumanok Publications, Inc.
2. https://www.illinoiscapacitor.com/pdf/Papers/Life%20expectancy%20of%20Aluminum%20electrolytic%20capacitors.pdf
3. Capacitor selection helps achieve long lifetimes in LED lights, https://www.edn.com/Home/PrintView?contentItemId=4311940
4. Understanding the Global Market for Aluminum Electrolytic Capacitors, Dennis M. Zogbi
5. High Voltage Capacitors World Markets, Technologies & Opportunities: 2016-2021, Paumanok Publications, Inc., www.paumanokgroup.com

Appendix

Side-by-Side Comparisons of EEStor and Commercial Capacitors

EEStor CMBT-glass dielectric vs. Kemet 40 volt 33µFarad

The projected volume calculation for a 40 volt, 33 microfarad MLCC, built from EEStor's CMBT-glass dielectric, is calculated based on its performance as reported in the Phase 8 Intertek report and found that the Kemet capacitor volume at 1.57 cm^3 (see data sheet below) would be 80% larger than that of EEStor's CMBT-glass capacitor. See the complete data and results here:

A Kemit 40 volt, 33 microfarad aluminum electrolytic capacitor is contained in a cylinder with a diameter of 10 mm and a length of 20 mm. The cylinder volume is thus: $\pi \times 5^2 \times 20 = 1570$ mm^3 or 1.57 cm^3 (https://www.mouser.com/datasheet/2/212/KEM_A4011_PEG124-1104316.pdf)

The projected volume calculation for a 40 volt, 33 microfarad MLCC, built from EEStor's CMBT-glass dielectric, is calculated based on the performance of Sample 344-2B as reported in the Phase 8 Intertek report. The k of 644 is that measured at the lowest field of 9.2 volt per micron.

Package Length =	10.20	mm
Package Width =	10.20	mm
Package Height =	8.40	mm
Dielectric Thickness =	10.00	µm
Conductor Thickness =	5.00	µm
k =	644	
Dielectric Resistivity =	8.32E+10	Ω-m
Voltage =	40.00	V

Field =	4.00	V/µm
One Layer Area =	1.0404	cm2/layer
Number of Layers =	560	layers
Total Area of Layers =	582.624	cm2
Part Volume =	0.8739	cm3
Layer Specific Capacitance =	57.0	nF/cm2
One Layer Capacitance =	59.30	nF/layer
Total Capacitance =	33,206.1	nF
Total Resistance =	1.43E+07	Ω
Leakage Current =	2,801.08	nA
Time Constant =	474	sec

The resulting MLCC capacitor would have a volume of 0.874 cm^3. The Kemet capacitor volume, at 1.57 cm^3 would therefore be 80% larger than that of EEStor's CMBT-glass capacitor.

EEStor CMBT-glass dielectric to Kemet 450 volt 10 µFarad

The projected volume calculation for a 450 volt, 10 microfarad MLCC, built from EEStor's CMBT-glass dielectric, is calculated based on its performance as reported in the Phase 8 Intertek report. Results of the comparison found that the Kemet 450 volt 10 microfarad would have a volume of 5.83 cm^3 (see data sheet above), making it 618% larger than the 0.8115 cm^3 EEStor CMBT-glass capacitor. See the complete data and results here:

A Kemet 450 volt, 10 microfarad aluminum electrolytic capacitor is contained in a cylinder with a diameter of 16 mm and a length of 29 mm. The cylinder volume is thus: $\pi \times 8^2 \times 29 = 5830\ mm^3$ or 5.83 cm^3. The projected volume calculation for a 450 volt, 10 microfarad MLCC, built from EEStor's CMBT-glass dielectric, is calculated based on the performance of Sample 344-2B as reported in the Phase 8 Intertek report. The k of 254 is interpolated from the k of 245 at a field of 46.9 volt per micron and k of 282 at a field 39.1 volt per micron.

Package Length =	10.20	mm
Package Width =	10.20	mm
Package Height =	7.80	mm
Dielectric Thickness =	10.00	µm
Conductor Thickness =	8.00	µm
k =	254	
Dielectric Resistivity =	8.32E+10	Ω-m
Voltage =	450.00	V

Field =	45.00	V/µm
One Layer Area =	1.0404	cm2/layer
Number of Layers =	433	layers
Total Area of Layers =	450.4932	cm2
Part Volume =	0.8115	cm3
Layer Specific Capacitance =	22.5	nF/cm2
One Layer Capacitance =	23.39	nF/layer
Total Capacitance =	10,126.6	nF
Total Resistance =	1.85E+07	Ω
Leakage Current =	24,365.62	nA
Time Constant =	187	sec

The resulting MLCC capacitor would have a volume of 0.8115 cm^3. The Kemet capacitor volume at 5.83 cm^3 would therefore be 618% larger than that of EEStor's CMBT-glass capacitor.

EEStor CMBT-glass dielectric to United Chemi-Con 450 volt 470 µFarad

The projected volume calculation for a 450 volt, 470 microfarad MLCC, built from EEStor's CMBT-glass dielectric, is calculated based on its performance as reported in the Phase 8 Intertek report. Results of the comparison found that the United Chemi-Con 470 microfarad, 450 volt capacitor (from data sheet below) would have a volume of 43.3 cm^3 making it 13% larger than the 38.02 cm^3 EEStor CMBT-glass capacitor. However, the lifetime and performance advantage of the EEStor ceramic dielectric allows a licensee to price it with much increased profitability. See the complete data and results here:

A United Chemi-Con EKMQ451VSN471MA45S 470 microfarad, 450 volt capacitor with a diameter of 35 mm and length of 45 mm, for a volume of: $\pi \times 17.5^2 \times 45 = 43{,}295$ mm^3 or 43.3 cm^3. (https://www.digikey.com/product-detail/en/united-chemi-con/EKMQ451VSN471MA45S/565-3031-ND/758243)

The projected volume calculation for a 450 volt, 470 microfarad MLCC, built from EEStor's CMBT-glass dielectric, is calculated based on the performance of Sample 344-2B as reported in the Phase 8 Intertek report. The k of 254 is interpolated from the k of 282 at a field of 39.1 volt per micron, and 245 at field of 46.9 volt per micron.

Package Length =	20.30	mm
Package Width =	15.30	mm
Package Height =	15.30	mm
Dielectric Thickness =	10.00	µm
Conductor Thickness =	8.00	µm
k =	254	
Dielectric Resistivity =	8.32E+10	Ω-m
Voltage =	450.00	V

Field =	45.00	V/µm
One Layer Area =	3.1059	cm2/layer
Number of Layers =	850	layers
Total Area of Layers =	2640.015	cm2
Part Volume =	4.7520	cm3
Layer Specific Capacitance =	22.5	nF/cm2
One Layer Capacitance =	69.82	nF/layer
Total Capacitance =	59,344.9	nF
Total Resistance =	3.15E+06	Ω
Leakage Current =	142,789.27	nA
Time Constant =	187	sec

470,000 nF / 59,344.9 nF = 7.9. So, 8 MLCCs of the above specification would be needed for 470 microfarad. 8 x 4.752 cm^3 = 38.016 cm^3, 8 x 59,344.9 nF = 474.8 microfarad.

In this case, the commercial capacitor is 43.3 cm^3 and the EEStor capacitor is 38.016 cm^3, so EEStor is marginally smaller per farad especially considering the unknown portion of the volume attributed to packaging. However, the lifetime and performance advantage of the EEStor ceramic dielectric confer its licensee a pricing and thus profitability advantage that make EEStor's dielectric disruptive across the entire aluminum electrolytic market.

Other ceramic capacitors could also replace AECs, however EEStor technology has a volume/price advantage over existing ceramic dielectrics that enable EEStor's licensees to ensure the EEStor solution is the value proposition.

Comparison of EEStor MLCC to Kemet 2.9 microfarad 500 volt cap MLCC

The Kemet 2.9 microfarad 500 volt cap is 19.56mmx18.29mmx6.89mm.
https://4donline.ihs.com/images/VipMasterIC/IC/KEME/KEME-S-A0002497309/KEME-S-A0002497309-1.pdf

The projected volume calculation for a 500 volt, 2.9 microfarad MLCC, built from EEStor's CMBT-glass dielectric, is calculated based on the performance of Sample 344-2B as reported in the Phase 8 Intertek report, k of 282 at a field of 39.1 volt per micron.

Package Length =	10.20	mm
Package Width =	10.20	mm
Package Height =	3.20	mm
Dielectric Thickness =	13.00	µm
Conductor Thickness =	8.00	µm
k =	282	
Dielectric Resistivity =	8.32E+10	Ω-m
Voltage =	500.00	V

Field =	38.46	V/µm
One Layer Area =	1.0404	cm2/layer
Number of Layers =	152	layers
Total Area of Layers =	158.1408	cm2
Part Volume =	0.3329	cm3
Dielectric Volume =	0.2061	cm3
Layer Specific Capacitance =	19.2	nF/cm2
One Layer Capacitance =	19.97	nF/layer
Total Capacitance =	3,035.9	nF
Total Resistance =	6.84E+07	Ω
Leakage Current =	7,310.50	nA
Time Constant =	208	sec

The EEStor 2.9 microfarad 500 volt capacitor has a volume of 0.33 cm^3 while the Kemet has a volume of 2.46 cm^3 . The Kemet ceramic MLCC is 645% larger for the same capacitance. The Kemet MLCC capacitance does not drop as much with temperature as the EEStor capacitor, so the EEStor capacitor will have to be oversized to compensate.

The Kemet capacitor is an X7R (-55° to 125°C With a capacitance change of + - 15%) while the EEStor capacitor is an X7U (-55° to 125°C with a capacitance change of + 22% , - 56%).

The capacitance for the EEStor capacitor will need to be 6.65 microfarads to ensure 2.9 microfarads at 125°C . An EEStor MLCC with this capacitance has a volume of 0.73 cm^3.

Package Length =	10.20	mm
Package Width =	10.20	mm
Package Height =	7.00	mm
Dielectric Thickness =	13.00	µm
Conductor Thickness =	8.00	µm
k =	282	
Dielectric Resistivity =	8.32E+10	Ω-m
Voltage =	500.00	V

Field =	38.46	V/µm
One Layer Area =	1.0404	cm2/layer
Number of Layers =	333	layers
Total Area of Layers =	346.4532	cm2
Part Volume =	0.7283	cm3
Dielectric Volume =	0.4508	cm3
Layer Specific Capacitance =	19.2	nF/cm2
One Layer Capacitance =	19.97	nF/layer
Total Capacitance =	6,651.1	nF
Total Resistance =	3.12E+07	Ω
Leakage Current =	16,015.77	nA
Time Constant =	208	sec

The EEStor 6.65 microfarad 500 volt capacitor has a volume of 0.73 cm^3 while the Kemet 2.9 microfarad 500 volt has a volume of 2.46 cm^3. The Kemet ceramic MLCC is therefore 239% larger than the EEStor capacitor for the same capacitance at temperature.