MRA Laboratories, Inc.

Certificate of Analysis

MRA Report #:	M18-090T
Report Date:	August 06, 2018
Report Type:	EEStor, Inc. Samples Performance Testing
Prepared for:	Mr. Ian Clifford EEStor, Inc. 715 Discovery Boulevard #107 Cedar Park, TX 78613
P.O. No:	3157-00'18

The following samples were submitted and identified on behalf of the client as:

Sample ID's:	LT-4775 – .0805-size MLCC chips made by MRA Laboratories, Inc. using EEStor CMBT powder and fired at 1300C/3h in air
Material types:	Densified and terminated MLCC chips
Quantity:	200 MLCC chips per sample
Testing Period:	July 30, 2018 – August 06, 2018
Objective:	To independently illustrate the performance of EEStor materials across the range of operating conditions

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Performed tests:

Test #1: Capacitance & Dissipation Factor vs. Frequency (20Hz – 2MHz) @1Vrms, RT, 0V dc-bias;
Test #2: Capacitance & Dissipation Factor vs. dc-bias (up to 500V) @1kHz, RT;
Test #3: Temperature Coefficient of Capacitance @ 1kHz, -55°C – 200°C temperature range, 0V dc-bias;
Test #4: Temperature Coefficient of Capacitance at dc-bias @ 1kHz, -55°C – 200°C temperature range, 200V dc-bias;
Test #5: Insulation Resistance @50V, RT and 125°C;
Test #6: HALT @200V, 180°C, 100h;
Test #7: Dielectric Breakdown Strength both at AC (up to 5000Vac) and DC (up to 6000Cdc) voltages;
Test #8: Cross-section and optical/SEM microstructure evaluation.

Summary:

The results are given on the following pages as tables and plots for information only.

Customer Samples Dimensions

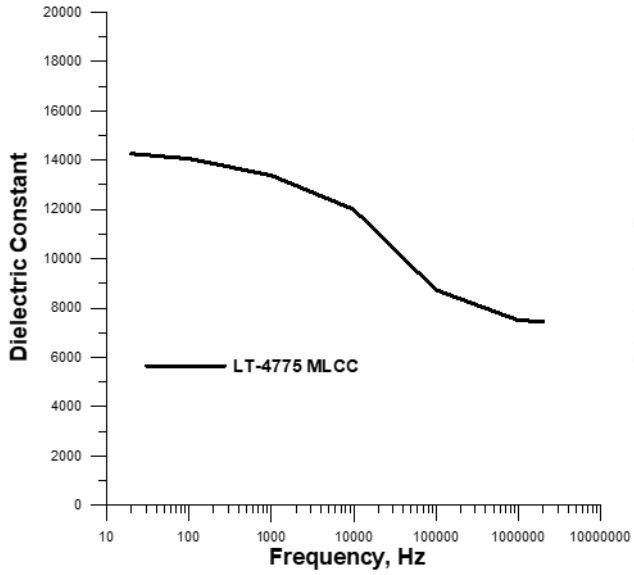
Sample ID#	**Customer ID#**	**MLCC design**	**Internal electrode dimensions (length and width of the active zone), μm**	**Active dielectric layer thickness, μm**	**Total electrodes area, μm²**
LT-4775 MLCC chips made with 30%Ag/70%Pd internal electrodes, sint. 1300°C/3h	CMBT powder	.0805-size, parallel design, 22.5 active layers	1156x560	19.7	647360
Used equipment: Precision optical scope, Unitron Bi-6426. Measured uncertainty: ±0.001mm. Room temperature: 24.7°C. Relative humidity: 52.0%.					

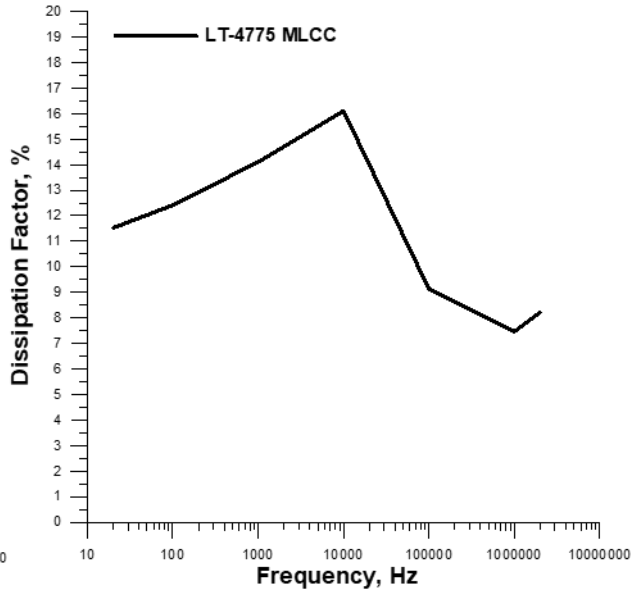
Test Results:

Test #1: Capacitance & Dissipation Factor vs. Frequency (20Hz – 2MHz)
(@ 1Vrms, 0V dc-bias, 1Vrms, room temperature)

Freq., Hz	LT-4775 MLCC (average of 5 chips)	
	Cap, nF	DF, %
20	94.032	11.523
100	92.710	12.412
1,000	88.216	14.106
10,000	79.135	16.108
100,000	57.612	9.131
1,000,000	49.501	7.468
2,000,000	49.174	8.206
Used equipment: Keysight E4980A precision LCR meter. Measured uncertainty: C, DF ±0.1%. Room temperature: 24.7°C. Relative humidity: 52.0%.		

Freq., Hz	LT-4775 MLCC (average of 5 chips) Estimated Dielectric Constant
20	14262
100	14062
1,000	13380
10,000	12003
100,000	8738
1,000,000	7508
2,000,000	7458



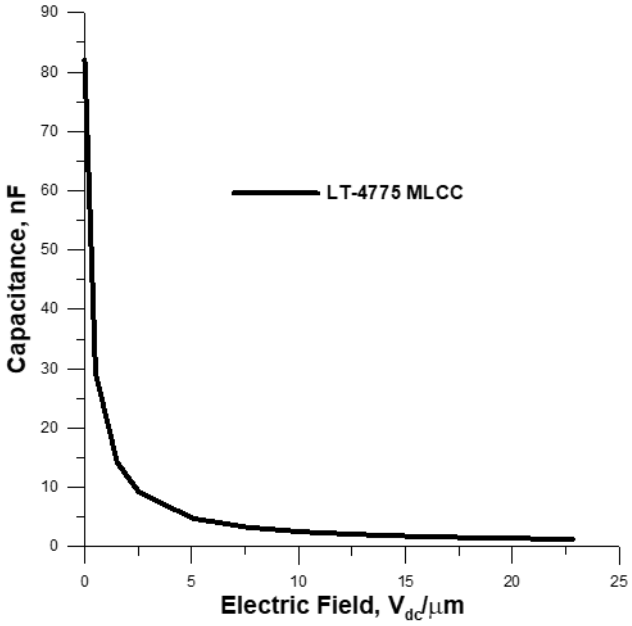


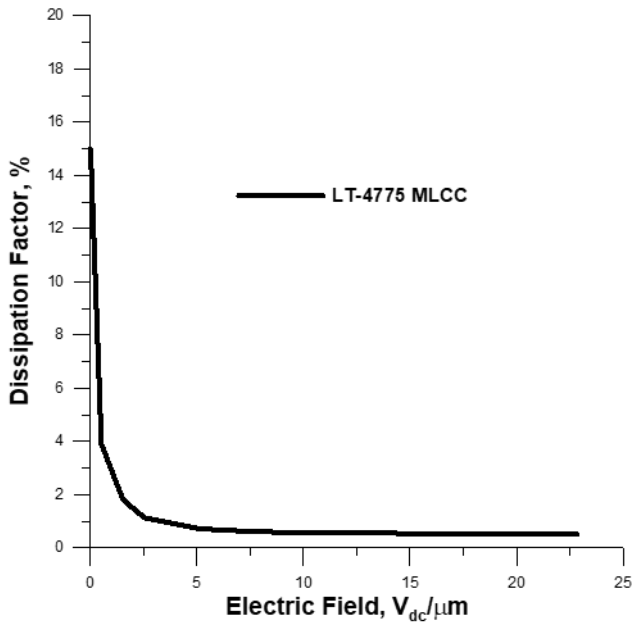
Test #2: Capacitance & Dissipation Factor vs. dc-bias (up to 500V)
(@ 1 kHz, 1Vrms, room temperature)

dc-bias, V	LT-4775 MLCC (average of 5 chips)	
	Cap, nF	DF, %
0	82.187	14.987
10	29.318	3.905
30	14.172	1.815
50	9.194	1.132
100	4.766	0.724
150	3.272	0.615
200	2.521	0.573
250	2.077	0.562
300	1.777	0.548
350	1.561	0.531
400	1.398	0.519
450	1.268	0.512
500	1.165	0.506

Used equipment: Keysight E4980A precision LCR meter.
Measured uncertainty: C, DF ±0.1%.
Room temperature: 24.7°C. Relative humidity: 52.0%.

dc-bias, V	LT-4775 MLCC (average of 5 chips)	
	E, V/ μm	Cap, %
0	0.000	100.000
10	0.508	35.672
30	1.523	17.244
50	2.538	11.187
100	5.076	5.799
150	7.614	3.981
200	10.152	3.067
250	12.690	2.527
300	15.228	2.162
350	17.766	1.899
400	20.305	1.701
450	22.843	1.543
500	25.381	1.417





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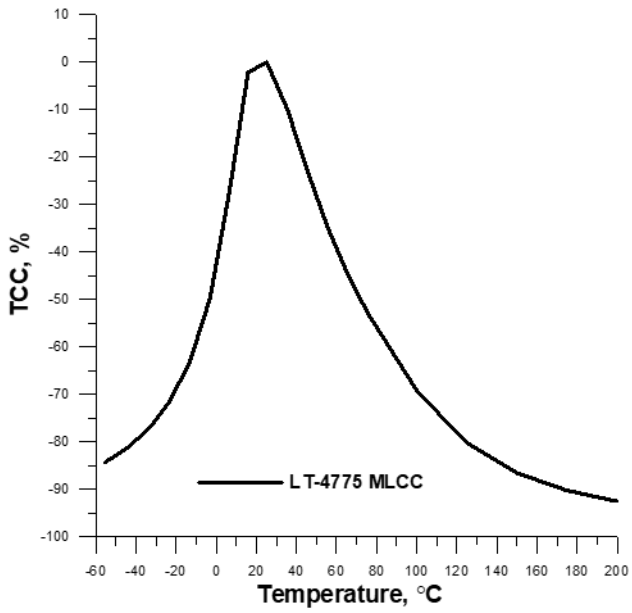
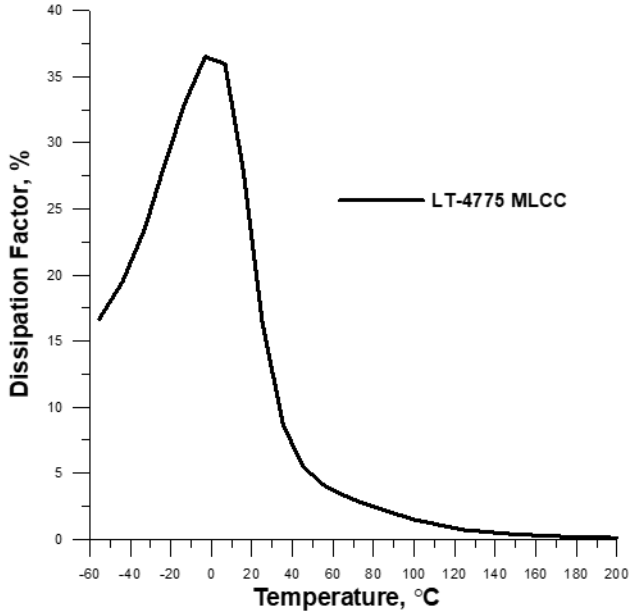
Test #3: Temperature Coefficient of Capacitance
(@ 1 kHz, 1Vrms, -55°C – 200°C temperature range, 0V dc-bias)

Temp., °C	LT-4775 MLCC (average of 3 chips)	
	Cap, %	DF, %
-55	-84.241	16.663
-45	-81.058	19.514
-35	-76.887	23.449
-25	-71.448	28.257
-15	-63.091	32.985
-5	-49.649	36.521
5	-26.885	35.974
15	-2.207	27.795
25	0.000	16.395
35	-9.884	8.596
45	-22.850	5.473
55	-34.704	4.080
65	-44.669	3.301
75	-52.825	2.679
100	-69.250	1.469
125	-80.153	0.695
150	-86.494	0.364
175	-90.186	0.200
200	-92.449	0.107
Used equipment: HP 4278A Capacitance meter and Delta 9023 environmental chamber. Measured uncertainty: C, DF ±0.25%. Room temperature: 24.7°C. Relative humidity: 52.0%.		





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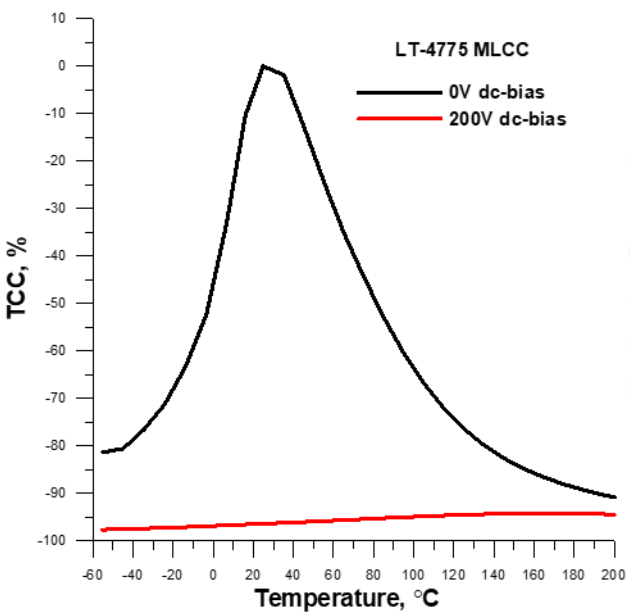
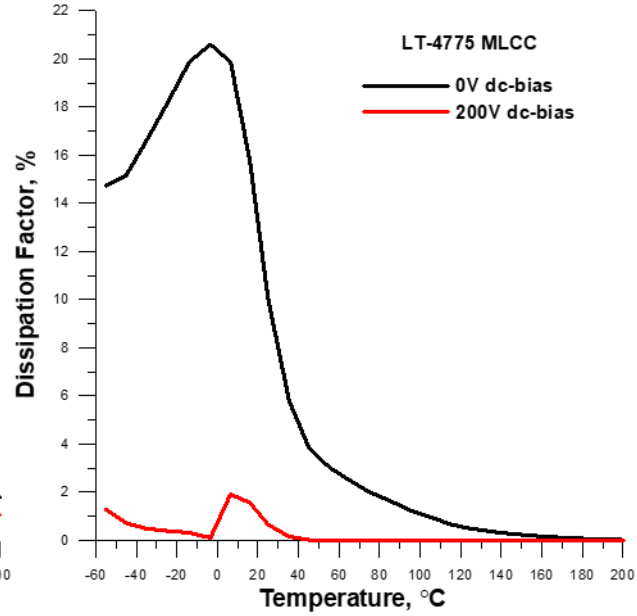
Test #4: Temperature Coefficient of Capacitance at dc-bias

(@ 1 kHz, 1Vrms, -55°C – 200°C temperature range, 200V dc-bias)

Temp., °C	LT-4775 MLCC (average of 3 chips)			
	0V dc-bias		200V dc-bias	
	Cap, %	DF, %	Cap, %	DF, %
-55	-81.309	14.736	-97.595	1.277
-45	-80.544	15.161	-97.488	0.702
-35	-76.615	16.637	-97.362	0.472
-25	-71.302	18.213	-97.225	0.380
-15	-63.321	19.879	-97.067	0.303
-5	-52.242	20.601	-96.882	0.095
5	-33.394	19.860	-96.681	1.901
15	-10.324	15.751	-96.494	1.552
25	0.000	10.063	-96.360	0.647
35	-1.898	5.797	-96.164	0.146
45	-12.826	3.800	-95.982	0.003
55	-24.396	3.021	-95.786	-0.010
65	-35.278	2.474	-95.585	-0.014
75	-44.540	1.980	-95.390	-0.020
85	-53.076	1.623	-95.184	-0.024
95	-60.654	1.221	-94.982	-0.027
105	-66.956	0.949	-94.792	-0.028
115	-72.208	0.645	-94.618	-0.027
125	-76.454	0.474	-94.468	-0.026
135	-79.880	0.351	-94.348	-0.026
145	-82.628	0.257	-94.260	-0.029
155	-84.844	0.183	-94.208	-0.027
165	-86.631	0.127	-94.192	-0.029
175	-88.103	0.082	-94.211	-0.031
185	-89.317	0.046	-94.263	-0.031
195	-90.336	0.021	-94.346	-0.032
200	-90.802	0.008	-94.399	-0.035

Used equipment: HP 4278A Capacitance meter and Delta 9023 environmental chamber.
Measured uncertainty: C, DF ±0.25%.
Room temperature: 24.7°C. Relative humidity: 52.0%.





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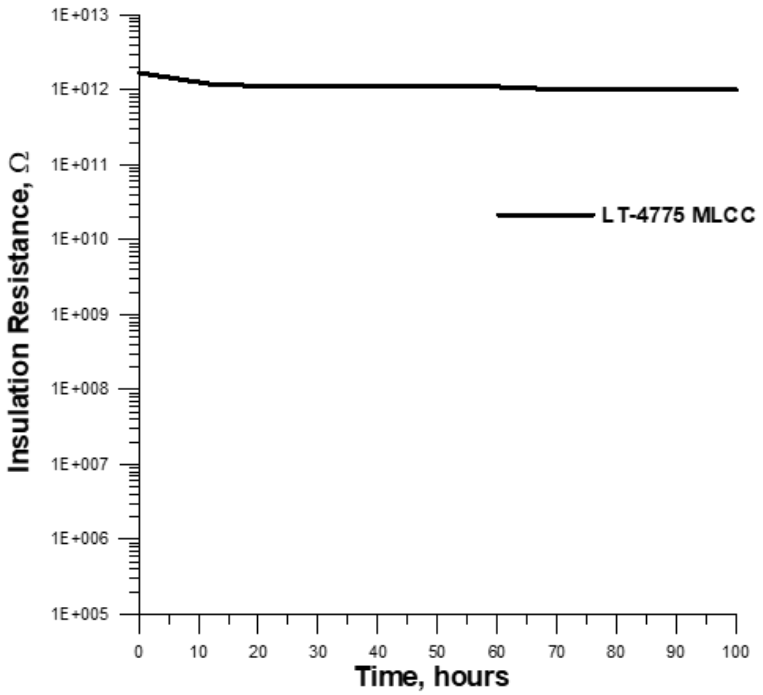
Test #5: INSULATION RESISTANCE

(@ 50Vdc, RT and 125°C, 2min)

Electrical Parameters	**LT-4775 MLCC (average of 5 chips)**
	Room Temperature
IR, Ω	$4.5*10^{12}$
ρ, Ω*m	$1.5*10^{11}$
R*C, MΩ*μF	$4.0*10^{5}$
	125°C
IR, Ω	$1.8*10^{12}$
ρ, Ω*m	$5.9*10^{10}$
R*C, MΩ*μF	$3.2*10^{4}$
Used equipment: Beckman Megaohmmeter and Delta 9023 environmental chamber. Measured uncertainty: IR ±0.25%. Room temperature: 24.7°C. Relative humidity: 52.0%.	

Test #6: Highly Accelerated Life Test
(@ 200Vdc, 180°C, 100h)

Time, h	LT-4775 MLCC (average of 20 chips), IR, Ω	Amount of failures
2	$1.6*10^{12}$	0/20
12	$1.2*10^{12}$	0/20
24	$1.2*10^{12}$	0/20
36	$1.1*10^{12}$	0/20
48	$1.1*10^{12}$	0/20
60	$1.1*10^{12}$	0/20
72	$1.0*10^{12}$	0/20
84	$1.0*10^{12}$	0/20
96	$1.0*10^{12}$	0/20
100	$1.0*10^{12}$	0/20
Used equipment: Custom made HT-HALT system. Measured uncertainty: IR ±0.25%. Room temperature: 24.7°C. Relative humidity: 52.0%.		



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Test #7: AC and DC Dielectric Breakdown Strength

(@ Room temperature)

Electrical Parameters	LT-4775 MLCC (average of 10 chips)
DC Dielectric Breakdown	
Ultimate Dielectric Breakdown, Vdc	905
Dielectric Breakdown Strength, Vdc/μm	45.9
AC Dielectric Breakdown	
Ultimate Dielectric Breakdown, Vac	208
Dielectric Breakdown Strength, Vac/μm	10.6
Used equipment: Chroma Sentry Plus HiPot tester 19073. Measured uncertainty ±0.25%. Room temperature: 24.7°C. Relative humidity: 52.0%.	

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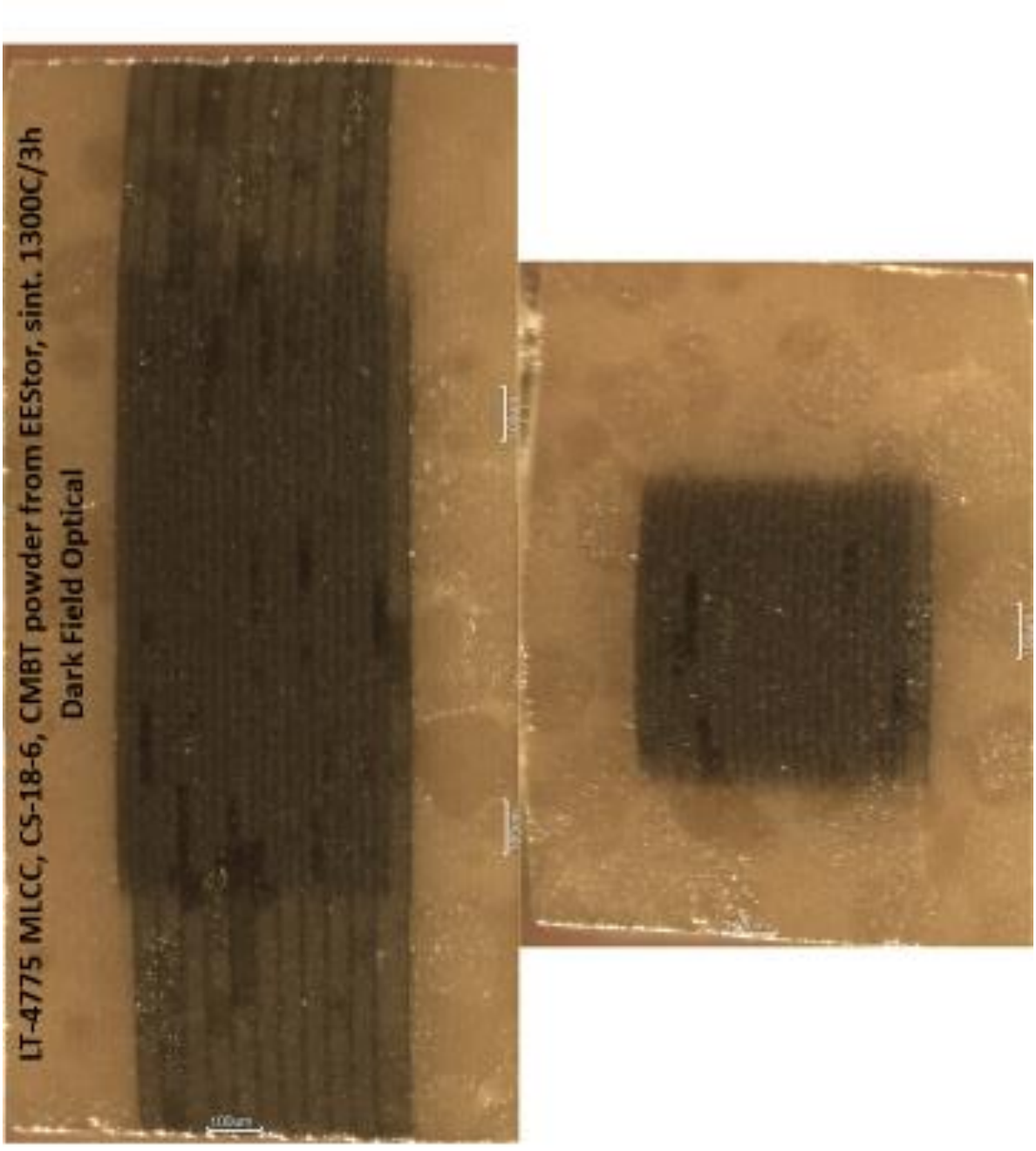
Test #8: Cross-section and optical/SEM microstructure evaluation



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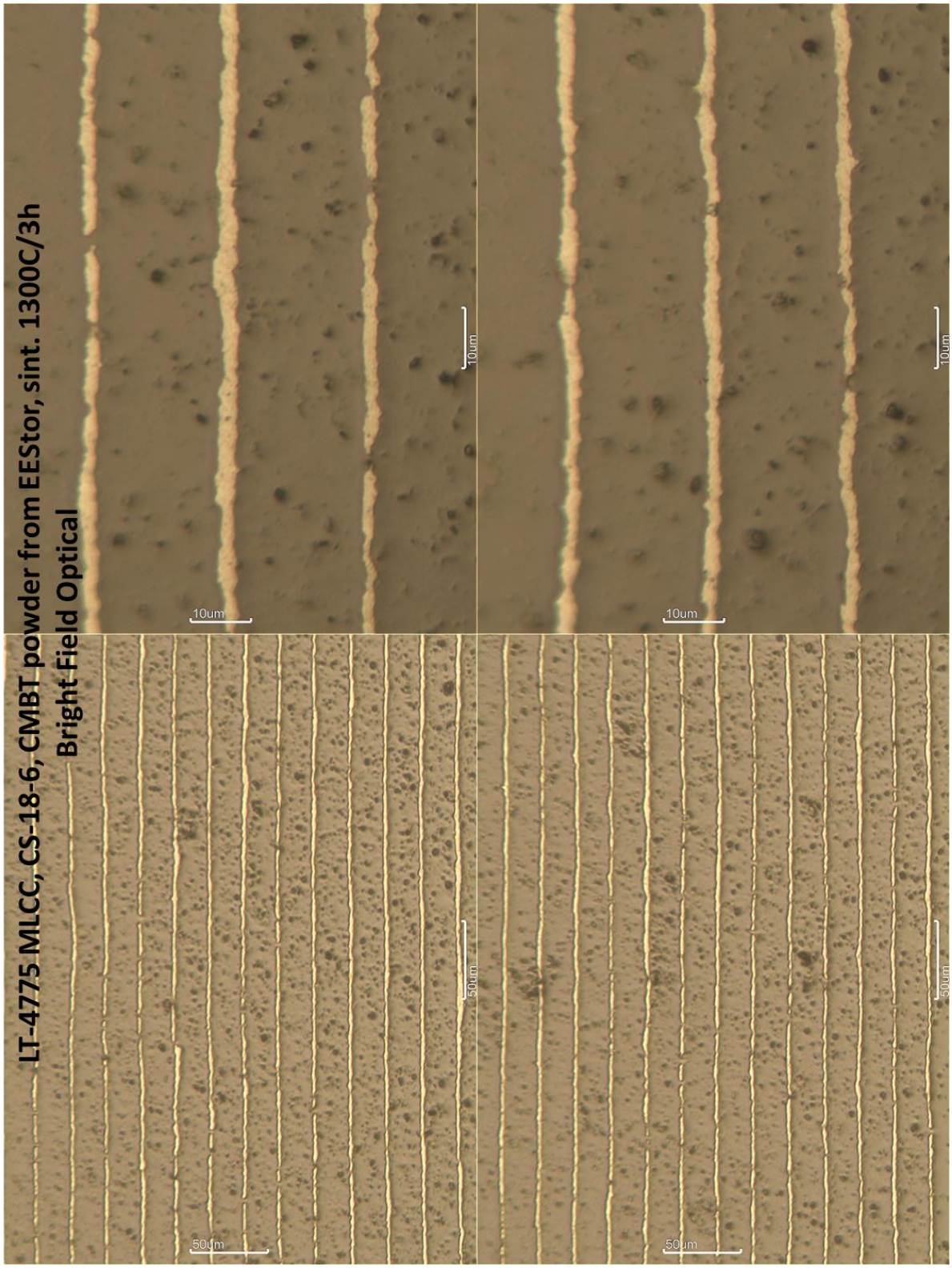

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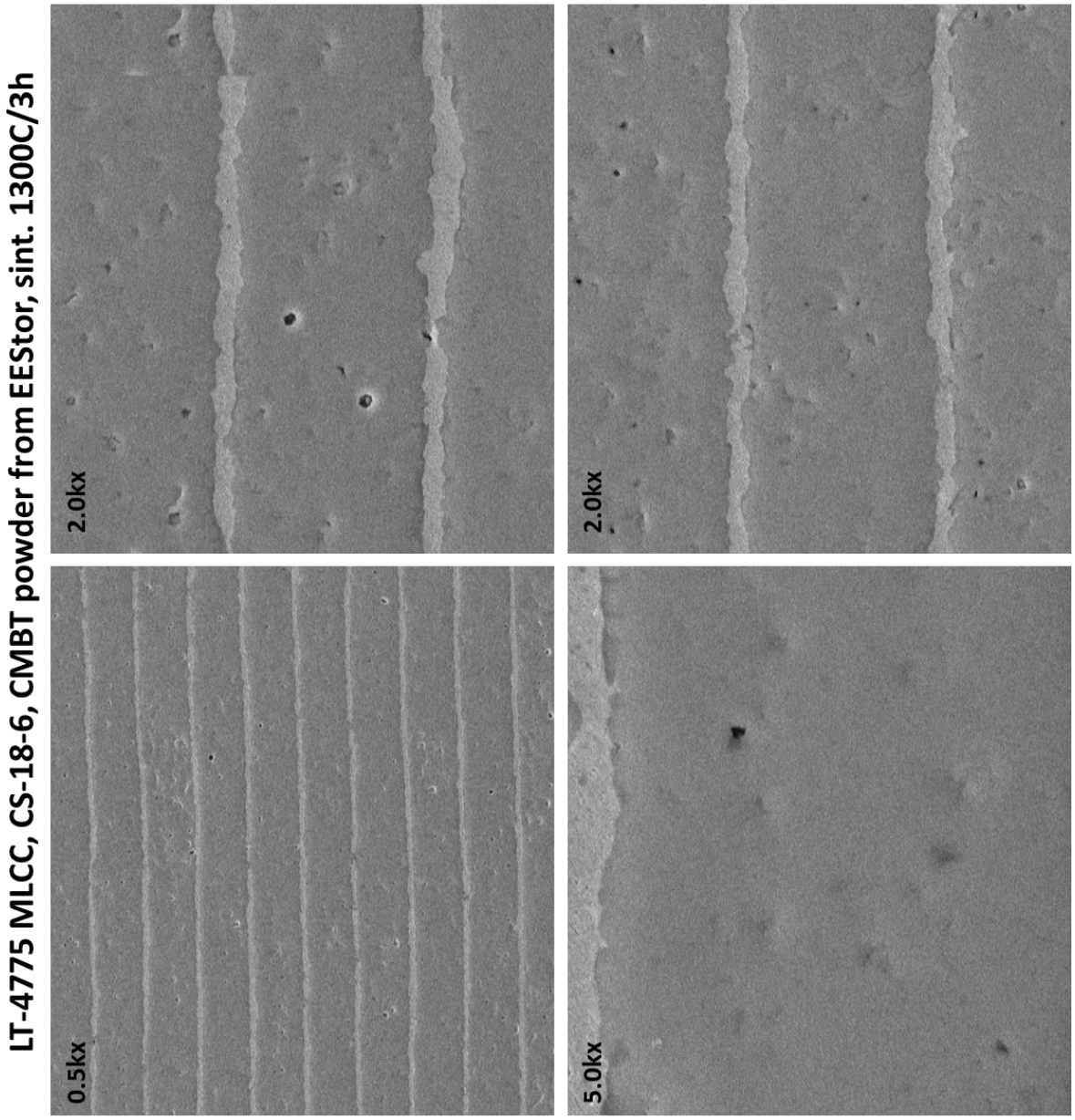

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Test Methods

The below methods were used to perform the tests.

General

All measurement equipment was powered up at least 30 minutes prior to testing and allowed to reach a stable temperature.

Test #1: Capacitance & Dissipation Factor vs. Frequency (20Hz – 2MHz)

Electrical parameters at variable frequencies were measured using Keysight E4980A Precision LCR Meter. The measurements were performed at room temperature at 1Vrms voltage condition. Open/short correction was performed prior to measurements in order to compensate for stray admittance and residual impedance of the probe. The measurements were performed one time per sample. Dielectric constant of the MLCC chips was estimated by using parallel plate design MLCC model. The dimensions of the MLCC chip's active zone and active dielectric layer thickness were measured using a precision optical microscope, while the capacitance was taken from measurements of the capacitance at variable frequencies at room temperature.

Test #2: Capacitance & Dissipation Factor vs. dc-bias (up to 500V)

Electrical parameters at variable dc-biases were measured using Keysight E4980A Precision LCR Meter coupled with Acopian High Voltage Power Supply and ART ASY0360 HV Bias Module. The measurements were performed at room temperature at 1Vrms voltage condition. Open/short correction was performed prior to measurements in order to compensate for stray admittance and residual impedance of the probe. The measurements were performed one time per sample.

Test #3: Temperature Coefficient of Capacitance

Temperature coefficient of capacitance was measured using HP 4278A 1kHz/1MHz Capacitance Meter coupled with Rokem Scanner and Delta 9023 Environmental Chamber. The measurements were performed in the temperature range from -55°C to 200°C for the ceramic samples. Three minutes were allowed for temperature stabilization prior to measurements of capacitance and dissipation factor at each temperature steps. Open/short correction was performed prior to measurements in order to compensate for stray admittance and residual impedance of the scanner. The measurements were performed one time per sample.

Test #4: Temperature Coefficient of Capacitance at dc-bias

Temperature coefficient of capacitance at dc-bias was measured using HP 4278A 1kHz/1MHz Capacitance Meter coupled with Rokem Scanner, Sorensen DLM 300-2 Programmable dc Power Supply, ART ASY0360 HV Bias Module, and Delta 9023 Environmental Chamber. The measurements were performed in the temperature range from -55°C to 200°C for the ceramic samples. Three minutes were allowed for temperature stabilization prior to measurements of capacitance and dissipation factor at each temperature steps with and without 200V dc-bias. Open/short correction was performed prior to measurements in order to compensate for stray admittance and residual impedance of the scanner. The measurements were performed one time per sample.

Test #5: Insulation Resistance

Insulation resistance at 50V dc-bias was measured using Beckman Megaohmmeter coupled with Delta 9023 Environmental Chamber. The measurements were performed at room temperature and at 125°C for the ceramic samples. 10 minutes were allowed for the temperature stabilization inside the chamber before each measurements. The insulation resistance was recorded after 2 minutes of dc-bias being applied. The measurements were performed one time per sample.

Test #6: Highly Accelerated Life Test (HALT)

Highly Accelerated Life Test (HALT) was performed at 180°C under the applied 200V dc-bias using a custom made high temperature HALT system consisting of Agilent 34972A LXI Data Acquisition / Switch Unit, Acopian High Voltage Power Supply, and Across Environmental Chamber. The insulation resistance of the samples was recorded every 30 minutes for the duration of 100 hours. The measurements were performed one time per sample.

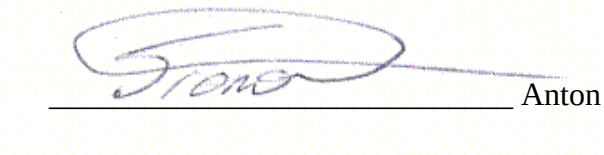
Test #7: AC and DC Dielectric Breakdown Strength

AC and DC dielectric breakdown strength measurements at room temperature were performed using Chroma Sentry Plus HiPot tester 19073. The ultimate dielectric breakdown both for AC and DC conditions was recorded during the voltage ramp up with the constant rate of 100V/sec. The samples were coated with a silicon oil to prevent surface arcing. The measurements were performed one time per sample.

Test #8: Cross-section and optical/SEM microstructure evaluation

Microstructural evaluation of the samples were performed using both optical, Unitron TMS-3906, and scanning electron, ISI-100B, microscopes. The ceramic samples were cross-sectioned and polished down to 1 micron alumina powder finish. Both bright field and dark field illumination was used in the optical microscope to reveal different features of the samples' microstructure.

Affirmation: I certify the above to be true and correct and to have witnessed the testing as described



_____ Anton Polotai, Senior Scientist

Cc: RM, SM, JW

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