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CENTRE NATIONAL D'ÉTUDES SPATIALES

EVALUATION OF AUTOMOTIVE GRADE CERAMIC CAPACITORS FOR SPACE APPLICATIONS

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ESA/ESTEC, NOORDWIJK, THE NETHERLANDS

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INTRODUCTION & CONTEXT



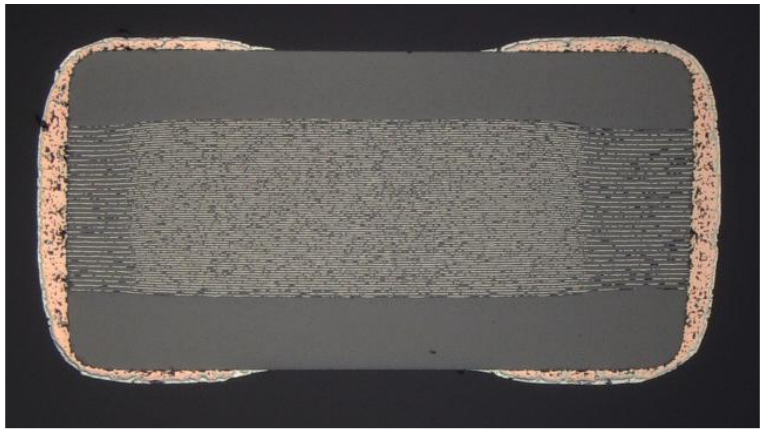
Growing use of COTS parts in space

- Cost ✓
- Lead-times ✓
- Performance ?
- Reliability for space ?

Multilayer Ceramic Capacitors

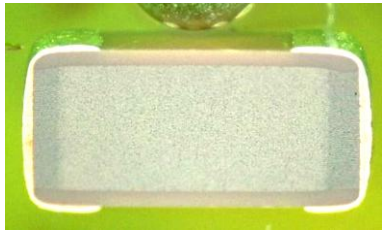
Many parts used ⚠

AEC-Q200 : automotive standard → solid baseline ✓
→ hasher conditions
(prolonged high-temperature exposure, extreme thermal cycling, vacuum ...) ?



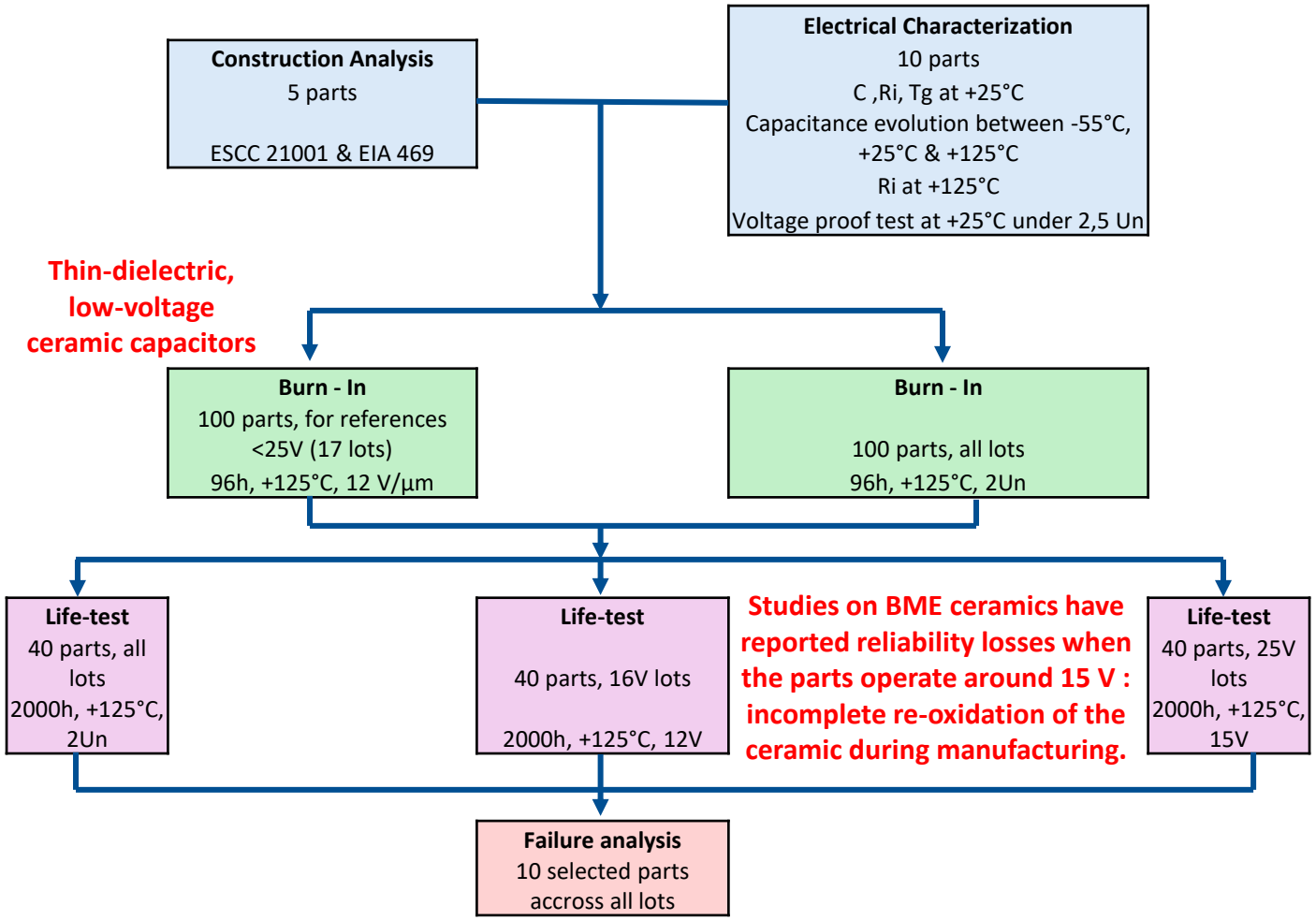
Can automotive-grade multilayer ceramic capacitors satisfy the stringent reliability standards required for space missions?

PART SELECTION & TEST SEQUENCE



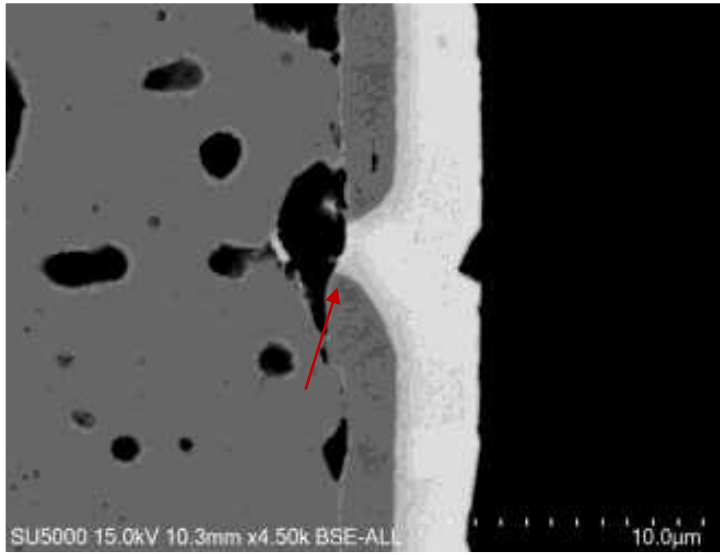
- **25 references of AECQ-200 MLCCs :**

Lot	Capacitance (F)	Voltage (V)	Size (EIA)	Manufacturer	Part reference
1	100 n	16	402	KEMET	C0402C104K4RACAUTO
2	100 n	16	402	TDK	CGA2B1X7R1C104K050
3	100 n	16	402	Taiyo Yuden	EMK105B7104KVHF
4	100 n	16	402	Murata	GCM155R71C104KA55
5	220 n	25	603	KEMET	C0603X224K3RACAUTO
6	220 n	25	603	Murata	GCM188R71E224KA55D
7	220 n	25	603	TDK	CGA3E1X7R1E224K080AC
8	220 n	25	603	Taiyo Yuden	TMK107B7224KAHT
9	1 µ	25	603	Murata	GCM188R71E105KA64D
10	1 µ	25	603	TDK	CGA3E1X7R1E105K080AC
11	1 µ	25	603	Taiyo Yuden	TMJ107CB7105KAHR
12	10 µ	16	1206	Taiyo Yuden	EMK316AB7106KLHT
13	10 µ	16	1206	TDK	CGA5L1X7R1C106K160AC
14	10 µ	16	1206	Murata	GCM31CR71C106KA64L
15	4,7 µ	50	1210	Kyocera AVX	12105C475K4Z2A
16	4,7 µ	50	1210	Murata	GCM32ER71H475KA55L
17	4,7 µ	50	1210	KEMET	C1210C475K5RACAUTO
18	4,7 µ	50	1210	TDK	CGA6P3X7R1H475M250AB
19	2,2 µ	100	1210	TDK	CGA6N3X7R2A225K230AB
20	2,2µ	100	1210	KEMET	C1210X225K1RACAUTO
21	2,2 µ	100	1210	Taiyo Yuden	HMK325B7225KMHT
22	2,2 µ	100	1210	Kyocera AVX	12101C225K4Z2A
23	22 µ	16	1210	TDK	CGA6P1X7R1C226M
24	22 µ	16	1210	Taiyo Yuden	EMK325B7226KMHT
25	22 µ	16	1210	Murata	GCM32ER71C226KE19L

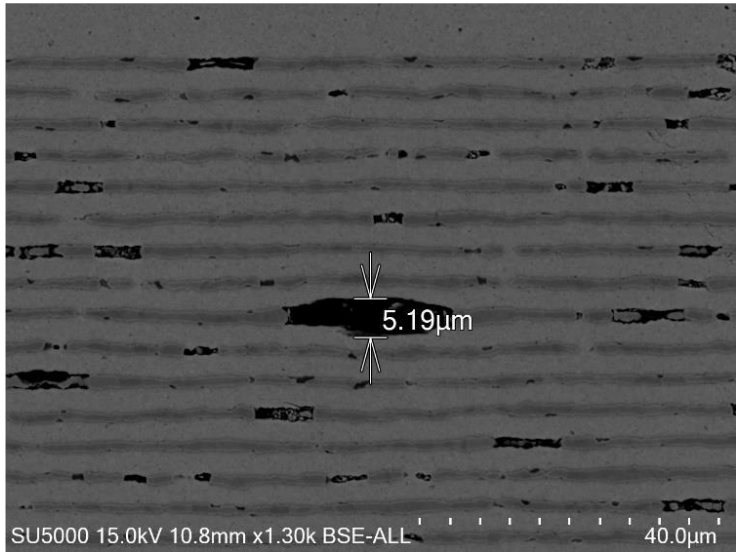


PHASE 1 : CONSTRUCTION ANALYSIS & ELECTRICAL CHARACTERIZATION

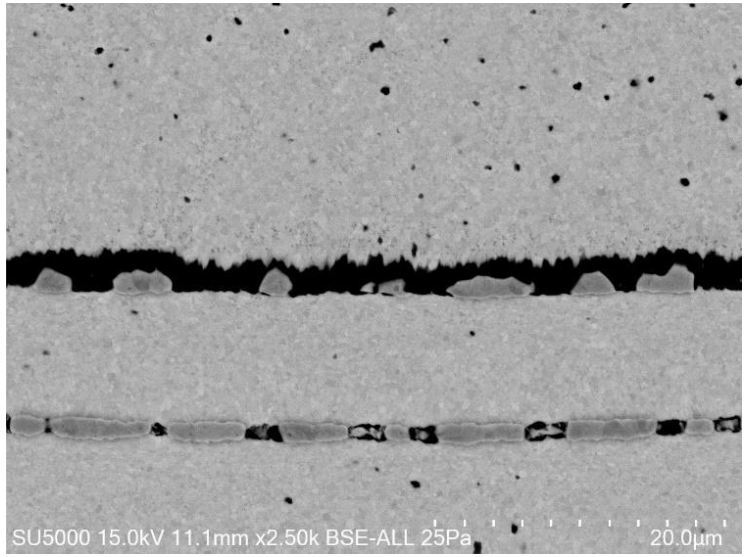
- Barrier-layer anomalies :



- Porosities and voids in the ceramic :



- Delamination :



- Out-of-specification capacitance values (exceeding the 10% tolerance specified in the product datasheet) :
  - 3% of tested parts of lot 11
  - 100% of tested parts of lot 12
  - 29% of tested parts of lot 13

PHASE 2 : SCREENING

- 96h, +125°C, 2U_N according to ESCC 3009 8.4:

Excessive leakage
OOS capacitance values
OOS dissipation factor

Catastrophic failures

OOS = Out of specification

Lot	C value	Voltage (V)	Initial	Rejected
1	100 nF	16		4% IR OOS + 1 catastrophic failure
2	100 nF	16		
3	100 nF	16		98% C OOS
4	100 nF	16		60% C OOS + 1% DF OOS
5	220 nF	25		45% C OOS
6	220 nF	25		64% C OOS
7	220 nF	25		
8	220 nF	25		1% C OOS
9	1 µF	25	Lower limit C	64% C OOS + 9% DF OOS
10	1 µF	25		6% C OOS
11	1 µF	25	3% C OOS	42% C OOS
12	10 µF	16	100% C OOS	100% C OOS
13	10 µF	16	29% C OOS	100% C OOS
14	10 µF	16	Lower limit C	100% C OOS
15	4.7 µF	50		100% C OOS
16	4.7 µF	50		97% C OOS
17	4.7 µF	50	Lower limit C	97% C OOS
18	4.7 µF	50		
19	2.2 µF	100		1 catastrophic failure
20	2.2 µF	100		100% C OOS
21	2.2 µF	100		49% C OOS
22	2.2 µF	100		100% C OOS
23	22 µF	16		
24	22 µF	16		97% C OOS
25	22 µF	16		26% C OOS + 1 catastrophic failure

PHASE 2 : SCREENING

- 96h, +125°C, 12 V/µm:

Higher field applied to thin-dielectric, low voltage devices that are more vulnerable to field-induced degradation

In some cases, this test further uncovered defects that remained hidden under the conventional test

Overall : all OOS parts at initial measurements continued to drift (up to 13% after high field test)

Lot	C value	Voltage (V)	Initial	Rejected
1	100 nF	16		78% C OOS + 8% IR OOS + 5% C & IR OOS + 4% catastrophic failures
2	100 nF	16		
3	100 nF	16		98% C OOS
4	100 nF	16		
5	220 nF	25		98% C OOS
6	220 nF	25		11% C OOS
7	220 nF	25		
8	220 nF	25		
9	1 µF	25	Lower limit C	100% DF OOS
10	1 µF	25		4% C OOS
11	1 µF	25	3% C OOS	69% C OOS
12	10 µF	16	100% C OOS	100% C OOS
13	10 µF	16	29% C OOS	78% C OOS
14	10 µF	16	Lower limit C	100% C OOS
23	22 µF	16		
24	22 µF	16		100% C OOS
25	22 µF	16		99% C OOS

OOS = Out of specification

PHASE 3 : LIFE TESTING

- 2000h, +125°C, 2U_N according to ESCC 3009 8.9 for all lots:

Excessive leakage
OOS capacitance values
OOS dissipation factor

Catastrophic failures

Lot	C value	Voltage (V)	Catastrophic failure during test	Rejected after final measurements	Passed
1	100 nF	16	19	19 IR OOS	5%
2	100 nF	16			100%
3	100 nF	16		1 IR OOS	98%
4	100 nF	16		14 C OOS	65%
5	220 nF	25			100%
6	220 nF	25		3 C OOS	93%
7	220 nF	25		1 C OOS + 1 DF OOS	95%
8	220 nF	25		19 C OOS	53%
9	1 µF	25	1		98%
10	1 µF	25	4	20 C OOS	40%
11	1 µF	25	1	39 C OOS	0%
12	10 µF	16		40 C OOS	0%
13	10 µF	16		1 C OOS	98%
14	10 µF	16	1	39 C OOS	0%
15	4.7 µF	50	3	35 C OOS + 1 C & DF OOS + 1 DF OOS	0%
16	4.7 µF	50	1	3 IR OOS	90%
17	4.7 µF	50		40C OOS	0%
18	4.7 µF	50			100%
19	2.2 µF	100	1	22 C OOS	43%
20	2.2 µF	100		40 C OOS	0%
21	2.2 µF	100		40 C OOS	0%
22	2.2 µF	100		40 C OOS	0%
23	22 µF	16			100%
24	22 µF	16			100%
25	22 µF	16			100%

OOS = Out of specification

PHASE 3 : LIFE TESTING

- 2000h, +125°C, 12V for U_N=16V lots and 15V for U_N=25V lots

This different stress **uncovers latent dielectric defects** that the 2Un test does not provoke.

✓ No catastrophic failure

Lot	C value	Voltage (V)	Catastrophic failure during test	Rejected after final measurements	Passed
1	100 nF	16		3 IR OOS + 1C OOS	80%
2	100 nF	16			100%
3	100 nF	16		31 C OOS	20%
4	100 nF	16		14 C OOS	65%
5	220 nF	25			100%
6	220 nF	25			95%
7	220 nF	25		2 C OOS	90%
8	220 nF	25		33 C OOS	18%
9	1 µF	25		40 OOS DF	0%
10	1 µF	25		5 C OOS	88%
11	1 µF	25		26 C OOS	35%
12	10 µF	16		40 C OOS	0%
13	10 µF	16		27 C OOS	33%
14	10 µF	16		40 C OOS	0%
23	22 µF	16			100%
24	22 µF	16		39 C OOS	3%
25	22 µF	16		40 C OOS	0%

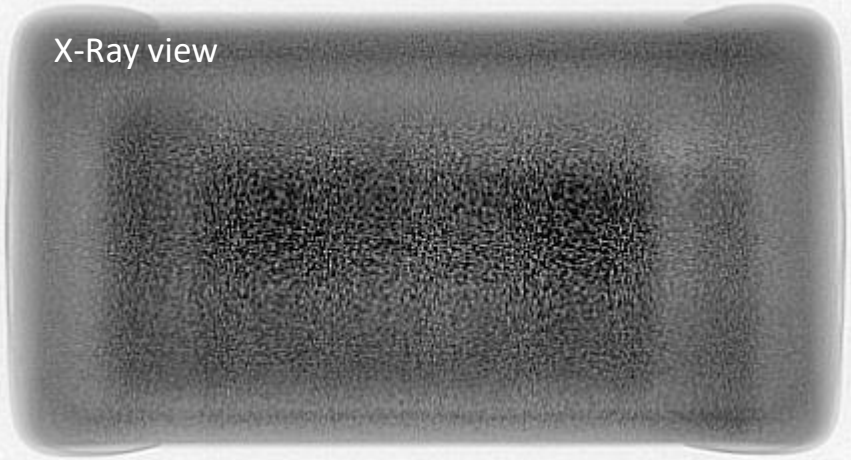
OOS = Out of specification

PHASE 4 : FAILURE ANALYSIS

- SN13, lot 14, Murata, 10µF, 16V) : electrical failure during 2UN life test

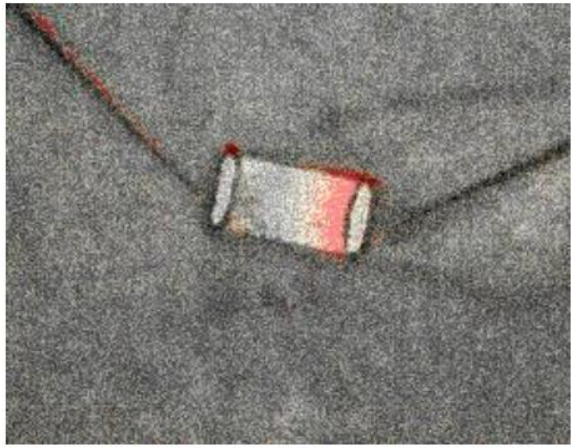
Optical view



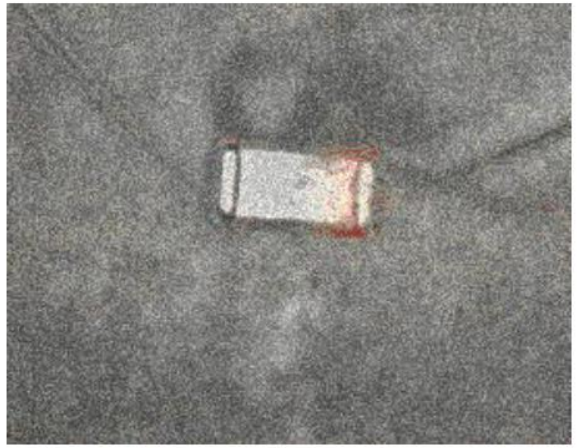


Lock-in thermography

Top view



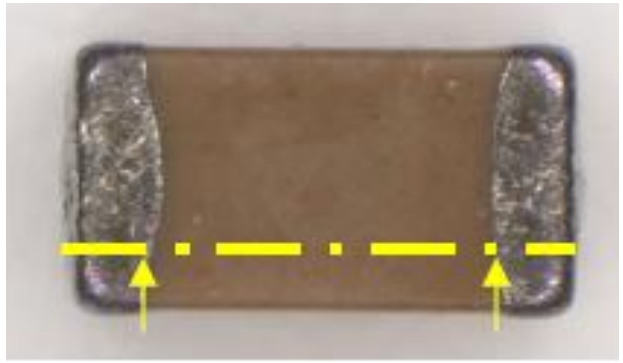
Side view (90°)

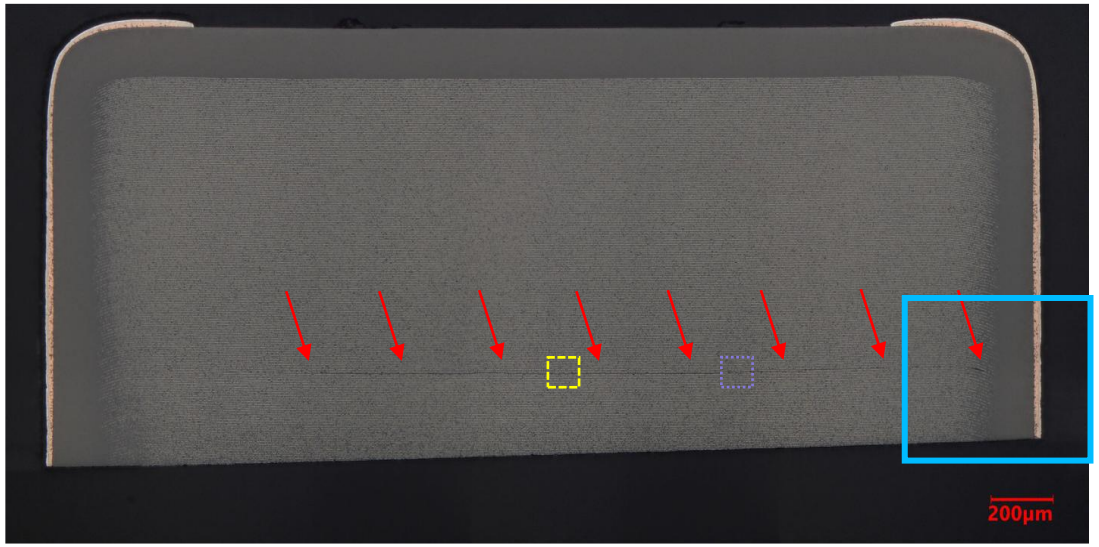


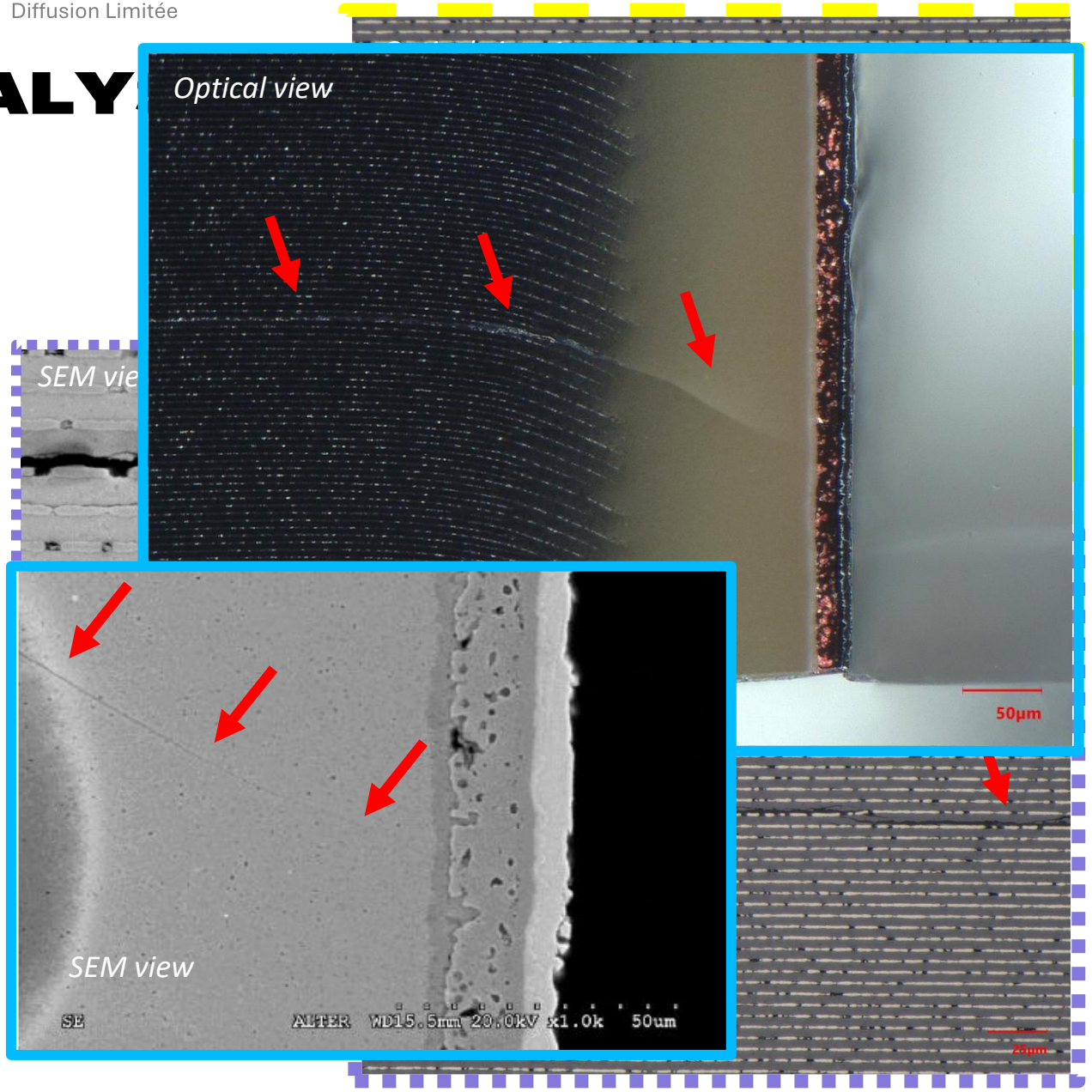
Setup

Parameter	Value
Voltage	0.08 V
Current	10 mA
Lense	Wide Angle 28mm
Frequency	1 Hz
Acquisition Time	8 minutes

PHASE 4 : FAILURE ANALY







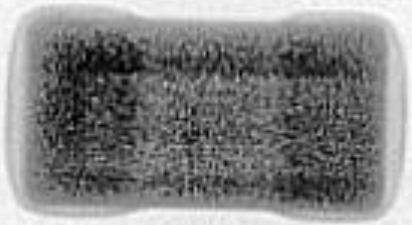
PHASE 4 : FAILURE ANALYSIS

- SN81, lot 1, Kemet, 100nF, 16V : insulation resistance dropped drastically after burn-in, and continued to decrease after the 12V life-test

Optical view

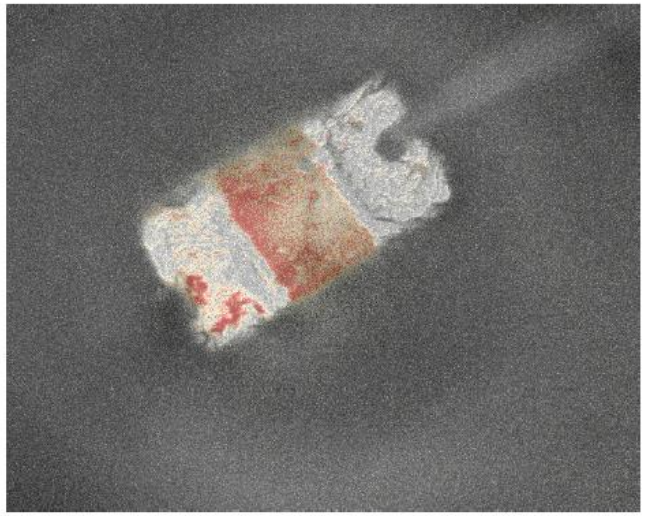


X-Ray view

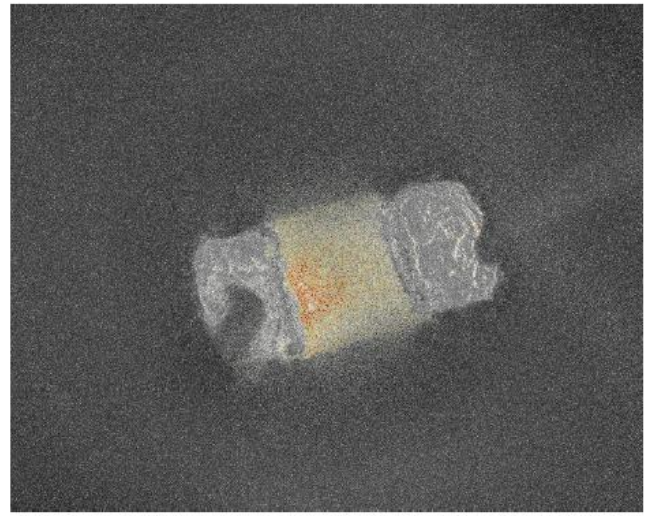


Lock-in thermography

Top view



Side view (90°)

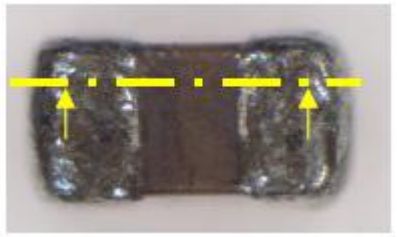


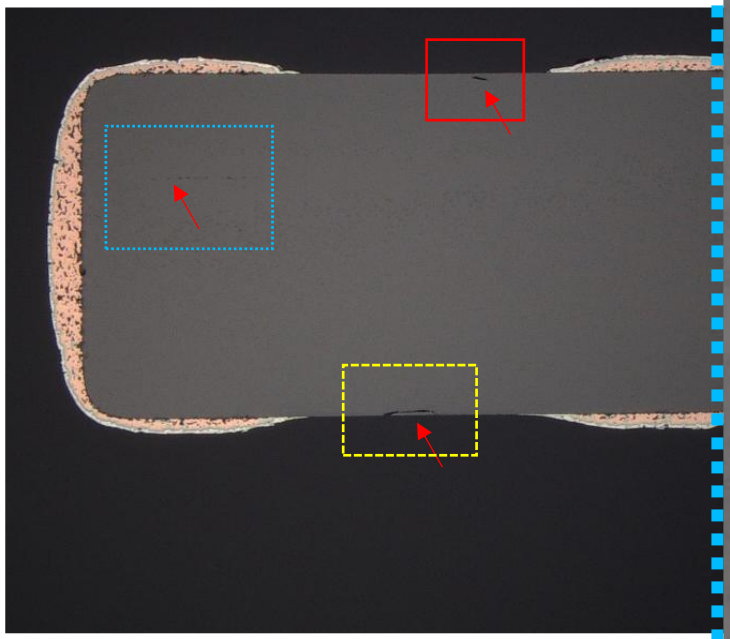
Setup

Parameter	Value
Voltage	12 V
Current	10 µA
Lense	5X
Frequency	5 Hz
Acquisition Time	8 minutes

PHASE 4 : FAILURE ANALYSIS

- SN81, lot 1, Kemet, 100nF, 16V : [illegible] se after the 12V life-test







CONCLUSION

The goal here is NOT to scare you away from using automotive grade COTS ceramic capacitor !

Automotive-grade MLCCs CAN be used in space missions, but only after their intrinsic limitations are fully understood and matched to the mission's requirements.

Understanding these failure modes enables designers to **choose the appropriate screening level, LAT flow, and derating strategy**, ensuring that the selected capacitors are fit for the intended operating environment while balancing cost and schedule constraints.

ACKNOWLEDGMENTS

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ANY QUESTION ?

THANK YOU FOR YOUR ATTENTION!

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