COTS Reliability – All COTS Devices Are Not Created Equal

Christine E. Pollock, Maria M. Petkova and Alan D. Devoe
Presidio Components, Inc.
San Diego, CA 92121
Telephone: 858-578-9390
Email: Christine@presidiocomponents.com

Abstract

MLCC's have traditionally been manufactured with precious metal electrodes (PME), typically mixtures of palladium and silver. Currently most manufacturers have switched to base metal electrodes (BME), typically nickel or copper. This switch has taken place in conjunction with a push toward higher layer counts and thinner dielectric layers. However, because the need for manufacturing standardization, medium voltage, lower layer count parts are now produced with BME. This paper presents a study of the 125C performance of 10 lots of BME versus that of 5 lots of PME. The part tested for this paper is an 0805 case code, 50 volt, .1 uF, made with X7R ceramic. BME samples from 8 different manufacturers were obtained from distributors. The 8 represented both US and offshore manufacturers. In only one instance was the part identified in the data sheet as having BME but all were confirmed as BME in EDS testing. This paper shows that BME parts do not perform equally as well as PME parts over the full military temperature range -55 to +125C. In fact, some BME lots do not meet the 125C insulation resistance requirements generally specified for X7R materials prior to test. All testing is carried out in accordance with Mil-PRF-55681.

Introduction

Currently, 50 volt rated .1 uF ceramic capacitors are available in a CDR04 (1812 case code) or CDR33 (1209 case code) established reliability (ER) style for military applications. Commercially the same value is available as an X7R 0805 case code. Many military customers would like to take advantage of these smaller, lighter offerings while not sacrificing performance and reliability. This part can still be cost effectively produced with PME technology and Presidio currently offers a COTS alternative in this technology. However Presidio's PME alternative is not available from distribution. Although previous papers (1) have reported a mixture of technology in the distribution pipeline, all parts purchased from distribution in 2004 for this research contained BME technology.

All parts tested were classified as X7R dielectric. EIA guidelines classify X7R as a capacitance change of +/- 15% over a range of -55 to +125C. These temperatures are also defined as the operating temperature range. Insulation resistance at 125C is typically specified as 10% of the 25C or room temperature requirement. For this cap value the specification is 1 GΩ. A search of manufacturer's websites either confirmed the 1 GΩ requirement, or for some, no specification was found. As previously stated, all 8 lots purchased from distribution had base metal electrodes but in only one case was this obvious from the distributor's catalog. BME-F identified parts as having Ni end caps and electrodes. The basic electrical testing performed in this study suggests that the performance of BME is different than traditional X7R material with PME electrodes.

Military test routines consist of screening steps such as voltage conditioning. This screening is typically carried out for ceramic caps at 125C and 2X rated voltage. This screening is designed to eliminate infant mortality. A discussion of infant mortality was presented in reference 2. No voltage conditioning screening was performed for this study. Parts tested in this study appear to exhibit a constant failure mode that is not suggestive of infant mortality as would be the case for defects introduced during the manufacturing process. Rather some lots appear to have an early wearout mechanism that is accelerated at 125C. See figure 2. Previous papers (2) suggested that

BME parts with higher capacitance values tested at 125C and 2X rated voltage would start to fail after 63 hours. Failure was defined as leakage current greater than 100 microamps. In this paper some parts are seen to fail versus traditional spec limits prior to test. However, the mil spec allows for IR roll off during life test. The minimum IR decreases from 1GΩ to 0.3 GΩ after 1000/2000 hours of test. There is no limit specified for 250 hours.

Mil-PRF-55681 is an established reliability specification. Testing 130 pieces for 4000 hours with 1 failure allowed would indicate "P" level established reliability. One vendor (BME-C) demonstrated "M" level reliability. Presidio has accumulated 6.3 million accelerated hours with 0 failures for PME product. This is equivalent to "P" level reliability. See Table II and reference 3.

TABLE II. FRSP-90.

FR level symbol	Qualified FR level 1/	Cumulative unit hours in millions (c = number of failures permitted)										
		c=0	c=1	c=2	c=3	c=4	c=5	c=6	c=7	c=8	c=9	c=10
	%/1,000 hr											
L	2/			("M"	row	divided	by	"L")				
M	1.0	.230	.389	.532	.668	.799	.927	1.054	1.171	1.300	1.421	1.544
P	0.1	2.30	3.89	5.32	6.68	7.99	9.27	10.54	11.71	13.00	14.21	15.44
R	0.01	23.0	38.9	53.2	66.8	79.9	92.7	105.4	117.1	130.0	142.1	154.4
S	0.001	230	389	532	668	799	927	1054	1171	1300	1421	1544

1/ For FR level expressed in terms other than %/1,000 hour, see 4.1c and 4.1d.

2/ Where a FR level greater than 1.0 percent is required, level "L" shall be specified and the cumulative unit hours computed as shown.

Some papers have indicated that BME might have significant problems in high humidity environments (4,5). Presidio tested all BME and PME lots for humidity, steady state, low voltage. All lots passed.

Vendors have no EIA guidelines for qualification testing therefore testing varies from vendor to vendor. One vendor tested at rated voltage and 85C for 1000 hours. Another vendor tested at 2X rated voltage and 125C for 100 hours.

Table 1: Part Selection .1 uF/50 Volt Rated

Attributes	COTS	Presidio	QPL
Case Size	0805	0805	CDR04 (1712) CDR33 (1209)
Electrode System	Ni	PdAg	PdAg
Dielectric Thickness	.4-.5 mils	.9 mils	1.5 mils 1.1 mils
Dielectric Material	K=4000	K=4000	K=2600
TC (-55/+125C)	+/-15%	+/-15%	+/-15%
VTC (-55/+125C)	?	-40% @ 25 V	-25% @ 50 V
Insulation Resistance 125C	0.6 – 6 GΩ	10 GΩ	50 GΩ
Voltage Breakdown	675 - 2650	1100	>2000
Qualification Basis	Not Standard	Std Mil-PRF-55681 Testing	Established Reliability S Level
Cost	¢	¢¢	$$
Delivery	2 Weeks	10 Weeks	26 Weeks

Experimental Procedures

As stated above, all competitor's parts were purchased from distribution. No attempt was made to determine manufacturing date codes. Once parts were received they were characterized electrically, cross sectioned, examined optically and using energy dispersive spectrophotometry (EDS). Voltage breakdown testing was run on 10 pieces from each lot to determine ultimate dielectric strength.

Life test was run at 2X rated voltage, 125C on 130 parts from each manufacturer. BME-B1's parts were rated at 25 volts and therefore tested at 50 volts. Once the difference was noted 50 volt rated parts were purchased and tested at 100 volts as BME-B2. All other parts were tested at 100 volts. There were several cases (BME-F and BME-G2) where less than 130 pieces were available for life test. Parts were tested at 250, 1000 and 2000 hours of life. The specifications used were Mil-PRF-55681. Insulation resistance at 125C was specified as 1 GΩ prior to life test and 0.3 GΩ at 250, 1000 and 2000 hours.

Humidity was run at 1.3 volts through a 100KΩ resistor, 85C and 85%RH.

Analysis Of The Data

No defects were found during optical or electron microscopy. Microstructure was excellent in all cases. SEM photos of BME-D parts are shown in figure 1.

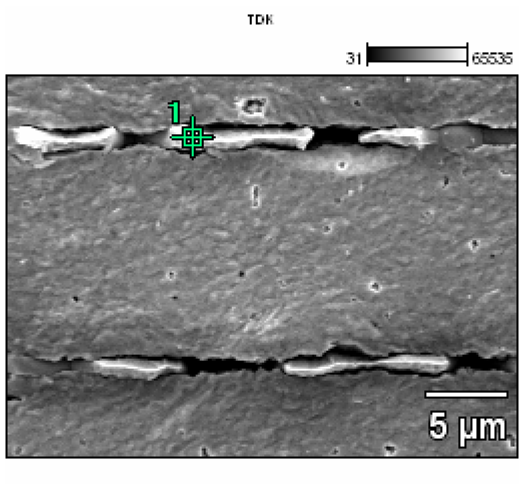

Figure 1

Initial electrical testing showed no unacceptable results for capacitance, dissipation factor, dielectric withstanding voltage (DWV) and 25C IR. However, three lots failed to meet the initial 125C IR requirement of 1 GΩ. See Table 2. Some lots that initially failed, "recovered" during testing. Although the initial 125C IR was lower than 1GΩ, IR remained stable during the test and parts "passed" post life test requirements. See BME-F and BME-H. Voltage breakdown results were 13 to 52X rated voltage with no unusually low results.

Table 2: Comparison of Properties and Life Test Performance

	Dielectric Thickness	Voltage Breakdown	Initial IR 125C	Failures At 0 Hours Life	Final IR 125C	Failures At 2000 Hours Life	Acc Hours Millions
Specified Limit			1 GΩ		0.3 GΩ		
BME-A	0.49	2642	6.2	0/130	2.20	31/130	2.080
BME-B1	0.58	674	2.2	0/130	1.80	21/130*	2.080

BME-B2	0.58	1207	2.6	0/130	0.1	118/130	2.080
BME-C	0.49	2324	1.5	0/130	1.6	4/130	2.080
BME-D	0.49	1732	1.8	2/130	0	130/130	2.080
BME-E	0.49	1806	0.6	130/130	0.25	99/130	2.080
BME-F	0.39	1496	0.8	78/78	0.75	0/78	1.248
BME-G1	0.49	1257	2.8	0/130	2.50	1/130	2.080
BME-G2	0.49	unknown	3.5	0/49	2.50	3/49**	0.784
BME-H	0.58	923	1.1	48/130	0.55	3/130	2.080
PME	0.90	1112	10.2	0/197	12.0	0/197	6.304***

* Tested at 50 volts only
**Testing stopped at 1000 hours
***Tested to 4000 hours

Life test results at 250 hours quickly indicated possible problems with BME-D and BME-G2. After 1000 hours BME-D parts were failing catastrophically. Of 130 pieces, 19 pieces read short, another 23 read less than 10 MΩ and another 43 read less than 100 MΩ. Also at 1000 hours, 22 pieces of BME-E parts fell below 0.3GΩ. Additionally, BME-A and BME-G1 had 2 and 1 piece(s) fall below 0.1GΩ. After 2000 hours of life test, 5 lots were failing catastrophically, 3 others had failures but passed "M" level requirements, 1 had no failures and passed "M" level requirements and the PME parts had no failures and met "P" level requirements. It is very interesting to note the difference in the number of failures between BME-B1 and BME-B2 at 2000 hours. Both have failed catastrophically but increased the overall number of parts below 0.3 GΩ by a factor of almost 6X. Average IR 125C was between 0.2 and 2 GΩ for the BME parts. Average IR 125C for PME after 4000 hour of test was 12 GΩ. As was the case with tests performed by NASA (1), there was no correlation between life test results and voltage breakdown results.

All lots passed Humidity, steady state, low voltage testing.

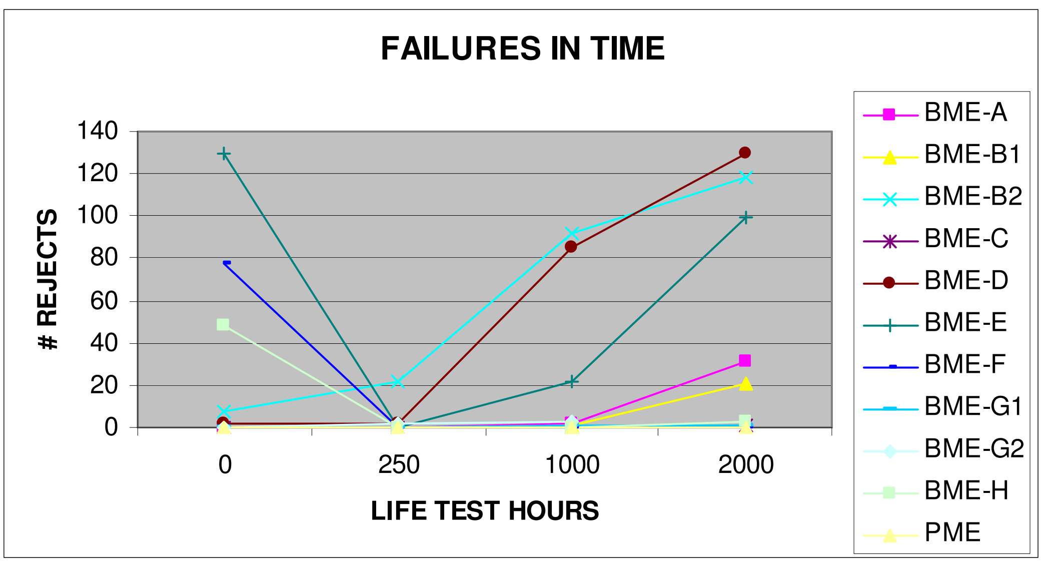

Figure 2

Conclusions

X7R ceramics with BME technology perform differently than X7R ceramics with PME technology. The 125C performance of all BME lots tested is suspect. Even initial test results indicate that many lots better meet the performance characteristics of X5R which is rated to 85C. Only 1/10 lots tested would meet the requirements of current military specifications.

PME technology not only meets military 125C requirements but also far exceeds BME technology for post life IR at 125C. Although not a topic of this paper 25C IR performance is typically 15X the minimum requirement post life test. PME is the best choice for COTS parts in military applications.

Dielectric thickness is an important consideration when choosing PME but appears to have little effect on BME performance. It would be interesting to see future work done investigating this supposition further.

Standardized qualification requirements need to be developed. DSCC has led this effort, creating DSCC Drawing 05006 for extended range 0805's. However customers must specify optional life testing to insure reliable performance at 125C. It is interesting to note that Mil-PRF-123 revision D specifically excludes the use of nickel electrodes.

References

1. Jay A. Brusse and Michael J. Sampson, "COTS Ceramic Chip Capacitors: An Evaluation of the Parts and Assurance Methodologies", CARTS 2004
2. Larry A. Mann, James J. Beeson, Michael S. Randall, Johnathon L. Paulsen, and Erik K. Reed, "Reliability of Base Metal Electrode Multilayer Ceramic Capacitors", 10th U.S.-Japan Workshop on Dielectric and Piezoelectric Materials, Providence, Rhode Island (2001), 39.
3. Mil-STD-690 "Failure Rate Sampling Plans and Procedures" Revision: D, Dated: 10 June 2005
4. Daniel N. Donahue, Craig D. Hillman, "Failures in Base Metal Electrode (BME) Capacitors, CARTS 2003
5. Daniel N. Donahue and Michael Pecht, "New Aging Mechanism in Multilayer Ceramic Capacitors", Advanced Packaging, June 2005
6.Michael S. Randell, Abhijit S. Gurav, Daniel J. Skamser, James J. Beeson, "Lifetime Modeling of Sub 2 Micron Dielectric Thickness BME MLCC", CARTS 2003