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Elevated Temperature Impact on Performance of LTCC Dielectrics

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Demand for High Temperature Electronics

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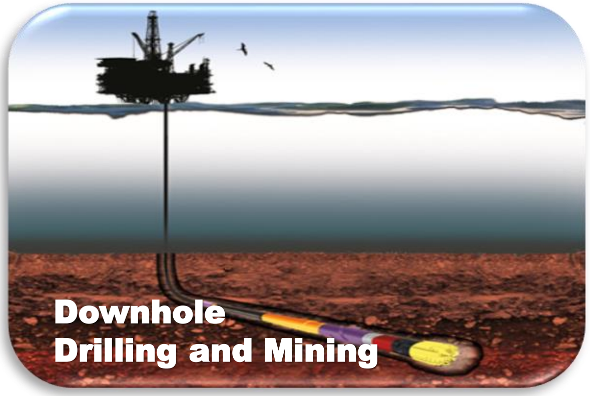
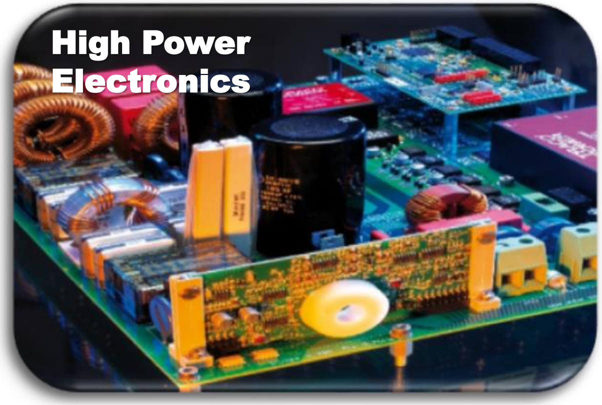
Operation at 200°C and above is required!

As performance expectations increase, to limit unnecessary design and testing iterations, it is important to understand materials behavior at elevated temperatures to account them during the design phase of a program.





LTCC Packages and High Temperatures?

Signal propagation and electrical resistivity of the LTCC material are two of the most important aspects for the electronic packaging.

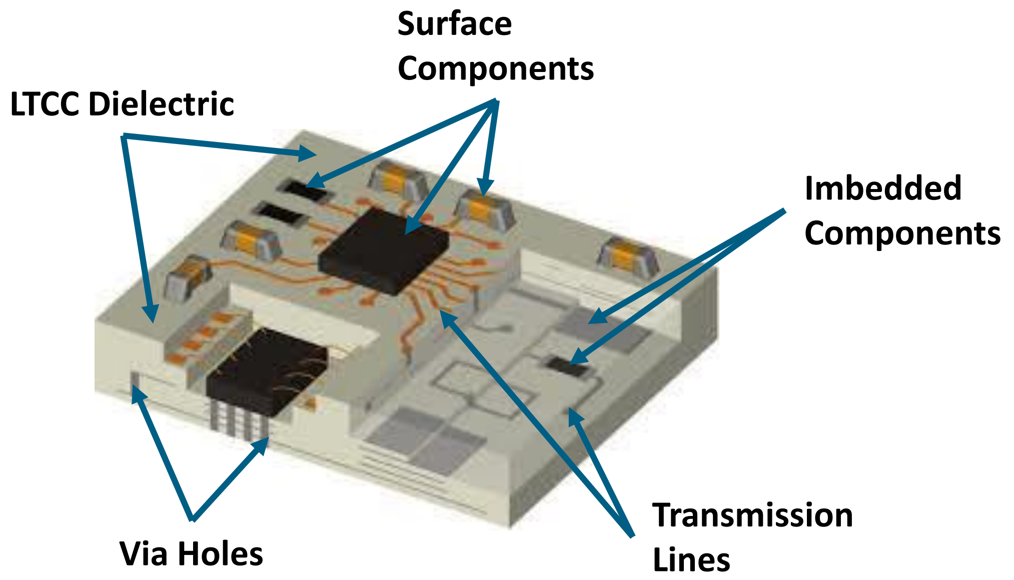
Signal Propagation:

$$t_d \sim l\sqrt{\varepsilon_r}/c$$

LTCC materials with low relative permittivity are required to increase the speed of the signal.

Electrical Resistivity:

The electrical resistivity of the LTCC material governs not only frequency at which the package can reliably operate via the value of the dielectric loss, but also the package density via the size of the separation gap between the adjacent conductor lines



Expected Influence of High Temperatures:

As the operating temperature elevates, the conductivity losses occurring in the glassy phase of the glass-ceramic LTCC material may not only significantly increase dielectric losses of the LTCC packages, but also contribute to the increase of relative permittivity of the ceramic, suppressing the signal propagation.

Understanding the impact of elevated temperature on the electrical and physical properties of LTCC materials is a good start to understand and identify when the current design rules may need to be questioned to achieve the required reliability for high temperature applications.

Ferro K3.8, A6M-E and L8 LTCC Systems

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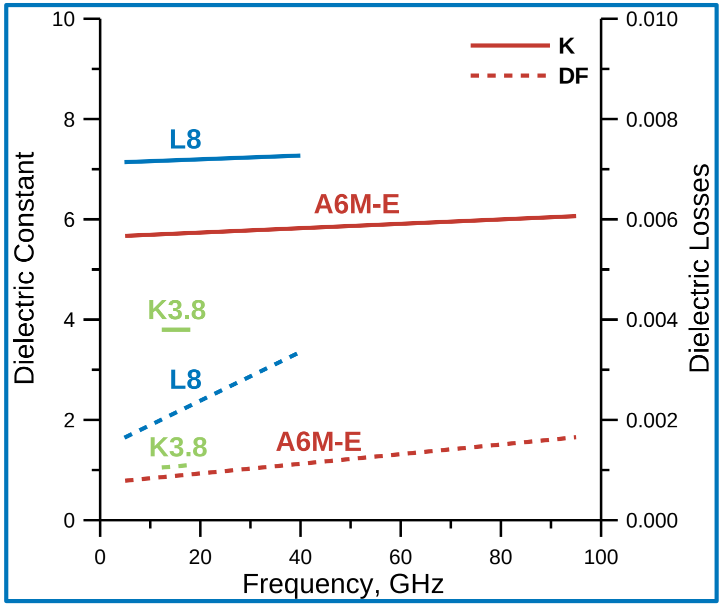
Properties		Ferro K3.8 (ERS3702)	Ferro A6M-E LTCC	Ferro L8 LTCC
Frequency Range		Targeting to 80GHz	Up to 110GHz	Up to 40GHz
Thermal coefficient of Expansion, ppm/°C		-	7.0	6.0
Tape shrinkage, %	X,Y	16.5	15.8 ±0.3	13.3 ±0.3
	Z	19.7	26.0	30.0
Fired density, g/cm³		>2.0	>2.4	>3.1
Flexural strength, MPa		145	170	275
Young's modulus, GPa			92	92
Thermal conductivity, W/m*K		-	2	2
Dielectric constant @10GHz		-	5.7 ±0.15	7.4 ±0.2
Loss tangent @10GHz		<0.0011	<0.0015	<0.0025
Insulation resistance, Ω		$>10^{10}$	$>10^{10}$	$>10^{10}$
Dielectric breakdown strength, Vdc/µm		>100	>30	>35
Electrolytic leakage current, mA/cm²		-	<1	<1



HIGH-FREQUENCY LTCC APPLICATIONS

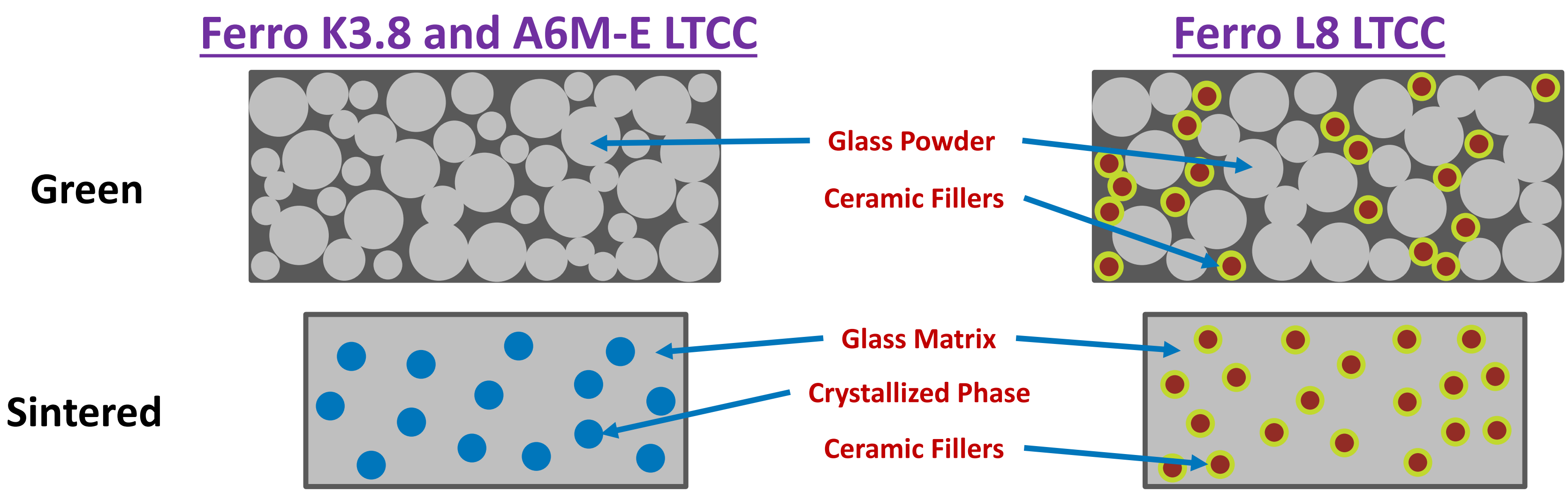
- ✓ RF front-end module for mobile phones
- ✓ IMST satellite antenna arrays
- ✓ Laminated waveguide and other new forms of transmission lines for mm-wave applications
- ✓ Integrated mm-wave antenna arrays
- ✓ Integrated RF modules such as high-performance VCO, balanced LNA, miniaturized RF filters and balun transformers

LOW-MID FREQUENCY LTCC APPLICATIONS

- ✓ Transmit/Receive Modules
- ✓ Electronic filters
- ✓ Optoelectronic switches
- ✓ Sensors

Ferro K3.8, A6M-E, and L8 LTCC Systems

Ferro K3.8, A6M-E and L8 dielectrics have distinct microstructure forming mechanisms:



The goal of this study is to evaluate the behavior of two commercially proven and highly reliable LTCC dielectric materials, Ferro A6M-E and Ferro L8, as well as the developmental Ferro K3.8 (ERS3702), at elevated temperatures up to 450°C to assess their applicability for high temperature operation. The secondary goal is to initiate a dialogue in attempt to establish reliability requirements for LTCC packages dedicated for high temperature operation.

Important to remember: In this paper, we focus only on basic high temperature electrical properties of the LTCC dielectrics, and not on the properties of the entire LTCC package. More studies need to be conducted to properly assess the performance and reliability of LTCC packages at elevated temperatures as they combine properties of both the semiconductor components and the LTCC dielectric together.

Samples Preparation for the High Temperature Characterization

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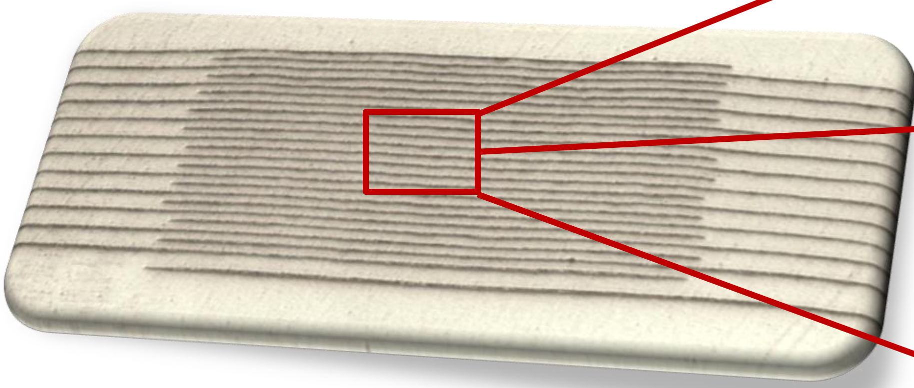
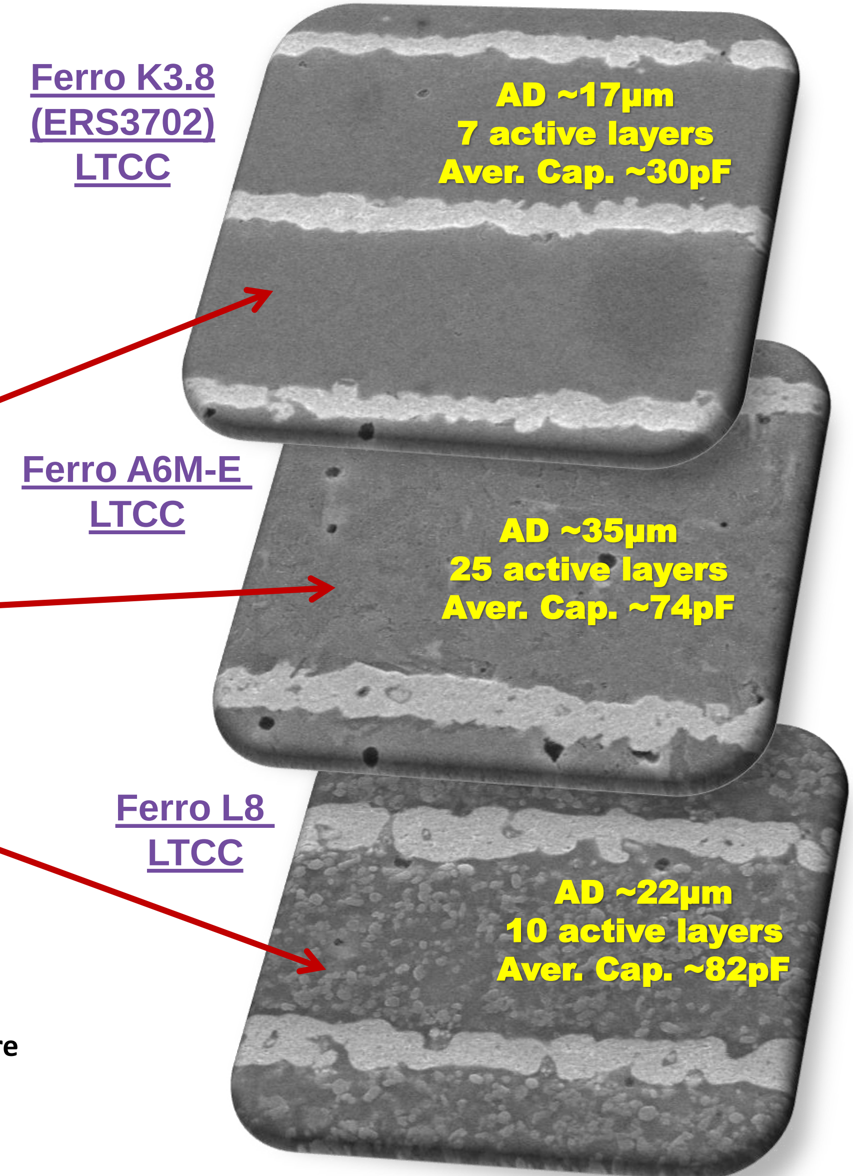
To improve accuracy of the high temperature electrical measurements of the low-K LTCC dielectrics, the test samples were fabricated in the form of multilayer ceramic capacitor chips.

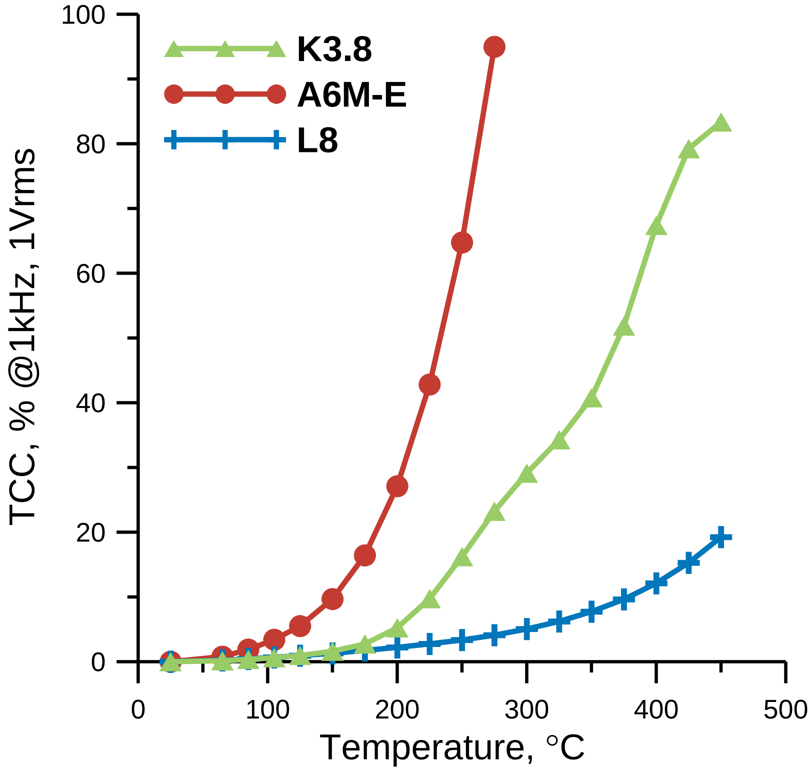
Commercially available Ferro A6M-E and Ferro L8 LTCC tapes and the Ferro K3.8 tape were used to manufacture .1206-type MLCC chips with silver metallization using a traditional MLCC buildup process.

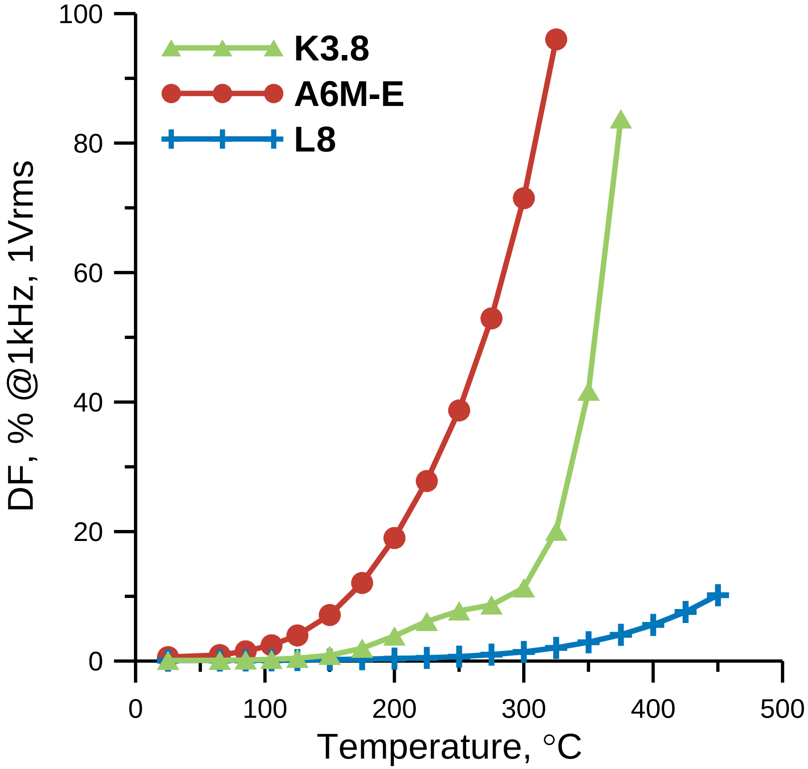




The A6M-E-based chips were fired using recommended binder burnout and firing temperature-time profiles with 850°C peak temperature and 15 minutes soak. For Ferro K3.8 and L8 based chips, the temperature-time profile with 825°C peak temperature and 30 minutes soak was used.

High Temperature Temperature Coefficient of Capacitance and Dissipation Factor





Ferro K3.8 (ERS3702), A6M-E, and L8 LTCC dielectrics exhibited different temperatures at which the conductivity losses through the glassy phase of the glass-ceramic composites start to contribute to the overall capacitance and insulation resistance.

High Temperature
Electrical Resistivity and Electrical Conductivity

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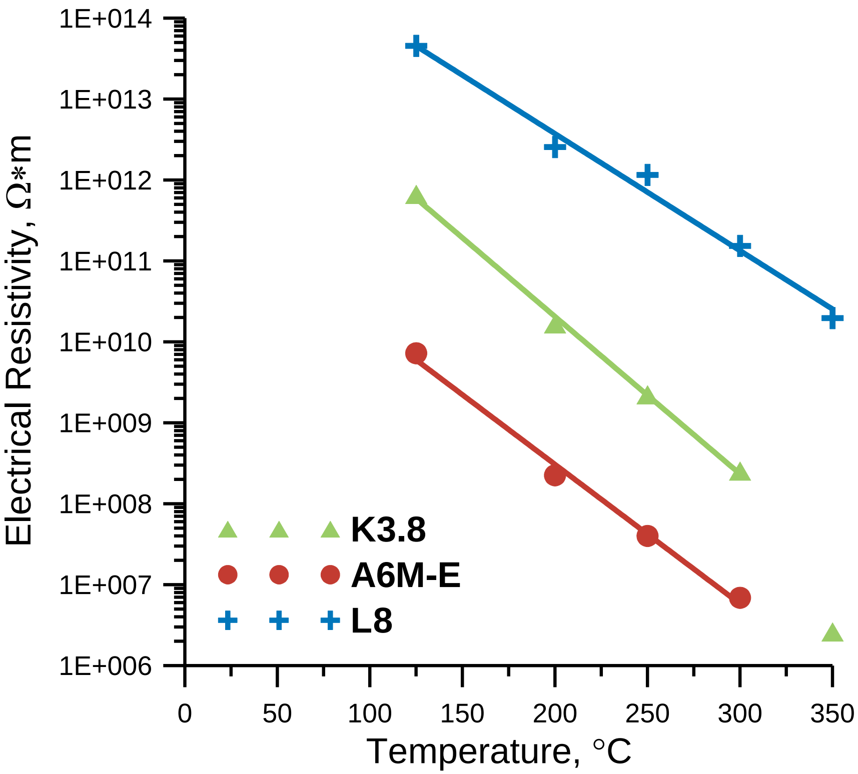
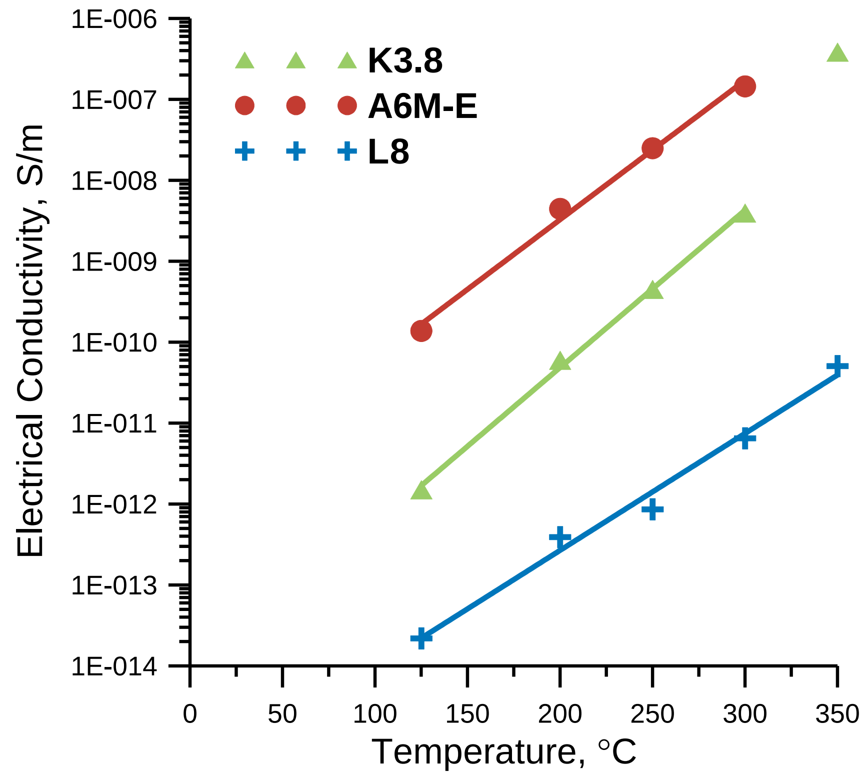
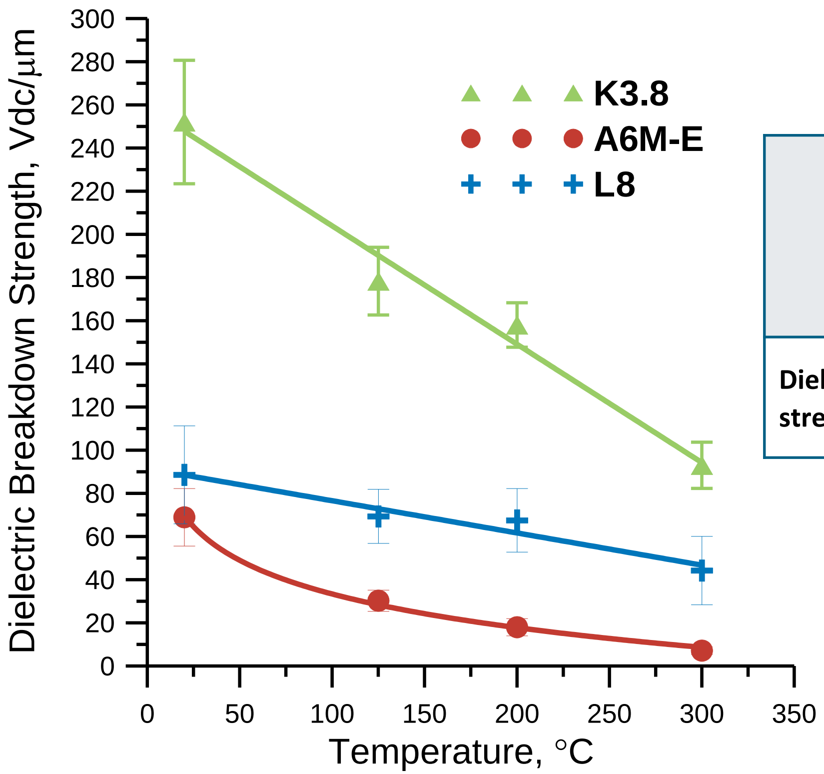




High temperature measurements of Ferro K3.8 (ERS3702), A6M-E, and L8 LTCC dielectrics suggest different temperature ranges at which the materials maintain insulative properties.

High Temperature Dielectric Breakdown Strength



Properties at Ambient Conditions	Ferro K3.8 (ERS3702)	Ferro A6M-E LTCC	Ferro L8 LTCC
Dielectric breakdown strength, Vdc/µm	>100	>30	>35

A non-linear behavior of Ferro A6M-E's DBS is likely the result of the contribution of electrical conductivity through the dielectric at elevated temperatures.

High Temperature Dielectric Reliability

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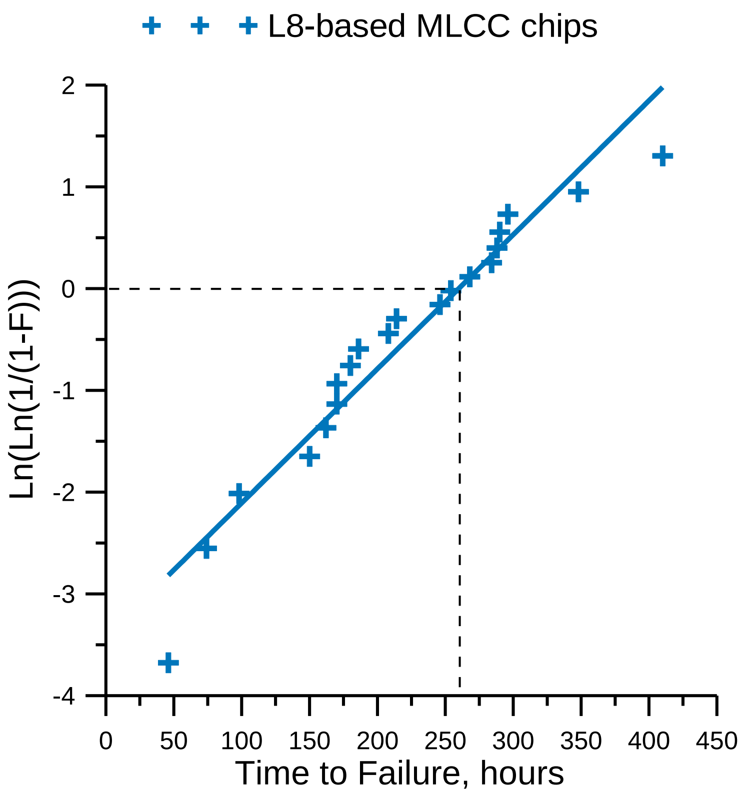
HALT: 300°C/50Vdc (2.3Vdc/μm)



Properties	After 2 hours	After 250 hours
Electrical Resistivity, Ω*m	$1.2*10^{11}$	$4.7*10^{10}$

HALT failure criterion:

A capacitor was considered failed when there was at least an order of magnitude increase of voltage across the resistor, which is in series to the tested capacitor.

MTTF of 250 hours and stable IR indicates that neither an ionic conductivity through the glass-ceramic dielectric or silver migration had any considerable impact on resistivity of the Ferro L8 material.

Conclusions

- This study was our first attempt to understand the effect of elevated temperatures on basic dielectric characteristics of two commercially successful LTCC materials widely used in the high reliability aerospace and defense applications.

- It is important to remember that this study does not reflect on the potential high temperature performance and reliability of the LTCC packages, as they consist of various semiconductor components and the LTCC dielectric as the host media but provides new physical property information which can help to better design components.

- The need to consider performance of semiconductor components at elevated temperatures elucidates the need to have an integrated approach for developing design guidelines and rules for high temperature LTCC packages. Collaboration between both, LTCC material designers and package designers is needed to advance the understanding of package design guidelines for future high temperature, high reliability applications.

Acknowledgements

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Thank You Very Much for Your Interest!

Questions?