Dielectric Performance of High Purity HTCC Alumina at High Temperatures

- A Comparison Study with other Polycrystalline Alumina

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Outline

- Background
  - 500°C electronics and sensors
  - Polycrystalline Al_2O_3 substrate materials as packaging substrates
  - 96% Al_2O_3 prototype packages for 500°C SiC electronics and sensors
  - Assembly issue of 96% alumina chip-level packages
  - A new high purity (HP) HTCC alumina material, for high temperature applications?
- Measurement of dielectric properties
  - AC impedance method and parallel plate capacitor
  - Capacitive test device and parallel RC circuit model
- Dielectric constant data of HP HTCC alumina
- AC conductivity data of HP HTCC alumina
- Summary and Discussion
- Discussion on metallization for HP HTCC alumina

Background – 500°C SiC electronics 96% alumina and previous work

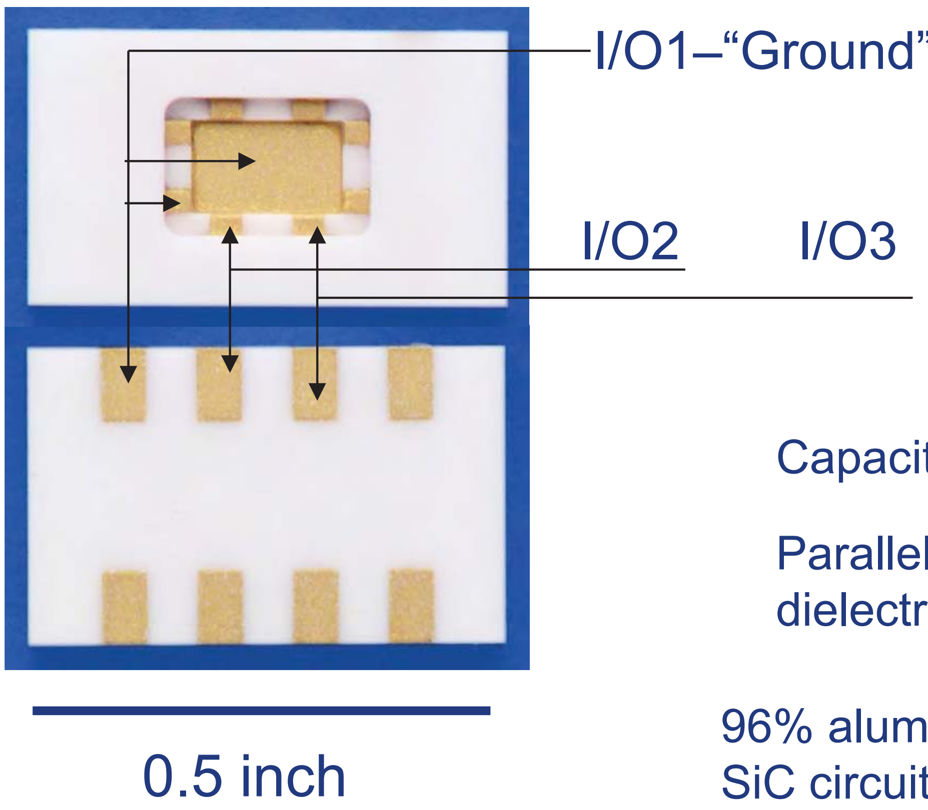
Background

- 500°C SiC electronics and sensors for aerospace engine control and long term Venus exploration
  - SiC devices and circuits (JFET, logic gates, and amplifiers) demonstrated at 500°C over thousands hours
- Al_2O_3 ceramic substrate material
  - Excellent electrical and dielectric properties as substrate for conventional electronics
  - Thin-film and thick-film metallization developed
  - 96% alumina suggested for applications at high temperatures
  - Dielectric properties of 96% alumina measured at temperatures up to 550°C
  - 96% alumina packaging system tested with SiC electronics at 500°C for over 10,000 hours
  - Chip-level packages not fabricated with co-fired process
- HP HTCC alumina available on market
  - 99.99+% pure and nano particles based HTCC alumina
  - Dielectric performance at high temperatures of HP HTCC alumina?

Background – 96% alumina based chip-level packages

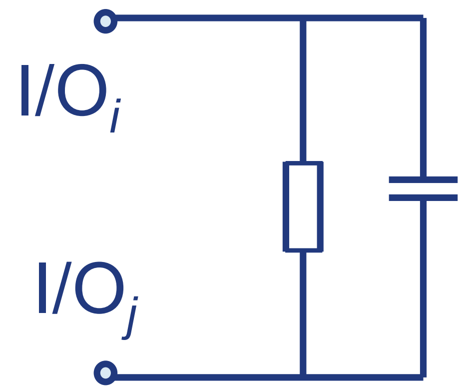
96% Al_2O_3 Substrate Based Chip-level Packages

96%Al_2O_3 Packages



Compatible PCB also developed

Parasitic Equivalent



Capacitance: dielectric polarization

Parallel resistance: DC leakage and AC dielectric loss

96% alumina packaging system tested with SiC circuits at 500°C for over 10,000 hours

Laboratory steps involved in fabrication

Background – Parasitic parameters of 96% alumina based chip-level packages at 500°C

96% Al_2O_3 Substrate Based Chip-level Packages

f (Hz) \ T (°C)	T_R	100	150	200	250	300	350	400	450	500	550
100	0.00nF	0.00nf	0.00nF	0.00nF	0.00nF	0.00nF	0.00nF	0.00nF	0.00	**5**	5
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.005	0.00	0.00
120	1.5	-	1	1	1.5	2	2.0	2.0	2.5	4	4
	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.000	0.0015	0.002	0.0025
1K	1.5	1.3	1.3	1.4	1.35	1.5	1.6	1.75	1.85	2.15	2.35
	0.001	0.000	0.00	0.000	0.000	0.001	0.001	0.002	0.0025	0.004	0.0055
10K	1.36	1.33	1.3	1.36	1.35	1.46	1.43	1.56	1.54	1.63	1.74
	0.003	0.000	0.000	0.001	0.001	0.002	0.004	0.006	0.010	0.015	0.020
100K	1.33	1.38	1.28	1.36	1.36	1.44	1.36	1.427	1.42	1.53	1.47
	0.015	0.006	0.006	0.007	0.009	0.0135	0.018	0.0255	0.036	**0.052**	0.071
1M	1.29	1.30	1.29	1.40	1.35	1.45	1.33	1.39	1.42	1.45	1.47
	-	-	-	-	-	-	-	-	-	0.043	0.12

Parasitic capacitance and conductance of neighboring pins of 96%Al_2O_3 Packages – usable for many low frequency low power 500°C SiC circuits

AC Impedance Method

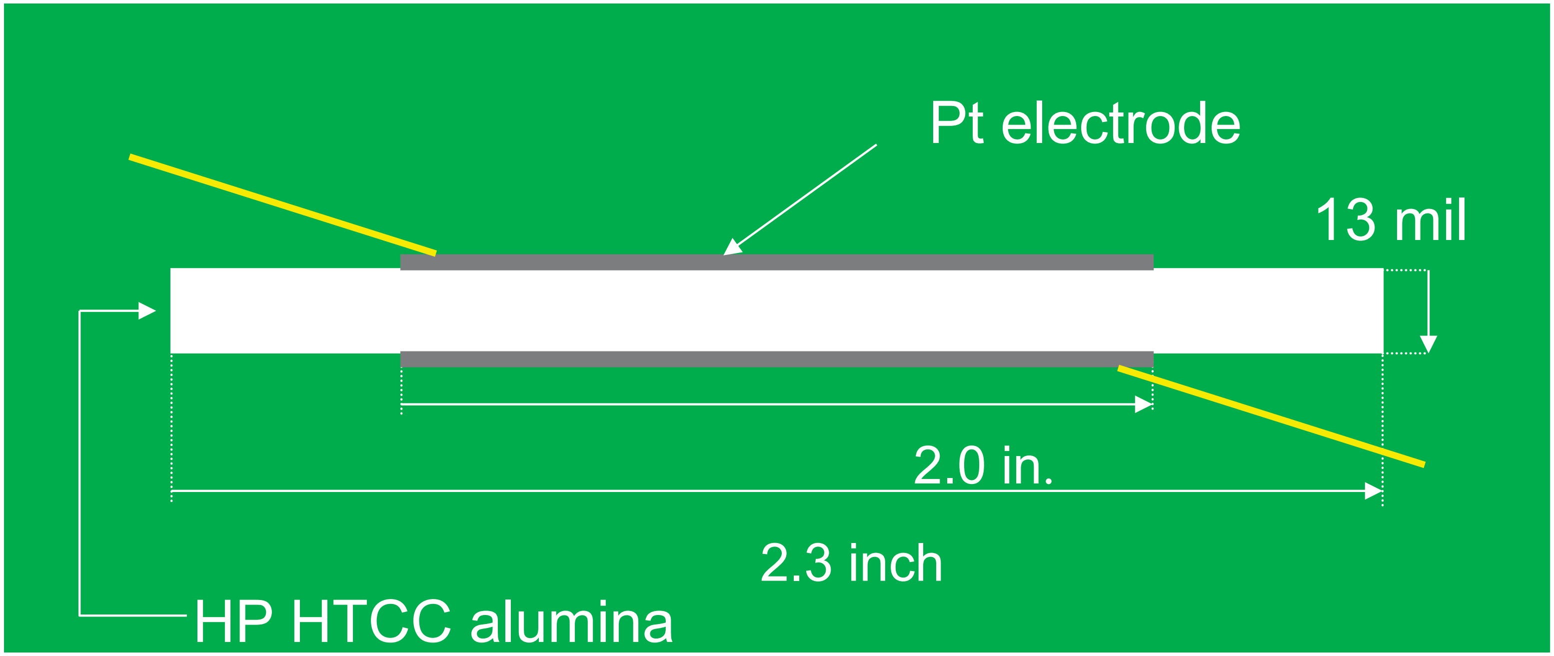
- Alumina dielectric based capacitive device
- AC impedance method is measured
- Dielectric constant and AC conductivity (parallel RC circuit model) measured through impedance

$$Y(T,\omega) = \sigma_{eff}(T,\omega) \bullet A/d + j\omega\varepsilon'\varepsilon_o(T,\omega)A/d$$

Y(T, ω) =1/Z(T, ω)
T: temperature
ω: frequency
A: electrode area
d: thickness of dielectric
σ_{eff}: *effective conductance*
ε': relative dielectric constant
ε_o: *vacuum dielectric constant*

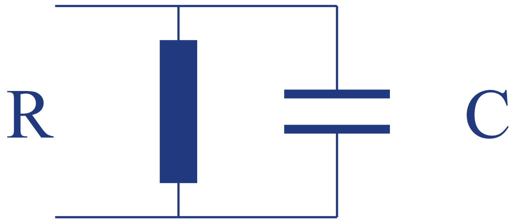
- Measured from room temperature to 550°C, in air ambient
- At 120 Hz, 1 kHz, 10 kHz, 100 kHz, and 1 MHz
- Measurements conducted in a box-oven

Capacitor Device for Dielectric Properties Measurement

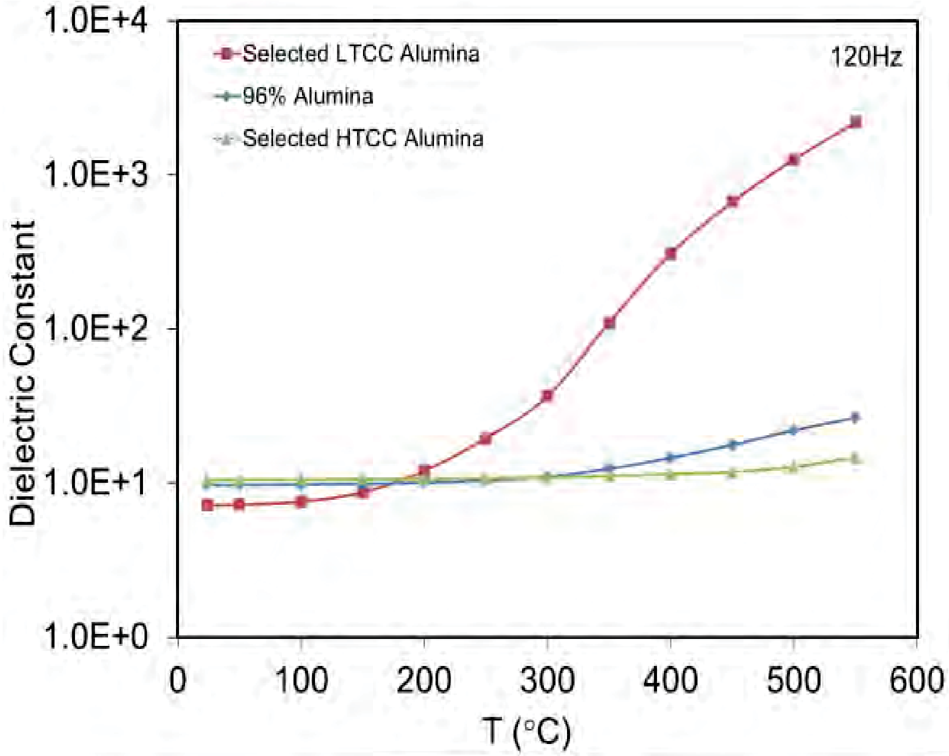


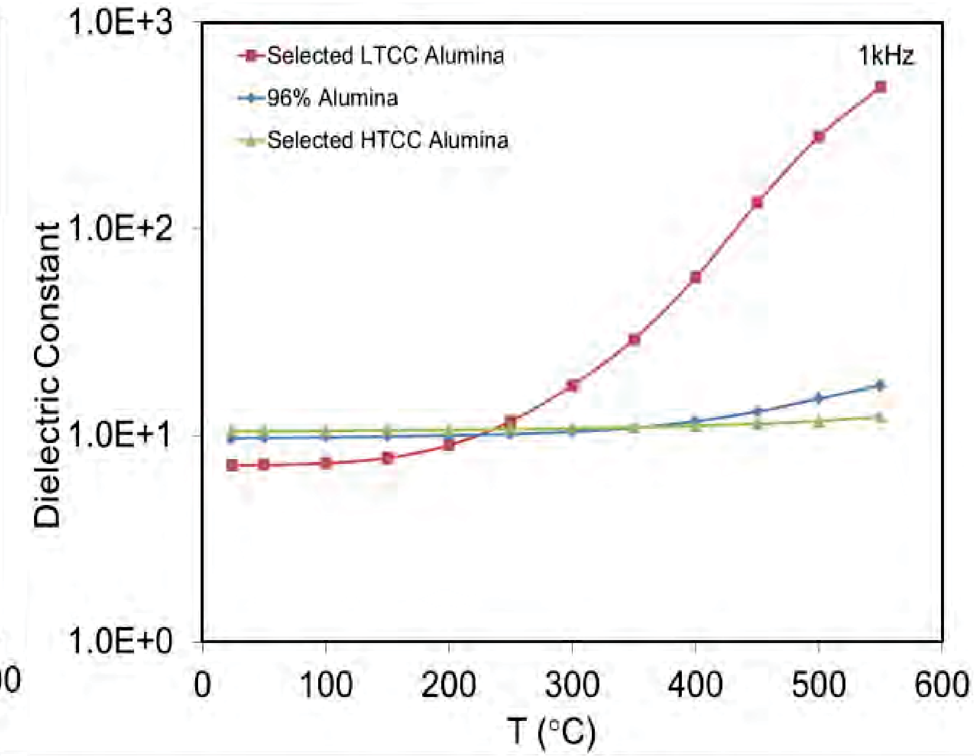
RC parallel equivalent circuit

- R for response of free charge carriers
- C for response of bound charge carriers



HTCC alumina compared with 96% alumina - Dielectric Constant

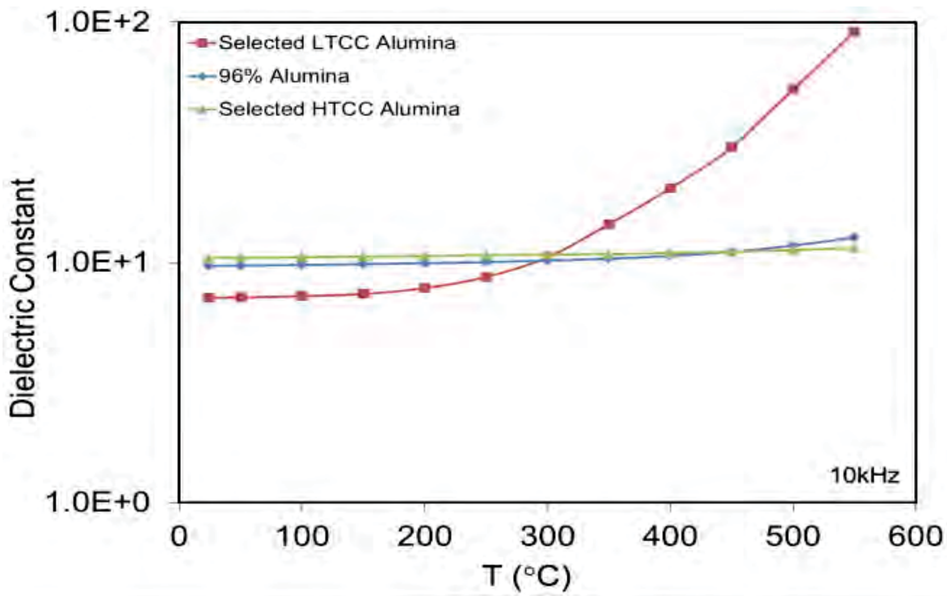


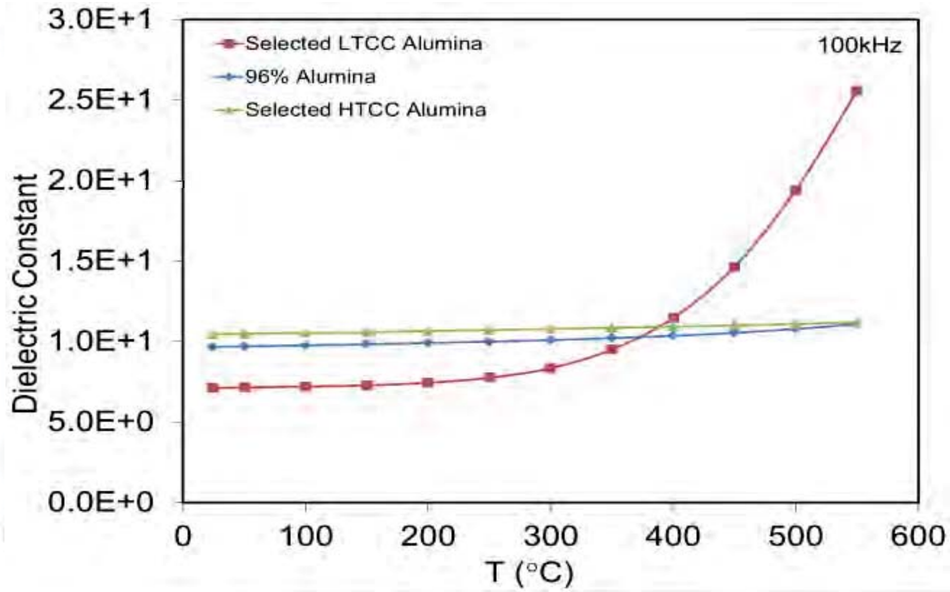


Dielectric constant of HP HTCC alumina is close to 96% alumina below 300°C and increases less with temperature at 120Hz and 1kHz, compared with 96% alumina

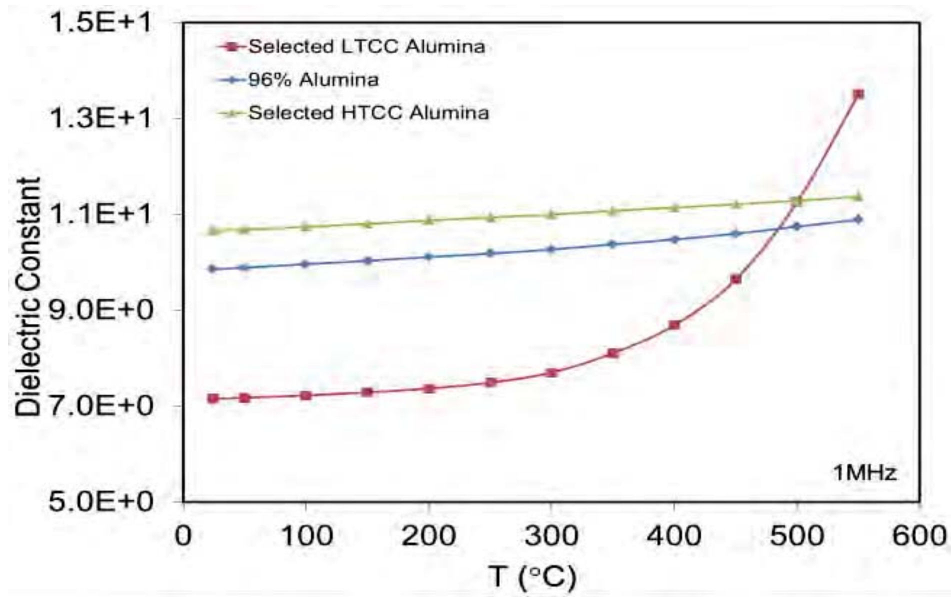
Dielectric constant of LTCC alumina stable below 300°C, increases more with T above 300°C

HTCC alumina compared with 96% alumina - Dielectric constant

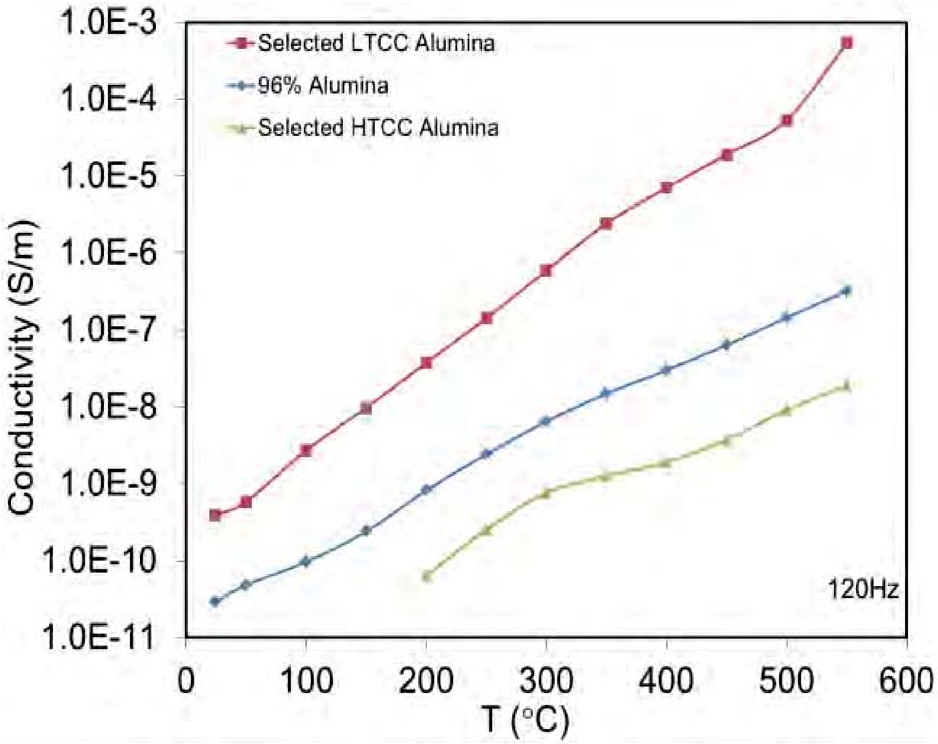


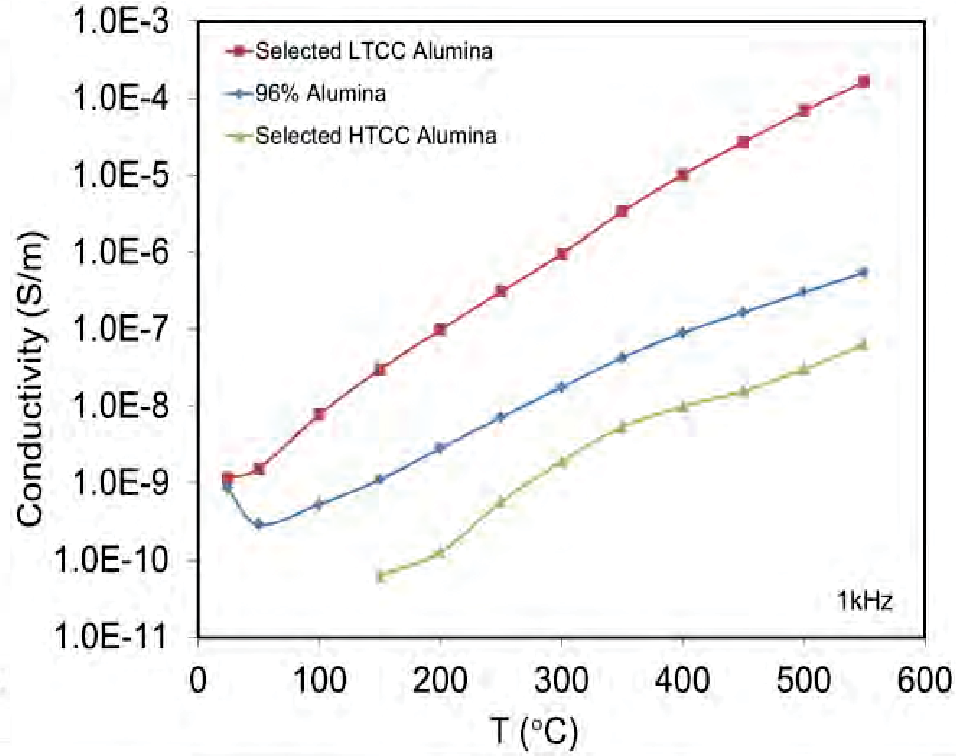


- Dielectric constant of HP HTCC alumina is close to 96% alumina and increases less with T
- Dielectric constant of LTCC alumina increases more rapidly with T above 300°C
- 100kHz and 1 MHz data are in linear scales



HTCC alumina compared with 96% alumina - Parallel conductivity

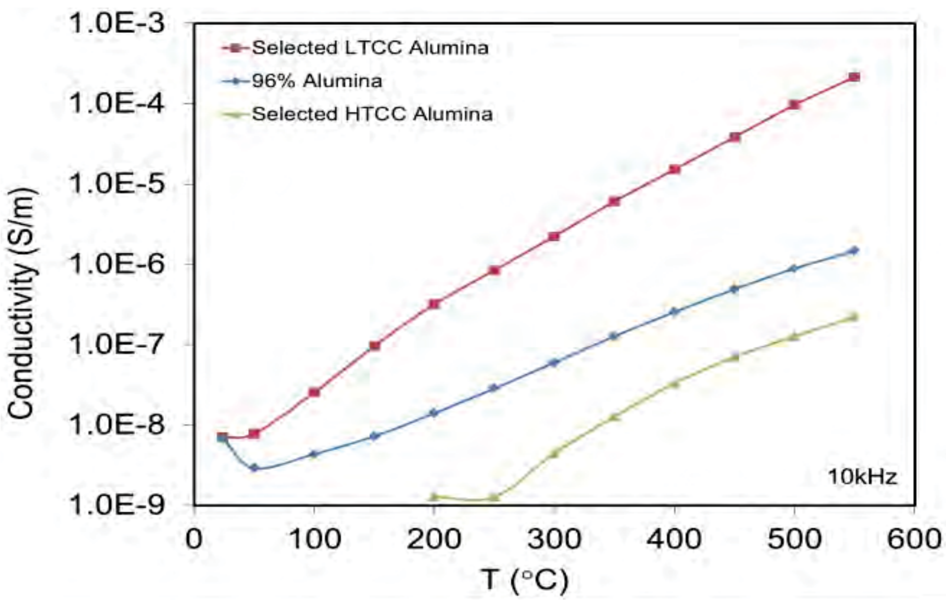


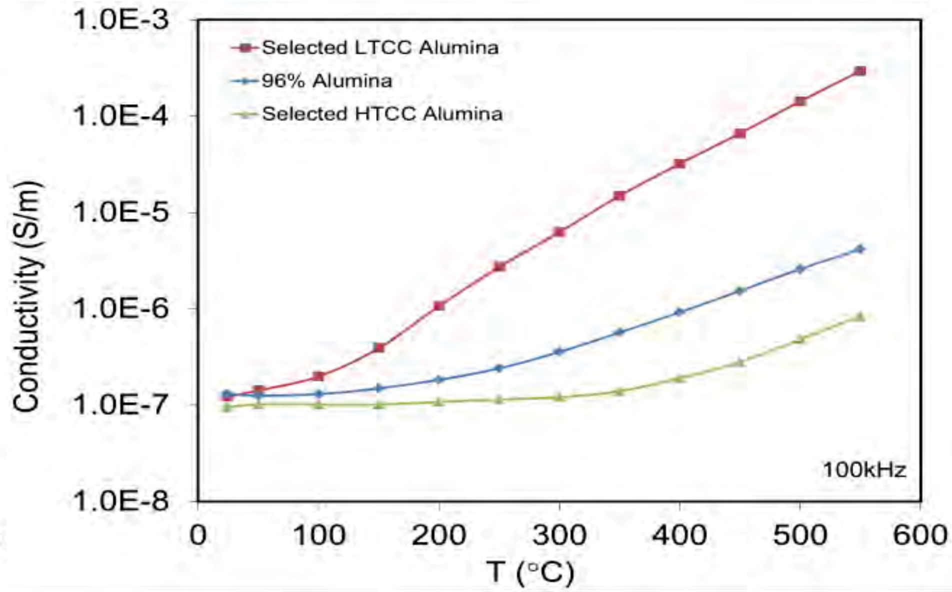


Conductivity of HP HTCC alumina is ~ an order of magnitude lower compared with 96% alumina at 120Hz and 1kHz

Conductivity of LTCC alumina is higher than 96% alumina and it increases rapidly ~ 300°C at both 120Hz and 1 kHz

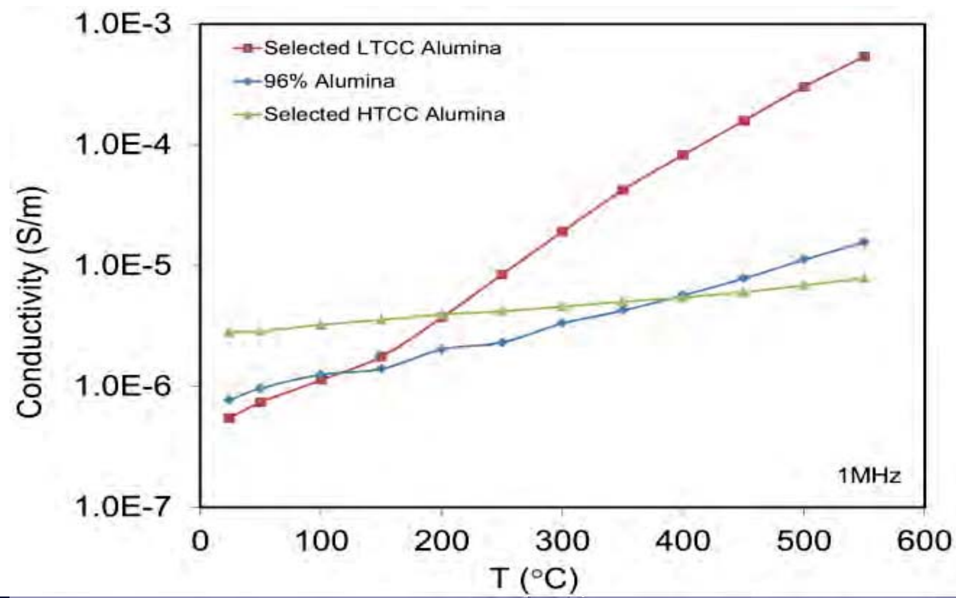
HTCC alumina compared with 96% alumina - Parallel conductivity



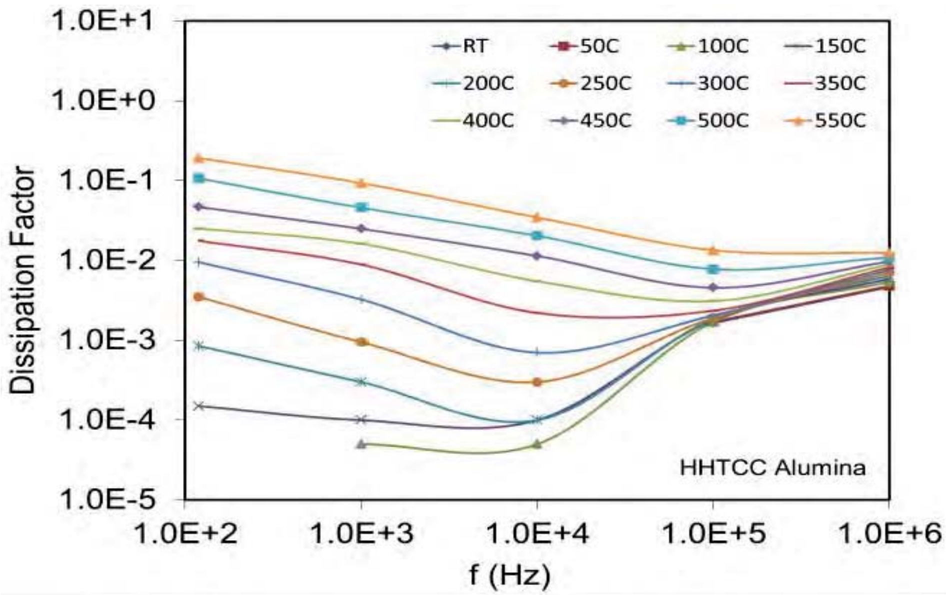


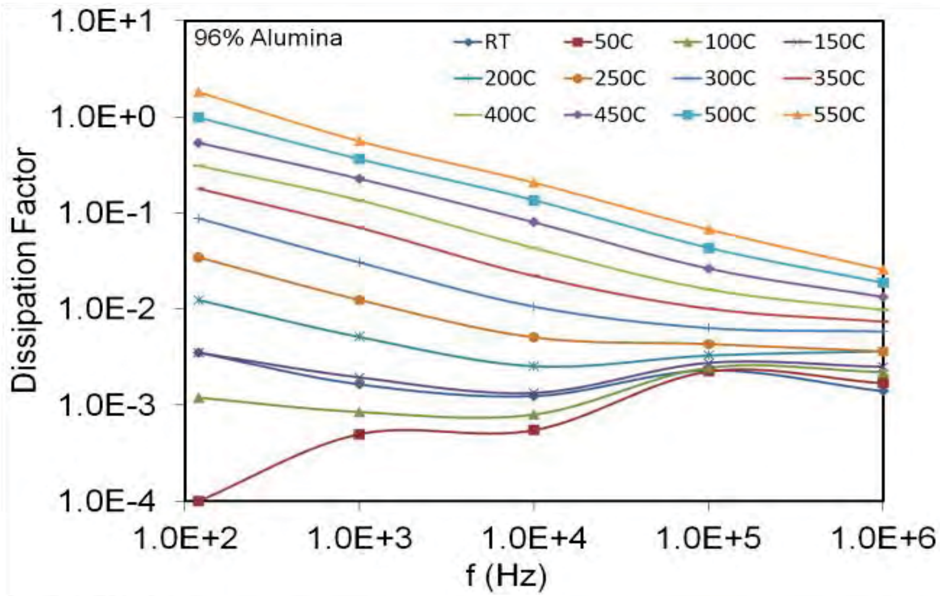
- Conductivity of HP HTCC alumina is lower and at temperatures above 400°C at 10kHz, 100kHz, and 1 MHz

- Conductivity of LTCC alumina is higher than 96% alumina and it increases rapidly above ~ 300°C at 10kHz, 100kHz, and 1 MHz



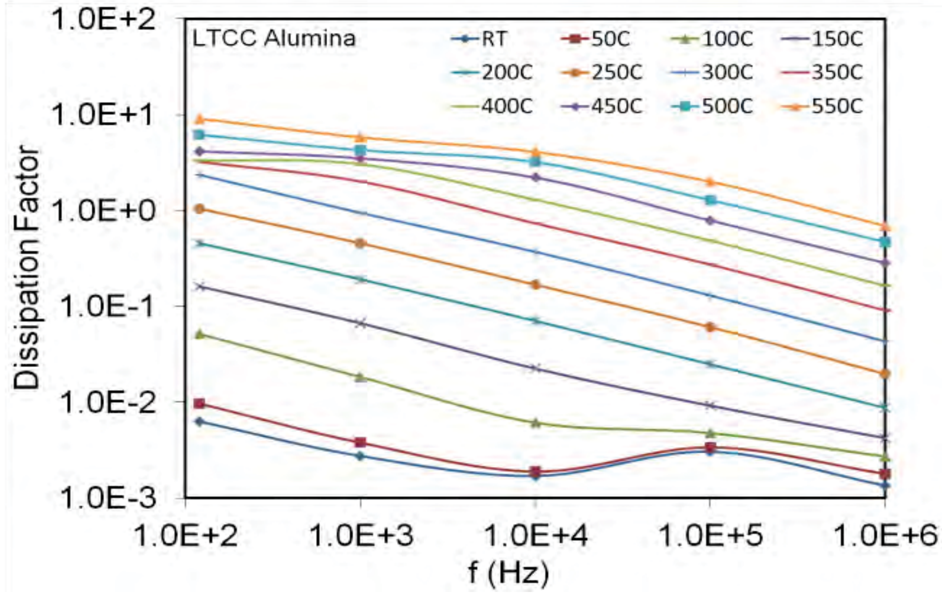
HTCC alumina compared with 96% alumina - Dissipation factor





Compared with 96% alumina

- Dissipation factor of HP HTCC alumina is always lower compared with that of 96% alumina at temperatures above 450°C
- Dissipation factor of LTCC alumina is always higher at temperatures above 100°C



Electrical Performance of Co-Fired Alumina Substrates At High Temperatures

Summary and Discussion

Compared with 96% Al_2O_3

- Dielectric constant of HP HTCC alumina is very close to that of 96% alumina, AC conductivity of HP HTCC alumina is lower compared with 96% alumina at temperatures above 400°C
  - Dielectric constant and AC conductivity of LTCC alumina increase with T rapidly above 300°C, so this material is more suitable for the temperature range below 350°C
  - Dissipation factor of HP HTCC alumina is lower at temperatures above 450°C
  - Dissipation factor of LTCC alumina is always higher at temperatures above 100°C
- HTCC alumina is usually better for hermetic sealing compared with LTCC alumina

Metallization for HTCC Co-fired Alumina

- HTCC alumina materials co-fired with thick-film metallization at T ~1550°C in noble environment
- More often metals with low CTE metals such as tungsten and molymanganese used with HTCC alumina
- These more conventional metal/alloys have relatively high electrical resistivity, and oxidation issues for long term operation in high temperature air ambient
- Platinum (Pt) thick-film materials designed for HTCC and HP HTCC alumina substrates more suitable for 500°C packaging applications
  - Aluminum oxide used as the binder for Pt thick-film materials designed for HTCC alumina
  - Alumina-alumina bonds at thick-film/substrate interface expected thermodynamically stable in a wide temperature range
  - An over-layer of gold on Pt surface may provide the material compatibility for gold wire-bonding, and gold/gold alloy die-attach

Thank You for Your Attention!

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