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Localized Temperature Stability in A Multilayer LTCC Package

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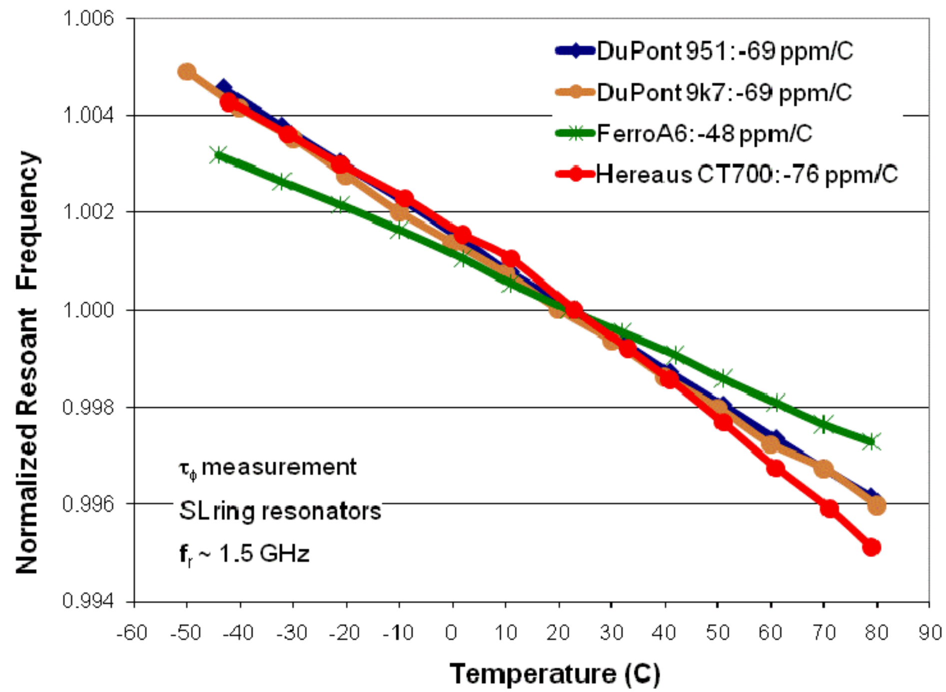
Outline

- Introduction
- Characterization
  - Temperature coefficient of resonant frequency, τ_f
  - The temperature coefficient of capacitance, τ_c
- τ_f compensating materials
  - Formulation and processing
  - Characterization
  - Cofireability with LTCC
- Temperature compensated stripline ring resonator
  - Panel fabrication
  - Near zero τ_f realization
- Summary

Introduction: τ_f

- Low τ_f is need for
  - Efficient use of wireless frequency bandwidth
  - Elimination of costly temperature compensation mechanisms

- Most existing LTCC dielectrics have non-zero τ_f
  - Require design tradeoffs with embedded resonant functions

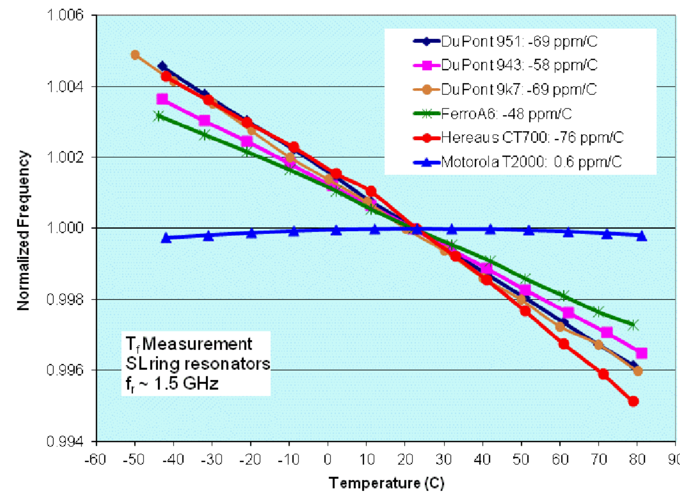


τ_f of commercial LTCC dielectrics

-50 to -80 ppm/°C

Introduction: τ_f compensation

- **Solid solution of dielectric ceramics with opposite τ_f**
  - Microwave dielectrics*
  - LTCC



- **Hybrid stacks having alternating layers with opposite τ_f**
  - Sequential sintering of Al_2O_3/TiO_2
  - Adhesive bonded structure

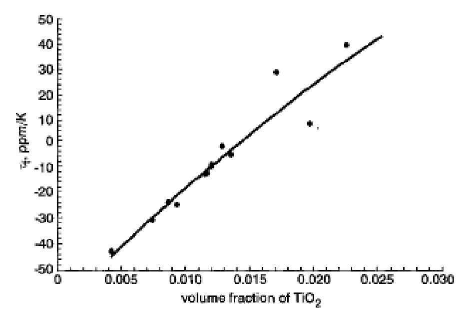
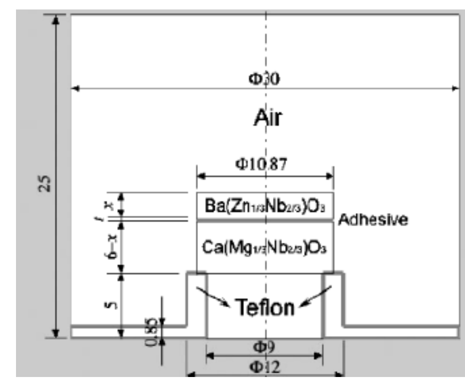


Fig. 4 τ_f against volume fraction of TiO_2
● measured
— predicted



* W. Wersing, "Microwave Ceramics for Resonators and Filters", Solids State and Mat Sci, 1(5), pp 715–731, 1996

N. Alford, Jet al "Layered Al_2O_3-TiO_2 Composite Dielectric Resonators With Tunable Temperature Coefficient for Microwave Applications", IEE Proc-Sci. Meas. Technol., Vol. 147, No. 6, pp 269-273, 2000.

L. Li and X. M. Chen, "Adhesive-Bonded $Ca(Mg_{1/3}Nb_{2/3})O_3/Ba(Zn_{1/3}Nb_{2/3})O_3$ Layered Dielectric Resonators with Tunable Temperature Coefficient of Resonant Frequency", J. Am. Ceram. Soc., 89, pp. 544–549, 2006.

Localized temperature stability in LTCC

Objective

to adjust the temperature coefficient by locally integrating a compensating dielectric with a τ_f opposite to that of host LTCC dielectric in a multilayer structure

- Applicable to many LTCC systems
- Use of existing cofireable materials

Challenges

- Development of τ_f compensating materials
- Cofiring of τ_f compensating materials in multilayer LTCC
  - Physical compatibility: match of shrinkage and shrinkage rate
  - Chemical compatibility: no or minimum interfacial reaction/inter-diffusion

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Candidates for τ_f adjustment

$\tau_f = -\frac{1}{2}\tau_K - \alpha$

$\tau_f = -\frac{1}{2}(\tau_c + \alpha)$

τ_K = temperature coefficient of dielectric constant

α= coefficient of thermal expansion (CTE)

α: 3-10 ppm/°C → τ_K/ τ_f dominates τ_f

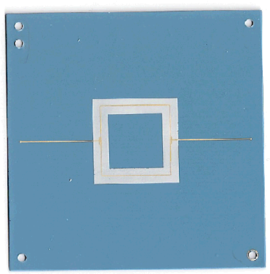
τ_K/ τ_f is in opposite sign of τ_f

Materials	Density (g/cm^3)	K	τ_K (ppm/°C)	τ_f (ppm/°C)	Sintering Temp(°C)
TiO_2	4.23	85	-750	370	~ 1200
$CaTiO_3$	3.98	180	-1850	920	~ 1400
$SrTiO_3$	5.13	300	-3000	1500	~ 1550
Al_2O_3	4.00	9.6	105	-60	~ 1600
V-glass	2.77	7.3	N/A	N/A	Tg= 625°C

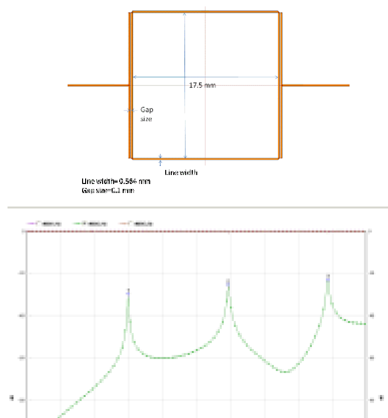
A commercial LTCC glass, V-glass, is selected to form cofireable τ_f compensating materials

Characterization of τ_f and τ_c

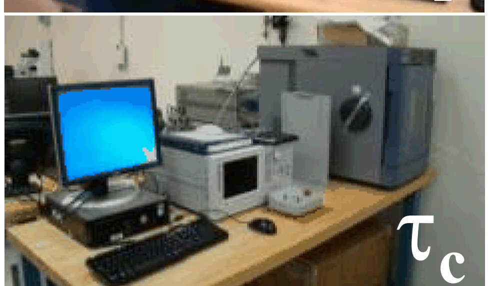
- **Test vehicle**

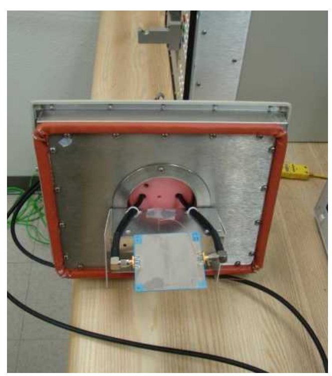


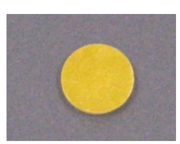
1.5GHz



- **Test setup**







- Test method
  - Resonant frequency f_r from reflection coefficient S11
  - Temperature range -50 to -80 ppm/°C
  - $$\tau_f = \frac{1}{f_r}\frac{\Delta f}{\Delta T}$$

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Formulation and processing of compensating materials

Compo-sition	V- Glass (wt%)	Al_2O_3 (wt%)	TiO_2 (wt%)	$CaTiO_3$ (wt%)	$SrTiO_3$ (wt%)	Total
Base	55	45	0	0	0	100
TO15	55	30	15	0	0	100
TO30	55	15	30	0	0	100
CTO10	55	35	0	10	0	100
CTO20	55	25	0	20	0	100
STO10	55	35	0	0	10	100
STO20	55	25	0	0	20	100

- **Powder was co-milled to size 2.0 to 2.2 mm using Al_2O_3 media**
- **ϕ12.5x1 mm pellets formed by uniaxial followed with isostatic pressure. Sintered at 850°C/30min**
- **Evaporated Au electrodes for dielectric measurement**
- **Pastes made using ESL441 organic vehicle and ESL401 thinner**

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Properties of compensating materials

Sample	Archimedes bulk density (g/cc)	Dielectric constant (1 MHz)	τ_c (ppm/°C)	τ_f (ppm/°C)
Base	3.19	7.8	190	-98.5
CTO10	3.20	9.7	83	-44.9
CTO20	3.15	12.0	-58	25.5
STO10	3.21	9.6	10	-8.7
STO20	3.30	12.2	-240	116.7

- **TO15 and TO30 lack of adequate densification**
- **CTO10 and STO10 still show positive τ_c , and thus negative τ_f**
- **STO20 was down selected for cofiring study and fabrication of proof-of-concept SL ring resonators**

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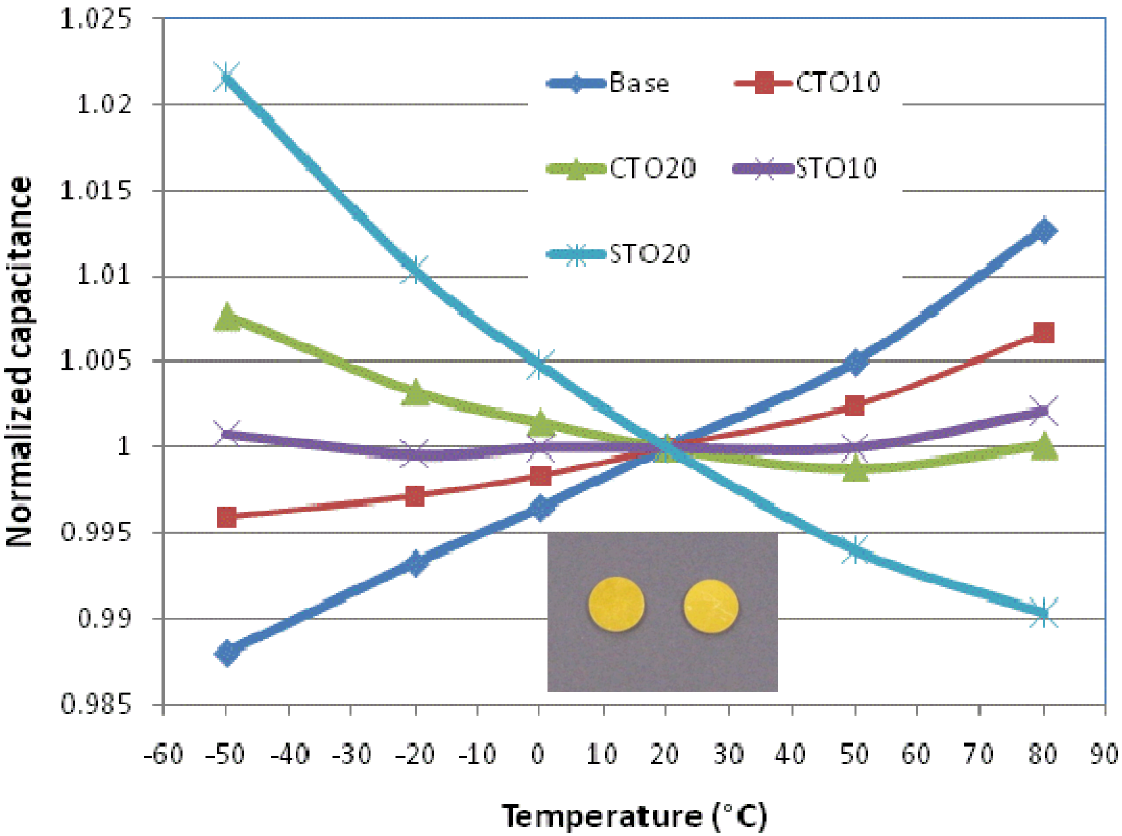
τ_c of compensating materials



- τ_c changes from negative to positive with the addition of $CaTiO_3$ and $SrTiO_3$
- STO20 is the has the largest τ_c

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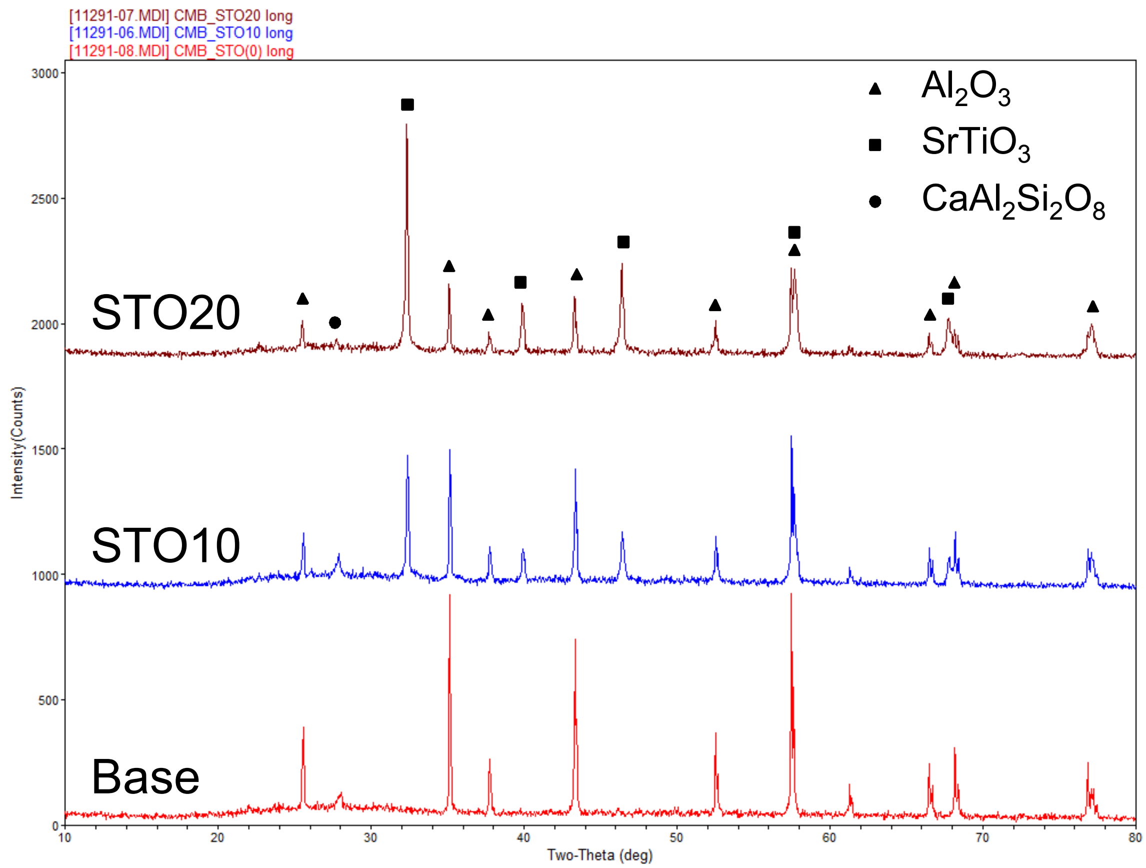
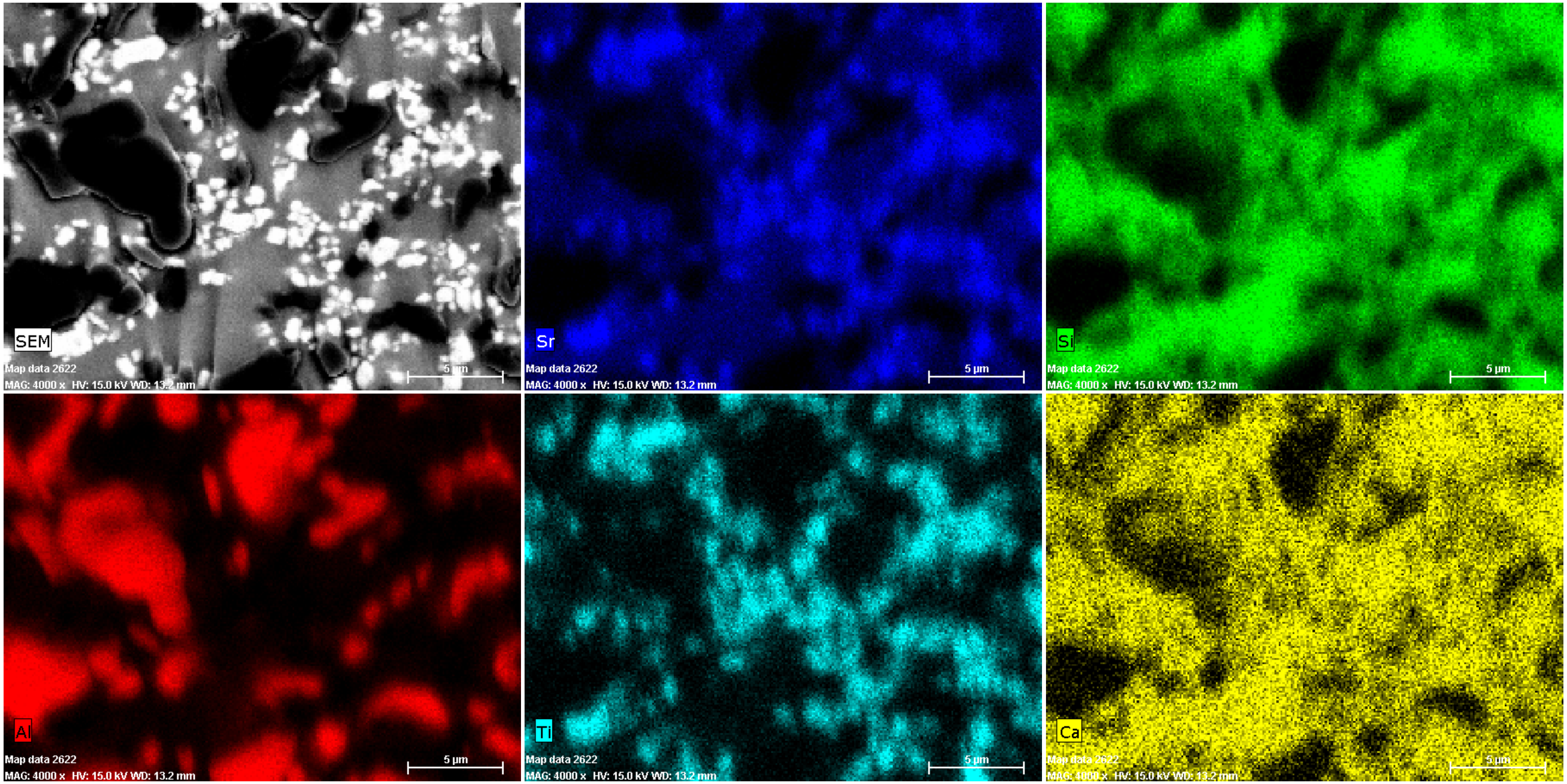
XRD of STO compositions



- Minor anorthite $CaAl_2Si_2O_8$ in base and STO compositions
- Clean Al_2O_3 and $SrTiO_3$ peaks in STO10 and STO20. No indication of compounds forming from glass-$SrTiO_3$ interaction. Important for process control.

SEM of STO20



- Clean Al_2O_3 and $SrTiO_3$ particles embedded in a glass matrix
- No or minimum glass-ceramics interaction or inter-diffusion

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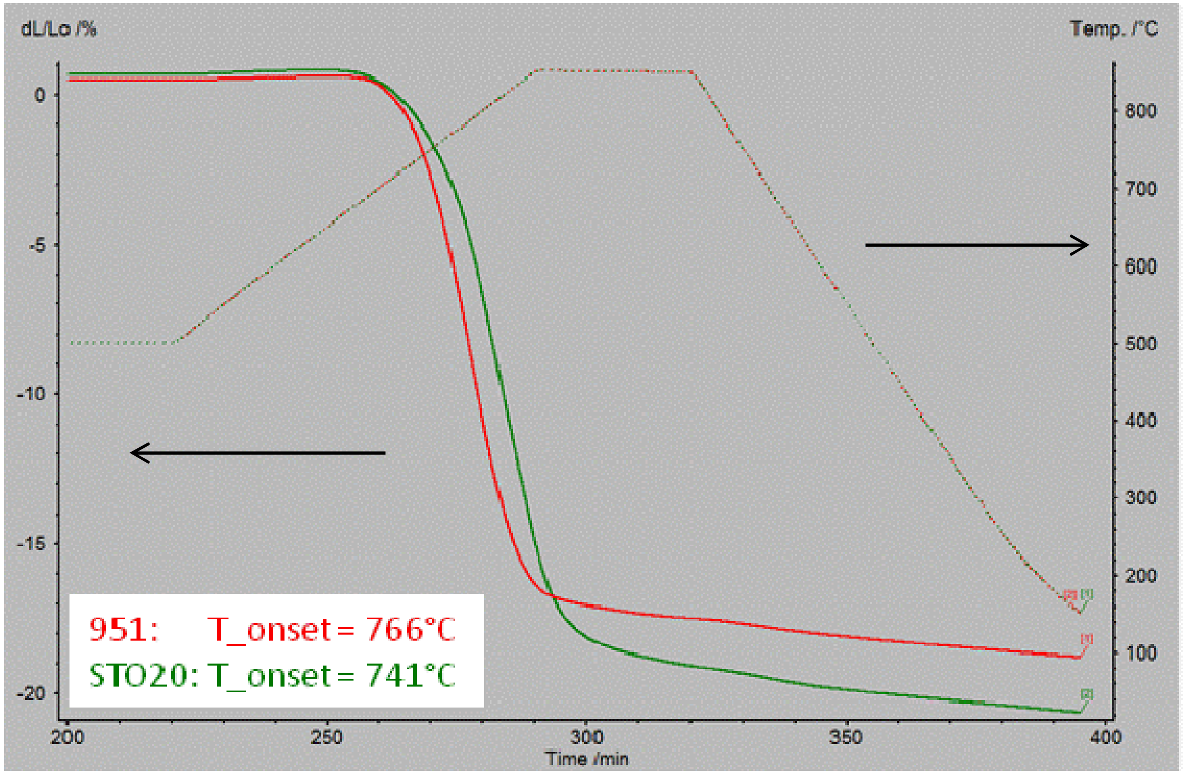
STO20 cofirability - dilatometry



- DuPont 951 LTCC is selected as the host dielectric
- The onset temperatures of shrinkage of STO20 and 951 are closely matched

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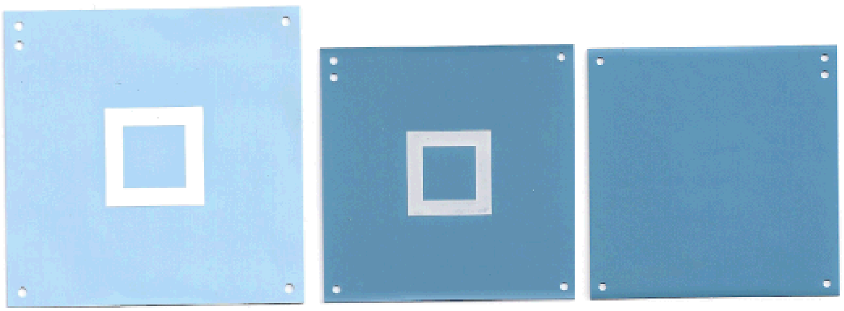
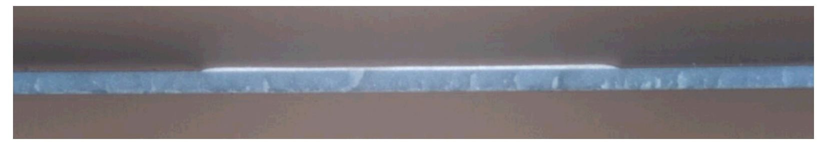
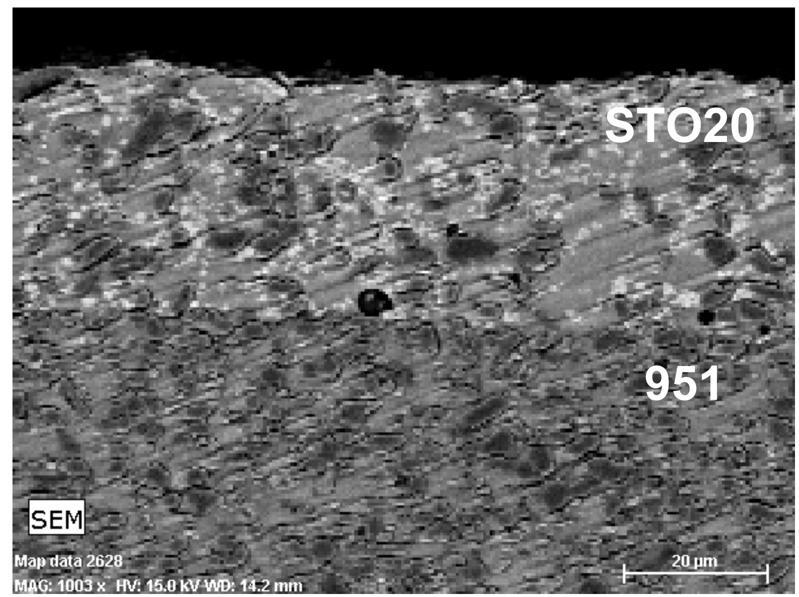
STO20 cofirability – printed layer on 951

Green | Sintered front | Sintered backside

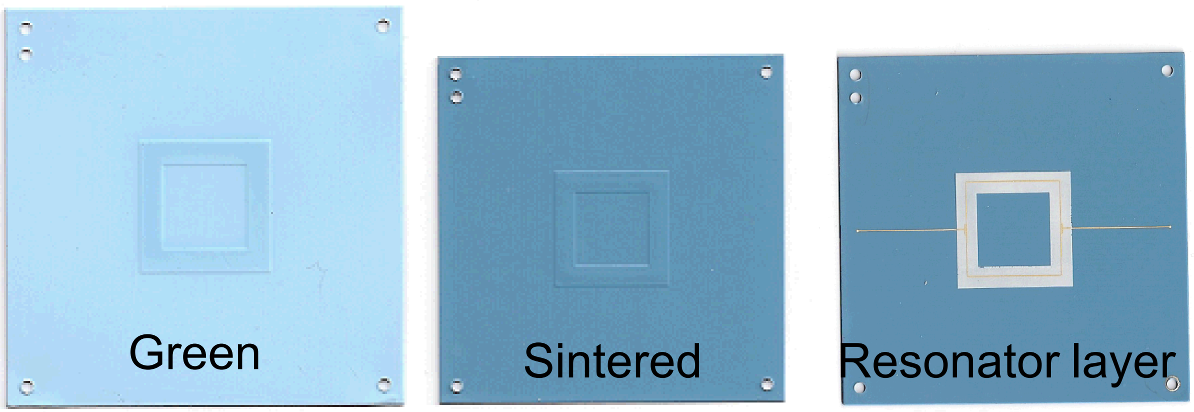


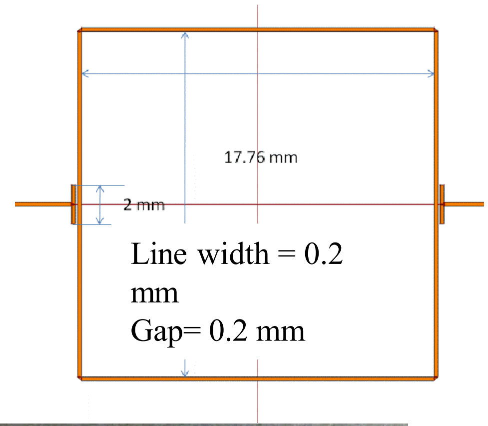




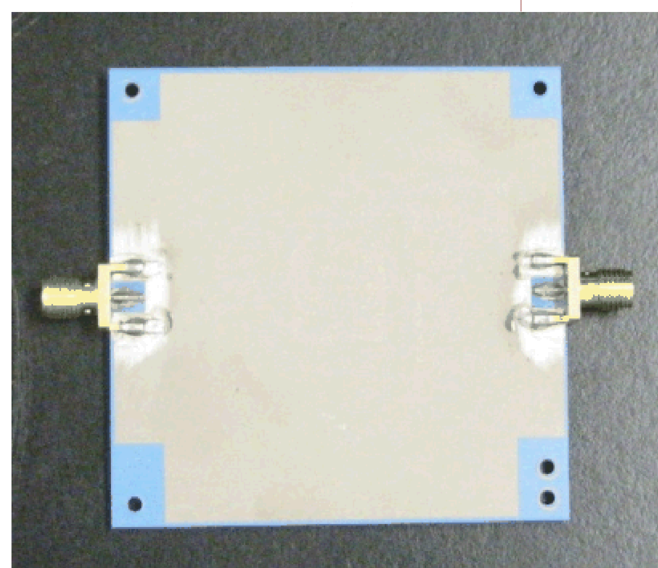
- **No deformation of cofired printed layer STO on a 10 mil 951 tape**
- **Both optical and SEM images show clean STO20/951 interface, suggesting no or minimum reaction**

SL resonator panels

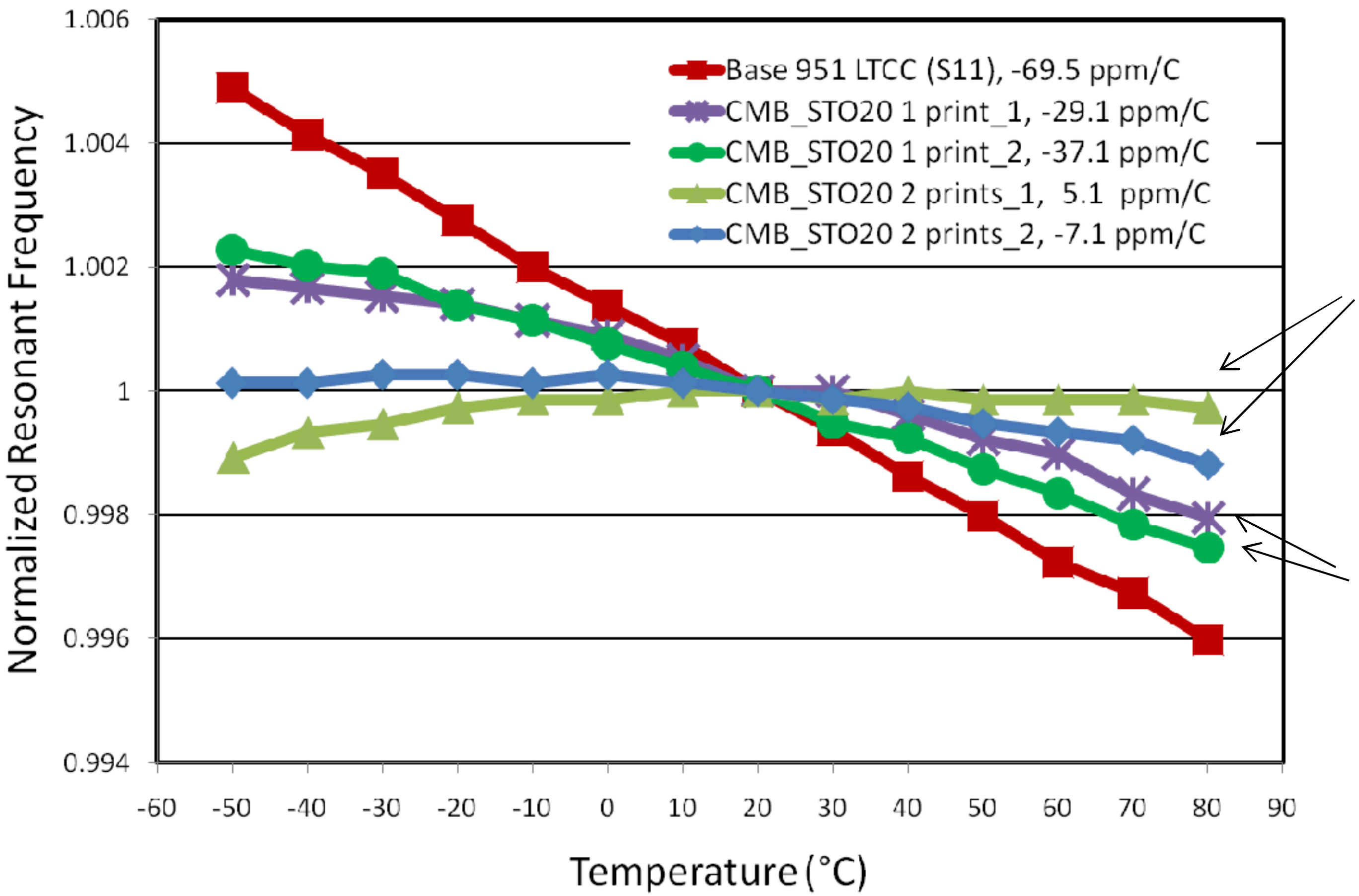


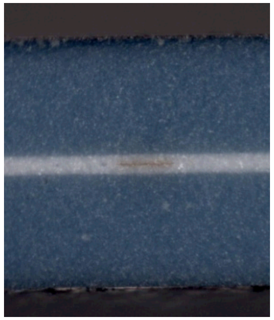


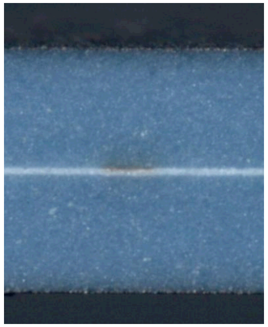
- **Standard LTCC fabrication with 951 matching conductors**
- **4 layers of 10 mil 951 tape. 50 Ω lines. f_r = 3GHz**
- **No localized deformation indicating sintering mismatch**
- **Embedded STO20 shown as “embossed” feature on the non-contact side during lamination**



τ_f Results

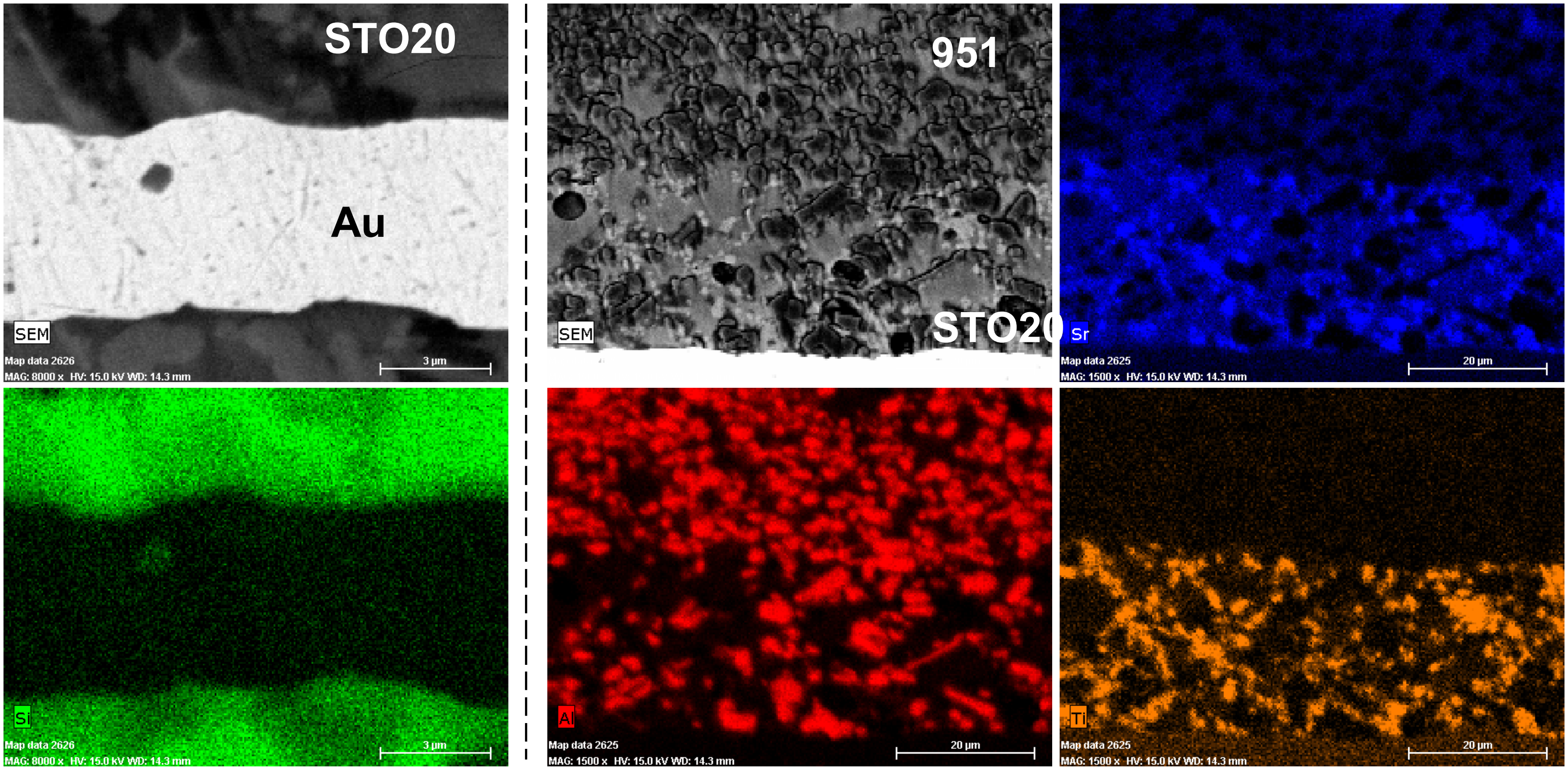






- A true near zero or zero τ_f is achievable
- Variation of τ_f possibly from variation of STO20 thickness

SEM cross-section of cofired STO20 in SL resonator panel



- **Cofired Au in STO20**
- **No reaction/inter-diffusion between STO20 and 951 LTCC**

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Summary

- SL resonators with a near 0τ_f have been demonstrated with a localized integration of τ_f compensating materials in a multilayer LTCC package

- The key is the development of shrinkage matched τ_f compensating materials

- The concept and approach are applicable to other LTCC systems, and potentially multilayer HTCC and PCB technologies

Status and future work

- Patent pending. Inquiries and collaboration are welcome
- Study on the composition window of compensating materials
- Modeling and simulation of τ_f adjustment

Acknowledgement

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