Compliant Dielectric and Magnetic Materials for Buried Components

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Capacitor and magnetic tapes compatible with a variety of LTCC tapes were formulated. One of the tapes with a dielectric constant of 100 was used to bury capacitors in LTCC tapes from DuPont and Motorola as well as ESL. The others comprise a lead free system with K values up to 250 and permeability ranging from 200 to >350 depending on firing temperature. These have been developed in response to the environmental challenge presented to electronics manufacturers. Thick film pastes and LTCC tapes have relied on lead oxide for low firing temperatures. This is important for LTCC tape systems so that high conductivity precious metals can be used in telecommunications applications.

Low fire, low loss, low K (4-7.5), tapes and associated silver conductors are described. Higher K (13-250) dielectrics, for buried capacitors and smaller multilayer packages are also discussed. Insertion loss of the LTCC tapes as a function of processing will be presented. Dielectric constant and TCC for buried capacitors and inductance increase for buried ferrite tape will be presented. Compatibility of dielectric and magnetic tapes with low K tape bodies will also be discussed.

Introduction:

New portable devices incorporate analog, digital, and RF functions in multilayer packages which include both active and passive components. The majority of these components (as much as 90%) are passives. Figure 1 shows a Bluetooth module built by Ericsson [1] with a single chip and more than three dozen passives. The ability to bury the passives would give more room on the top layer for active chips which provide the multifunctionality required.

A capacitor dielectric tape with K=100 was developed to be compatible with a variety of LTCC tapes. (DuPont 951, Motorola T2000 and ESL 41020). When buried capacitors are built using the process conditions recommended by the tape manufacturers, the data in Table 1 is obtained. K values of approximately 100 are realized with dissipation factors around 1%. Higher K values result from the Pd free 953-1G electrodes. Data for ΔC and DF from -55°C to 125°C indicate that these capacitors satisfy X7R specifications. The loss characteristics of these three LTCC tapes are shown in Figure 2.

Figure 3 shows a polished cross section of the

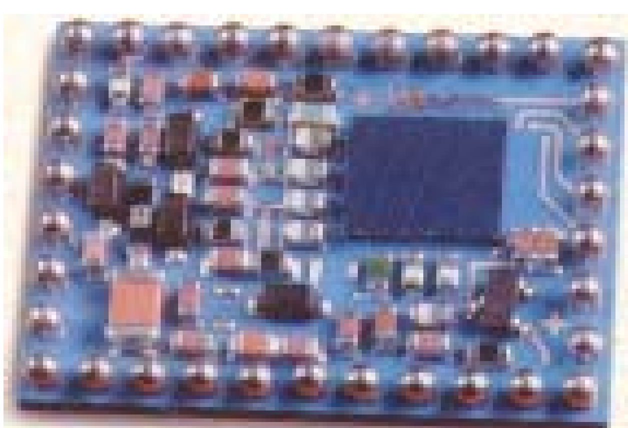

Figure 1
Bluetooth Module from Ericsson

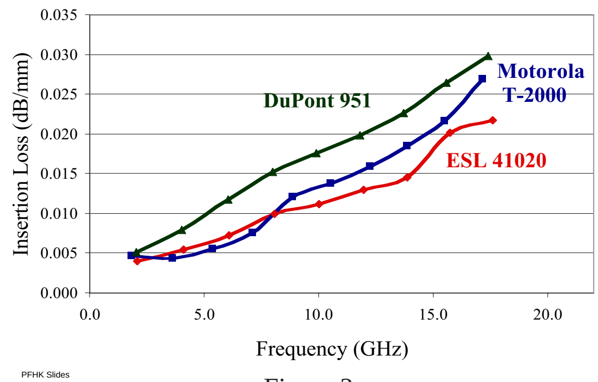

Figure 2
Loss of LTCC Tape

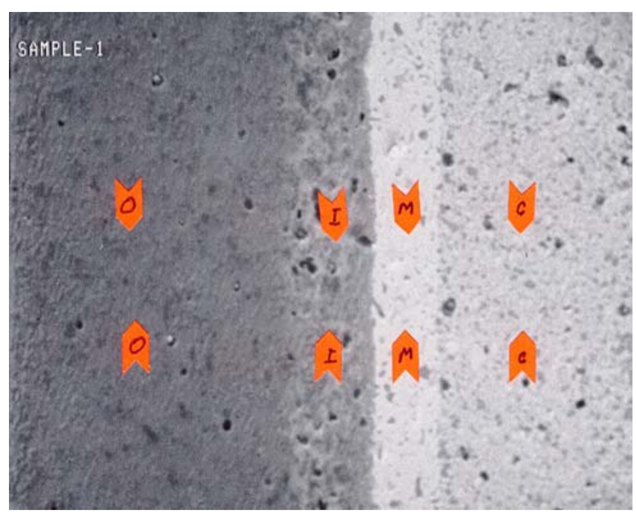

Figure 3
41210 Buried in 41020

41210 tape with Pd/Ag terminations buried in ESL 41020 LTCC tape (the photomicrographs of this combination buried in DuPont 951 and Motorola T-2000 LTCC tapes are similar). All of the buried capacitors showed four distinct layers; the

Table 1
Properties of Embedded Capacitors

Designation	Body Tape	Electrode	Dielectric Constant	% DF
102/121	ESL 41020	963-CT	104	1.0
102/121	ESL 41020	953-1G	120	0.7
951/121	DuPont 951	963-CT	98	1.3
951/121	DuPont 951	953-1G	105	1.3
T2000/121	Motorola T-2000	963-CT	126	0.9
T2000/121	Motorola T-2000	953-1G	135	1.0

capacitor dielectric "C" (41210), conductor "M" (963-CT), LTCC matrix "O" (41020, DuPont 951 or Motorola T2000) and an intermediate layer "I" which formed between the LTCC tape and the conductor . The capacitor dielectric and the conductor exhibited great compliancy, showing excellent bonding between them and the LTCC tape, even though they were quite different in composition and recommended firing conditions. All the combinations exhibited constrained shrinkage differing from normal values in the 13-15% x-y shrinkage range to about 3% when they were laminated and fired together.

The intermediate layer results from the constrained shrinkage which occurs when materials with different densification characteristics are cofired. Interfacial shear stress causes shrinkage gradients in the part[2] and a porosity distribution which is different for each tape. Backscatter SEM scans also indicate that lead has diffused into the intermediate layer. This will result in a lowering of the T_g and allow the layer to act as a stress relieving buffer between the LTCC and the capacitor tape.

The ESL 41210 capacitor tape as well as the DuPont 951 contain lead. Lead and lead compounds provide unique contributions to the properties of electroceramic products like capacitors, thermistors and various transducers. Lead based glasses are used in IC's, coatings, displays, thick-film hybrids and, lead in combination with tin, has been the solder standard for low cost, low melting temperatures and good ductility. Unfortunately, lead in even minute quantities can cause brain, nervous system, liver and kidney problems, especially in children. One of the primary concerns is that lead from lead containing products disposed of in land fills will be leached into the soil and wind up in water supplies resulting in the poisoning of humans and the ecosystem. This would result in increasingly difficult disposal of hazardous materials as landfills become fuller and consumers acquire and dispose of more appliances.

Lead-Free System

In light of this growing concern, we decided to develop a green system to meet the demanding ecological and technical requirements of the industry. We also felt that there were other issues (increased functionality, lower loss, and cost reduction) that needed to be addressed in the development of the materials system for high frequency telecommunications applications. Increasing the functionality means putting more ICs on the surface of the module which in our approach is accomplished by burying some or all of the surface mounted capacitors and inductors.

Conductors and dielectric tapes developed to meet the telecommunications application needs are listed in Tables 2 and 3.

Table 2
Lead Free, Cofireable Conductors

Designation	Description
903-CT-1	High Conductivity Ag
903-CT-1A	Ag Matched for Shrinkage
953-1G	Low Cost Pt/Ag
963-G	Pd/Ag Solderable Electrode
902-G	Ag via fill
962-G	Ag/Au via transition
903-CTA	Solderable top layer Ag
953-AG	Leach Resistant Pt/Ag
803-MG	Wire Bondable Au
Solder	95.5% Sn-3.8% Ag- 0.7% Cu
9904	Top layer photoimageable Ag*
8804	Top layer photoimageable Au*

* post fireable only

These lead free materials are compatible and cofireable for use in multilayer applications. The conductor system is based on silver which provides high conductivity, low cost, and good solderability. Compatible Au, Pd/Ag and Pt/Ag, pastes are also available where special properties are needed. A wide range of LTCC dielectrics are also available. These include K values up to 16 for size reduction capability.[3]

The loss characteristics for these LTCC structural tapes were determined using ring resonator patterns. The process and measurement technique are described in an earlier publication [4]. These tapes were fired at a higher temperature than reported for the K=4 tape because loss characteristics improved at 875°C. Line widths were adjusted to maintain 50 ohm impedance. Silver conductors were used throughout. Hold time was varied from 15 minutes to 90 minutes at peak temperature. The heating rate from 450 to 875 was also varied from 2°C/minute to 15°C/minute. These parameters were found to have no effect on loss characteristics

Table 3

Lead Free, Cofireable Dielectric

Designation	Description	
41110	K - 4	LTCC Tape
41020	K - 7.5	LTCC Tape
41050	K - 13	LTCC Tape
41060	K - 16	LTCC Tape
41230	K - 18	Capacitor Tape
41240	K - 50	Capacitor Tape
41250	K - 100	Capacitor Tape
41260	K - 250	Capacitor Tape
40010	Ferrite Tape	

Figures 4 shows loss characteristics for all four LTCC tapes as compared to FR-4. The intermediate K dielectric tapes show better loss characteristics than FR-4 and have the additional advantages of higher thermal conductivity and the ability to accommodate multilayer structures.

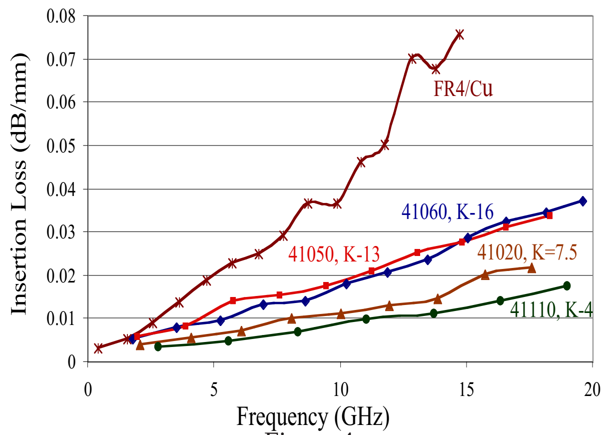

Figure 4
Loss vs. dielectric Constant

Buried Capacitors

Lead-free capacitor tapes were embedded in these four lead-free LTCC host tapes and fired at peak temperatures of 850 - 875 °C. Hold times at peak ranged from 12 to 60 minutes. These same capacitor tapes were also buried in DuPont 951, Motorola T-2000 and Ferro A-6 and except for A6 fired at a peak temperature of 875°C. The Ferro A-6 was fired at 850°C. The 41240, 41250 and 41260 tapes were compatible with all the host LTCC tapes except ESL 41110 with which only low value tapes were compatible. Results are shown in Table 4. Again, we see the somewhat surprising result that the buried capacitor tapes are compatible with a number of compositionally different LTCC host materials.

The same electrode was used for each test sample, 953-CT-1G (a Pt/Ag comductor designed for use in buried tape systems). The conductor metallurgy does make a difference as seen in Table 5 where Ag, Pt/Ag and Pd/Ag are compared.

Buried Inductors

Inductors represent another component that designers would like to see removed from the premium surface positions and buried in the interior of the part. This can be done easily in those cases where the inductor consists of printed conductive coils. Our objective was to determine if the inductance of such structures could be enhanced by burying them in low firing ferrite tape. The permeability vs. firing temperature for the ferrite tape developed for use in LTCC applications is shown in Figure 5. This lead-free tape exhibits the expected grain size vs. permeability behavior shown in Figure 6.

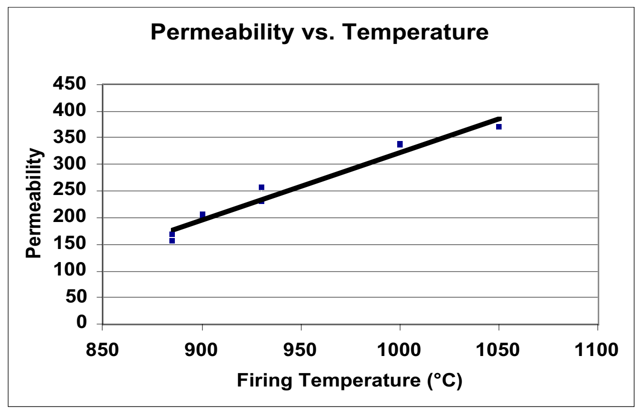

Figure 5
Permeability vs. Firing Temperature

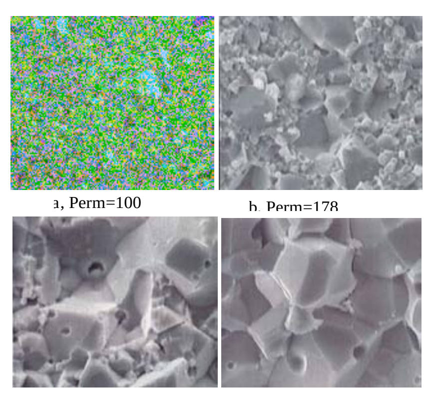

Figure 6
Permeability vs. Grain Size

Table 4

Lead Free Capacitor Tapes Buried in Various LTCC Host Tapes						
Host Tape	ESL Buried Capacitor Tape	ESL Electrode Designation	Time at 875°C (min)	Dielectruc Constant @1 KHz	Dissipation Factor %DF	Max |%ΔC| -55 to 125°C
DP 951	41240	953-CT-1G	20	57	0.2	3.1
	41250			106	0.3	6.7
	41260			282	1.2	16.5
Motorola T2000	41240		30	67	0.8	5.5
	41250			100	1.0	9.1
	41260			250	1.2	16.7
Ferro A-6	41240		10*	58	1.0	3.4
	41250			100	0.5	4.6
	41260			194	1.6	12.9
ESL 41110	41020		12	8.4	0.2	4.6
	41060			18.2	0.1	3.3
ESL 41020	41235		30	27	0.1	1.6
	41240			77	0.2	7.5
	41250			126	0.6	6.7
	41260			182	1.0	16.9
ESL 41050	41230		60	18	0.1	1.4
	41235		30	28	0.1	1.6
	41240		15	60	0.3	5.8
	41250		60	108	0.6	5.7
	41260		15	225	1.3	15.2
ESL 41060	41240		30	86	0.3	3.4
	41025			117	0.7	9.0
	41260			273	1.5	10.2

Table 5

Effect of Electrode Composition on the Properties of Buried Capacitor						
Host Tape	ESL Buried Capacitor Tape	ESL Electrode Designation	Time at 875°C (min)	Dielectric Constant @ 1KHz	Dissipation Factor %DF	Max $\|\% \Delta C\|$ -55 to 125°C
ESL 41060	41240	903-CT-1	30	88	0.3	3.5
		963-CT-G		89	1.3	5.0
		953-CT-1G		86	0.3	3.4
	41250	903-CT-1		139	1.0	5.9
		963-CT-G		176	0.7	2.2
		953-CT-1G		117	0.7	9.0
	41260	903-CT-1		265	1.4	5.8
		963-CT-G		373	1.2	15.5
		953-CT-1G		273	1.5	10.2

Testing of the magnetic tape involved sandwiching a conductive silver spiral in ferrite tape layers which were in turn placed in LTCC tape products from ESL, DuPont and Ferro. Table 6 presents data showing the increase in inductance resulting from the presence of ferrite tape buried in the LTCC bodies.

Examination of the microstructure of these composite structures indicate good compatibility between the LTCC tapes and the ferrite tape. Increasing the number of ferrite layers increases the inductance.

Compatibility was determined from backscatter electron images prepared from a multilayer structure built with ferrite tape and capacitor tape buried in structural tape. Figure 7 shows that no voids or delamination result from

Table 6

Inductance Enhancement from Ferrite				
Host Tape	ESL Buried Ferrite	Configuration #Ferrite/#LTCC	Firing Schedule	Inductance µH
ESL 41050	40010	0/8	875/60	1.83
		2/6		3.75
		4/4		5.80
		6/2		9.65
D951		0/8	D875	1.77
		4/4		5.71
Ferro A-6		0/8	Ferro 850	1.70
		4/4		4.47

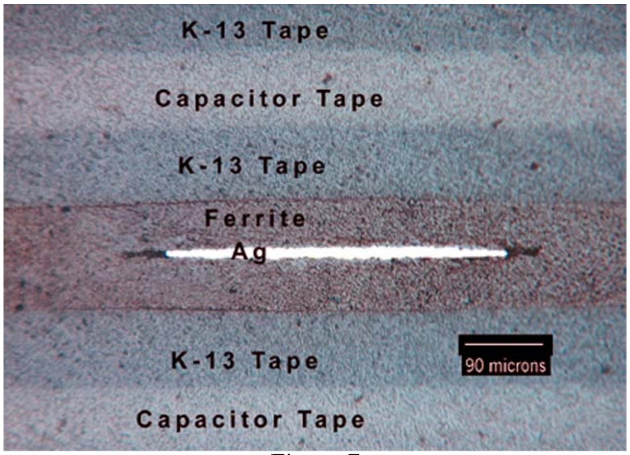

Figure 7
Ferrite Tape Buried in 41050 LTCC Tape

cofiring these tapes under the conditions required to optimize loss characteristics. The results listed in Table 6 reinforces the notion that this tape is compatible with other systems.

Summary:

Materials systems were developed for high frequency telecommunications applications. They consisted of:

- LTCC tapes with insertion loss values lower than those achievable with FR-4/Cu technology. The tapes have K values from 4 to 16 which can provide increased signal velocity, better isolation or size reduction with proper material selection.
- A capacitor tape system suitable for embedding in a variety of LTCC tapes from different tape manufacturers (ESL, DuPont, Ferro and Motorola).
- A complete lead free materials system including LTCC tape, compatible conductor, embeddable capacitor tapes, ferrite tape and solder.
- A wide range of cofireable, low cost, low loss silver based conductors.
- Materials amenable to low cost parallel processing.
- Embeddable capacitor tapes with a K value range of 13-250.
- An inductance enhancing LTCC compatible ferrite tape.

References:

1) Advanced Packaging , March, 2000
2) S-Y Tzeng and J-H Jean; Stress Development During Constrained Sintering of Alumina/Glass/ Alumina Sandwich Structure; Journal American Ceramic Society; vol. 88, No. 2, pp 335-340, 2002
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4) A.H. Feingold, C. Huang, and S.J. Stein,; Low K, Low Loss, Low Fire Tape System for Microwave Applications; Proceedings of IMAPSEurope Prague June 2000; pp.163-168