Low K, Low Loss, Low Fire Tape System for Microwave Application

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The rapidly growing wireless industry needs new high performance materials to build low loss, high density, thermally stable integrated packages. Applications include automotive safety, control, global positioning system (GPS) mapping and entertainment, multifunctional portable phones, home entertainment, office voice, video and data transmission through wireless local area networks (WLAN). This paper describes ceramic tapes developed to meet these needs. The GHz operating frequencies of these systems require substrate materials with lower loss, low dielectric constant (K) and good power handling characteristics which are important in many of these applications. Low loss is a critical requirement for lightweight portable devices for long battery life.

The dielectric constant of 4.2 is lower than alumina and some other ceramic materials which have been used in multilayer packages. This is important because higher dielectric constant results in slower signal velocity, and higher resistivity in thinner trace widths of transmission lines. Higher K also contributes to cross-talk problems between traces.

The system described here is fired at 850 °C and thus allows the use of high conductivity precious metal conductors. Top layer, buried and ground plane silver and gold conductors can be co-fired to simplify the overall process. Photoimageable gold and silver conductors are available for use with this tape. They are used in applications where precise edge definition and fine line conductors are required. Wire bondable gold and solderable silver are also available as top conductors.

Data will be presented on loss characteristics at frequencies up to 20 GHz. Ring resonator measurements have been made on such systems using cofired silver and gold conductors. Isolation of parallel lines as a function of separation and dielectric constant will be discussed. High frequency measurements of photoimaged silver on low K dielectric will also be reviewed.

Introduction:

The need for low K, low loss, low fire ceramic tape systems is driven by the increased speed and multifunctionality of new wireless devices. Hand held phones now combine voice and data capabilities and provide access to internet functions which require graphics. In order to accomplish this and maintain portability, high density multilayer circuits using low loss materials must be used. Multifunctionality demands high density circuitry with adequate isolation between functional areas. This can best be accomplished using glass/ceramic systems with low dielectric constant. Low K is also important because signal propagation velocity is a function of permitivity. This paper describes a lead free tape system which satisfies these needs, and the techniques used to characterize it.

Experiment*:*

Microstrip ring resonators were prepared to evaluate dielectric constant and loss characteristics of dielectric/metal systems. The ring configuration was chosen to minimize parasitic losses due to radiation and surface waves(1). It also eliminates end effect corrections required for linear resonators.

Dielectric constant is obtained from resonant frequency measurements. Harmonics of the primary resonance provides data at higher frequencies. The microstrip configuration used for these experiments yields an effective dielectric constant which includes a contribution from the air above the part. Equations developed by Owens (2) based on geometrical considerations allow the extraction of material dielectric constant from the data obtained.

Loss characteristics were obtained from values of Q at each resonant peak. These were then “unloaded” to calculate insertion loss for the system of interest. Equations developed by Tyler and Gaspar (3) address this issue and were used for these calculations. In this configuration the metal and dielectric system are evaluated together to yield attenuation or insertion loss for the system. From empirical equations available in the literature (4), conductor loss can be calculated and subtracted from the total loss to yield the dielectric loss or tanδ.

Isolation data was obtained between parallel transmission lines printed on substrates of various dielectric constants. Spacing between lines were integral multiples of 50 Ω widths, calculated for each substrate based on thickness and dielectric constant.

All measurements were made with a Hewlett Packard 8720D Vector Network Analyzer (5). A modified universal test fixture from InterContinental Microwave(6) was used along with a calibration kit to de-imbed the cable and fixture up to 20 GHz. Calibration was done prior to each measurement to insure consistency.

Parts were prepared by screen printing conductors onto laminated tape substrates which were cofired using the profile shown in Figure 1. Alumina resonators built with ESL thick film conductors were post fired using a standard 850°C profile.

Results and Discussion:

Dielectric Constant:

Figure 2 is a photograph of a typical resonator used in these studies. The resonance spectrum for a 2 1/2 inch diameter resonator is shown in Figure 3. Resonance occurs when the ring circumference is equal to the guide wavelength. In a microstrip configuration the effective dielectric constant is therefore obtained from

$$K_{eff} = (cn/\Pi D f_{res})^2 \qquad (1)$$

where c is the speed of light, n is the order of the harmonic, D is the ring diameter and f_{res} is the resonant frequency. The material dielectric constant can then be obtained (2) from geometric measurements and

$$K_{rel} = \frac{2K_{eff} - 1 + [(1+10h/w)^{-.555}]}{[(1+10h/w)^{-.555}]} \qquad (2)$$

where h is the distance between the signal and ground planes and w is the trace width. A plot of material dielectric constant as a function of frequency for this low K dielectric is shown in Figure 4. The slight increase in K with frequency is due to microstrip dispersion. This phenomena reflects the increased portion of electromagnetic field in the substrate at higher frequencies (7), thus increasing the apparent dielectric constant.

Low dielectric constant yields higher signal propagation velocity through a dielectric medium which is given by:

$$v_p = c/\sqrt{K} \qquad (3)$$

The signal velocity is more than 50% higher in a material with K=4.2 than in alumina. As devices run at higher speeds, this becomes an important consideration. Polymers such as FR4 and Teflon® also have low dielectric constants, but multifunctional devices dissipate more power and require materials such as class/ceramics for mechanical and thermal stability.

A 50 ohm trace on low K dielectric is twice as wide as an equivalent trace on alumina. The resulting increased conductivity yields lower IR loss and higher printing yield. This is particularly important in multilayer structures where ground and signal planes may be close together resulting in narrow 50 ohm transmission lines.

Isolation:

Cross-talk is another important consideration in high density circuits. Inductive coupling between transmission lines increases with dielectric constant. Multilayer structures contain buried traces that are completely surrounded by dielectric. The effective dielectric constant is higher because none of the traces are in contact with air (K=1). Consequently, isolation is a more important consideration with multifunctional devices. It is therefore desirable to use a material with a low dielectric constant. The low K dielectric described here provides significantly better isolation between signal traces than alumina or other LTCC materials. One inch long parallel traces were printed and cofired on dielectric tape along with post-fired traces on alumina. The ratio of trace width to substrate thickness for 50 ohm impedance lines is obtained from equations in Edwards (8).

Measurements were made at K=4.2, K=7.5 and K=9.75 (alumina). S_{12} values up to 20 GHz are shown in Figures 5 and 6. Figure 5 presents isolation as a function of separation. Designers generally consider three line widths as the spacing required to obtain acceptable isolation. For the K=4.2 dielectric, this results in greater than 10dB isolation at all frequencies for these long parallel lines. Better isolation will result for more typical short microwave transmission lines since coupling increases with length. Figure 6 shows isolation as a function of dielectric constant at constant equivalent separation. Using a material with lower dielectric constant significantly improves isolation between traces, thus minimizing cross-talk. At 5 GHz, the difference between K=7.5 material and the low K material is approximately 7.5dB, for alumina the difference is 14 dB. Therefore, cross-talk is more than 5 times higher for the K=7.5 material and 25 times higher for alumina than low K dielectric at equivalent spacing. As a result, traces can be spaced much closer together on low K dielectric to achieve acceptable isolation.

Attenuation:

As functionality increases, power consumption becomes a major concern. Minimum signal attenuation is therefore critical to maintain or increase battery life in portable wireless devices. This property is characterized by Q which is a system property relating to the efficiency of use of power supplied to the device. It is defined as the ratio of energy stored to energy lost per cycle. For a ring resonator, Q of the system can be obtained from:

$$Q = \Delta f_{3dB}/f_{res} \qquad (4)$$

where Δf_{3dB} is the frequency range at half height and f_{res} is the resonant frequency or one of its harmonics. The 8720D VNA calculates Q directly at the resonant and harmonic peaks. The value obtained, however, it that of a resonator under load which varies with gap separation. This value is corrected using:

$$Q_U = Q_L/(1- \sqrt{10^{-L/10}}) \qquad (5)$$

where L is loss in dB. Attenuation for the metal/ceramic system can then be calculated using(9):

$$\alpha = (0.693\, f_{res}\sqrt{K_{eff}}\,)/cQ_U \ \ (\text{dB/in}) \qquad (6)$$

Measurements were made on rings of varying sizes to optimize the response over a wide range of frequencies. Loss characteristics were consistent regardless of ring size (Figure 7). Data for the low K tape with a cofired silver conductor is presented in Figure (8) along with that for FR4 (10) and alumina. The low K dielectric has significantly better loss characteristic than that of FR4 and is very close to alumina.

Future Work:

The resonators used in these experiments (Figure 2) were screen printed and cofired with silver. The loss characteristics could be further improved by photoimaging and post firing. Figures 9 illustrates this with photoimaged silver on 96% alumina. At 15 GHz approximately .0015dB less attenuation results. Figure 10 is a photograph of photoimaged 15μm silver lines on low K, thick film dielectric. Work is currently underway to integrate this technology with our cofireable low K tape.

Conclusions:

A new low fire glass/ceramic lead free tape system has been developed and characterized. The dielectric constant, K=4.2, is significantly lower than alumina and other

LTCC systems currently available. Lower K yields higher signal propagation velocity for faster circuits and better isolation for denser circuits. The loss characteristics of screen printed and cofired silver are excellent and compare to those of alumina. Work on photoimaged, cofired low K tapes is in progress.

References:

(1) T. Edwards, Foundations for Microstrip Circuit Design 2nd Edition, pp. 109-111
(2) Owens, R.P., ‘Accurate analytical determination of quasi-static microstrip line parameters’, The Radio and Electronics Engineer, 46, No.7, July 1976, 360-364
(3) Tyler & Gasper, ISHM Proceedings 1989 p 390-399
(4) Hammerstad,E.O., and Bekkadal,F., ‘A Microstrip Handbook’, ELAB Report, STF44 A74169, University of Trondheim, Norway, 1975,pp. 98-110
(5) Hewlett Packard (Agilent Technologies), Palo Alto, CA 94303
(6) InterContinental Microwave Santa Clara, CA 95054
(7) T. Edwards, Foundations for Microstrip Circuit Design 2nd Edition, p 79
(8) ibid. p 53
(9) ibid. pp 110-112
(10) Skurski, M.A., Smith, M.A., Draudt, R.R., Amey, D.I., Horowitz, S.J., and Champ, M.J., Microwaves &RF, Feb 1999, pp. 77-8

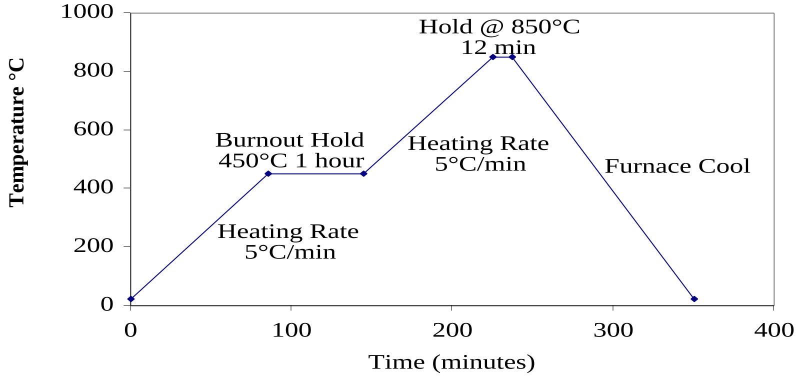

Figure 1
Furnace Profile

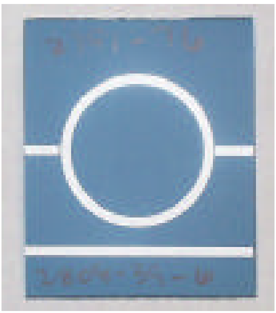

Figure 2
Ring Resonator on Low K

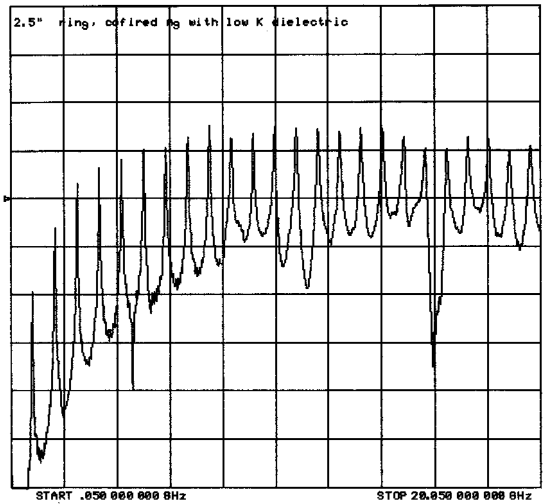

Figure 3
Resonance Trace

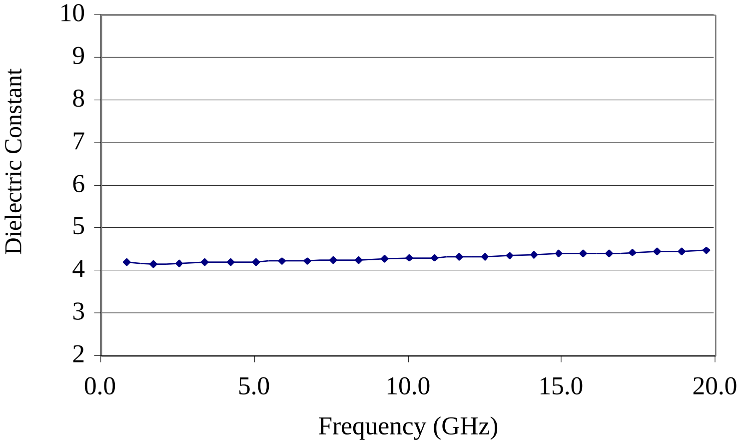

Figure 4
Dielectric Constant vs. Frequency

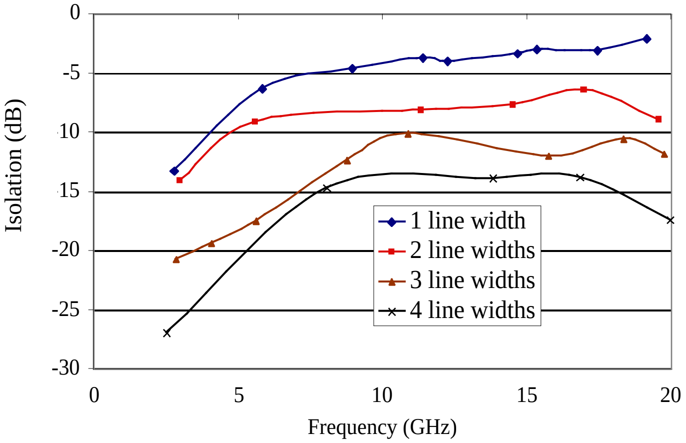

Figure 5
Isolation vs Separation

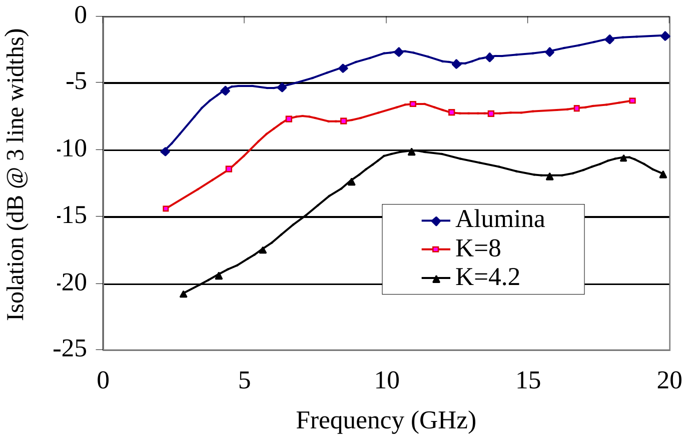

Figure 6
Isolation vs Dielectric Constant

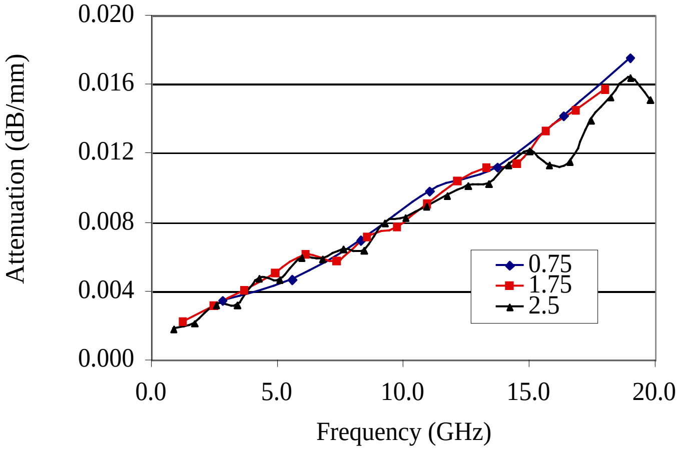

Figure 7
Ring Size Comparison

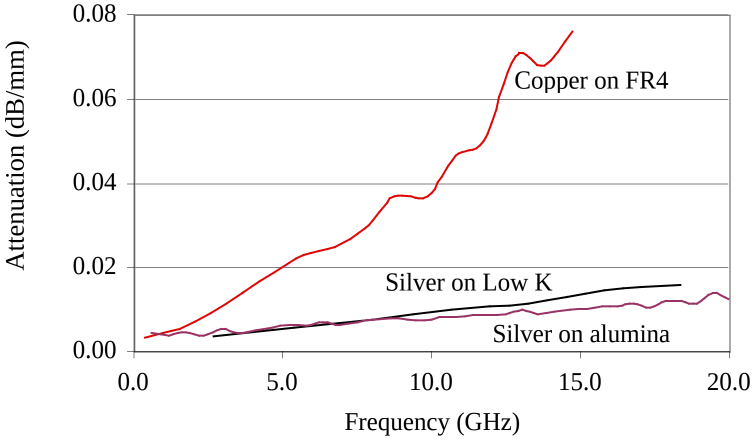

Figure 8
Attenuation vs. Frequency

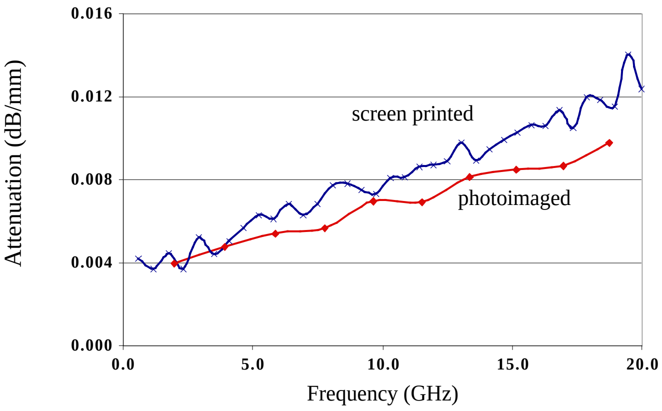

Figure 9
Photoimaged Silver on 96% Alumina

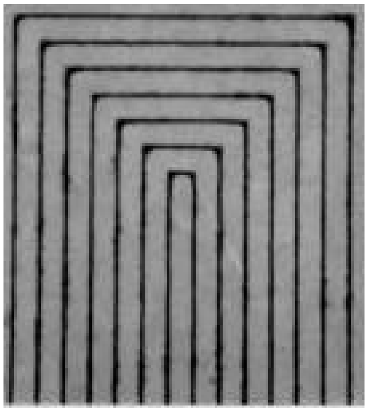

Figure 10
Photoimaged Silver on Low K Dielectric