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Enhanced High-Frequency LTCC for RF and Microwave Packaging

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Previous work has demonstrated that Ferro A6M is the proven leader for high frequency, low loss Low Temperature Cofire Ceramic (LTCC) applications where reliable performance is critical. More than one million electronic packages have been made from this material in the past 20 years for critical applications including advanced radar, antenna and filter applications. Recent work has shown that this material can also be successfully used to produce active devices that operate above 90 GHz.[1], [2]

The key attributes of A6M include its low and stable relative permittivity and low loss tangent over an unusually large and quite high frequency range.[3], [4] Low bulk density and compatibility with highly conductive metals are also properties that make A6M ideal for many demanding electronic packaging applications. Additionally, the ability to embed resistors and attached metal components provides flexibility to the designer in managing the requirements of a complex packaging system. These attributes have led to its use in many high frequency designs and multiple high volume applications where the use requirements can best be met by A6M.

Despite its excellent electrical performance, A6M has been limited in some applications due to its green tape properties. It requires careful handling to avoid cracking and chad or sliver generation. This is due to the nature of the organic system used, which can also result in a strong solvent (MIBK) odor. Some customers have also requested a ceramic tape that is easier to laminate and cut in the green state. These issues can limit production volume. In some cases, the only alternative has been to use lower performance packaging materials in an effort to meet volume demand and timing. This paper describes recent work resulting in a new Ferro LTCC product called A6M-E, for "A6M Enhanced." It incorporates improvements to the physical properties of LTCC tape that improve its processing characteristics, while maintaining the excellent electrical performance of A6M.

Development

Work to address increased tape green strength, improved lamination and green cutting began with a review of the organic system used to disperse the ceramic powders used in A6M. It was felt that the green strength of A6M tape was lower than other tape systems due to the nature of the organic system used. The high purity recrystallizing calcium borosilicate powders were not changed, in an effort to assure that desirable dielectric and bulk properties were maintained.

One proposed solution was to evaluate the A6M inorganic components with a proven tape binder system used to produce another Ferro LTCC product, A6S. The organic system used to produce A6S is higher in resin and plasticizer content, and does not use

MIBK as a solvent. After bench scale testing, slurry and tape were made in a production scale ball mill and casting operation using standard casting conditions to produce 5 mil thick unfired tape. The experimental run was labeled A6M-E, (for "A6M Enhanced"), and testing was conducted using standard A6M as a control. Evaluation methods included tape quality, tape consistency, green tape properties and green processibility, binder burnout, firing shrinkage, compatibility with existing metal pastes and dielectric properties. Standard test methods were used for all characterization with the exception of high frequency dielectric properties.

For high frequency relative permittivity and loss tangent, NIST in Boulder, CO was engaged to employ methods under investigation by IEEE Microwave Theory and Techniques Group 1787, charged with Developing Industry Standards for High Frequency Characterization for LTCC Materials. A "Split Post Method" was used for values measured below 10 GHz and a "Split Cylinder Method" was used for other measurements up to 31.5 GHz. For this testing, bare samples were fabricated from standard A6M and the experimental A6M-E with approximate dimensions 55 x 55 x 0.8 mm. Of greatest interest was whether the changes in tape had any impact on high frequency properties of the experimental A6M-E relative to standard A6M.

Test Results

1) Tensile and Flexural Strength

Material	Tensile Strength (green) (kPa)	Flexural Strength (fired) (MPA)
A6M	1715	214
A6M-E	2454	228

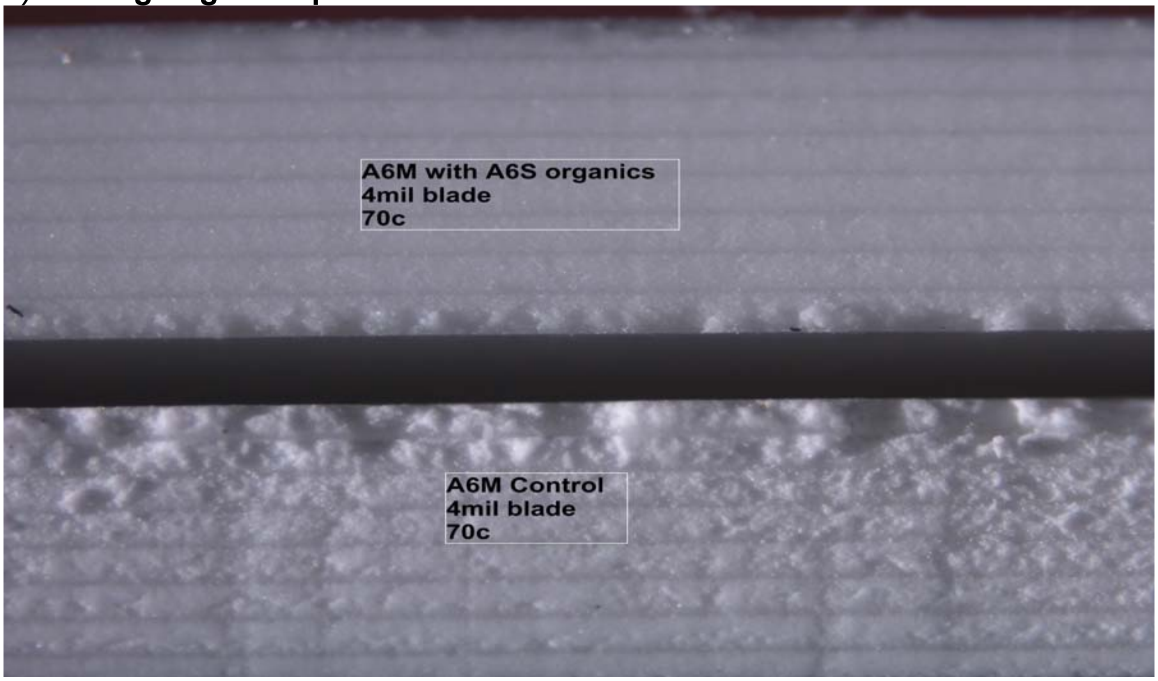
2) XY Shrinkage and Density

Material	Peak Temperature (°C)	Laminate Density (g/cm^3)	Fired Density (g/cm^3)	XY Shrinkage (%)	Z Shrinkage (%)
A6M	853	1.72	2.50	15.8	12.8
A6M-E	853	196	2.52	14.8	12.5

3) Electrical results – DC

Material	Leakage Current (µA/cm^2)	Insulation Resistance (Ω)	Breakdown Voltage (V/mil)
A6M	0.00	8.6×10^{12}	1815
A6M-E	0.00	2.5×10^{12}	2032

4) **Cutting edge comparison**



5) Via Fill

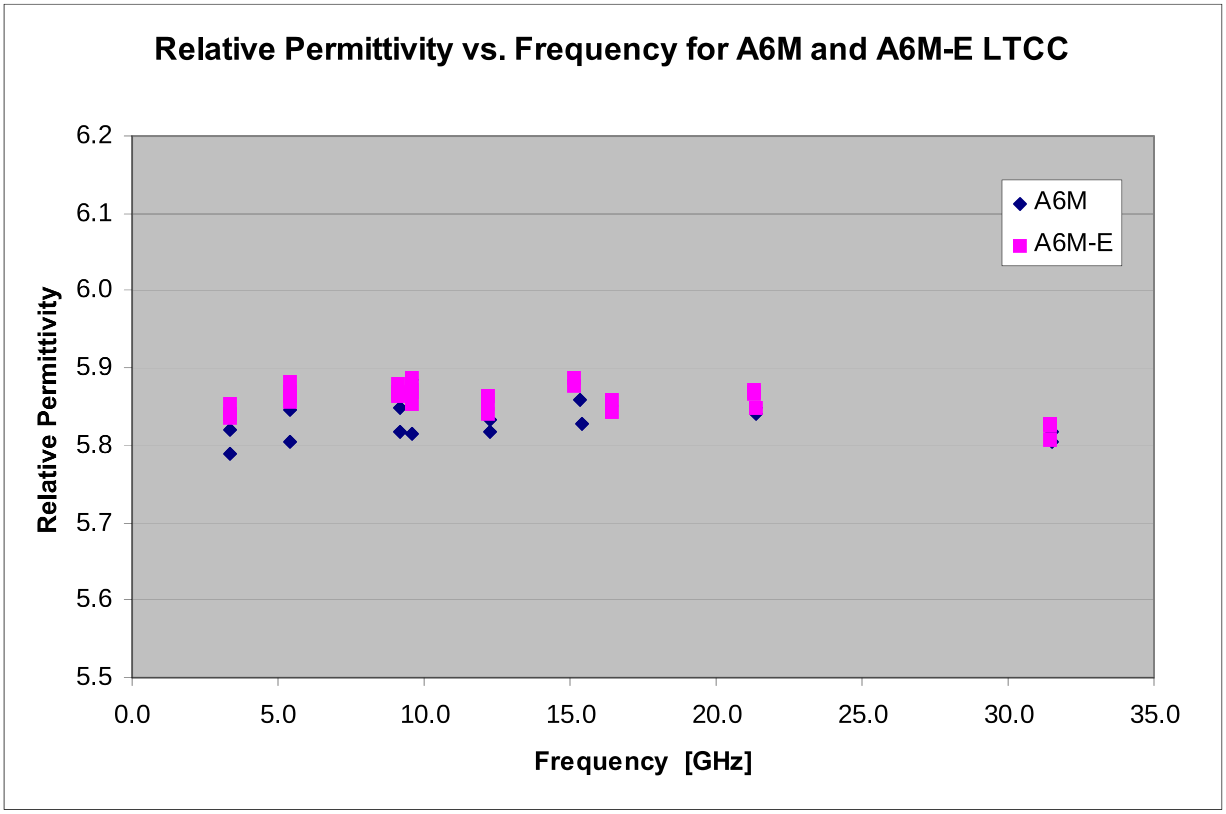
Initial testing has shown that it works well with standard gold via paste CN30-078, with no posting or sunken via issues.

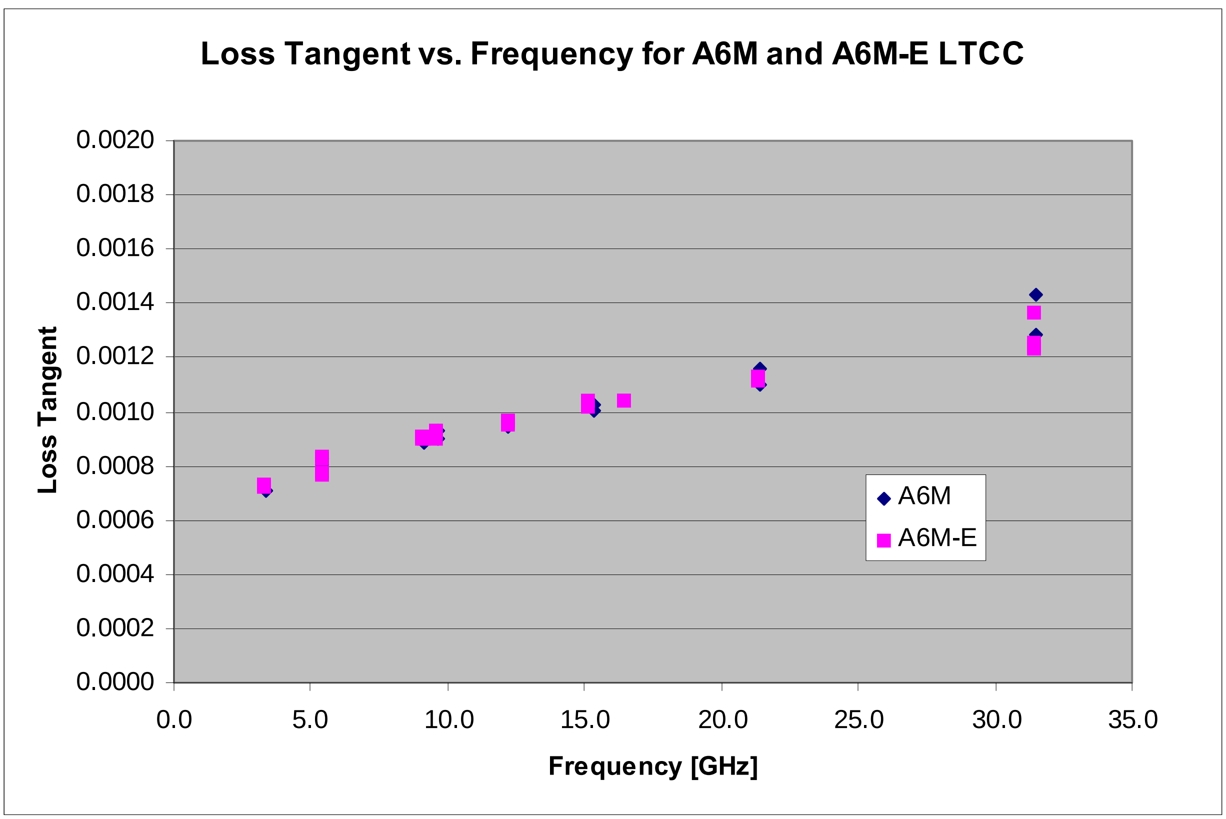
6) Distortion Coupons – (7 layer laminates - 3 layers full metallization)

Material	**Distortion (mils)**
A6M with Conductor up	0.0
A6M-E with conductor up	0.0
A6M with Conductor down	8.1
A6M-E with conductor down	3.0

10 layer laminates with 3 planes of CN30-025JH Au conductor
No significant difference detected between A6M and A6M-E

7) High Frequency Properties





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Conclusions

Desirable green tape strength improvement, better green cutting performance, and higher laminate density were realized with A6M-E. Lower firing shrinkage was a direct response to higher laminate density, indicating better particle packing. It is anticipated that the improvements in tape properties will also result in equivalent or better control of shrinkage than A6M. Testing to date has also shown that standard Ferro gold via and conductor pastes are compatible with A6M-E and can be used to make high performance electronic packages. Excellent dielectric properties at high frequency were realized for A6M-E with virtually no difference compared to the A6M control.

All targeted goals have been met with A6M-E LTCC tape. The next steps are to do additional production tape runs, reaffirm improved properties and gain customer validation of processing improvements through beta testing.

References:

[1] J. Aguirre, H. Pao, H. Lin, P. Garland, D. O'Neill, K. Horton, "An LTCC 94 GHz Antenna Array", IEEE, International Symposium on Antennas and Propagation Symposium, July 5-12, 2008, San Diego.

[2] P. Garland, J. Aguirre, H. Pao, H. Lin, D. O'Neill, K, Horton, "Manufacturing Challenges for a W-band Laminated Waveguide Phased Array", Antennas and Propagation Symposium, IEEE, International Symposium on Antennas and Propagation Symposium, July 5-12, 2008, San Diego.

[3] R. Kulke, W. Simon, C. Gunner, G. Mollenbeck, K. Kother, M. Rittweger: "RF-Benchmark up to 40 GHz for various LTCC Low Loss Tapes", IMAPS-Nordic, Proceedings pp.97-102. Sept. 2002, Stockholm.

[4] L. Chai, A. Shaikh, V. Stygar, M. Janezic, R. Geyer, C. Holloway, T. Starr, D. Paulson, "Characterization of LTCC Materials at Microwave Frequencies", IMAPS Advanced Technology Workshop for Microwaves, March 26-27, 2001, Denver.