Millimeter-wave Performance of Alumina High Temperature Cofired Ceramics IC Packages

Rick Sturdivant
Microwave Packaging Technology, Inc.
333 City Blvd West, 17th Floor
Orange, CA 92868
Phone: 310-980-3039, Fax: 714-908-8034
Email: rsturdivant@mptcorp.com, www.mptcorp.com

Abstract

High Temperature Cofired Ceramic (HTCC) alumina packages have been used in a multitude of applications from microprocessors to MEMS. However, the application of HTCC alumina to high frequency electronics has not been wide spread. This is primarily due to electrical performance concerns. Specifically, HTCC uses a refractory metal system with molybdenum or tungsten which are less conductive than gold or copper. The electrical performance of the HTCC 92% alumina is also important. The purpose of this paper is to present measured data of microwave packages using HTCC alumina to 30GHz. First, there is a review showing how the electrical performance parameters of concern are related to fundamental material properties. Finally, measured data is presented on a few package examples at millimeter-wave frequencies.

Key Words: Microwave, Millimeter-wave, HTCC, Packaging, RF Performance.

1.0 Introduction

High Temperature Cofired Ceramic (HTCC) alumina packages have been commonly used in electronic packages for decades. This is due to the benefits, cost and existing manufacturing infrastructure.

The benefits include electrical performance, mechanical stability, thermal properties and compatibility with existing microelectronics processes. Table 1 outlines typical electrical characteristics of HTCC dielectric materials. It is important to note that the electrical performance at millimeter-wave frequencies is a combination of dielectric and conductor effects.

HTCC is very stable mechanically as compared to other ceramics or organic packaging. The Young's Modulus for 92% alumina is about 275 GPa compared to plastics which are 50 to 100 times less.

Material Parameter	Value
Dielectric Constant (10 GHz)	9.2
Dielectric Constant (30 GHz)	9.2
Loss Tangent (10 GHz)	0.003
Loss Tangent (30 GHz)	0.004
Dielectric Strength	11.6 KV/mm, 295 V/mil

Table 1. Electrical properties of HTCC.

Thermally, HTCC offers fairly good performance at about 20W/mK compared to glass at 2 W/mK and plastics at 0.2 W/mK typically. However, when thermal performance is important, plastic packages use copper inserts to improve thermal performance.

A very important benefit of HTCC is the ability to achieve hermetic IC packages. This is an important benefit for microwave

and millimeter-wave ICs which usually have exposed active devices. For most military and some high reliability commercial applications, hermeticity is necessary.

The international manufacturing base for HTCC alumina has excellent capacity for high volume requirements. US Domestic suppliers include Adtech Ceramics [1].

Although the number of applications using HTCC at millimeter-wave frequencies is increasing, wide spread use of HTCC has been limited possibly due to misunderstood electrical performance capabilities of the material system.

The purpose of this paper is to present a millimeter-wave package design and measured data up to 30 GHz. The detailed design was conducted using the Finite Element Method (FEM). Electrical measurements were conducted using a probe station.

In addition to measured results, a discussion is presented to show how the fundamental material properties affect electrical performance. Specifically, insertion loss is affected by the ceramic material parameters and by the metal material parameters. Simple equations are given for quick calculations that permit comparisons and trade studies.

When a designer is faced with a decision on the type of package to use for a millimeter-wave IC, one of the most important parameters of concern is the insertion loss the package will exhibit. This is because insertion loss will degrade gain, noise figure, output power and other parameters of concern. In some applications the expected insertion loss is the performance parameter of most concern. Excessive insertion loss has been thought to be a major reason to not choose HTCC alumina for packaging at microwave and millimeter-wave frequencies. However, we will present measured results that show the insertion loss of HTCC IC packages can be as good as high quality coaxial connectors.

2.0 Package Description

A package was designed for a millimeter-wave IC. The IC is based upon a GaAs wafer process. The application is low power, so thermal issues were not a concern.

The main issues were hermeticity and very good electrical performance to 24GHz. Also, the package had to be surface mount attached to a laminate substrate. Several approaches were possible. For instance the package could have been a leaded package, ball grid array or leadless. For this application, a leadless approach was chosen. In this application, the package was directly soldered to the laminate board. This approach was compatible with the surface mount attachment of the other components on the motherboard.

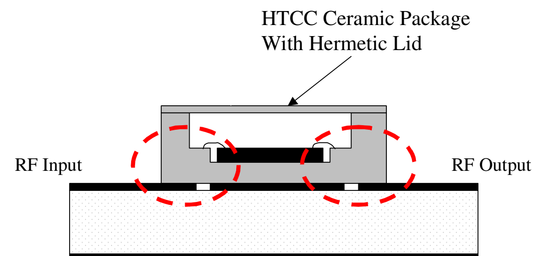

Figure 1. Illustration of the ceramic IC package mounted onto the laminate motherboard.

Figure 1 illustrates a cross section of the package and motherboard. Note that the package is directly solder attached to the motherboard. The IC is wire bonded from the IC surface to pedestals inside the package. The lid is hermetically attached to the package. This appears to be a standard IC package. For the most part, it is. However, the technical challenge is to design the transitions in the motherboard and package so that high frequency performance is achieved.

The transition area is shown in the figure with dashed circle. For the motherboard,

metal traces, vias, substrate thickness and substrate material all effect the transition. For the IC package, the contact pads on the bottom, internal vias and traces effect the transition.

3.0 Package Electrical Design

The majority of the electrical design was conducted using the Finite Element Method (FEM) with HFSS from Ansoft Corporation [2].

The design was conducted with an optimization around the insertion loss and return loss. The goal was to achieve better than 20dB return loss and better than 0.2dB insertion loss at 20GHz. Figure 2 shows the simulated insertion loss. The return loss was simulated to be 25dB at 20GHz.

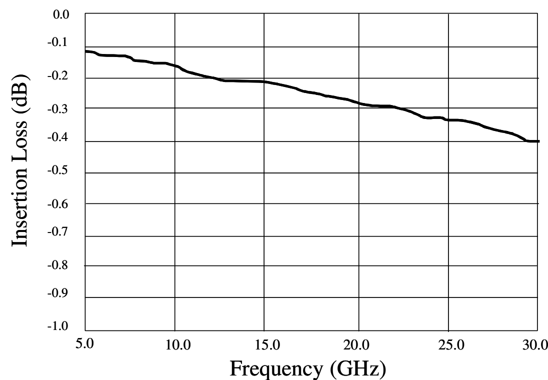

Figure 2. HFSS modeled insertion loss.

4.0 Measurement Method

Measurements were conducted using a millimeter-wave probe station. A measurement motherboard was fabricated and the packages were solder mounted. The probes contacted the motherboard and the inside of the package.

Figure 3 illustrates the measurement method. Coplanar waveguide probes were used to inject the signal into and out off the test fixture. The tests were conducted using an Agilent 8722E vector network analyzer. A TRL calibration was used to de-embed the launch.

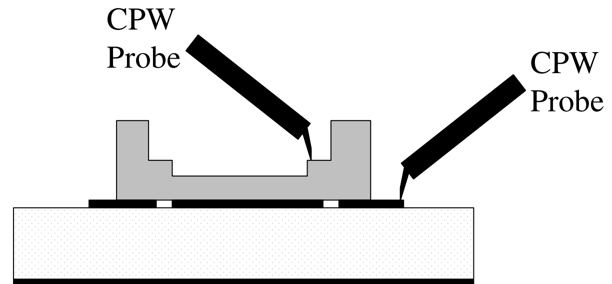

Figure 3. Illustration of measurement method.

This test arrangement can be a little difficult since the probes contact different launches. One probe contacts the alumina package while the other probe contacts the motherboard. However, two sets of measurements were conducted using calibrations from standards on the motherboard and the alumina substrate. When compared the results agreed within the expected measurement error.

5.0 Measured Results

The package was fabricated. It used 92% white alumina. All traces were gold plated inside the package and on the mounting motherboard. The motherboard was Rogers 4003 and used ½ oz copper traces.

The test fixture was assembled. The measured results are shown in Figure 4.

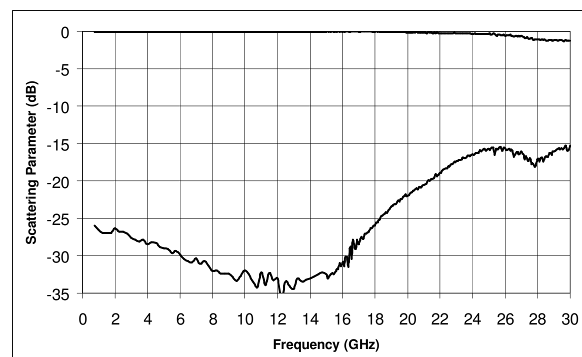

Figure 4. Measured results from the HTCC ceramic transition.

The results show that the insertion loss is less than 0.2dB per package transition at 20GHz. The measured return loss is better than 20dB at 20GHz. As a comparison, many high quality microwave coaxial connectors quote 0.2dB or worse insertion loss at 20GHz.

6.0 Conclusions

The main result of this investigation is that HTCC alumina can achieve insertion loss performance at millimeter-wave frequencies that make it of interest to designers. For this application, it was demonstrated that HTCC alumina can be used to 24 GHz. It is expected that this can be extended to 30GHz with additional design effort.

Relationship Between Fundamental Material Parameter and Electrical Performance

The fundamental material parameters such as dielectric constant, loss tangent and metal conductivity impact electrical performance. This impact can be quantified using simple relationships that are well known to the microwave engineering community. They are repeated here for completeness.

For a TEM wave, the insertion loss due to dielectric losses are given by :

$$\text{Dielectric Loss} = \frac{\pi \cdot \tan\delta}{\lambda}$$

Where $\tan\delta$ is the loss tangent and λ is wavelength.

Metal losses are a bit more tricky to model, but the easiest method is based upon the incremental inductance rule [3].

$$\alpha_c = \frac{1}{2\mu_0 Z_0} \sum_j R_{sj} \frac{\partial L}{\partial n_j}$$

Where Rs is the surface skin resistivity and is given by $(\pi f \mu \rho)^{1/2}$, where ρ is the resistivity of the metal.

References

[1] Adtech Ceramics.
Contact: Bill Minehan (423)755-5400.
http://www.adtechceramics.com

[2] Ansoft Corporation.
Contact: Jim Krasovic (619) 276-0842 or Main office at (412) 261-3200
http://www.ansoft.com

[3] R. Sturdivant, “Transmission line conductor loss and the incremental inductance rule”, Microwave Journal, Sept. 1995.