

# Mechanical Integrity Issues of MCM-Cs for High Reliability Applications

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## Abstract

During the qualification of a new high reliability low-temperature cofired ceramic (LTCC) multichip module (MCM), two issues relating to the electrical and mechanical integrity of the LTCC network were encountered while performing qualification testing. One was electrical opens after aging tests that were caused by cracks in the solder joints. The other was fracturing of the LTCC networks during mechanical testing. Through failure analysis, computer modeling, bend testing, and test samples, changes were identified. Upon implementation of all these changes, the modules passed testing, and the MCM was placed into production.

**Key Words:** Multichip module, multichip module ceramic (MCM-C), LTCC substrate, mechanical integrity, high reliability, test vehicle

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## Introduction

During the development of a new thick film network, several issues were encountered that created an opportunity to demonstrate the advantages of the low temperature cofire ceramic (LTCC) multichip module (MCM) technology. Since this would be the first application of this technology, an extensive qualification plan was devised, and a specialized mechanically equivalent test vehicle was designed. During the qualification testing, five failures occurred. These failures were electrical opens after aging and mechanical testing. An extensive analysis of these failures was undertaken with the assistance of Sandia National Laboratories that showed mechanical and metallurgical issues. In the end, all these problems were resolved, and the LTCC MCM (or MCM-C) was qualified and put into production.

## The Application

One of the products that AlliedSignal Federal Manufacturing & Technologies and Sandia National Laboratories are involved with is the design and manufacture of high reliability systems for military applications. The issues in this type of manufacturing are similar to those of most companies: build a high quality product that will survive through the product life cycle and do this at a reasonable cost. In this particular application a new thick film network was requested by one of our customers for an existing system. At the end of the design process the hybrid microcircuit (HMC) consisted of an ASIC, microprocessor chip set, and other components packaged in leadless chip carriers (LCCs). It also included surface mount capacitors, diodes and printed resistors. All these components were placed on an alumina thick film multilayer interconnect network that measured 53.3 by 38.1 by 0.64 mm thick (2.1 by 1.5 by 0.025 inches thick). During the development of this thick film HMC, several problems were encountered that led the project toward an alternate technology. The technology selected was an LTCC MCM.

To meet system requirements, it was decided that the LTCC MCM (or MCM-C) would be designed as a drop-in replacement. However, due to the lower strength of LTCC compared to alumina, the substrate thickness was increased from 0.64 mm (25 mils) to 1.0 mm (40 mils). Also, since this would be the first production of this technology in a high reliability application, an extensive qualification plan would be required.

## Qualification Plan

The qualification plan developed was divided into two parts. The first part included baseline work on integrated resistors and metallization strength. The second, and by far the more complex part, was a matrix of mechanical and environmental testing. Mechanical testing consisted of shock and vibration, and environmental testing consisted of accelerated aging and temperature cycling. In addition, these tests were performed in such a way as to emulate the environments that this part would see during its lifetime. This lifetime includes shipment, long-term storage, and operational use. During the development of this plan, it was determined that a mechanically equivalent test vehicle should be employed.

### Test Vehicle

The advantages of building a mechanically equivalent test vehicle are that it would allow for monitoring of the assemblies while under test, and it could be built at a greatly reduced cost because it would not use fully functional components. The test vehicle was designed and built so that all the components on both sides would form several continuity loops. Special LCCs were fabricated that had adjacent internal bond pads wire bonded together. Discrete surface mount components were fabricated with shorting bars. This design would allow the continuity loops to go through the substrate, solder joints, into the LCC, across a wire bond, and back down into the substrate over the same structures. This would allow every structure of this MCM to be continually monitored while under test.

### Test Failures

The baseline evaluation on the resistors [1] and metal adhesion did not reveal anomalies that could produce potential failures. However, there were five test vehicles that failed the qualification tests. These failures appeared as electrical opens during the testing and were grouped into two categories. The first category was parts that failed during a mechanical test. The second was failures occurring after aging tests. The parts that failed the mechanical test had cracks in the substrates. Those that failed aging were suspected of having excessive intermetallic growth causing cracks in the solder joints.

### Failure Analysis

Two avenues of analysis were pursued with the assistance of Sandia National Laboratories to determine the cause of the test vehicle failures. The mechanical test failures gave rise to an investigation into the robustness of the design and led to finite element analysis (FEA) and additional mechanical testing. The failures after aging resulted in an investigation that included microscopic examination of the solder joints and ultimately to an additional test coupon with a redesigned surface mount pad.

### Solder Joint Failures

Test vehicles that failed during the aging tests were cross-sectioned and examined microscopically [2]. Optical microscope examination found cracks in some solder joints. Examination with a scanning electron microscope (SEM) confirmed this and also showed the growth of an intermetallic in the solder joint. In some cases the intermetallic had totally consumed the printed metallization. Manufacturing steps were examined and found not to be the cause of this growth. This meant that the thermal environment specified for this MCM-C was the primary cause. Since system thermal requirements could not be changed to alleviate the formation of the intermetallic, a way had to be found to increase the time it would take for the intermetallic growth to reach the substrate. It was decided that a specially designed test pattern would be built that would look at different printing approaches and find the one that resulted in the most metallization remaining after aging the parts. The test patterns looked at double- and triple-printed platinum gold thick film metallization. One test pattern also looked at including a dielectric

"picture frame," printed within the stack, that partially covered the pad and extended past its perimeter. The results of this investigation are shown in Table 1. The best results were the triple print with the dielectric "picture frame" in the stack.

### Substrate Failures

The test vehicle substrates that broke during the mechanical testing indicated that they were not robust enough to meet the customer's requirements. This led to an investigation into the production processes and to a finite element analysis [2]. An FEA model of the test vehicle was built, and an analysis was performed. This analysis accurately predicted where the failures had occurred and provided a solution. It showed that if the MCM substrate thickness was increased from 1.0 to 1.3 mm (40 to 50 mils) and a center support was added to the existing corner supports, the stresses in the board would be reduced by more than half. The results of this work are summarized in Table 2.

Throughout the qualification tests production processes were also carefully examined. The one that came under scrutiny was the substrate sizing operation where scribing and separation are performed using a yttrium aluminum garnet (YAG) laser. To examine this process more closely blank LTCC substrates, 1.3 mm (50 mils) thick, were cut into bars for a modified four-point-bend test. Some were cut with the YAG laser and some with a precision diamond saw. The bars cut with the laser were tested in two configurations: with the laser incident side (entry side) in tension and with it in compression (exit side in tension). Bars of alumina were also made using the same processes. This test showed that there was a 30 percent reduction in the strength of LTCC when the laser incident side was in tension. The results are summarized in Table 3. Based on these results, the diamond saw process was chosen as the base line approach for substrate sizing.

### Conclusion

As a result of all this work:

- the surface mount pad configuration was improved by triple printing the metallization and adding a dielectric "picture frame" into the print stack;
- the substrate thickness was increased from 1.0 mm (40 mils) to 1.3 mm (50 mils);
- a center support was added to the existing corner supports in the next assembly housing; and
- diamond sawing was chosen to cut the part to size.

With all these changes implemented, the modules passed testing, and this MCM-C was placed into production.

This work shows that if an MCM-C is going to be placed in a high reliability application, mechanical integrity should be a concern. Familiar problems such as intermetallic growth and novel problems such as mechanical failure can occur. Carefully planned part design, qualification testing, and failure analysis will accurately determine causes of failures and plans for corrective action.

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[1] Howard Morgenstern, Sam Bandler, and Gregg Barner, "Characterization of Printing and Laser Trimming of DuPont 2000 Series Resistors on DuPont 951 'Green Tape <sup>TM</sup>,'" *1996 Proceedings*,

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[2] Fernando Uribe, Stephen Garret, Sandra Monroe, Steven Burchett, " *Characterization of the Mechanical Properties of LTCC 'Green Tape  $\hat{O}$ '* ", Sandia Report SAND97-0497, March 1997 (Available from National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161)