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Subsidiary of SRI International

CERAMIC/METAL COMPOSITE CIRCUIT-BOARD-LEVEL TECHNOLOGY FOR APPLICATION SPECIFIC ELECTRONIC MODULES (ASEMs)

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TECHNICAL REPORT

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FT. MONMOUTH, NJ 07703

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Barry J. Thaler
Member Technical Staff, Electronic Packaging

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Summary

The Phase 2 program started on April 12, 1995. During the past 2 months the emphasis has been on preparing for the Technology Transfer to a merchant circuit board manufacturer. To support this Technology Transfer, a glass supplier, SEM-COM, has been identified to provide sufficient quantities of the custom glasses developed by Sarnoff during Phase 1. An initial order of glass has exhibited properties similar to those measured on Sarnoff-melted glasses. LTCC-M substrates fabricated with those glasses at Sarnoff also exhibit similar characteristics. Documentation has been prepared outlining the major LTCC-M materials and processes. As soon as the contract is modified, transfer of the Phase 1 LTCC-M technology will commence.

The LTCC-M technology continues to be optimized for use with the Technology Demonstration Vehicles and for high density packaging requirements. The bonding layer has been modified to accommodate requirements to fabricate many small packages in a large area format and then cut them into individual packages at the end of the fabrication process. This new bonding layer is compatible with either grinding or laser-based cutting techniques. The adhesion of the thick film top conductor pads has been improved by the use of a glass underlayer that is printed and cofired with the green tape stack. The improved adhesion will be required as high density circuits require smaller component attachment pads.

Plans are in place to deliver two Technology Demonstration Modules by the end of January, 1996. These modules are the Advanced PCMCIA Card and the Optoelectronic Transceiver Module.

Section I

WBS Task 2.1: Technology Transfer to Merchant Suppliers

A. TASK OBJECTIVE

Transfer the LTCC-M technology to a merchant circuit supplier. This task will require a steady supply of several custom glasses that were developed during the Phase 1 program. One or more glass producers will be qualified to supply materials to the David Sarnoff Research Center or its designee to produce LTCC-M circuit boards and packages. After a glass source for the green tape ceramic has been qualified, the Phase 1 technology will be interactively transferred to a merchant circuit board supplier. The merchant circuit board supplier will be qualified by the fabrication of test structures and technology demonstration modules.

B. INTRODUCTION

During Phase I of this Project all the glasses needed to fabricate LTCC-M substrates on Cu/Mo/Cu cores were formulated and prepared at Sarnoff. This enabled us to readily prepare small amounts of many different compositions needed to attain required attributes in the glasses. A commercial source for these glasses is needed to ensure their adequate supply to a manufacturing operation. We have identified SEM-COM, a merchant supplier of specialty glasses to the electronics industry as this source. The KU-14 glass formulation has been produced by SEM-COM. An initial quantity of 10 lbs. was produced and sent to Sarnoff for green tape production, testing, and analysis.

C. DEVELOP COMMERCIAL GLASS SUPPLIER

Five (5) different glasses are used in LTCC-M. Each one will be qualified through tests performed at Sarnoff. The qualification process will involve testing the important attributes of the glasses relevant to the successful fabrication of LTCC-M substrates. Table I.1 lists these tests and evaluations for the glass KU-14 and the status of the test in question.

Table I.1: Qualification Evaluations

Test or Attribute	Status or Comments
1. Composition Verification	Vendor Documentation , Completed
2. Differential Thermal Analysis	Completed; Equivalent to Sarnoff Glass
3. Coefficient of Thermal Expansion	In Progress
4. Particle Size of Ground Powder	Completed
5. Surface Area of Ground Powder	In Progress
6. Green Tape Characterization	In Progress
7. Dielectric Constant & Loss	Completed Equivalent to Sarnoff Glass
8. LTCC-M Lock-in, and Camber	Completed; Equivalent to Sarnoff Glass
9. Microstructure	In progress

10. X-ray Diffraction Analysis	In progress
11. Via Ink Behavior	In progress
12. Feed through Insulation	In progress
13. Lock-in, Adhesion	Completed; Good

Preliminary Results:

1. The DTA of the KU-14 glass made at SEM-COM has the same characteristics, within the uncertainties of the method, as that of glass made at Sarnoff in the location of the glass transition and crystallization regions. Figure I.1 shows the DTA diagrams of Sarnoff and SEM-COM glasses.
2. Particle size distribution of SEM-COM ground glass showed a higher degree of fines. This could account for the need to add 40% more binder to the slurry composition than is necessary with Sarnoff-ground glass powder to obtain acceptable green tapes.
3. The dielectric constant and loss tangent of crystallized SEM-COM KU-14 containing ABT-38 are 5.6 and 1.5 x 10^{-3}, respectively, at 15 GHz.
4. The dielectric tape made with the SEM-COM KU-14 had good lock-in and sintering behavior. There was little or no camber observed in 7-layer parts on 20 mil Cu/Mo/Cu.

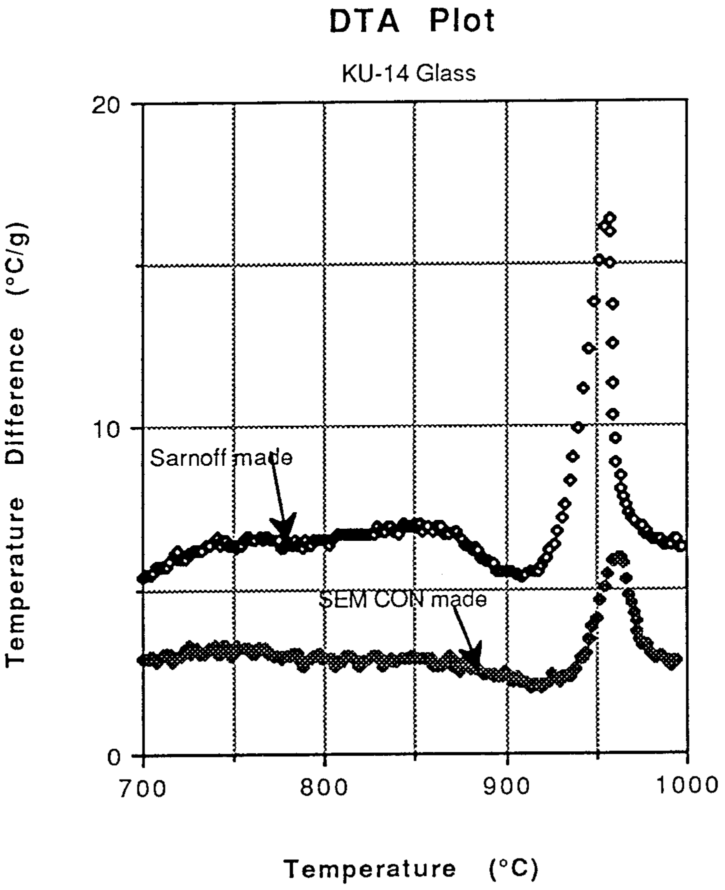

Figure I.1: DTA data for KU-14 glasses

D. PLAN FOR NEXT QUARTER

- Complete KU-14 glass qualification with the purchase of additional 10 lbs. batches to verify repeatability of the results.
- Qualify glasses KU-6, KU-8, and MSR-31.
- Begin qualification of glass G-14.
- Begin LTCC-M Technology Transfer to a merchant circuit board supplier.

Section II

WBS Task 2.2: Customize LTCC-M for Specific Applications

A. TASK OBJECTIVE

Extend the LTCC-M technology to meet any requirements of the technology demonstration modules, and any general packaging trends of the electronics industry.

B. INTRODUCTION

Progress is reported for three of the major technology extension areas of this Phase 2 program; namely in the singulation of multiple fabricated packages or modules from a large panel, the extension of LTCC-M to higher density circuits; formation of precise cavities in LTCC-M substrates. One of the major advantages of LTCC-M for producing low cost packages and modules is that it allows all substrate work to performed in a large area format, and the individual modules then singulated in the final process steps. Thus, all labor and processing costs can be amortized over a relatively large number of pieces, instead of the few parts afforded by a small area format. Minor changes in the LTCC-M materials system have allowed small packages (1/2" x 1/2" to 1" x 1") to be individually cut from multi-up substrates. This has been demonstrated by standard grinding techniques, as well as by laser cutting.

To extend LTCC-M to higher density circuits, the reduced size of the component connection pads require increased adhesion of the top conductors to the ceramic. Thick film inks developed this past quarter have shown significantly improved top conductor adhesion. These new inks are not expected to increase the module cost.

C. OPTIMIZE LAMINATION FOR PRECISE CAVITIES

Objective:

To develop simple, robust, and versatile process for obtaining cavities of predetermined sizes very precisely.

A secondary objective is to develop a method where the cavities obtained in the sintered LTCC-M substrate correspond exactly to the size of the die used to punch the green tape. This will take advantage of the zero-shrinkage aspect of LTCC-M process.

Types of cavities:

1. Small and large rectangular cavities all the way to the metal core
2. Cavities of other shapes (ovals, circles, L-shaped etc.)
3. Tiered cavities (with and without metal bonding pads)
4. Shallow and deep cavities

Problems to solve:

(i) Controlling cavity shape and size during lamination, and co-lamination steps
(ii) Preventing or controlling the cavity expansion during sintering
(iii) Reducing cavity edge contouring (or ensuring vertical cavity walls)
(iv Preventing cracking of cavity walls
(v) Bond pad metallization on steps of cavity

(vi) Cleaning and plating cavity floor

Approaches and their problems/challenges:

(a) Iso-static lamination and co-lamination. (While iso-static laminators eliminate most of the aformentioned problems, they are expensive, size-limited, have low throughput, and involve additional processing steps (bagging etc.)

(b) Lamination in uni-axial press with hard inserts to retain cavity shape/size. (Precisely-known inset thicknesses, generally empirically determined, are needed The inserts can become part of the lamination die plate)

(c) Lamination with spring-loaded hard inserts (Avoids the need for precise insert thickness because of the spring loading. Tool costs will be high.)

(d) Lamination using compressible Neoprene-type inserts
(Thickness and compressibility of the Neoprene inserts had to be matched to that of the green laminate otherwise the cavity walls will either be pushed in or out depending on the degree of compression of the insert during lamination. The logistics of placing and removing inserts in the individual cavities need to be solved)

(e) Lamination with uni-directionally (z-direction) compressible inserts (e.g.. corrugated paperboard)

(f) Lamination with inert tape inserts:
(Tape insert has similar compression and setting behavior to the LTCC laminate. Also it can be left in place during sintering and easily washed off after sintering. Methods for cavity filling with the inert tape material have to be simple and not time or labor-intensive.)

(**Note**: All the above methods are aimed at reducing or eliminating cavity shape /size changes during the lamination steps only. Another goal of this task is to develop a method to prevent the small but finite cavity expansion during sintering.

Approaches to evaluate:

A. Lamination in uniaxial press with hard inserts

B. Lamination in uni-axial press with inserts having unidirectional compressibility (cardboard)

C. Lamination with inert tape material

Evaluation Method:

Step 1: Establish base-line problem without no inserts

- Measure cavity size/shape changes after lamination, co-lamination steps, and after sintering. Variables : Lamination pressure, # layers, tiered and non-tiered cavities.

Step 2: Repeat 1 above with the chosen type of insert

Step 3 : Ascertain the need for inert-layer sintering constraint with the chosen approach(es).

Step 4: Evaluate the best method chosen for cavities of other shapes and configurations.

EXPERIMENTS:

<u>Step 1. Establish the base line;</u>

1. Use ABT 41 SC tape
2. Punch 16-cavity pattern
3. Make 5- and 10-layer laminates at lamination pressures shown in Table II.1 below (Use no inserts)
4. Measure cavity dimensions and not cavity shape changes if any
5. Use 3000 lbs. co-lamination pressure for all parts
6. Measure cavity size and not shape changes if any

7. Sinter using 910°C peak zone settings
8. Measure cavities and note shape changes if any

TABLE II.1

Lamination Pressure (on 3'x3" laminate)	# Layers = 5	# Layers = 10
3000 lb.	x	x
5000 lb.	x	
7500 lb.	x	x
10000 lb.	x	

Step 2: Cavity lamination with inserts:

Objective: To devise a method for shoring up the cavity walls with suitable inserts during lamination and co-lamination in a uniaxial laminator. Three types of inserts are to be evaluated:

(1) Machined metal slugs
(2) Uni-directionally compressible inserts:
    (Examples: Polyester foams, laminated paper boards such as cardboard)
(3) Inserts of inert tape (example: LN-1 tape)

Evaluation Method: (For 1 and 2 above)

1. Collate 5 and 10 layer laminates on the lamination block provided with alignment pins.
2. Place the inserts under evaluation into each of the cavities and gently tap them in to ensure proper seating in the cavity areas.
3. Laminate at the suggested pressure (**5000 lb.**) and temperature (**200°F**)
4. Remove the inserts without damaging the cavities in the laminates.
5. Co-laminate on to Cu/Mo/Cu **at room temperature and 1000 lb. pressure on 3"x 3"**
6. Fire

Note: measure cavity sizes after these steps: lamination, co-lamination, and sintering

Evaluation method for 3 above:

1. Collate 5 layers of green tape on the lamination block using pins.
2. Tack Laminate the layers at 500 lb. (on 3"x3") at 200°F
3. Stuff the cavities with powdered LN-1 tape or with LN-1 tape cutouts to the brim and tamp down the filling to ensure dense packing. Wipe off excess LN-1 powder from the top surface of the laminate.
4. Press again in the lamination press at the suggested pressure at 200°F
5. Co-laminate on Cu/Mo/Cu at 3000 lb. at 200°F.
6. Fire

Note: Measure cavity sizes after lamination, co-lamination, and after firing. measurement as before.

Unless explicitly noted, the following sample preparation processes will be followed:

(i) ABT-41 SC tape
(ii) 5-layer laminates

(ii) Use lamination pressure of 5000 lb., at 200°F in all cases except as noted
(iii) Co-lamination as noted

TABLE II.2: Experimental Matrix

CONDITIONS	With Metal Inserts		Foam Inserts		LN-1 Inserts	
	1	2	3	4	5	6
1. Top LN1 layer	No	yes	No	yes	No	yes
2. Pre-lamination	No	No	No	No	500 lb./ at 200°F	
3. Lamination	5000 lb.. (3"x3") at 200°F					
4. Remove insert before Co-lamination	Yes	Yes	Yes	Yes	No	No
5. Co-lamination	1000 lb. at Room Temperature				3000 lb. at 200°F	
Fire on Cu-Mo-Cu	870 C- 910 C- 910°C Profile					

Step 3: Assess the need for top inert layer to prevent cavity expansion during sintering.
This evaluation will be carried out in conjunction with the above lamination methods. See experimental matrix in Table II.2 above.
Step 4: Extend to other cavity configurations:
Experiment to be defined

D. HIGH DENSITY CONDUCTORS

Previous Ag and AgPd top conductor thick film ink formulations showed adequate adhesion for plating and solderability tests, as well as substrate probing. However, when components were attached by soldering and pull tested all of these inks failed by delamination at the top conductor-ceramic interface or by failure within the top conductor. Failure within the glass-ceramic is the preferred failure mechanism. Thus the exhibited failure mechanisms are a cause for concern, especially for the smaller component attachment pads that will be used in high density circuit board designs.

Initial experiments concentrated on co-fired AgPd top conductors having a significantly higher glass content. These top conductors (50 mil square pads) showed better adhesion, with the glass-ceramic breaking during component shear adhesion testing. However, the glass content of these inks was too high for reliable electrical contact to connecting vias. Experiments with post-fired AgPd conductors showed very poor adhesion to the glass-ceramic; this is due to high degree of crystallization that occurs during the cofiring process step.

The subsequent round of adhesion experiments utilized a glass layer beneath the top conductor pads. The glass layer was screened onto the green tape as a thick film paste, and co-fired with the LTCC-M circuit board. The AgPd top conductor was subsequently screen printed and post-fired onto the circuit board. The KU-8 glass (same glass used in the via formulation) was found to be a good glass layer. Initial shear adhesion experiments using a KU-8 glass underlayer with a (low glass content) post-fired AgPd top conductor have exhibited good adhesion to the glass-ceramic. The failure mechanism is failure of the glass-ceramic. Additional glass underlayer compositions are being investigated, and will be reported in the next report.

E. LOW COST SINGULATION PROCESS

Singulation is the dicing of ceramic-metal boards into individual packages or circuit boards. The problem is complicated by the fact that the best cutting processes for ceramics are not particularly compatible with those for metals, particularly the Cu/Mo/Cu laminated sheet, and *visa versa*.

Cutting with an abrasive wheel requires a two-stage process with separate abrasive wheels required for ceramic and metal. This is the cutting method that was primarily used during Phase 1. Using the Phase 1 LTCC-M materials and processes, cutting success was limited. As the substrate size was reduced to 1/2" x 1/2", more and more cutting damage became apparent; this was seen as reduced adhesion of the ceramic to the metal after cutting.

An obvious process to cut the two layers simultaneously is by laser. The first samples cut by this method showed extensive cutting damage, which sharply reduced the ceramic to metal adhesion.

The most desirable process might not require cutting the fired ceramic material. Removal of the green tape from the boundary area before firing, requires only the metal be cut. Cold cutting blades and rollers are under test.

Based on loss of adhesion strength of small samples cut with a laser or an abrasive wheel, it was decided to reexamine the ceramic to metal bonding layer. Measurement of the adhesion strength of the ceramic to the metal base requires application of a force normal to the interface, i.e. the "pull test". Unfortunately, any force which has a component that is not normal to the interface, such as to cause bending, of the metal substrate may also destabilize the interface by instigating crack propagation in that plane. This produces a measurement which sometimes reflects the stability of the interface rather than its strength. Thus far, all data for any given sample preparation is consistent with a single failure mode; different experimental set-ups that restrain the sample from bending to various degrees only influence the absolute breaking strength, not the failure mode. Therefore, a single "pull test" set-up should accurately compare different ceramic to metal bonding processes.

LTCC-M substrates were subjected to pull testing by an Instron machine. Using a 0.025" diamond cutting wheel, samples were cut into 1/2" squares from the standard 3" x 3" substrates. Nail-heads were bonded to the roughened ceramic with epoxy. Penetrant dye was applied to determine whether any separation had occurred during the cutting operation. Testing was accomplished by attaching the whole board to a flat plate by clamping it as near to the test piece as possible and then pulling. Note that except for the case of total detachment, the area of the sample does not play a role; the pullout occurs only in the area of the nailhead.

The adhesion strength test results are shown in Table II.3. In this table, sample 12 corresponds to the baseline materials and processes developed during Phase 1 of this program. The primary conclusion drawn from this data is that good bonds (>20 lbs.) may be formed by the firm attachment of the glass-ceramic to the metal oxide. Indeed, the bonding layer is usually fractured. The ceramic to metal adhesion was improved by removal of the Bi_2O_3 from the bonding layer formulation.

Table II.3

Sample #	Ceramic Cutting	Bonding Pattern	Bonding Layer	Adhesion (lbs)	Failure Mode
1	Dia. Wheel	25/35	Phase 1	15	bonding layer
2	Dia. Wheel	100%	31A	27	bonding layer
3	Dia. Wheel	20/40	Phase 1	22	bonding layer
4	Dia. Wheel	0		<5	NiO-ceramic interface
5	razor	100%	Phase 1	25	Ni-NiO interface
6	Dia. Wheel	100%	M48	22.5	ceramic
7	Dia. Wheel	0		0	NiO-ceramic interface
8	Dia. Wheel	100%	Phase 1	0	Ni-NiO interface
9	Dia. Wheel	100%	M9	0	Ni-NiO interface
10	Dia. Wheel	100%	31+Cu	26	bonding layer
11	Dia. Wheel	100%	31+FSi	12	bonding layer
12 (std)	Dia. Wheel	100%	Phase 1	11	Ni-NiO interface
13	Dia. Wheel	20/40	31A	29	bonding layer
14	Dia. Wheel	20/40	Phase 1	7.5	Ni-NiO interface

Using the results from Table II.3 as a guide, LTCC-M samples made with Bonding Layer Ink #31A were cut into 1" x 1" squares (by Applied Laser Systems) using a YAG laser. This cutting previously compromised the adhesion of the Phase 1 LTCC-M system. The new bonding layer did not exhibit any signs of reduced adhesion.

F. PLAN FOR NEXT QUARTER

- Complete first round of cavity lamination experiments, and recommend tooling for the cavities required by the Optoelectronic Transceiver Module Technology Demonstration Vehicle.
- Extend cavity lamination experiments to other geometries.
- Optimize AgPd top conductor for small, high strength component attachment pads.
- Begin development of materials and processes aimed filling 4 mil diameter vias for LTCC-M.
- Continue microscopic analysis of laser cut LTCC-M substrates.
- Continue development of singulation methods for cutting green tape prior to firing.
- Begin reliability experiments of LTCC-M samples that have been singulated.

Section III
WBS Task 2.3: Fabrication and Testing of Technology Demonstration Modules

A. TASK OBJECTIVE

The objective of this task is to design, fabricate, assemble, and test 4 different technology demonstration modules. These modules are: (1) an optoelectronic transceiver module, (2) a power amplifier package, (3) an advanced PCMCIA card, and (4) a Power Electronic Building Block (PEBB).

B. INTRODUCTION

The initial tasks in this area involve the general circuit and component design. When these tasks are complete the circuit layout can begin. A general set of LTCC-M design guidelines has been communicated from Sarnoff to the circuit designers, ETA and AMP. In the case of the PCMCIA card designer, ETA, this information is being implemented within their CAD system for circuit layout.

C. OPTOELECTRONIC TRANSCEIVER MODULE

Under this program Sarnoff, and AMP will develop a package that will integrate an optoelectronic MCM, an optical fiber, several silicon devices, and several passive components. Presently, the silicon devices are in the design stage. Based on the best available data, a crosstalk analysis of several package designs is also underway. This is expected to be completed by July. At this point, package layout for fabrication in LTCC-M technology will begin. The goal of this program is to provide LTCC-M packages to AMP (for module assembly) by the end of January, 1996.

D. ADVANCED PCMCIA CARDS

Under this program, Sarnoff and ETA will develop a RF modem module, based on a PCMCIA Type II card format, capable of being used in a variety of hand-held communications device platforms. With the initiation of this program, Sarnoff has coordinated with ETA the respective activities necessary to produce first prototypes of ETA's Tracker device by mid-December, 1995. In order to accomplish this development goal, which is critical to meeting ETA's product deployment commitment, the following major program milestones were identified and mutually agreed upon:

- Define Infrastructure Schedule - 6/08/95
- Coordinate Circuit Function with Physical Layout - 6/12/95
- Circuit Schematic/Layout Supplied to Sarnoff - 6/23/95
- LTCC-M Board Fabrication - 9/8/95
- Bare Board Tests - 9/15/95
- Prototype Boards Delivered to ETA - 9/18/95

To date, most of the program effort has been directed towards identifying and comparing critical circuit components available from various vendors with specific attention given to availability in terms of lead time and form factors necessary to accomplish circuit miniaturization. In order to minimize the time to do this, ETA has identified known products, built using traditional packaging technology, that perform the majority of the Tracker functions. ETA then became a licensed vendor for these products. By doing this, ETA will be able to copy the circuits they require and translate them to an LTCC-M compatible layout once the components are identified.

Once ETA has defined the product functionality and layout to their satisfaction, they will send this information to Sarnoff. ETA will begin the circuit design while Sarnoff examines compatibility issues between the components selected and assembly processes appropriate for the LTCC-M substrates. Sarnoff is expecting to receive this information no later than 6/12/95.

E. PLAN FOR NEXT QUARTER

- Receive final layout and fabricate bare substrate for the Advanced PCMCIA Card Technology Demonstration Vehicle
- Complete layout of the Optoelectronic Transceiver Module
- Conduct assembly tests to assess compatibility of LTCC-M substrates with the module assembly equipment and operations.

Section IV
Important Findings

A. TECHNOLOGY TRANSFER TO MERCHANT SUPPLIERS

- Properties of KU-14 glass obtained from SEM-COM are quite similar to those obtained from glass lots melted at Sarnoff.
- LTCC-M substrates made from green tape formulated with SEM-COM KU-14 glass show similar properties to those made with Sarnoff melted glass.
- Modification (addition of KU-6 glass) of green tape formulation for better control of thermal expansion properties during scale up.

B. CUSTOMIZE LTCC-M FOR SPECIFIC APPLICATIONS

- Bonding layer formulation modified to improve ceramic-to-metal adhesion of LTCC-M substrates.
- Small packages can be fabricated by either grinding methods or laser (YAG) cutting methods
- Use of a glass layer beneath the AgPd top conductor pads improves their adhesion strength in shear tests.

C. FABRICATION AND TESTING OF TECHNOLOGY DEMONSTRATION MODULES

- General design guidelines made available to designer
- Sarnoff has coordinated with ETA the respective activities necessary to produce first prototypes of the Advanced PCMCIA Card by mid-December, 1995.
- Sarnoff has made inputs to AMP for device design that with be compatible with LTCC-M packages.

Section V
Significant Developments

The ABT-38 green tape formulation, containing glass KU-14 has been somewhat modified by the addition of another glass, KU-6. This addition allows far greater control of the thermal expansion of the glass-ceramic. This is expected to greatly ease the technology transfer of LTCC-M to a merchant circuit board manufacturer. The new formulation, ABT-41, shows excellent dielectric properties ($\tan \delta \sim 0.0015$) at microwave frequencies (15 GHz).

The bonding layer formulation has been modified to allow small package singulation by laser cutting. Small parts cut by a YAG laser do not exhibit any signs of reduced ceramic-to-metal adhesion.

Section VI
Plan for Further Research

TECHNOLOGY TRANSFER TO MERCHANT SUPPLIERS

- Complete KU-14 glass qualification with the purchase of additional 10 lbs. batches.
- Qualify glasses KU-6, KU-8, and MSR-31.
- Begin qualification of glass G-14.
- Begin LTCC-M Technology Transfer to a merchant circuit board supplier.

CUSTOMIZE LTCC-M FOR SPECIFIC APPLICATIONS

- Complete first round of cavity lamination experiments, and recommend tooling for the cavities required by the Optoelectronic Transceiver Module Technology Demonstration Vehicle.
- Extend cavity lamination experiments to other geometries.
- Optimize AgPd top conductor for small, high strength component attachment pads.
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- Continue microscopic analysis of laser cut LTCC-M substrates.
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- Receive final layout and fabricate bare substrate for the Advanced PCMCIA Card Technology Demonstration Vehicle
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13. ABSTRACT *(Maximum 200 words)*

The quarterly progress for the Ceramic/Metal Composite Circuit-Board-Level Technology for Application Specific Electronic Modules is described in this report. Data is reported for the following tasks: Technology Transfer to Merchant Suppliers, Customize LTCC-M for Specific Applications, and Fabrication and Testing of Technology Demonstration Modules.

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