David Sarnoff Research Center

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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Certificate of Technical Data Conformity

The David Sarnoff Research Center hereby certifies that, to the best of its knowledge and belief, the technical data delivered herewith under Contract No. DAAB07-94-C-C009 is complete, accurate, and complies with all requirements of the contract.

Date: 9/13/95

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Summary

This past quarter the LTCC-M Technology Transfer began to Alcoa Electronic Packaging, Inc. Initially, Alcoa will use glasses provided by SEM-COM to produce the green tape and the thick film inks. The glasses will be qualified by Sarnoff for use in LTCC-M. SEM-COM has melted 4 of the 5 custom glasses that were developed during the Phase 1 program. The glasses needed to produce the LTCC-M green tape have already been qualified by Sarnoff. The green tape formulation has been modified to accommodate the slight differences between glass formulations melted by Sarnoff and the same formulations melted by SEM-COM. The characteristics of the fired substrates made from the modified formulations are nearly identical to those previously made from Sarnoff melted glasses. An evaluation plan is in place to compare Alcoa produced green tape and thick film inks to those produced by Sarnoff.

The LTCC-M technology continues to be enhanced. Processes have developed that allow cavities in the green tape to fired to the size they were punched. Additionally the adhesion of Ag and AgPd thick film top conductors has been significantly improved. Initial results from accelerated aging tests do not show any deterioration in the adhesion strength of soldered conductors.

The original plan was to start fabrication of the Advanced PCMCIA Card and complete the final package design of the Optoelectronic Transceiver module during this past quarter. Both of these systems have suffered delays that have not allowed the final substrate designs to be completed. It is anticipated that these designs will be finalized early next quarter. Work is underway to support the development of the Power Amplifier and Power Electronic Building Block package designs.

Section I
WBS Task 2.1: Technology Transfer to Merchant Suppliers

A. TASK OBJECTIVE

Transfer the LTCC-M technology to a merchant circuit supplier, Alcoa Electronic Packaging, Inc. 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 Alcoa Electronic Packaging. 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. During this past quarter SEM-COM has supplied Sarnoff with 2 batches of KU-14 glass, and 1 batch each of KU-6, KU-8, and MSR-31. Each batch consisted of 10 lbs., which was milled per Sarnoff's specifications, 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. Table I.1 shows the status of the glasses melted by SEM-COM. 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.2 lists these tests and evaluations for the KU-14, and KU-6 glasses, as well as for ABT-52SC green tape. This table indicates the status of the test in question.

Table I.1: Status of Glasses Melted by SEM-COM

Glass	LTCC-M Use	Melted by SEM-COM	Characterized	Qualified in LTCC-M
KU-14	Green Tape	✔	✔	✔
KU-6	Green Tape	✔	✔	✔
KU-8	Via Ink	✔		
MSR-31	Glaze	✔		
G-14	Cu/Mo/Cu Feedthroughs			

Table I.2: Qualification Evaluation of KU-14 and KU-6

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	Measured at SEM-COM
4. Particle Size of Ground Powder	Completed
5. Surface Area of Ground Powder	In Progress
6. Green Tape Characterization	Completed Requires additional resin in tape
7. Dielectric Constant & Loss	Completed; Good
8. LTCC-M Lock-in, and Camber	Completed; Equivalent to Sarnoff Glass
9. Microstructure	Completed; Good
10. X-ray Diffraction Analysis	Completed, Same crystal phases observed
11. Via Ink Behavior	In progress
12. Feedthrough Insulation	In progress
13. Lock-in, Adhesion	Completed; Good

<u>**Results**</u>:

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. The DTA of KU-6 glass melted by SEM-COM shows similar characteristics to the glass melted at Sarnoff. Figure I.2 compares the DTA data from the Sarnoff and SEM-COM melted glasses.
3. Particle size distribution of SEM-COM ground glasses show 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.
4. The dielectric constant and loss tangent of crystallized SEM-COM KU-14 and KU-6 glasses contained in ABT-52 are 5.4 and 1.1×10^{-3}, respectively, at 15 GHz.
5. The ABT-52 dielectric tape made with the SEM-COM glasses exhibited good lock-in and sintering behavior. There was little or no camber observed in 5 and 10-layer parts on 20 mil Cu/Mo/Cu.

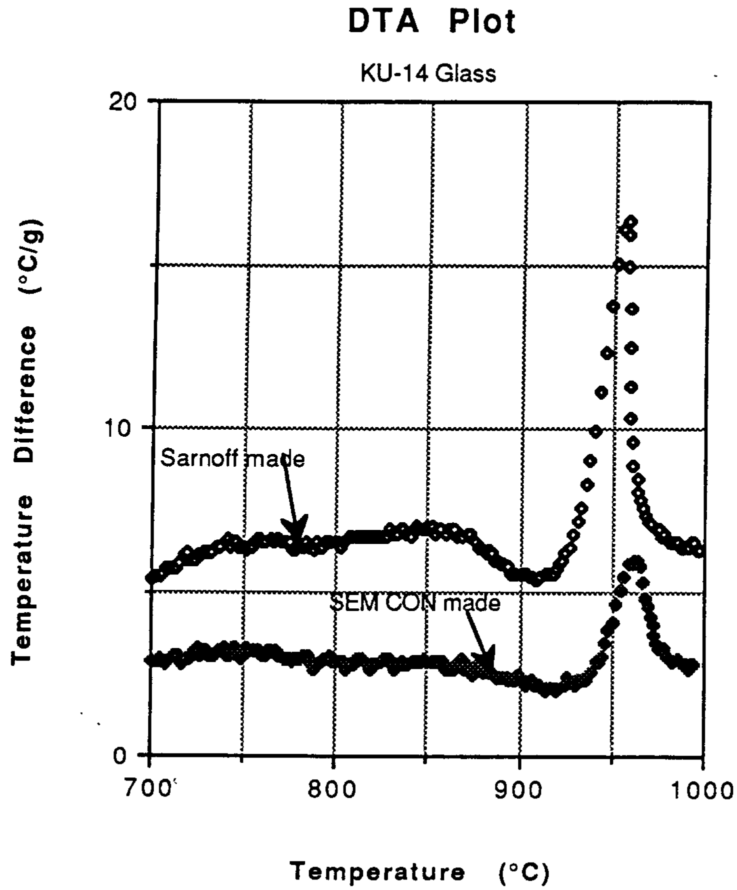


Figure I.1: DTA data for KU-14 glasses

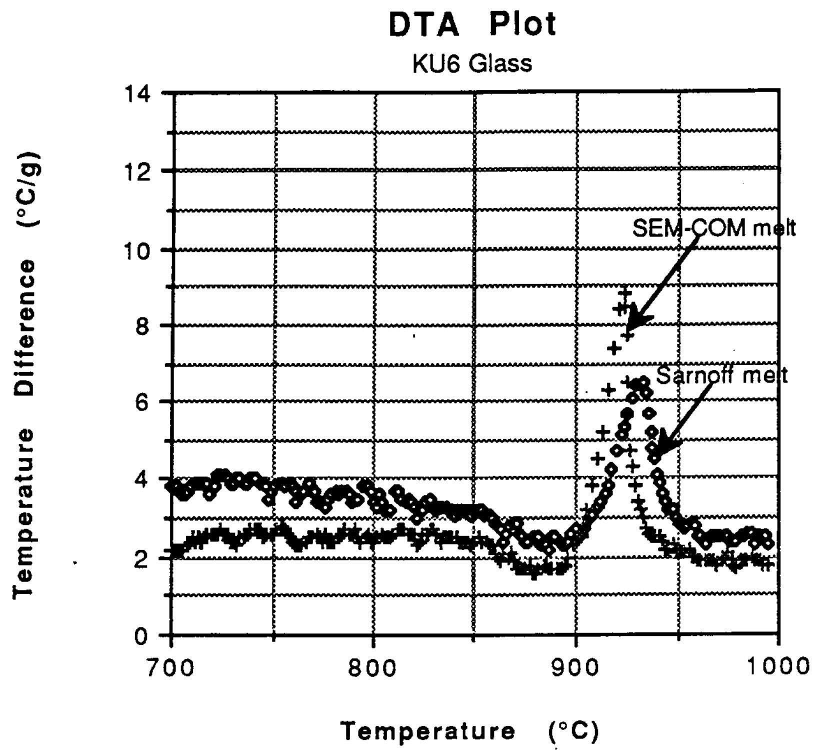


Figure I.2: DTA data for KU-6 glasses

D. TECHNOLOGY TRANSFER TO ALCOA ELECTRONIC PACKAGE

The technology transfer to Alcoa Electronic Packaging, Inc. began with a series of hands-on meetings at the David Sarnoff Research Center in July, 1995. Detailed information was provided to Alcoa outlining the LTCC-M materials and processes in the areas of raw materials characterization, green tape formulations and slurry preparation, thick film ink formulations and milling, thick film ink printing and via filling, tape lamination and firing.

The technology will be transferred to the Alcoa Technical Center (Alcoa Center, PA) and will be implemented using equipment suitable for high volume production of ceramic circuit boards and packages. The general approach for this technology transfer to high volume manufacturing is shown in Figure I.3. The initial work will concentrate on establishing a data baseline for incoming materials. The raw materials will be characterized at Alcoa using the tests shown in Figure I.4. Upon receipt of the initial order of glass from SEM-COM, Alcoa will commence making the ABT-52SC green tape formulation. The initial tapes will be extensively tested as indicated in Figure I.5. Using Sarnoff prepared Cu/Mo/Cu metal cores, the Alcoa made green tape will fired into LTCC-M substrates and the evaluations indicated in Figure I.6 will be performed by Alcoa.

AEP Approach for Technology Transfer and Evaluation

- Transfer and adapt technology from DSRC to ATC/AEP people and facilities.
- Assess process robustness by running designed experiments.
- Assess technology for scale-up potential by comparing to existing alumina-tungsten knowledge base.
- Benchmark manufacturability by building "real" products, as well as specific test vehicles.
- Determine future market potential by:
  - Developing large-scale manufacturing costs
  - Determining competitive approaches
  - Assessing competitive position
- Develop path to large scale manufacturing by:
  - Cost effective processes
  - Cost effective suppliers

Figure I.3: Approach to high volume manufacturing

TECHNOLOGY TRANSFER UPDATE

General Characterization

- Powders
  - Materials Specifications
  - Particle size distribution correlation
  - Surface area measurements
  - Chemical Analysis
  - TGA
  - DTA - Ts, Tg, Tmp
- Organics - Raw materials through pre-mix vehicles
  - Materials specifications
  - Rheological characterization
  - Densities

Figure I. 4: LTCC-M raw materials characterization at Alcoa

TECHNOLOGY TRANSFER UPDATE

Slurry and Tape Casting

- Current tape is adequate for prototyping and technology assessment. Anticipate need for refinement for volume manufacturing.
- Planned Tests:
  - Rheological Characterization
  - Mechanical Properties
  - Stability during processing
  - Compare DSRC and AEP Formulations using AEP casting equipment
  - Role of particle size distribution
  - Fine feature printability (AEP inks)
  - Via Fill (AEP inks)

Figure I.5: LTCC-M green tape evaluation to be performed by Alcoa

TECHNOLOGY TRANSFER UPDATE

Firing

- Setup laser profilometer to quantify camber measurements.
- Measure camber before and after firing (concern on flatness of metal core ?)
- Matched profile developed and documented.
- Currently running temperature/time process window experiment.

Figure I. 6: Fired LTCC-M substrate evaluations to be performed by Alcoa

E. PLAN FOR NEXT QUARTER

- Complete melting of custom glasses by SEM-COM
- Complete transfer of ABT-52SC Green Tape formulation to Alcoa
- Complete transfer of silver buried conductor and via conductors to Alcoa
- Set-up all firing profiles at Alcoa
- Begin transfer of LTCC-M metal preparation process to Alcoa

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 four of the major technology extension areas of this Phase 2 program; namely the singulation of multiple fabricated packages or modules from a large panel, formation of precise cavities in LTCC-M substrates, development of high adhesion top conductor ink formulations, and the extension of LTCC-M to higher density circuits. One of the major advantages of LTCC-M for producing low cost packages and modules is that it allows substrate fabrication to be 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. Last quarter, standard grinding techniques and YAG laser cutting were demonstrated as approaches to achieve this for fired substrates. This quarter, laser cutting was demonstrated as an approach for singulating the green tape while it is still attached to the large area Cu/Mo/Cu plate for firing and subsequent processing. The latter approach preserves the large area processing, which may be important for reducing the overall package fabrication costs.

The best known cavity packages are single chip packages such as DIPs, and Quad Flat Packs (QFPs) used for microprocessor packaging. In these and other packages, the dimensional tolerances of the needed cavities must be tightly controlled to specified values for reasons such as automatic device placement including wire bonding, minimizing and controlling the wire bond lengths, controlling the module profile after device placement, ensuring good thermal contact between the device and the substrate etc. In conventional multilayer ceramic process, the x, y shrinkages are of the order of 15% during firing, so the individual green tape layers are punched to a known over size, determined empirically, to obtain the desired cavity size. In as much as close shrinkage control in sintering is a great challenge requiring close raw material and constant process control and monitoring, it was felt that multilayer ceramic processes that totally suppress the lateral shrinkage during sintering, will also enable easier achievement of desired cavity dimensions. Extensive work is reported for development of processing to produce cavities that replicate their punched size after firing.

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. Presently several inks are undergoing reliability testing, and thus far there has been no decrease in the conductor adhesion. These new inks are not expected to increase the module cost.

C. OPTIMIZE LAMINATION FOR PRECISE CAVITIES

Background:

Cavities in single chip and multichip ceramic packages are needed for one or more of the following reasons:

1. To mount the device on a heat sink attached to the bottom of the substrate
2. To provide one or more levels of peripheral wire bond pads for device attachment
3. To lower the profile of the module (through the attachment of devices to recessed bond pads in the substrate.

Objectives:

To develop a simple, robust, and versatile process for obtaining cavities of predetermined sizes very precisely in the LTCC-M technology.

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 make use of the zero-shrinkage attribute of the LTCC-M process.

Types of cavities:

1. Small and large rectangular cavities through 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 durin: lamination and co-lamination steps: Since both lamination and co-lamination are now generally carried out above the glass transition temperature of the butvar resin of the green tape, plastic flow of the tape into the cavity region becomes a concern.

(ii) Preventing or controlling the cavity expansion during sintering: Although the LTCC-M process can be characterized as a zero-x,y, shrinkage process, at the very edges of the substrate (or of cavities, which are bounded by four (4) such edges, one can detect a small but finite degree of shrinkage. This will cause the cavity edges to pull back during sintering causing three problems viz. (a) cavity size expands, (b) this expansion tends to cause tearing at sharp cavity corners, and (c) the cavity edges tend to roll up and set a little thicker than other regions creating unwanted ridges at cavity edges.

(iii) Reducing cavity edge contouring (or helping to form vertical cavity walls): The degree of the lateral shrinkage of the layers mentioned in (ii) increases with the increasing distance from the shrinkage-restraining metal core. This manifests as a slight outward sloping of the cavity walls.

(iv) Preventing cavity cracking: Due to the small degree of cavity expansion mentioned above, sharp cavity corners tend to tear or crack during firing. The corners have to provided with a suitable radius to avoid this cracking.

Other important issues related to cavities in ceramic packages are:

(v) Bond pad metallization on steps of cavity: These pads have to be on a planar surface, present smooth surfaces, have good adhesion to ceramic, for consistently good bond quality.

(vi) Cleaning and plating cavity floor

Approaches and their problems/challenges:
(a) Iso-static lamination and co-lamination. (Iso-static laminators are expensive, size-limited, have throughput limitations, and involve additional processing steps (bagging etc.)
(b) Lamination in uni-axial press with hard inserts to retain cavity shape/size. (Precisely known insert thicknesses 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.)
(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.
(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.)

Approaches chosen for evaluation:
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

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.

CAVITY LAMINATION EXPERIMENTS
1. Cavities extending to the metal core

Step 1: Establish Base-line:
1. Use ABT 41 SC tape
2. Punch 16-cavity pattern (square cavities)
3. Make 5 and 10-layer laminates at lamination pressures shown in table below (Use no inserts)

4. Measure cavity dimensions and not cavity shape changes if any
5. Use 3000 lb. co-lamination pressure for all parts
6. Measure cavity size and not shape changes if any
7. Sinter 870, 915,915°C
8. Measure cavities and note shape changes if any

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

Results:

PROCESS STAGE	**Cavity Dimensions (inches)**			
	3000 LB lamination	**5000 LB lamination**	**7500 LB lamination**	**10000 LB lamination**
PUNCHED	0.178	0.178	0.178	0.178
LAMINATED	0.156	0.158	0.154	0.150
COLAMINATED	0.147	0.146	0.145	0.141
FIRED	0.167	0.167	0.168	0.165

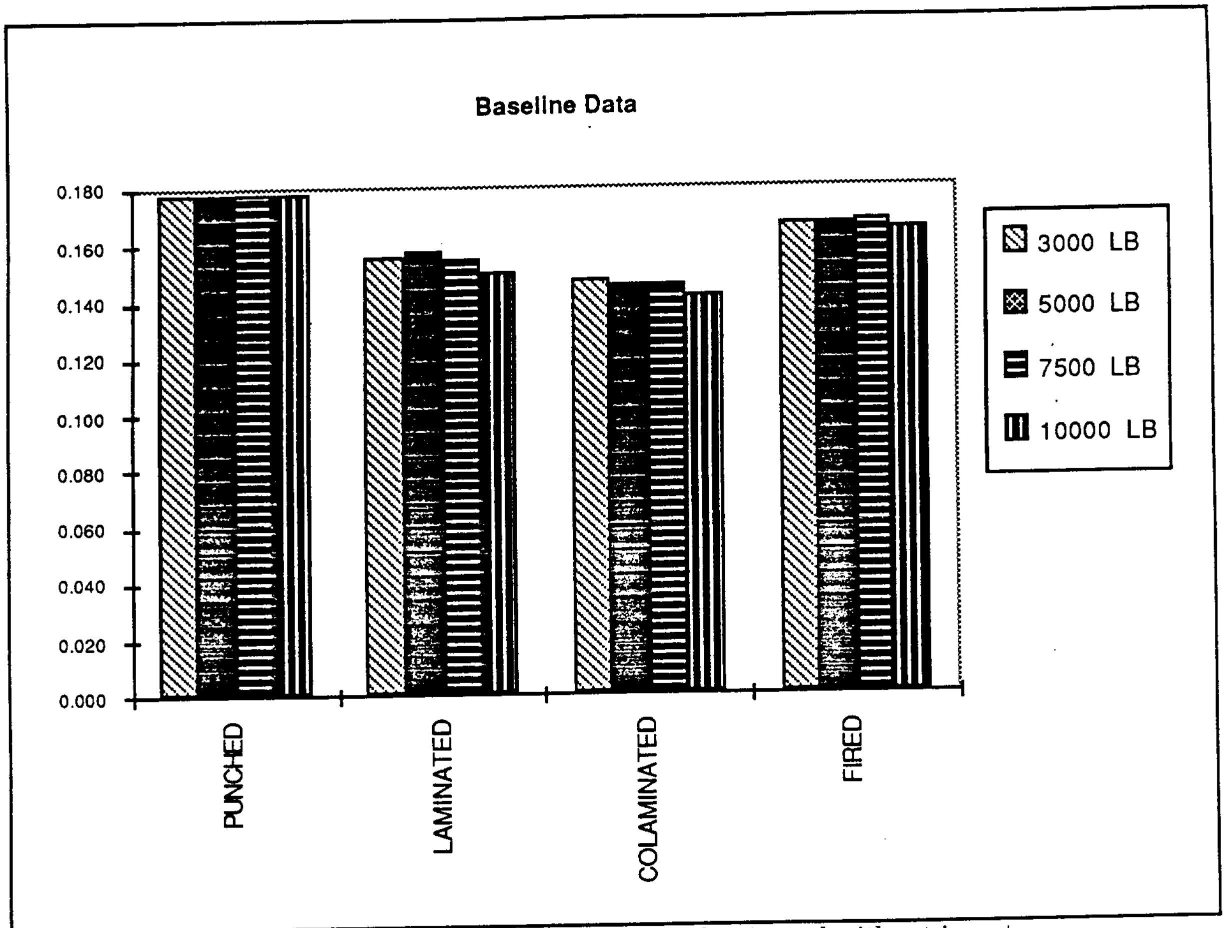


Figure II.1: Baseline data for cavities laminated without inserts

<u>**Step 2: Cavity lamination with inserts**</u>:
Objective: To devise a method for shoring up the cavity walls with suitable inserts during lamination and co-lamination in a uniaxial laminator

3 types of inserts were evaluated:
(1) ***Machined metal slugs*** : machined brass inserts of a size equal to the desired final cavity size to be placed in the stack of green tape layers at the cavity locations. The green tape layers are punched with a cavity punch slightly larger (0.005") on a side than the inserts, to allow for their easy placement in the cavity locations. The thickness of the inserts was chosen to be slightly larger than the laminated thickness of 4 green tape layers (= 32 mils). The top laminating plate had slots machined in it corresponding to the 16 cavities in the green tape, these slots being slightly oversized with respect to the inserts, so that the latter can extend into these slots during the lamination process.
(2) ***Uni-directionally compressible inserts:***
(Examples: Polyester foams, laminated paper boards such as cardboard). Polyester foam packing material from envelopes, was cut to the approximate size of the cavities in the green stack and stuffed into them before lamination. After lamination, the foam plugs were removed with tweezers. The idea was to merely explore what degree of cavity shape retention that the foam would provide in lamination.

(3) Inserts of inert tape (example: LN-1 tape):

This experiment was based on the hope that, if the cavities are filled with a tape of a refractory material, such as alumina, made with the same binder system as the glass green tape, then stuffing the laminate with the powdered alumina tape would effectively counter the tendency of the cavity walls to move in during the lamination step. The alumina tape plug can be left in place during sintering, and the powdered alumina resulting from it can be removed quite easily after firing by washing in water stream, ultrasonic cleaning etc.

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 lbs**) 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

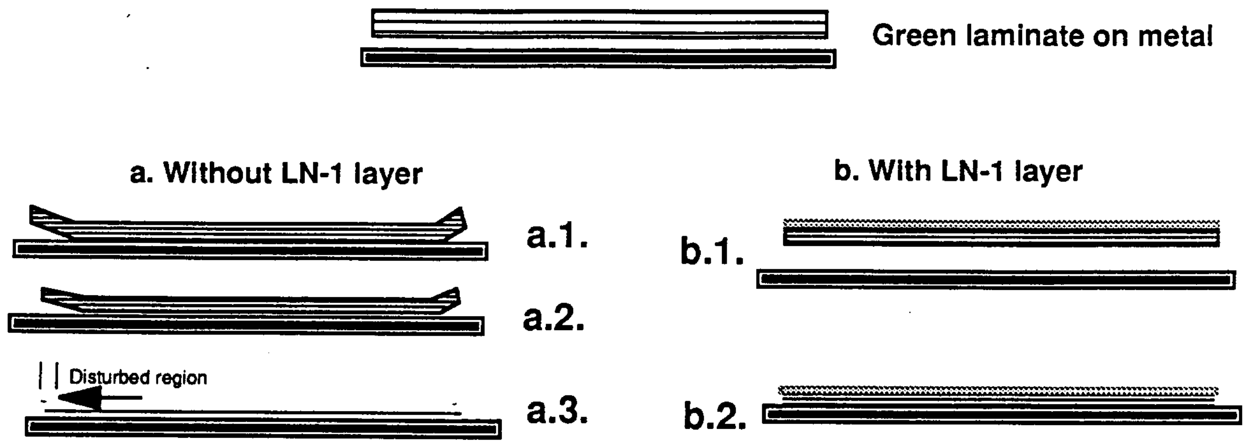
Evaluation method for 3 above:

1. Collate 5 - 10 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 dow: 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: Cavity measurement as before.

Step 3: To assess the need for top inert layer to prevent cavity expansion during sintering. This evaluation was carried out in conjunction with the above lamination methods.

Based on some prior experiments, it was felt that laminating a layer of inert alumina tape on top of the stack of the glass-ceramic layers would be effective in preventing the small amount of localized free sintering that invariably occurs during LTCC-M sintering. The mechanism of their formation of the ridge in the glass-ceramic at substrate and cavity edges, and its suppression in the presence of a top layer of LN-1 is illustrated in Figure II.2.



a.1. Initial free sintering of the green laminate is confined only to the edges of the laminate which lift up.

a.2. The central parts of the laminate complete sintering totally constrained by the core, while the lifted edges do so with much less constraint. As a result, the edges set up thicker than the center.

a.3. Eventually, the edges collapse on to the core surface and become bonded to the core like the rest of the substrate. The edges will remain thicker than the rest of the substrate

b.1. Initial free sintering of green laminate will be constrained on both sides, with metal on the bottom and LN-1 on the top.

b.2. The laminate will lie perfectly flat on the metal core with no edge lift up. For small number of layer (~ 10) the edge will be near perpendicular. For higher layer counts, a wedge shaped edge will form.

NOTE: Even in this case, there may be a small, but uniform shrinkage of the laminate during firing. The magnitude of this shrinkage will be smaller than when LN-1 is not used, and the edge lip will not form.

Figure II.2: Ridge formation during LTCC-M firing.

The evaluation procedures are the same as outlined above for laminates without a top layer of refractory tape, except, in each case, the original green tape stack will include an LN-1 tape which has also been cavity punched .

LAMINATION EXPERIMENTS WITH INSERTS

Use:
(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

Experiment 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 200F	
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 - 915 - 915°C Profile					

Results:

INSERT	PRESSURE	Cavity Dimensions (inches) LAMINATED	COLAMINATED	FIRED
None	3000 lbs	0.156	0.147	0.167
None	5000 lbs	0.158	0.145	0.167
None	7500 lbs	0.154	0.145	0.168
None	10000 lbs	0.150	0.141	0.151
Foam	5000 lbs	0.159	0.156	0.179
Foam+LN1	5000 lbs	0.159	0.147	0.168
LN1	5000 lbs	0.157	0.157	0.169
LN1+LN1	5000 lbs	0.155	0.149	0.165
Brass	1000 lbs	0.166	0.166	0.184
Brass+LN1	1000 lbs	0.166	0.166	0.179

2. Fabrication of cavities with a glass-ceramic base:

Objectives:

The above set of experiments were carried out for forming cavities opening all the way to the metal core. In the following experiments, forming methods for cavities extending only partially through the glass-ceramic layer stack were studied.

The complicating issue here is the need to transmit the same lamination pressure to the tape layers at the location of the cavity floors, that the rest of the green stack experiences, to avoid the problems of localized variations in shrinkages which cause problems such as cracking, buckling, delamination etc.

Based on the previous set of experiments, it was apparent that hard inserts are needed to arrive at predetermined cavity sizes after lamination. The conclusion is carried over to this set of experiments. Because of expediency, we used free floating inserts (i.e.. inserts that would extrude into the cutouts in the top laminating plate) which did not exert any downward force during lamination. This was suited for cavities to the metal core, because there was no need for any downward lamination pressure at the cavity sites in this case. However, if the cavity floor is made of glass-ceramic layers, free floating inserts have to replaced with inserts that are hard mounted to the top laminating plate. But, here, the complication is the need to machine these inserts to precisely the same thickness as the after lamination thickness of the cavity layers.

To overcome the above difficulties, we adopted a two stage lamination process, wherein the bottom layers of the cavity structure were first laminated together at a certain lamination pressure. The cavity-punched layers were then stacked on the previously-laminated bottom layers, and the combined stack is subjected to another lamination step at a significantly lower lamination pressure than used for the bottom layers. The idea is that, while the lamination pressure used for the second lamination would be sufficient to adequately laminate the top layers to each other and to the bottom stack, the second lamination would not materially alter the green density of the already laminated bottom laminate. As the results show, this was indeed the case. In manufacturing practice, one would not resort to the two step lamination process.

Experiment 1:

1. Laminate 4 (four) blank layers of tape at 2500 lb.. and 185°F
2. Do not remove the laminate from the fixture
3. Place 6 (six) layers of punched tape on top of the blank laminate
4. Place brass inserts into the punched layers
5. Place the cavity template on top well aligned with the inserts (Note spray cavity template with non-stick spray first)
6. Laminate once again, but at 185°F and 1000 lb..
7. Measure cavity
8. Co-laminate at room temperature at 500 lb. pressure
9. Measure cavity
10. Fire
11. Measure cavity

Experiment 2

Do everything same as above, except in step 3, place 5 layers of punched ABT tape and 1 top layer of punched LN-1 tape.

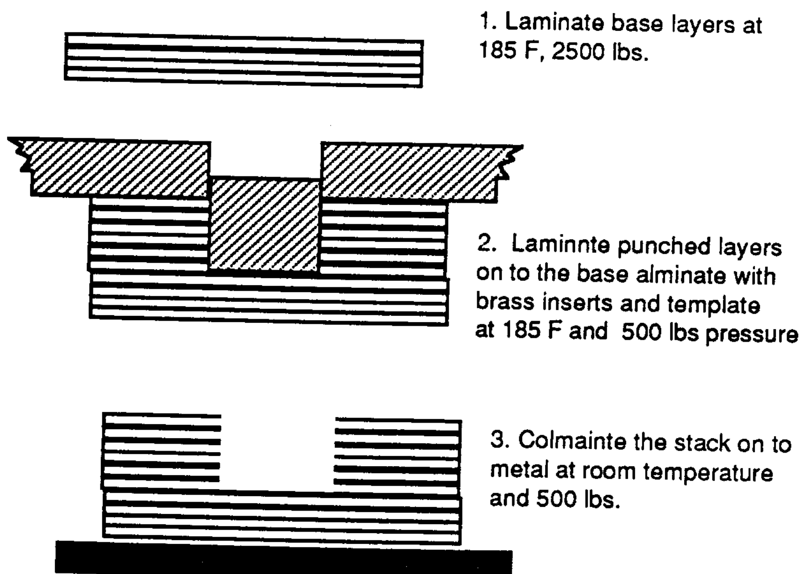


Figure II.3: Lamination of cavities with free inserts.

Results:

Measured Cavity Dimensions (inches)

	At Punching	At Lamination	Fired on CuMoCu w/Ln1	On Blanks w/LN1	On Blanks w-LN1 with Ag conductors
Average	0.177	0.166	0.179	0.175	0.177
Standard deviation	0.002	0.009	0.004	0.003	0.001
Maximum	0.181	0.170	0.186	0.182	0.181
Minimum	0.168	0.161	0.171	0.164	0.173

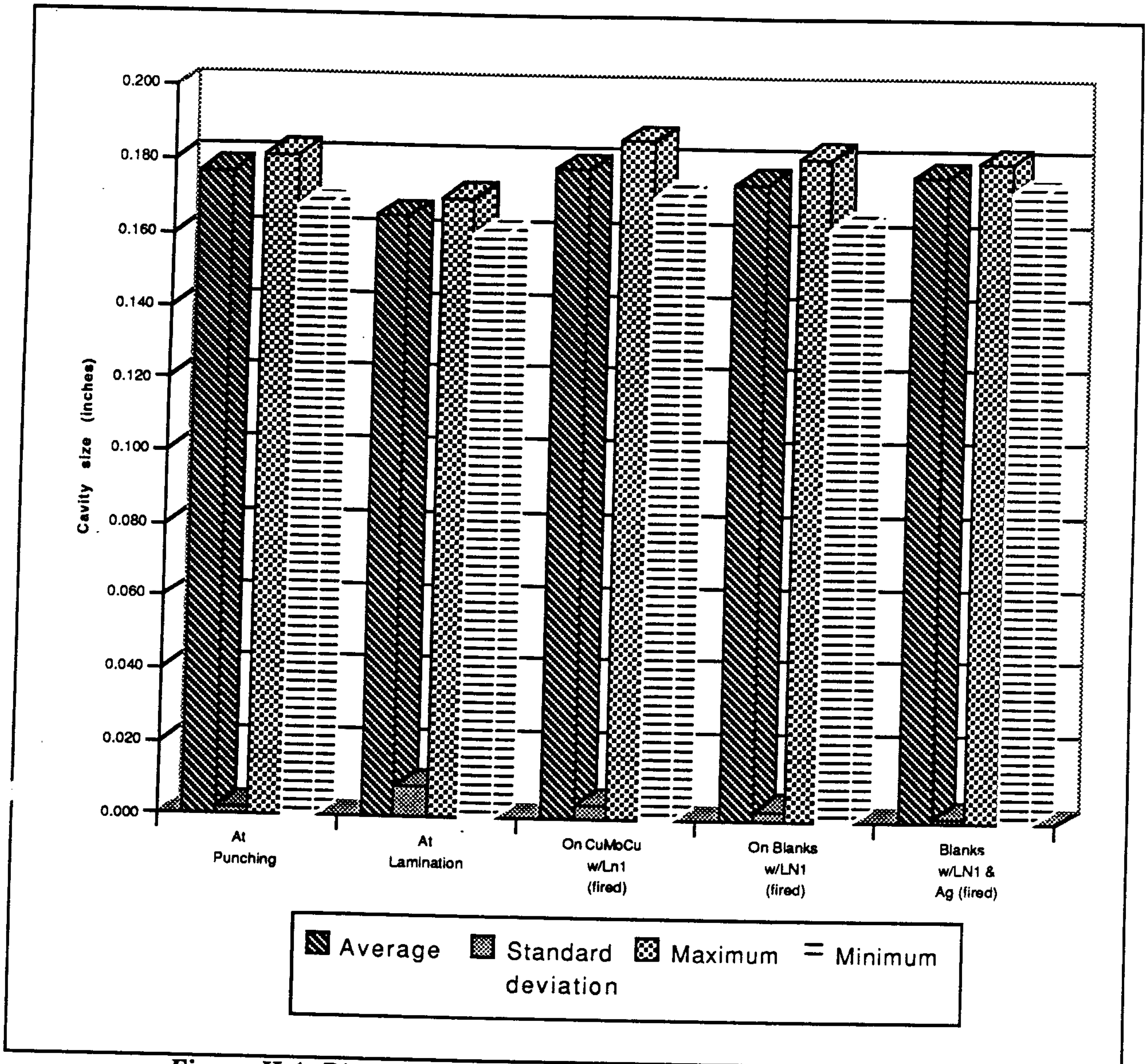


Figure II.4: Dimensions of cavities that were laminated with inserts.

3. Fabrication of multi-step or tiered cavities
Background

Multi-step or tiered cavities are important for single chip packages such as those used for microprocessor packaging. The tiered steps are needed to accommodate multiple rows of bonding pads in these packages. Among the important issues to be dealt with here are dimensional accuracy of the cavities and bond shelves, the flatness of the bond shelves and of the cavity floor, the need for straight-walled cavities, absence of delamination in the cavity layers, the adhesion of bond fingers printed on the cavity steps, and positional accuracy of the bond fingers.

Evaluation Approach

The formation of tiered cavities is complicated because of the need to transmit the same lamination pressure on to the bond shelves as is exerted on the rest of the laminate surface, the need to contend with the ridging problem at the many edges of the cavity structure, the need for good dimensional control of the bond ledges, and the need to achieve all of this in the presence of closely printed thick film bond fingers on the cavity ledges.

Our approach to their fabrication is based on the learning of the previous experiments that dealt with forming simple cavities or cavities with a glass-ceramic base. These earlier experiments have established the need for hard inserts during lamination, and the need for refractory tape 1 top layer to prevent ridge formation at cavity edges. These practices will also be followed in the formation of multi-step cavities. Important issues here are (i) is the refractory layer needed on the ledges of the cavity, (ii) if needed, how to deliver it to these ledges, and (iii) what are the implications if the refractory particles imbed in the bond fingers.

Status

A cavity punch template has been designed to obtain a 16-cavity pattern with slightly larger cavity sizes than the 0.180" nominal cavity size used hitherto. The tapes punched with this new size, in combination with the tape punched with the 0.18" punch, will enable the fabrication of one-stepped cavities.

The machined insert for lamination of the tiered cavity is not quite ready. The insert thickness for the lower cavity is designed to be 0.030", which is the thickness of a 4-layer laminate.

Preliminary experiments with alumina powder as an insert shows that the two critical issues are delamination of the cavity structure due to insufficient lamination pressure at cavity locations and edge curl up or ridge formation. The results of these experiments will be reported on next quarter.

D. HIGH ADHESION TOP 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 adhesion experiments, performed last quarter, showed that a glass layer beneath the top conductor pads improved the adhesion. These experiments were extended this quarter. The glass layer was screened onto the green tape as a thick film paste. After lamination, the top conductor was screen printed on top of the glass layer and the LTCC-M board was co-fired. All measurements reported here utilized a glass layer that was a 50/50 (by weight) mix of KU-8 and KU-14. Top conductors included a AgPd (30 wt% Pd) ink, AgPd-9M6A and two silver inks TC-6 and TC-7. After firing, the two silver conductors were electrolessly plated with Ni and Au layers.

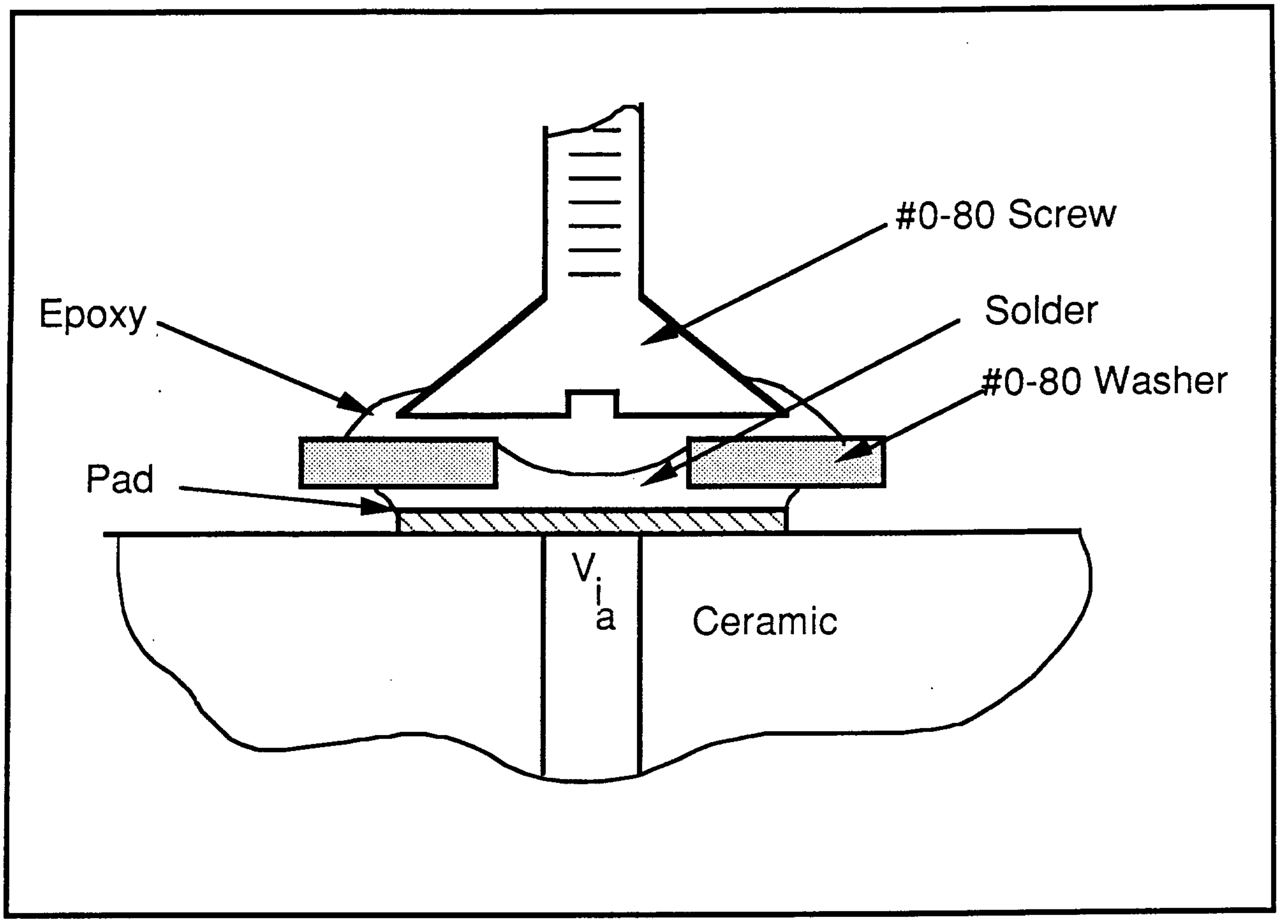


Figure II.5: Stud attachment to conductor pad for adhesion testing.

Adhesion Test Method:

In order to ensure a proper conductor pull test, the attachment of the studs must be well controlled. In the present study, top conductor pads (attached to studs) are pulled in pure tension by an Instron Universal Testing Machine. The attachment of the stud to the pad, an 0.080" square, is illustrated in Figure II.5. Solder paste (62-36-2, Sn/Pb/Ag) is applied the desired pads, and gold-plated #0-80 flat washers are soldered down by slowly raising the temperature from 60°C to 230°C, at which point the solder melts and flows, (about 10 seconds), then letting it cool slowly on a refractory ceramic sheet. The washer is solvent-cleaned and roughened, then the pulling stud, a 0.5" long #0-80 flat-headed screw is epoxied to the washer using a small dab of Uniset #930-12-4F thermoset epoxy. The sample is preheated at 60°C, then slowly raised to 100°C for 1 hour, then allowed to cool on a refractory ceramic sheet.

Adhesion Test Data

The adhesion data for electrolessly plated silver top conductors TC-6 and TC-7 are shown in Figures II.6 and II.7. Both of these conductor formulations contain custom glasses that are resistant to etching by the plating baths. Prior to plating, TC-6 pads were etched for 5 seconds in an HF bath; this surface preparation was required to obtain satisfactory plating of this conductor formulation. Both formulations show good adhesion of the conductor pad to the ceramic. The TC-6 pads failed by removal of large chunks of the ceramic from the substrate, while the TC-7 pads failed by delamination of the plating from the thick film pad. Next quarter, tests will determine whether an HF etch also improves the adhesion of the plating to the TC-7 pads. The initial thermal cycling data shown in these figures, do not indicate any crack formation or loss of conductor adhesion. These tests will continue into next quarter.

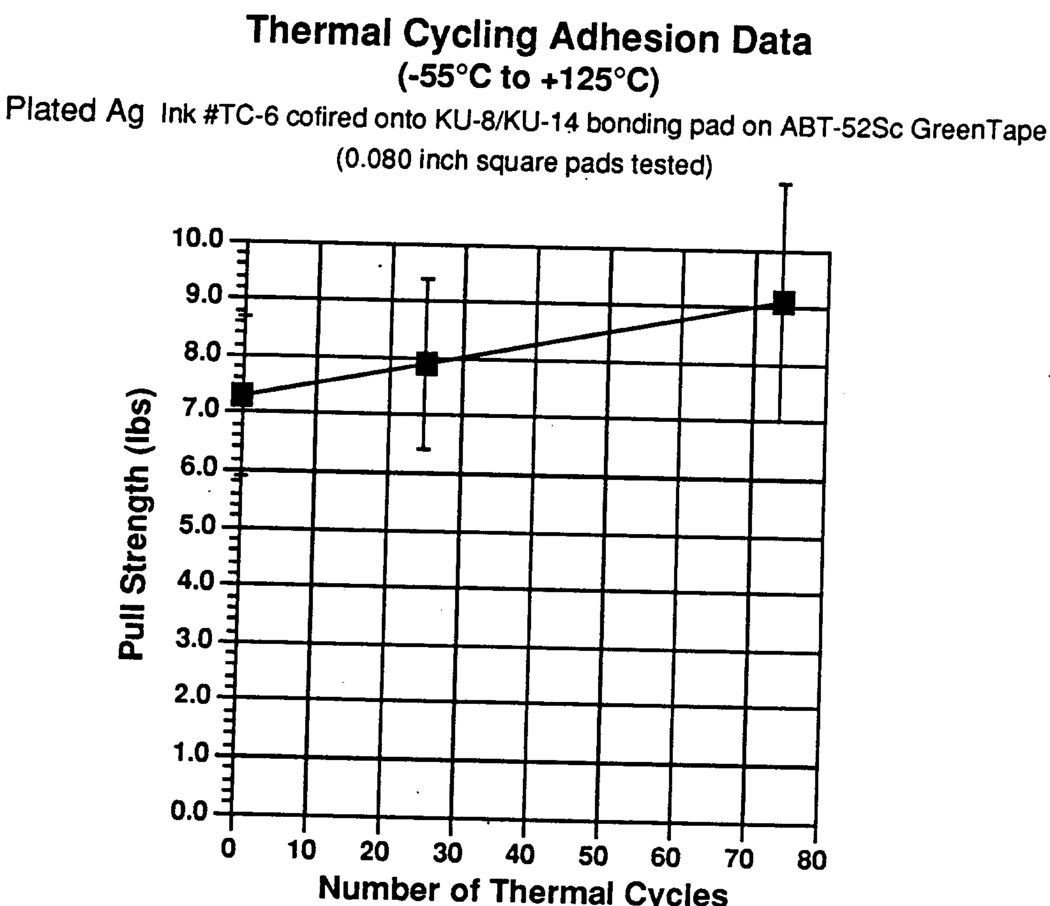
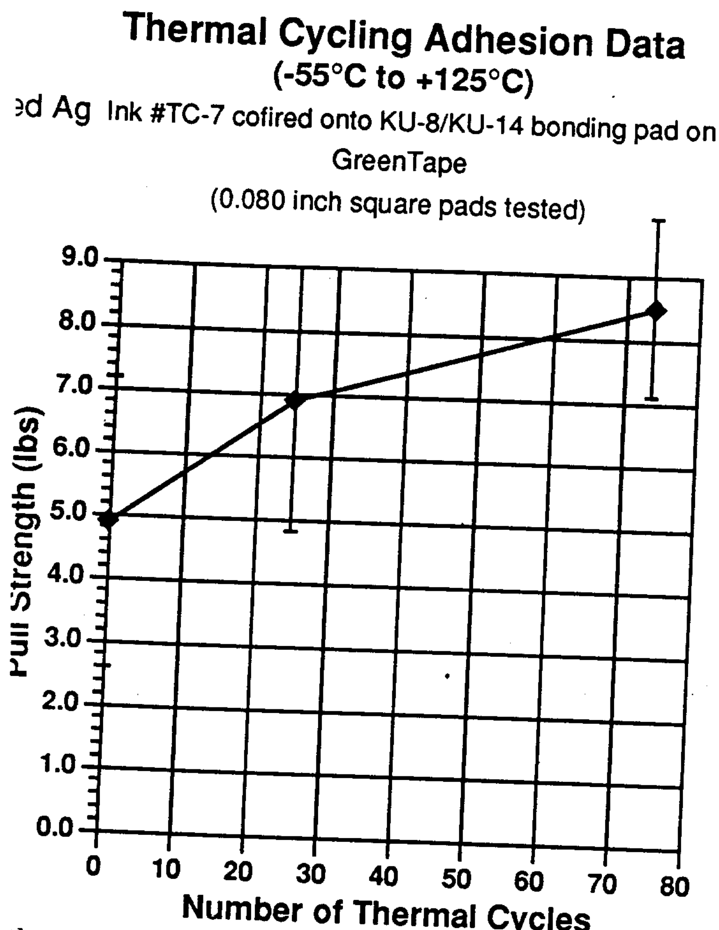


Figure II.6: Initial thermal cycling data for Au-plated silver thick film conductor formulation TC-6.



thermal cycling data for Au-plated silver thick film conductor formulation TC-7.

ıbility Test Data

ımented reliability failure mechanism is loss of adhesion strength ·evated temperature (125 - 150°C), due to the formation of brittle ɜes with Sn-Pb solder. Pads printed with AgPd ink #9M6A have 150°C storage, with the aged adhesion results shown in Figure ours, the adhesion strength maintains its constant high value. ıt this AgPd conductor densely sinters during the co-firing step. vill continue.

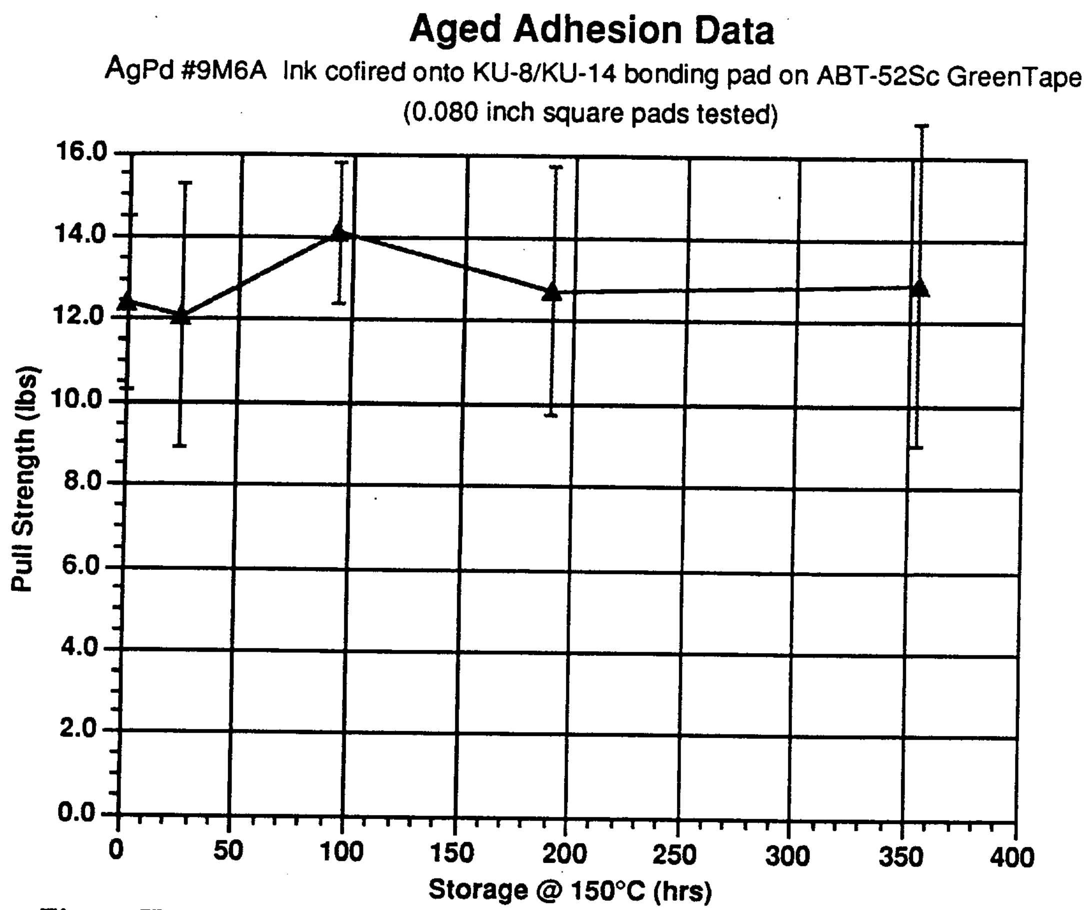


Figure II.8: Initial aged adhesion data for soldered AgPd (30% Pd) conductors.

E. LOW COST SINGULATION PROCESS

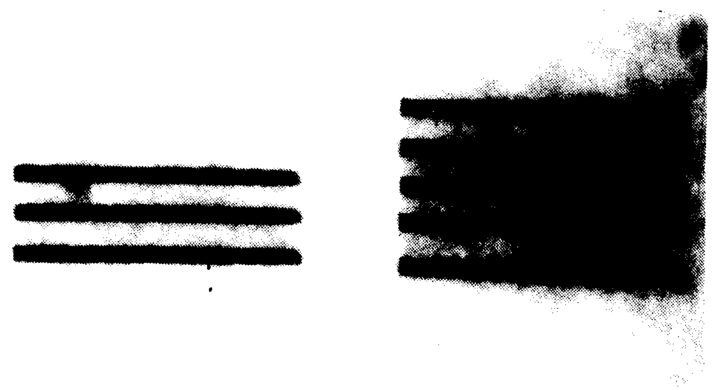
Singulation is the dicing of ceramic-metal boards into individual packages or circuit boards. The problem is complicated by the fact that the best cutting processes for ceramics are not particularly compatible with those for metals, particularly the Cu/Mo/Cu laminated sheet, and *visa versa*. Last quarter it was demonstrated that LTCC-M substrates could be singulated using traditional grinding wheels (a diamond wheel to cut the ceramic followed by an alumina wheel to cut the metal core) as well as by a YAG laser (Applied Laser Systems). This quarter effort was expended to cut the green tape after it was laminated to the metal core, but before the firing step; the metal core can be subsequently cut after the firing step.

To accomplish this task requires a method that will remove green tape without damaging the surrounding green tape or the Ni coating on the Cu/Mo/Cu metal core. The green tape was cut by ESI using a frequency quadrupled YAG laser. Cutting speed was 20mm/sec. Examples of 4 mil slots cut in 20 mil thick laminates are shown in Figure II.9. No damage to the underlying Ni layer could by discerned by optical microscopy.

David Sarnoff Research Center

Laser Scribing of Green Laminate on Metal Core

- **Feasibility demonstartion at ESI using frequency-quadrupled YAG laser**
  1. **Cutting of green laminate through to the metal allows easier singulation because only metal has to be cut after firing**
  2. **Laser cutting has advantages over saw cutting:**
     - Self-stopping at the metal core (Avoids cutting through the core)
     - Ability to cut non-rectangular shapes
     - Very small kerf for cutting
     - Fast
     - Cutting without contaminating top surface of laminate
     - Chamfering edges while cutting



100 micron (4mil) slots thorough 20 mil green laminate to Cu-Mo-Cu Core

Figure II.9: Laser cut slots (4 mil wide) cut in 20 mil thick green tape on Cu/Mo/Cu.

F. HIGH DENSITY CONDUCTOR PATTERNS

Efforts are continuing to further increase the conductor density within LTCC-M layers. One of the major density limitations is the size of the vias. Presently, hard tooling for punching vias is limited to punches greater than or equal to 6 mils in diameter. The principal cause of this size limitation is breakage during tool shipment and set-up. Sequential punching using a hard punch is used down to about 4 mil diameters. Such punches rapidly wear out and need to be replaced often. This quarter use of a frequency quadrupled YAG laser was investigated for drilling holes in 8 mil thick layers of LTCC-M green tape. Using a trepanning method, 3 mil diameter holes were cleanly drilled in the green tape. Figure II.10 shows a typical holes drilled by ESI using this method. The precision of these holes suggests that this method can be used to drill significantly smaller holes.

David Sarnoff Research Center

LASER VIA HOLE FORMATION

- **Work carried out by ESI (Electro Science Industries), Oregon with their proprietary frequency-quadrupled YAG laser**

\- To demonstrate ability to fabricate vias smaller than possible by punching

-- To obtain preliminary data on conditions, speed, economics of the method

Conditions

Ave. Power	235 mw
Type of cut	Trepan
Transport speed	2mm/s
No. of passes	1
No. hole/second	4

3 mil via holes in 8 mil green tape cut at the rate of 4 holes/second

Figure II.10: 3 mil diameter holes laser drilled in 8 mil thick LTCC-M green tape.

G. PLAN FOR NEXT QUARTER

- Continue fabrication of stepped cavities using stepped inserts, LN-1 tape for ridge suppression, and alternatives to LN-1 tape for accomplishing the same.
- Fabricate cavities much larger size than the 0.18" size we have worked with untill now, with the object of determining if the dimensional tolerances, edge problems, etc scale with cavity size.
- Continue reliability testing of Ag and AgPd thick film top conductors
- Begin brazing pins to Ag thick film top conductors
- In close cooperation with Alcoa, continue development of singulation methods for cutting green tape prior to firing.
- Begin reliability experiments of LTCC-M samples that have been singulated.
- Begin development of materials for filling 4 mil diameter vias using commercial Injection Via-fill equipment.

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 four technology demonstration vehicles planned for this program were chosen because each module had clear military applicability, and also met the requirements of the consumer marketplace. Table III.1 shows the application of each demonstration module to the needs of the US armed forces.

Table III.1:
Military Relevance of LTCC-M Technology Demonstration Vehicles

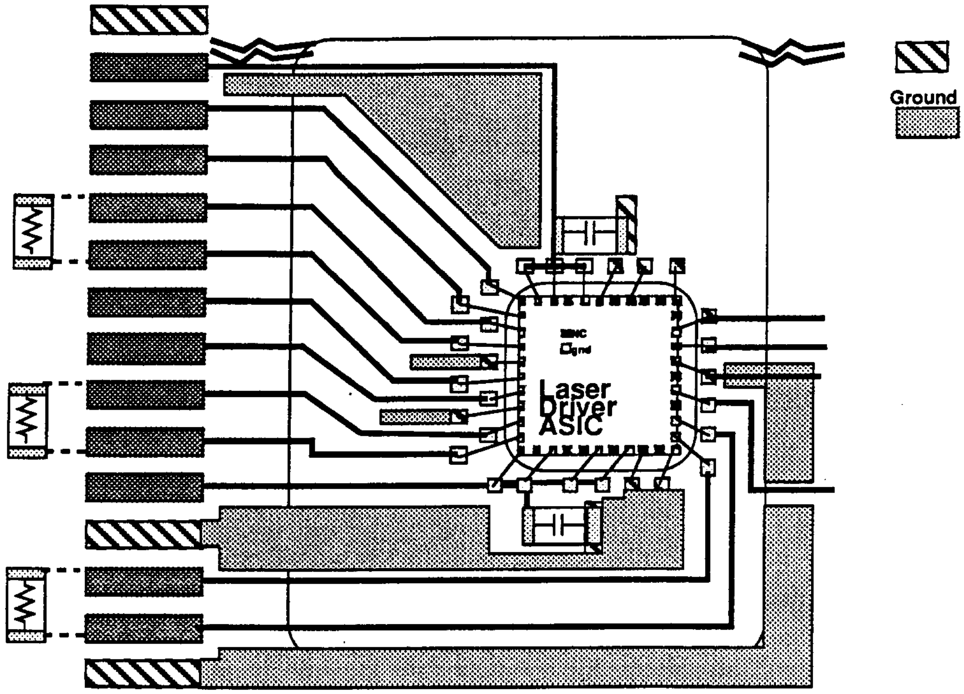
Prototype Application	Supporting Co.	Type	Military Relevance
Advanced PCMCIA Card (ORBCOMM Modem)	ETA	Mixed Signal Module	1. Similar electronics needed for global tracking of high value and critical military materials and components (e.g. armaments) 2. Supports DoD: • Materials Command • Logistics Command • Transportation Command • "Total Asset Visibility" program 3. Technology applicable to the following: • NSA (R2) dual function PCMCIA card • Trackers • Message Terminals • CESEL • Special Forces replacement of high frequency radio systems (miniaturization) • Global extension of communications in Force 21 "Digital Battlefield" 4. Applies to Military Global Mobile Information Systems
High Power Motor Controller (Power Electronics Building Blocks)	Harris	High Power Single Chip Package	1. Supports US Navy Contract # N-00024-94-C-4088 (an Advanced Tech. Demo. with Naval Sea Systems Command) 2. Computer controlled Integrated Variable Speed Electric drive for ships (surface and subsurface) and tanks 3. Computer controlled Electric Actuators for airplanes, ships, and tanks 4. Auxilliary Power Unit Generators, Solid State Power Controllers for airplanes 5. Power Inverters and Converters for ships and airplanes
Optoelectronic Transceiver Module	AMP	MCM	1. Supports the construction of low cost broadband networks at military bases and installations. 2. Such networks support: • ATM based switching architectures • Transfer of large amounts of graphical and multimedia data • Digital signals • Encrypted signals 3. Supports ARPA contract "Manufacturable Low Cost Single-Mode Bi-directional Links for Fiber in the Loop Optical Networks" • Currently LTCC-M is the sole technology for this application
Power Amplifier Packages (microwave)	Raytheon	GaAs single chip package	1. Portable government cellular communications systems and wireless LANs 2. Applies to Military Global Mobile Information Systems

The initial tasks in this area involve the generation of specific information for package design, followed by implementation of Sarnoff's general LTCC-M design rules, as well as 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.

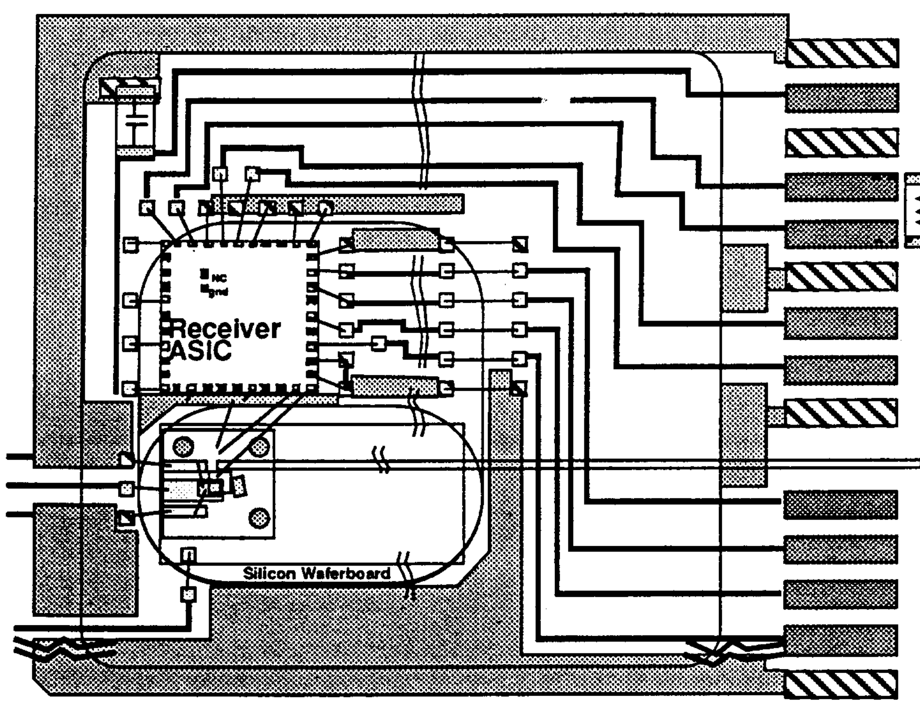
C. OPTOELECTRONIC TRANSCEIVER MODULE

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. The goal of this program is to provide LTCC-M packages to AMP (for module assembly) by the end of February, 1996.

Presently, the silicon devices have been through the first qualification stage, and one custom IC required another design and fab cycle. This redesign cycle is expected to be complete by November 1, 1995. Based on the best available data, a crosstalk analysis of several package designs was completed this quarter, and resulted in a preliminary package design shown in Figure III.1. Final package design awaits redesign and qualification of the custom IC. At this point, hard tool design for fabrication in LTCC-M technology will begin.



(a) Laser driver package section



(b) Reciever section of package

Figure III.1: Preliminary package design for Optoelectronic Transceiver MCM

D. POWER AMPLIFIER PACKAGE

1. Task Objective

The objective of this task is to design, fabricate, assemble and test a low cost, power amplifier package for a GaAs microwave device. The package will be designed, assembled and tested by Raytheon and fabricated by Alcoa.

2. Introduction

This technology demonstration vehicle design has not been finalized yet. To assist in the design and fabrication of the technology demonstration vehicle, two test patterns are being designed by Raytheon. These test patterns, transmission lines and inductors, will be fabricated at Sarnoff and tested at Raytheon. Design rules will be generated based on the information gained from the test patterns. The design rules will be vital for the fabrication of the prototype.

3. Test Circuits

The first test pattern consists of a 6 x 4 array of transmission lines with ceramic seal rings which cover a portion of the lines. This pattern was designed to be very similar to an actual package. Space was left for placement of an active device.

There are two different circuit designs on this first test board, twelve of each. Both types of circuits consist of three transmission lines which are covered in sections by a ceramic seal ring. Type A circuits, shown in Figure III.2, have a plain seal ring. Type B circuits, shown in Figure III.3, have vias running through the seal ring which are connected to the Cu/Mo/Cu base plate at the bottom and are connected by a printed metal ring at the top. These represent two possible scenarios for the prototype.

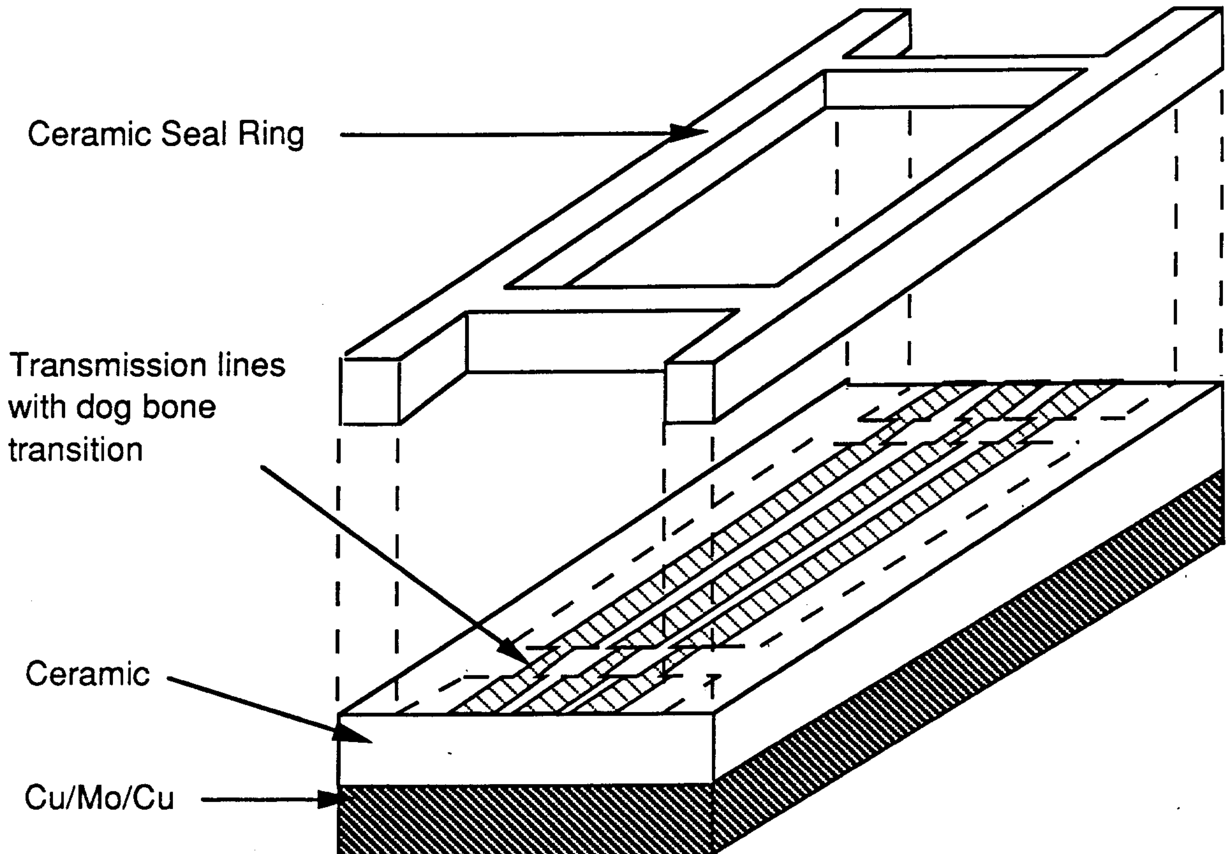


Figure III.2: Seal ring int ded for glob top seal (no conductor on top).

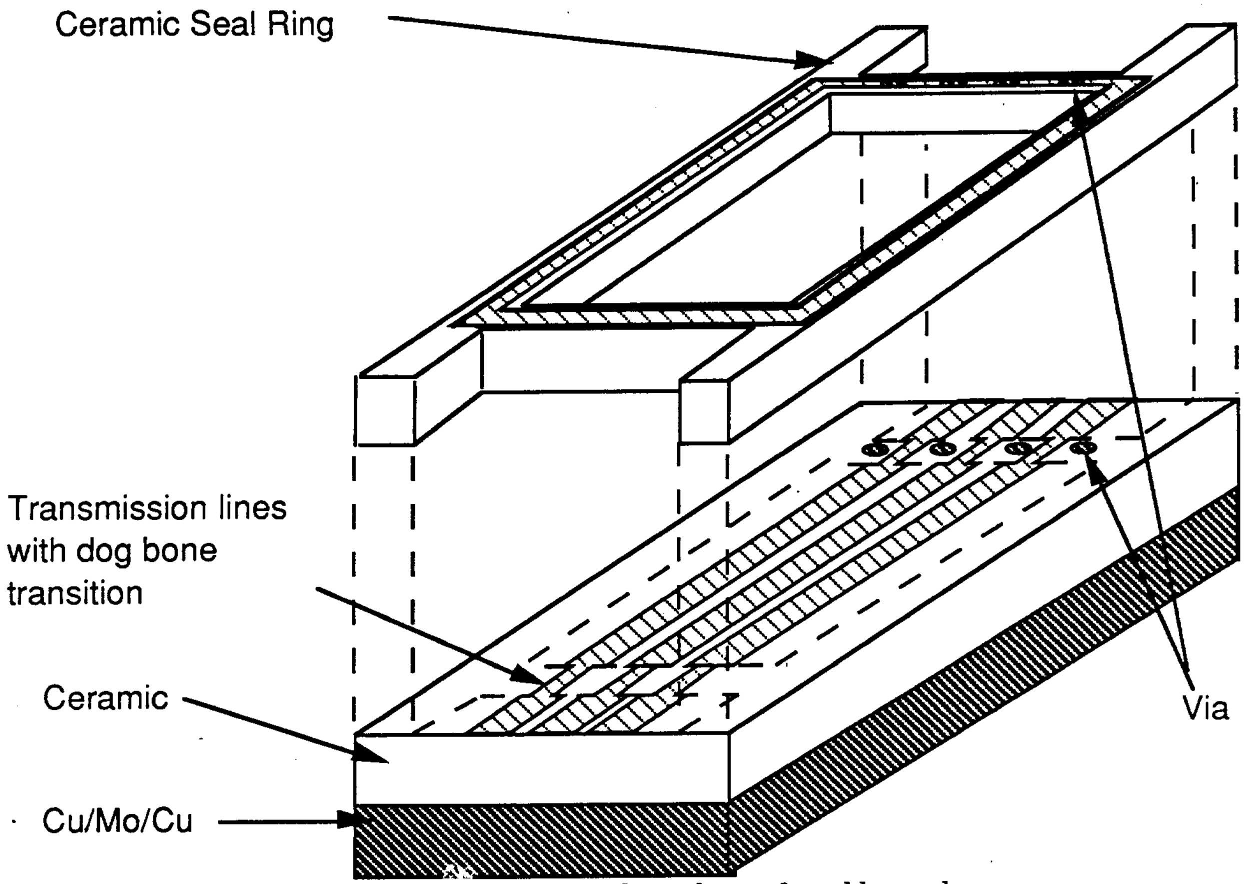


Figure III.3: Seal ring with conductor for solder seal

The transmission lines become narrower as they pass under the seal ring to allow for changes in electrical properties due to the additional dielectric material in the seal ring. (This is commonly referred to as a 'dogbone' transition.) A critical issue in the fabrication of packages is how well the seal rings can be aligned to the transmission lines. Severe misalignment will affect the electrical performance of the circuits. Misalignments in the horizontal direction, from 0.001" to 0.008", have been deliberately built into this pattern to study the effects of misalignment. The complete test pattern is shown in Figure III.4.

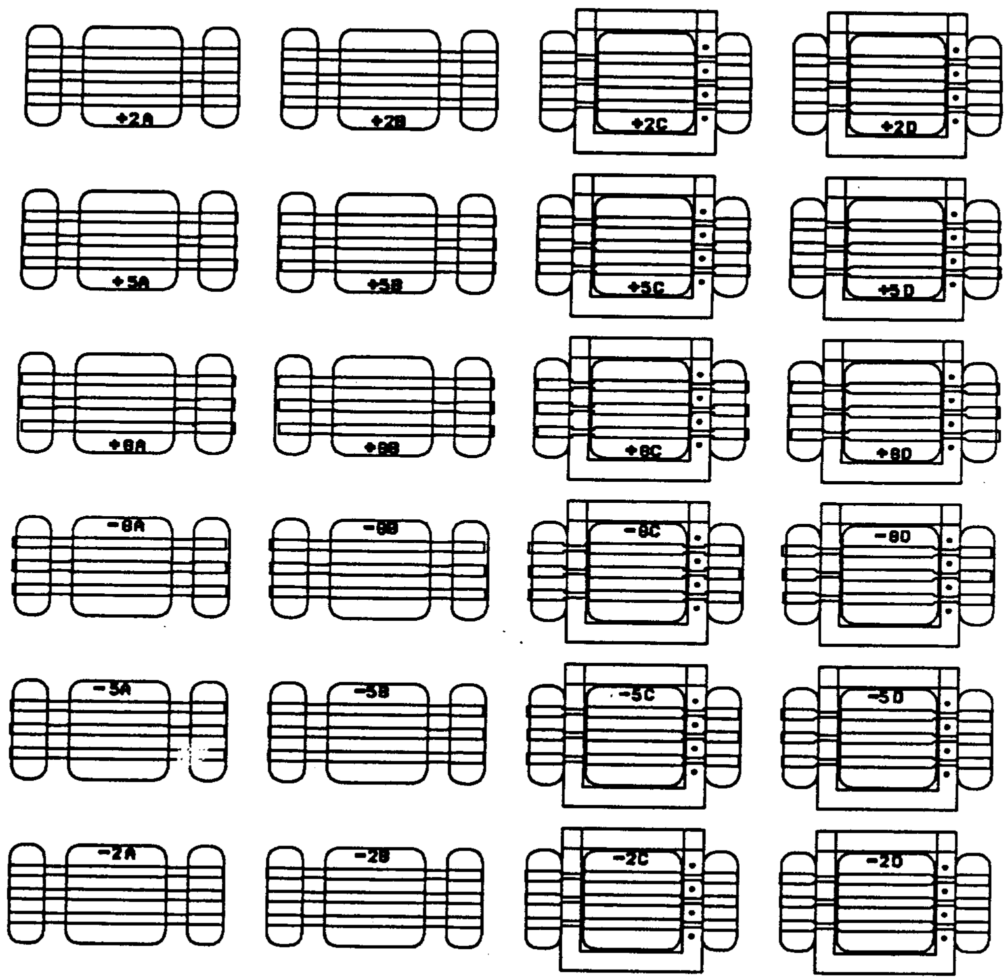


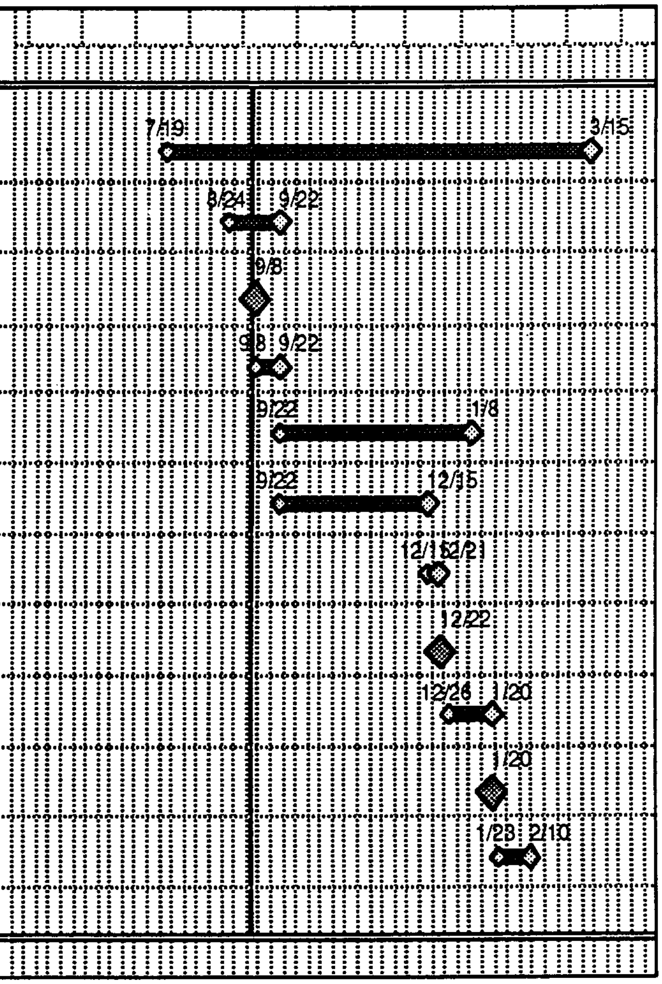
Figure III.4: Transmission line test array

E. ADVANCED PCMCIA CARDS

Program Description: Under this program, Sarnoff and ETA will develop a RF modem module, based on an extended PCMCIA Type II card format, capable of being used in a variety of hand-held communications device platforms. Using the planned ORBCOMM satellite constellation, a combination of the modem card with ETA's RAVEN FORTEZZA-based encryption card will enable Armed Forces personnel to securely communicate with each other anywhere in the world. Also, this card will be one of three card assemblies used in their Tracker device that will be able to track friendly forces and equipment.

Revised Schedule:

Activity Name	Start Date	Finish Date
RF Modem Prototype Development	7/19/95	3/15/96
Circuit/Layout Development	8/24/95	9/22/95
Circuit Schematic/Layout Supplied to Sarnoff	9/8/95	
Layout Validation by Sarnoff	9/8/95	9/22/95
Prototype Fabrication	9/22/95	1/8/96
LTCC-M Board Fabrication	9/22/95	12/15/95
Bare Board Tests by Sarnoff	12/15/95	12/21/95
Prototype Boards Delivered to ETA	12/22/95	
Component Assembly by ETA	12/26/95	1/20/96
Prototype Assembly Completed	1/20/96	
Card-Level Tests	1/23/96	2/10/96



Program status: Due to ORBCOMM system delays, major portions of the ETA prototype program have slipped in schedule by approximately 3 months. It has been established that the substrate will be a single two-sided substrate. Critical circuit components from various vendors have been identified and their availability confirmed. ETA has also identified CTS in West Lafayette, Indiana, as their assembly house for component placement on the LTCC-M substrate because of their experience with other ceramic substrate technologies.

ETA has nearly completed the prototype's functional and circuit layout. Shown in Figure III.5 is the general parts layout for this RF modem card. Upon completion, ETA will send the layout to Sarnoff. Once received, Sarnoff will verify that the design conforms to Sarnoff's general guidelines for LTCC-M circuit board layout.

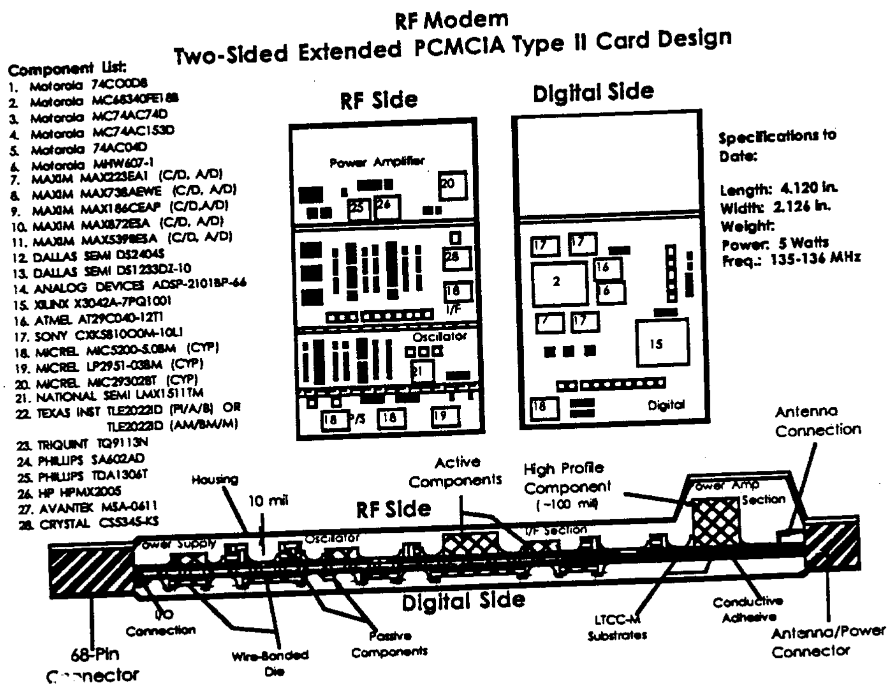


Figure III.5: Parts identification for ORBCOMM RF modem layout

F. POWER ELECTRONIC BUILDING BLOCKS (PEBB)

The objective of this task is to design, fabricate, assemble and test a low cost, PEBB "lid" in support of the U.S. Navy PEBB program. PEBB "lids" are high power device substrates that connect the power device to the control signals on a printed wiring board, yet are part of the thermal management system that draws the heat away from the device (and the printed wiring board). The "lid" package will be designed, assembled and tested by Harris and fabricated by Alcoa.

Prior to design of the "lid" in LTCC-M, high voltage design rules must be established. Samples having varying AgPd conductor line spacing were prepared by Sarnoff for measurement by Harris. The surface high voltage breakdown data is expected next quarter.

A challenging aspect of this "lid" design is the requirement that the LTCC-M metal core be patterned **after** the part is fired. The most desirable patterning process is etching. Thus, the Cu/Mo/Cu core must be very thin to achieve manageable etching times. Presently, Sarnoff is exploring the use of 5 mil thick Cu/Mo/Cu cores. This is 2x thinner than any previously metal core, and 4x thinner that the standard core that has been used throughout this program. Firing LTCC-M on 5 mil thick core has presented some new problems that require changes in the standard LTCC-M process.

The first attempts to fabricate LTCC-M on thin Cu-Mo-Cu showed that locking of the substrate to the core was not occurring satisfactorily. It was first surmised that the visible camber of the thin Cu-Mo-Cu upon glazing was the probable cause for the lock-in problem. To address this, the glazing pattern was changed from a sheet pattern to a dot pattern. With this change, nearly flat Cu-Mo-Cu cores resulted, but the locking problem still persisted. Firing the substrates with the core weighed down at the edges with alumina bars also failed to resolve the locking problem on 0.005" Cu-Mo-Cu.

When the green laminate was topped by a layer of alumina tape (LN-1), successful locking to thin metal core was achieved consistently. It is surmised that during the firing process, the laminate first locks in the center regions of the substrate. With continued heating, the thermal expansion differences between the core and the locked-in part of the substrate are such as to cause the core to bend away at the edges from the laminate. This, in combination with the natural tendency of the laminate edges to curl up during the initial part of sintering, causes the core and the substrate to move away from each other at the edges as the firing proceeds. This prevents edge locking. The presence of LN-1 layer on the laminate completely suppresses the tendency of the laminate to curl up during firing and thereby helps to achieve good locking to the metal core. Figure III.6 schematically illustrates the cause for the lock-in difficulties to thin Cu/Mo/Cu and the solution to the problem through the use of top LN-1 layer.

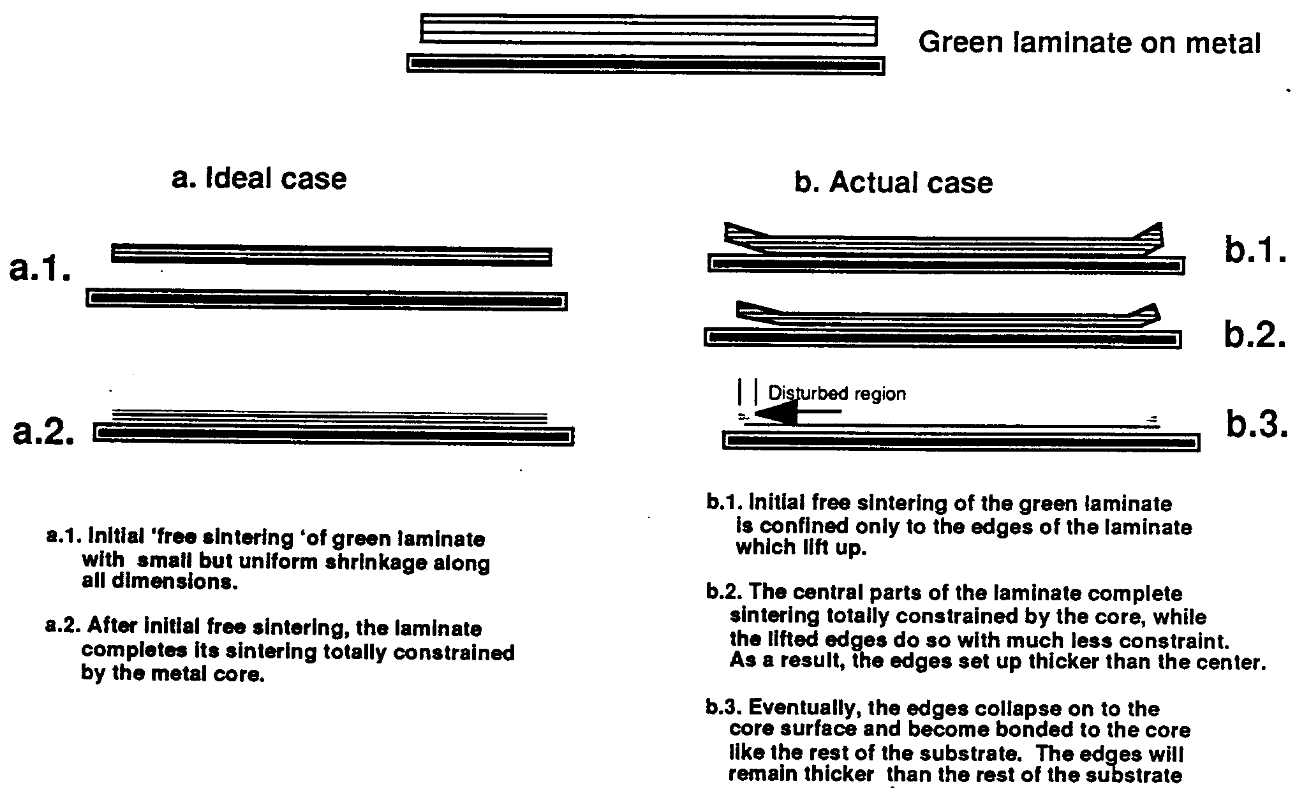


Figure III.6: Lock-in issues encountered with very thin (0.005") Cu/Mo/Cu metal cores

G. PLAN FOR NEXT QUARTER

Optoelectronic Transceiver Module

- Complete final package design
- Begin hard tool fabrication

Power Amplifier Package

- Fabricate 50Ω feedthrough test vehicle
- Measure 50Ω feedthrough test vehicle data
- Design and fabricate inductor test vehicle
- Measure inductor test vehicle data
- Begin design of technology demonstration vehicle

Advanced PCMCIA Cards

- Complete design and layout
- Complete hard tool fabrication
- Begin substrate fabrication
- Send test Boards to CTS for assembly trials

Power Electronic Building Blocks

- Complete surface high voltage testing
- Choose Cu/Mo/Cu patterning process
- Begin design and layout of technology demonstration vehicle

Section IV
Important Findings

A. TECHNOLOGY TRANSFER TO MERCHANT SUPPLIERS

- Technology Transfer to Alcoa Electronic Packaging, Inc. begun.
- LTCC-M substrates made with all green tape glasses melted by SEM-COM.
- LTCC-M green tape formulations modified to account for differences between Sarnoff and SEM-COM melted glasses.

B. CUSTOMIZE LTCC-M FOR SPECIFIC APPLICATIONS

- Processing have been developed so that cavities can been fired to their punched size; the processing makes use of a refractory cover layer and brass inserts during lamination.
- It has been demonstrated that a frequency quadrupled YAG laser is effective for cutting green tape without damaging the plating of the underlying metal core.
- Use of a glass layer beneath the top conductor pads improves their adhesion strength; initial reliability test results do not show any indication of loss of adhesion.

C. FABRICATION AND TESTING OF TECHNOLOGY DEMONSTRATION MODULES

- Developed novel method of oxide removal from metal core, allowing it to be electroplated and used for package ground for the power amplifier and optoelectronic transceiver packages.
- Developed processing steps to allow the Power Electronic Building Block "lid" packages to be fabricated from thin (5 mil thick) Cu/Mo/Cu cores.
- Preliminary Optoelectronic Transceiver packages designed; final design awaiting qualification of redesigned receiver IC.

Section V
Significant Developments

The green tape formulation has been modified (now it is ABT-52) to account for differences in glass melting and quenching procedures used by SEM-COM. This new formulation shows similar characteristics to the LTCC-M substrates made from Sarnoff melted glasses. ABT-52, shows excellent dielectric properties ($\tan\delta < 0.0015$) at microwave frequencies (15 GHz).

The technology transfer to Alcoa Electronic Packaging, Inc. has begun. A series of hands-on meetings between Sarnoff engineers and Alcoa engineers were held to acquaint Alcoa with all Sarnoff materials, processes, and procedures used for making LTCC-M green tape and the thick film inks designed especially for this system. Alcoa has begun setting up equipment to implement the LTCC-M processing. All raw materials for producing green tape and thick film inks have been ordered by Alcoa. A series of evaluations have been planned for incoming materials, as well as green tape and inks produced by Sarnoff and Alcoa.

LTCC-M processing has been slightly modified so that very thin metal cores can be used. This is required for fabrication of the Power Electronic Building Block technology demonstration vehicle. This development is quite significant since the Cu/Mo/Cu metal core is one of the major raw material costs, so reducing the amount of Cu/Mo/Cu in a substrate offers a significant cost reduction. Additional weight reductions are also possible by the use of thin Cu/Mo/Cu cores.

Section VI
Plan for Further Research

TECHNOLOGY TRANSFER TO MERCHANT SUPPLIERS

- Complete melting and qualification of custom glasses by SEM-COM
- Complete transfer of ABT-52SC Green Tape formulation to Alcoa
- Complete transfer of silver buried conductor and via conductors to Alcoa
- Set-up all firing profiles at Alcoa
- Begin transfer of LTCC-M metal preparation process to Alcoa

CUSTOMIZE LTCC-M FOR SPECIFIC APPLICATIONS

- Continue fabrication of stepped cavities using stepped inserts, LN-1 tape for ridge suppression, and alternatives to LN-1 tape for accomplishing the same.
- Fabricate cavities much larger size than the 0.18" size we have worked on until now, with the object of determining if the dimensional tolerances, edge problems, etc. scale with cavity size.
- Continue reliability testing of Ag and AgPd thick film top conductors
- Begin brazing pins to Ag thick film top conductors
- In close cooperation with Alcoa, continue development of singulation methods for cutting green tape prior to firing.
- Begin reliability experiments of LTCC-M samples that have been singulated.
- Begin development of materials for filling 4 mil diameter vias using commercial Injection Via-fill equipment.

FABRICATION AND TESTING OF TECHNOLOGY DEMONSTRATION MODULES

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- Choose Cu/Mo/Cu patterning process
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10. SPONSORING/MONITORING AGENCY REPORT NUMBER
Data Item
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11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

12. DISTRIBUTION CODE

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.

14. SUBJECT TERMS

15. NUMBER OF PAGES
46

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	200 words

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2. The Defense Technical Information Center received the enclosed report (referenced below) which is not marked in accordance with the above reference.

Technical Report
15 June 95 - 14 Sept 95
DAAB07-94-C-C009

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