(2)

REPORT OF
DEPARTMENT OF DEFENSE
ADVISORY GROUP ON ELECTRON DEVICES

APPENDIX TO SPECIAL TECHNOLOGY AREA REVIEW ON MICROWAVE PACKAGING TECHNOLOGY

FEBRUARY 1993

OFFICE OF THE UNDER SECRETARY OF DEFENSE FOR ACQUISITION
WASHINGTON, D.C. 20301-3140

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* Included in this section is a listing of materials and their properties commonly used in MW and MMW MCMs. The information comes from the Raytheon-Texas Instruments MIMIC Phase 2 Joint Venture and other Air Force sources.

MICROWAVE PACKAGING TECHNOLOGY WORKSHOP

AGENDA

18 June 1992

0730-0845	REGISTRATION/CONTINENTAL BREAKFAST
0845-0945	INTRODUCTION/DISCUSSION OF PACKAGING ISSUES TIM KEMERLEY, WRIGHT LABORATORY
0945-1030	MICROWAVE MULTICHIP MODULE PACKAGES RONALD NASTER, GENERAL ELECTRIC
1030-1045	BREAK
1045-1130	MILLIMETER WAVE MULTICHIP MODULE PACKAGES BARRY ALLEN, TRW
1130-1215	MW/MMW PACKAGE DESIGN, MODELING & SIMULATION PETER PARRISH, EESOF & ACHIM HILL, COMPACT SOFTWARE
1215-1330	LUNCH
1330-1415	PACKAGING MANUFACTURING TECHNOLOGY JOHN BEDINGER, TEXAS INSTRUMENTS
1415-1545	MILITARY vs COMMERCIAL PACKAGES JOHN TYLER, AVANTEK; RICK PERKO, M/A-COM; MICHAEL FLANDERS, COORS ELECTRONIC PACKAGE CO.
1545-1600	BREAK
1600-1800	PARALLEL SESSION WORKING GROUP DISCUSSIONS

1. MW MCM PACKAGES - CARL THOMAS, ROME LAB
2. MM WAVE MCM PACKAGES - KURT SHALKHAUSER, NASA-LERC
3. MW/MMW PACKAGE DESIGN, MODELING & SIMULATION - BARRY PERLMAN, LABCOM ETDL
4. MILITARY vs COMMERCIAL PACKAGES - JOE COLUSSI, NAWC-ADWARM

ADJOURN

DRAFT AGENDA

19 June 1992

0730-0830	CONTINENTAL BREAKFAST
0830-1200	PARALLEL SESSION WORKING GROUP DISCUSSIONS - COMPLETE FINDINGS AND RECOMMENDATIONS - PREPARE SUMMARY PRESENTATION
1200-1315	LUNCH
1315-1600	EACH SESSION PRESENTS FINDINGS & RECOMMENDATIONS TO WORKSHOP PARTICIPANTS

ADJOURN

MICROWAVE PACKAGING TECHNOLOGY WORKSHOP

Georgia Institute of Technology
18-19 June 1992

ATTENDANCE LIST

NAME	AFFILIATION
Adams, Richard W.	Ceramics Process Systems Corp.
Allen, Barry R.	TRW, Inc.
Basine, James M.	General Research Corp.
Bedinger, John	Texas Instruments
Bierig, Robert W.	AGED, WG/A
Borkowski, Michael	Raytheon Co.
Brockett, William S.	Martin Marietta
Brodzinsky, Albert	Vela Associates, Inc.
Bugeau, John L.	Lockheed Sanders, Inc.
Burkett, Frank S. Jr.	Hercules Defense Electronics
Calcatera, Mark	USAF, WL/ELMT
Caldwell, Mike	Scientific-Atlanta
Caposell, Charles D.	USN, NASC
Coates, Doug	USAF, WL/MTEC
Cohen, Eliot	DARPA
Collette, Susan	Motorola
Colussi, Joseph M.	USN, NAWC
Cook, Arnold J.	PCAST Equipment Co.
Corbin, Victor	Raytheon Co.
Costello, John	Westinghouse Electric Corp.
Crouse, William A.	TRW Space & Defense
Davern, William E.	General Electric Co.
Davidson, Tom	USN, NSWC
Decker, Richard	Lehigh University
Dickens, Larry	Westinghouse Electric Corp.
Dreyer, Gary	Hughes Aircraft Co.
Edwards, William J.	USAF, WL/EL
Elwood, Persis A.	USAF, WL/MTEC
Ely, Kevin J.	ITT - MEC
Enloe, Jack H.	W.R. Grace
Felix, Joseph J.	GEC - Marconi
Fitzhugh, Thomas E.	Hughes Aircraft Co.
Flanders, Michael	Coors Electronic Package Co.
Foster, Phil	MIC Technology
Fullerton, Craig	Motorola, Inc.

Microwave Packaging Technology Workshop
Attendance List
Page 2

Gamble, Richard A.	USN, NCCOSC
Gelnovatch, Vladimir G.	USA, SLCET-M, ETDL
Goetz, Martin P.	StratEdge Corp.
Griffith, Gordon H.	USAF, WL/MLP
Gupta, K.C.	University of Colorado
Hannon, Gregory E.	Lanxide Electronic Components
Harris, Mike	Georgia Institute of Technology
Henry, Michael Paul	USA, MICOM
Herman, Martin	Jet Propulsion Laboratory
Hertling, David R.	Georgia Institute of Technology
Higgins, R.J.	Georgia Institute of Technology
Hill, Achim	Compact Software
Itoh, Tatsuo	UCLA
Johnson, Gerald E.	Martin Marietta
Kagiwada, Reynold	TRW, Inc.
Katzenstein, West	USN, NAWC-WPNS
Kehias, Lois T.	USAF, WL/ELMD
Kemerley, Robert T.	USAF, WL/ELM
Klug, James J.	Harris Microwave Semiconductor
Kohl, Paul	Georgia Institute of Technology
Konsowski, Steve	Westinghouse Electric Corp.
Kopp, Bruce	Johns Hopkins University, APL
Koziarz, Walter A.	USAF, RL/ERDR
Kruchek, Charles L.	General Research Corp.
Krumm, Charles F.	Hughes Aircraft Co.
Lampen, James	Raytheon Co.
Landis, Richard C.	Martin Marietta
LaPalme, Richard	HRB Systems
Lee, Tim	COMSAT
Lewandowski, Bob	USN, NASC
Li, Tom	Martin Marietta
Licciardello, Joseph A.	Raytheon Co.
Luce, Wyatt E.	Westinghouse Electric Corp.
McNulty, Mike	GE Aerospace
Macropoulos, Bill	M/A-COM, Inc.
Mah, Misoon Y.	USAF, WL/ELRD
Mandal, Robert P.	Teledyne Monolithic Microwave
Marchiando, Michael A	USAF, WL/MTEM
Martin, Pierre E.	M/A-COM, Inc.
Mason, James	Texas Instruments
Mass, Steve	TRW, Inc.

Microwave Packaging Technology Workshop
Attendance List
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Miller, Roger F.	GE Aerospace
Misoni, John	USN, NCCOSC
Naster, Ronald J.	General Electric Co.
Nguyen, Richard	USN, NCCOSC-NRAD
Orender, Robert J.	USN, NSWC
Owens, Joe	Hughes Aircraft Co.
Parrish, Peter T.	EEsof, Inc.
Paul, Bradley J.	USAF, WL/ELMT
Peischl, Mark	GEC Marconi
Perko, Richard	M/A-COM, Inc.
Perlman, Barry S.	USA, SLCET-MP
Peterson, Robert K.	Texas Instruments
Reinhardt, John E.	USA, MICOM
Rhein, James E.	Raytheon Co.
Robison, Dale L.	USN, NAWC
Romenesko, Bruce M.	Johns Hopkins University, APL
Roqueta, Elier C.	ITT - MEC
Rucker, Charles T.	Georgia Institute of Technology
Russell, Kenneth J.	The Aerospace Corp.
Saloom, Joseph A.	AGED, WG/A
Sandeau, Rene	Martin Marietta
Shalkhauser, Kurt	NASA/Lewis Research Center
Shimoda, Raynor	Boeing
Sobolewski, Lisa	DARPA
Staecker, Peter	M/A-COM, Inc.
Theim, Clare D.	USAF, RL/ERSD
Thomas, Carl	USAF, RL/OCTP
Tyler, John R.	Avantek, Inc.
Vorhaus, James L.	Avantek, Inc.
Wagner, Charles E.	USAF, WL/MTEC
Weidner, Ken	Coors Electronic Package Co.
Wein, Deborah S.	StratEdge Corp.
Whicker, Lawrence R.	Westinghouse Electric Corp.
Young, Brian	Hughes Aircraft Co.
Ziegner, Bernhard A.	M/A-COM, Inc.

MICROWAVE PACKAGING TECHNOLOGY WORKSHOP

AGED WORKING GROUP A

18-19 JUNE 1992

ROBERT T. KEMERLEY
WRIGHT LABORATORY
WRIGHT-PATTERSON AFB

M4 24 1

THE IMPORTANCE OF ELECTRONICS PACKAGING

- ELECTRONIC EQUIPMENT IS A DRIVER IN DoD SYSTEMS AND A SIGNIFICANT FACTOR IN THE US ECONOMY
- AN INDIGENOUS INTERNATIONALLY COMPETITIVE ELECTRONICS INDUSTRY IS CRITICAL TO MAINTAINING A LEAD IN BOTH DEFENSE AND COMMERCIAL AREAS
- FUTURE ELECTRONIC EQUIPMENTS REQUIRE LOW COST HIGH DENSITY MULTI-COMPONENT ASSEMBLIES (MCAs) AND ASSEMBLIES OF MCAs
- ELECTRONIC PACKAGING IS IDENTIFIED AS AN AREA PROVIDING OPPORTUNITY FOR SYSTEM PERFORMANCE ENHANCEMENT FOR BOTH DEFENSE AND COMMERCIAL APPLICATIONS

M4 24 6

STRATEGY FOR ELECTRONIC PACKAGING

- INCREASE COORDINATION OF ELECTRONIC PACKAGING INVESTMENTS WITHIN THE DoD AND OTHER GOVERNMENT AGENCIES

- INCREASE DoD PARTICIPATION IN COOPERATIVE EFFORTS WITH THE INDUSTRY IN ELECTRONIC PACKAGING INCLUDING R&D, STANDARDS, SPECIFICATIONS, TESTING, AND MANUFACTURING

- WORK WITH THE ELECTRONICS INDUSTRY TO FORMULATE A COORDINATED STRATEGY

M4 24 10

MICROWAVE/MILLIMETER WAVE PACKAGING ISSUES

- THE MOVE TO MICROWAVE/MILLIMETER WAVE MULTI-CHIP ASSEMBLIES WITH HIGH DENSITY INTERCONNECTS IS CAUSING A SIGNIFICANT SHIFT IN THE CURRENT PRACTICES OF HOW PACKAGES ARE BEING DESIGNED AND MANUFACTURED

- THE LONGER TERM TREND IS TO MOVE TO SUBSYSTEM OR MULTI-LEVEL PACKAGING SCHEMES TO ACHIEVE HIGHER LEVELS OF SYSTEM INTEGRATION

- PACKAGING COSTS ARE BEING EMPHASIZED EARLY IN SYSTEM DEVELOPMENTS

M4-24 9

MICROWAVE/MILLIMETER WAVE PACKAGING ISSUES

AREAS THAT REQUIRE DETAILED PLANNING AND INVESTMENT

- ADVANCED MATERIALS
- MULTI-LAYER SUBSTRATES
- HIGH DENSITY INTERCONNECTS
- DESIGN, MODELING, AND SIMULATION
- MANUFACTURING TECHNOLOGY
- SUBSYSTEM/MULTI-LEVEL PACKAGES
- TESTING AND CHARACTERIZATION
- PACKAGING DESIGN HANDBOOK AND STANDARDS
- QML
- RELIABILITY
- MILITARY -VS- COMMERCIAL TECHNOLOGY

M4 24 8

WORKSHOP GOALS

FOR DoD MICROWAVE/MILLIMETER WAVE MULTICHIP PACKAGING AND INTERCONNECT TECHNOLOGY REQUIREMENTS

- DEFINE PACKAGING AND INTERCONNECT TECHNOLOGY AND MANUFACTURING PROBLEMS/ISSUES
- RECOMMEND SOLUTIONS TO THESE PROBLEMS BY DEVELOPING AN INVESTMENT STRATEGY THAT CAN BE USED BY GOVERNMENT AND INDUSTRY
- BUILD UPON AND COUPLE TO THE 2-4 MAR 92 AGED ELECTRONICS PACKAGING TECHNOLOGY STAR

M4 24 2

WORKSHOP APPROACH

- IDENTIFY, PRIORITIZE AND RESOLVE ISSUES ASSOCIATED WITH DoD MICROWAVE/MILLIMETER WAVE PACKAGING AND INTERCONNECT TECHNOLOGIES
- WORKSHOP AGENDA
  - SPECIAL INTEREST PRESENTATIONS
  - PARALLEL WORKING GROUPS
  - SUMMARY FEEDBACK SESSION
- WORKSHOP FINDINGS AND RECOMMENDATIONS DOCUMENTED IN A REPORT

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FUNCTIONS OF WORKSHOP PARTICIPANTS

JOINT INDUSTRY/GOVERNMENT SESSION CHAIRMEN LEADING DISCUSSIONS

INDUSTRIAL SPEAKERS

- SPECIAL FOCUS PRESENTATIONS

GOVERNMENT SESSION CHAIRMEN

- PROVIDE SUMMARY BRIEFINGS OF SESSION RESULTS
- PROVIDE 1-2 PAGE SUMMARIES OF SESSION RESULTS

WORKSHOP PARTICIPANTS

- ACTIVELY PARTICIPATE IN SESSION DISCUSSIONS
- PROVIDE INFORMATION ON ISSUES AND SOLUTIONS
- FILL OUT ISSUE AND FEEDBACK WORKSHEETS

M4-24 4

PARALLEL WORKING SESSIONS

1. MICROWAVE MCM PACKAGES
2. MILLIMETER WAVE MCM PACKAGES
3. MICROWAVE/MILLIMETER WAVE PACKAGE DESIGN, MODELING AND SIMULATION
4. MILITARY -VS- COMMERCIAL PACKAGES

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ISSUE WORKSHEET

SESSION TITLE:________________

Issue Title:

Importance: ___ Showstopper: ___ Needs to be done: ___ Nice idea: ___

Description of Issue:

Suggestion # 1 for Resolution of Issue:
Resources Needed: ___ MYrs/Yr for ___ Years
By this type of organization: ________________

Suggestion # 2 for Resolution of Issue:
Resources Needed: ___ MYrs/Yr for ___ Years
By this type of organization: ________________

Suggestion # 3 for Resolution of Issue:
Resources Needed: ___ MYrs/Yr for ___ Years
By this type of organization: ________________

FEEDBACK FOR SESSION ______________

The sessions are large and time is short. This is your mechanism to endorse or object to the findings and recommendations. It is very important that you complete this feedback form. They will be analyzed to develop a sense of priority of the findings and recommendations. It is also important that you circle all of the following descriptors that characterize where you are "coming from". SUPPLIER USER GOVERNMENT INDUSTRY ACADEMIA COOPERATIVE CONSULTANT ENGINEER MARKETING MANAGEMENT MATERIALS COMPONENTS SUBASSEMBLY SYSTEM

Optional Information: Name: ______________ Affiliation: ____________

Issue Title:
Suggestion # ___

Circle: Strongly Agree 10 8 6 4 2 Strongly Disagree

Comments that you want reflected in the final report on the issue:

Issue Title:
Suggestion # ___

Circle: Strongly Agree 10 8 6 4 2 Strongly Disagree

Comments that you want reflected in the final report on the issue:

Issue Title:
Suggestion # ___

Circle: Strongly Agree 10 8 6 4 2 Strongly Disagree

Comments that you want reflected in the final report on the issue:

DoD AGED WORKING GROUP A ACKNOWLEDGES

- GEORGIA INSTITUTE OF TECHNOLOGY, MR C.T. RUCKER
- PALISADES INSTITUTE FOR RESEARCH SERVICES, MS P. MYERS

FOR THEIR SUPPORT IN ORGANIZING THE MICROWAVE PACKAGING TECHNOLOGY WORKSHOP

Microwave Multichip Module Packaging

GE Aerospace

Microwave Packaging Technology Workshop
Georgia Institute of Technology

Ron Naster
GE - Electronics Laboratory
Syracuse, New York
(315) 456-2046

Microwave Multichip Module Package - Outline

GE Aerospace

- Microwave Packaging Requirements
- Packaging Concepts and Assemblies
- Materials and Housing
- Interconnects
- Advanced Systems and Technology
- Development Needs

Present Microwave Packaging Requirements - 1992

GE Aerospace

- **Reliable Enclosure**
  - Hermetic enclosure requires leak rate less than 5×10^{-8} atm-cc/sec for active components.
  - High thermal conductivity required to dissipate high power from confined areas.
  - Materials must match CTE of GaAs and Silicon.
- **Highly Reproducible Performance**
  - Required to maintain channel phase and amplitude tracking.
  - Places tight tolerance on line width and dielectric thickness dimensions
- **Low Cost**
  - Required to meet budgets for large arrays
  - Must be consistent with tight tolerances and use of high performance materials.
  - Forces designs which are compatible with batch processing and automated assembly and test.

RJN 6/12/92-4

Present Microwave Packaging Requirements - 1992

GE Aerospace

- **Weight and Size**
  - Must fit within phased array antenna grid spacing and stay within platform weight budget.
- **Mode Suppression**
  - Package geometry must be designed to avoid circuit-to-package coupling to eliminate package induced performance anamolies and waveguide modes.
- **Interconnect**
  - Low Loss is required to achieve high efficiency, high transmit power and low noise figure.
  - Well controlled 50 ohm impedance is required for power transfer.
  - Greater than 60 dB isolation is required between microwave interconnects and between microwave interconnects and control and power supply lines.
- **Feedthroughs**
  - Low resistance DC feedthroughs are required for high current distribution.
  - Low loss 50 ohm microwave feedthroughs

RJN 6/12/92-40

Microwave Packaging - Drivers

GE Aerospace

- **SYSTEM REQUIREMENTS - Stressing performance specifications impose severe requirements on package heat sinking, loss, and consistency.**
  - High transmit power
  - Low receiver noise figure
  - Module-to-module tracking
- **DISTRIBUTED SYSTEMS - Trend to decentralize and distribute support electronics at antenna forces microwave/digital integration.**
  - Distributed signal control functions
  - Distributed power conditioning
  - Intra-module calibration
  - Distributed beamsteering computation logic
  - Digital beamforming
- **DIVERSE COMPONENT INTEGRATION - Module performance is best achieved through integration of dissimilar microwave/digital technology.**
  - Microwave: GaAs (MESFET, HEMT, HBT), InP, Si, and SiC, Diamond
  - Digital: GaAs, Si
  - Power conditioning: Si
  - Optical: GaAs
- **HIGH DENSITY PACKAGING - High packing density is required to integrate electronics in antenna grid spacing and meet system size and weight requirements.**
- **HEAT SINKING - Increased module performance and functionality increases heat sinking required for reliable operation.**

High density packaging is required to integrate diverse component technology into future systems.

RJN 6/12/92-35

Power Dissipation/Antenna Area

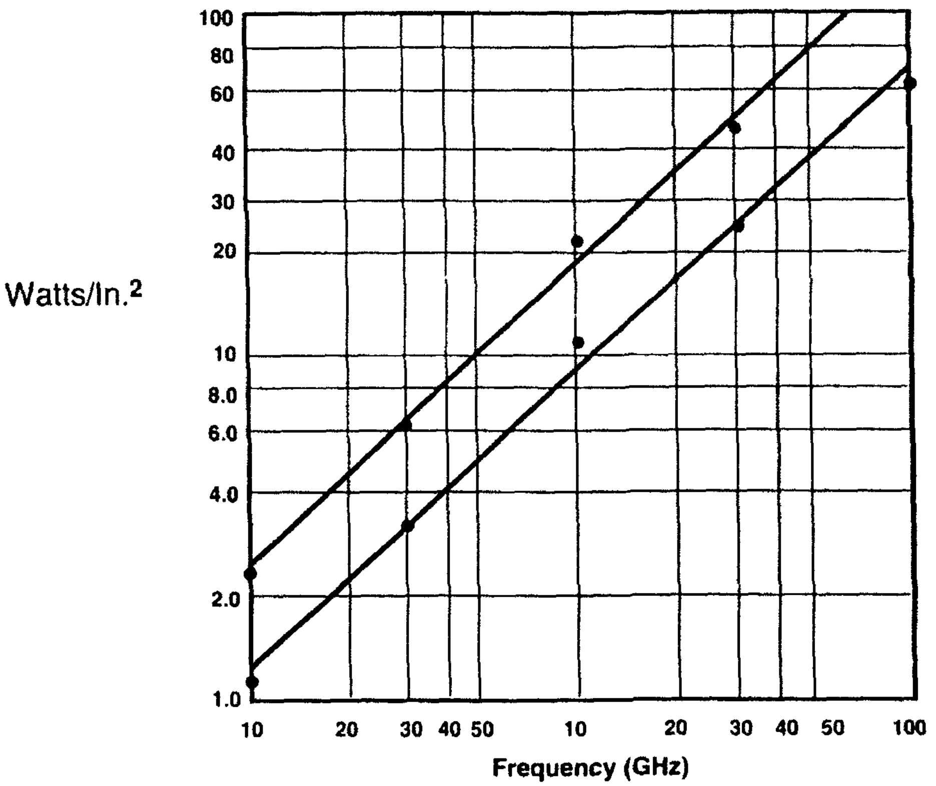
GE Aerospace

Freq. (GHz)	P_o (Peak) (Watts)	η (%)	P_{Dis} (Watts)	P_{Dis}/Area (Watt/in^2)
1	200-400	50	40-80	1.2-2.4
3	50-100	45	12-24	3.2-6.4
10	12-24	40	3.6-7.2	11-22
30	2-4	30	.9-1.9	24-48
100	.2-.4	15	.22-.45	63-126

Duty Factor = 20%

Phased Array Dissipated Power

GE Aerospace



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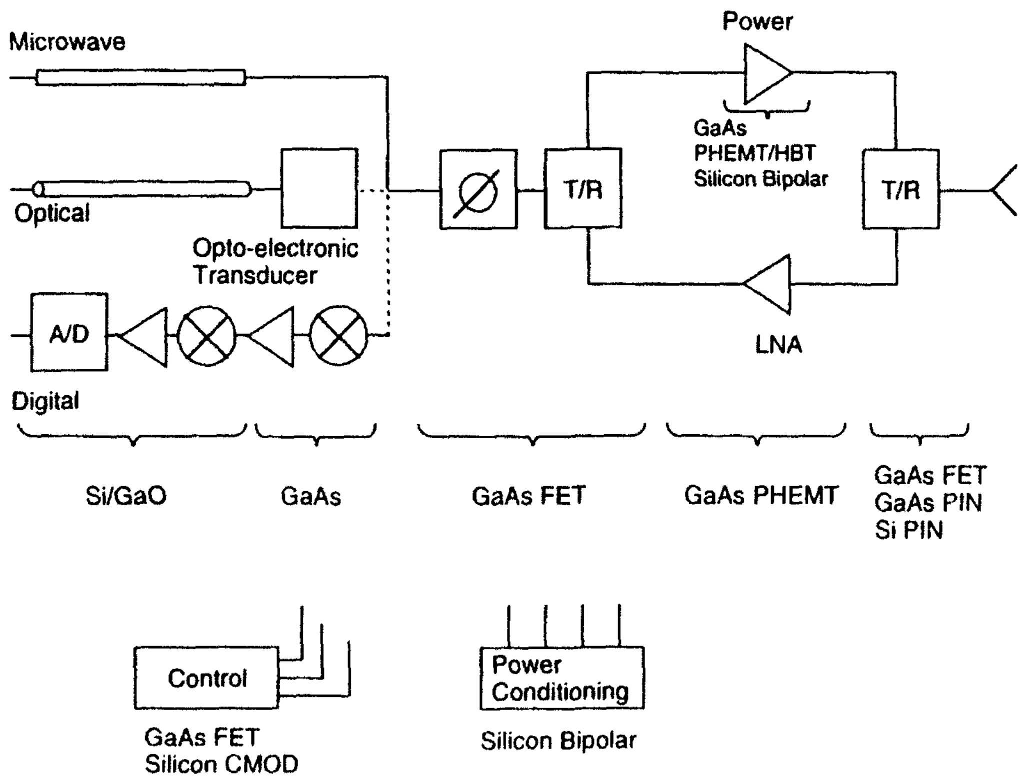
T/R Module Architecture

GE Aerospace



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Semiconductor Properties (Room Temperature)

GE Aerospace

Material	k Thermal Cond. W/in-C	CTE Coef of Therm. Exp. ppm/C	γ Density Lb/in³	E Elastic Modulus 10^6 psi	ρ Resistivity μΩ-cm	ε_r Dielectric Constant (at Microwave Frequencies)	δ Loss Tangent (at Microwave Frequencies)
Gallium Arsenide	1.0	5.8	.19	12.4	8.1	12.8	.0016
Indium Phosphide	1.8	4.6	.17	—	—	12.3	—
Silicon	3.4	3.2	.084	15.5	850.	11.0	.001-.01
Silicon Carbide	6.8	3.7	.116	48.1	—	—	—
Diamond, Type 2A	50	.8	.127	—	$>10^{26}$	5.7	—
Germanium	1.5	5.8	.19	11.4	45.	15.7	—

RJN 6/12/92

Ceramic/Glass Properties - Room Temperature

GE Aerospace

Material	k Thermal Cond. W/in-C	CTE Coef of Therm. Exp. ppm/C	γ Density Lb/in³	E Elastic Modulus 10^6 psi	ρ Resistivity μΩ-cm	ε_r Dielectric Constant (at Microwave Frequencies)	δ Loss Tangent (at Microwave Frequencies)
Air	.00066		.000042			1.0	
Alumina							
99%	.93	6.7	.141	55	$>10^{20}$	9.9	.0001
96%	.89	6.4	.141	47	$>10^{19}$	9.2	.0003
94%	.70	6.0	.141	43	$>10^{19}$	8.8	.001
Alumina Nitride	2.5-4.3	4.1	.116	40	$>10^{19}$	8.8	.001
Barium Titanate	.19	9.5	.200		$>10^{18}$	38	.0002
Beryllia 99.5%	6.3	6.7	.105	48.5	$>10^{21}$	6.7	.004
Sapphire	1.2	5.6	.144	55	$>10^{21}$	11.0	.001-.002
Silic (fused)	.04	.6	.079	10.6	$>10^{17}$	3.8	.0012
Glass (variable)	.025		.092	8.7	$>10^{22}$	5-6	.002
7059 (BaBoSilicate)		4.6		9.8	$>10^{14}$	4.8	.005
7070		3.2	.077	7.4		4.1	.0025
7740		3.3	.081	9.1		4.6	.026
Quartz	.04	.6	.079	12.5		3.8	.0001

Packaging Material Properties - Metals

GE Aerospace

Material	k Thermal Cond. W/in-C	CTE Coef of Therm. Exp. ppm/C	γ Density Lb/in³	E Elastic Modulus 10⁶ psi	ρ Resistivity μΩ-cm	εr Dielectric Constant (at Microwave Frequencies)	δ Loss Tangent (at Microwave Frequencies)
Copper, pure forms	9.9	16.8	.323	17.6	1.72		
Gold	7.5	14.2	.698	11.5	2.4		
Aluminum, 1000	5.7	23.4	.097	10	2.6		
6000	4.9	23.4	.097	10	2.6		
2000, 3000, 5000	4.6	23.4	.097	10	2.6		
7000	3.1	23.4	.097	10	2.6		
Molybdenum	3 6	4 9	.369	47 8	4 8		
Brass	1.2-5.2	18.5	.308	16 5	3.9		
Beryllium	3.9	11.5	.067	42	4.6		
Nickel	1.9	13.3	.322	30	6 9		
Kovar	.45	4.9	.302	19	45-85		
Invar	.28	1.6	.290	20.5			
C/I/C (12.5/75/12.5) (Cu/Invar/Cu)		3.1(x-y) 4.2(z)		19.0			
(16/68/16)		4.2(x-y) 5.4(z)		19.0			
(20/60/20)		5.5(x-y) 6.7(z)		19.0			
Silver	10.6	19.6	.379	11.6	1.62		

Die Attach Properties (Room Temperature)

GE Aerospace

Material	k Thermal Cond. W/in-C	CTE Coef of Therm. Exp. ppm/C	γ Density Lb/in³	E Elastic Modulus 10⁶ psi	ρ Resistivity μΩ-cm	εr Dielectric Constant (at Microwave Frequencies)	δ Loss Tangent (at Microwave Frequencies)
Gold/Tin (80/20)	1.4	15.9	.542	8.6			
Tin/Lead (63/67)	1.3	24.7	.305	4	15.0		
(60/40)	1.3	23.9	.308		15.0		
(50/50)	1.3	24.8	.321		15.6		
(40/60)	1.1 -	24.6	.335		17.0		
(30/70)	-		.351		18.5		
(20/80)	.95	26.5	.368		19.8		
(10/90)	.91		.389				
Sn/Ag (96.5/3.5)			.375		12.3		
Sn/Pb/Ag (62/36/2)	1.3	27	.307	3.3			
Indium	2.0	32.7	.264	1.6	9.0		
Epoxy, Able 826-1	.053	32	.087	.2	300		
Able 84-1 LMI	.048	55					

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Composite Electronic Packaging

GE Aerospace

Composites Advantages
- High thermal conductivity
- Tailorable CTE
- Low density
- Low cost in high volume applications
- Weight savings to 80%
- Net shape fabrication

Key Materials
- Silicon carbide particle/aluminum
- Diamond particle/aluminum
- Carbon fiber/aluminum
- Carbon fiber/copper
- Carbon fiber/epoxy - aluminum laminate
- Carbon fiber/epoxy - copper laminate

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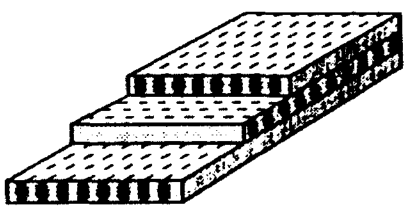
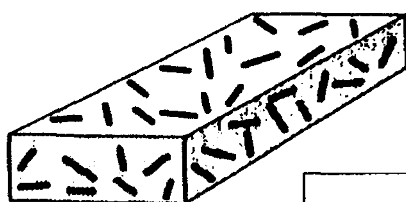
Reinforcements

GE Aerospace

Continuous Fibers

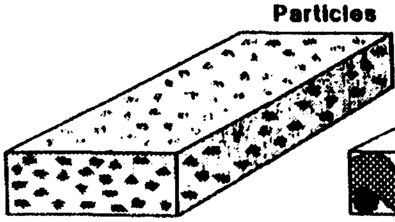


Discontinuous Fibers, Whiskers

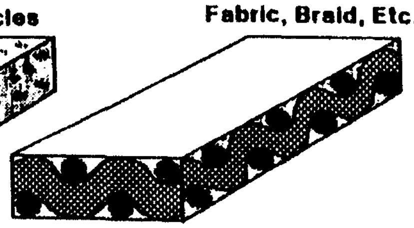


	Reinforcement		
Matrix	**Metal**	**Ceramic**	**Poylmer**
Metal	X	X	X
Ceramic	X	X	X
Poylmer	X	X	X

Particles



Fabric, Braid, Etc.



Metal Matrix Composite Properties (Room Temperature) *GE Aerospace*

Material	k Thermal Cond. W/in-C	CTE Coef of Therm. Exp ppm/C	γ Density Lb/in^3	E Elastic Modulus 10^6 psi	ρ Resistivity $\mu\Omega$-cm	ε_r Dielectric Constant (at Microwave Frequencies)	δ Loss Tangent (at Microwave Frequencies)
P100Gr (20%)/1100A	5.5 (x-y)	10.3 (x-y)	.093	18 (x-y)			
	3.8 (z)	27 (z)		6.8 (z)			
(25%)/	5.5 (x-y)	8.3 (x-y)	.091	20 (x-y)			
	3.5 (z)	27 (z)		6.0 (z)			
(30%)/	5.5 (x-y)	6.7 (x-y)	.090	22 (x-y)			
	3.1 (z)	27 (z)		5.4 (z)			
(40%)/	5.5 (x-y)		.086	26 (x-y)			
	2..1 (z)			4.2 (z)			
(50%)/	5.7 (x-y)		.083	30 (x-y)			
	2.0 (z)			3.2 (z)			
P75Gr (10%)/1100Al	5.1(x-y)	17.3 (x-y)	.097	12.5 (x-y)			
(20%)/	4.6 (x-y)	12.6 (x-y)	.093	15.1 (x-y)			
		27 (z)		6.8 (x-z)			
(30%)/	4.1 (x-y)	8.9 (x-y)	.090	17.7 (x-y)			
		27 (z)		5.4 (z)			
SiC (40%)/Al	2.5	12.6	.105	21			
(60%)/	4.06	7.0	.10	26.1			
(70%)/	4.06	6.2	.10	26.1			
CM-15	4.7	7.0	.36	—			
CW-10	5.3	6.5	.61	—			
CW-15	5.7	7.0	.59	—			
CW-20	6.3	8.5	.57	—			

RJN 6/12/92-10

Fiber-Reinforced MMCs

GE Aerospace

- **Advantages**
  - Very low CTEs possible
  - Very high conductivities possible (>copper)
  - Low density
  - Easily machined (some)
- **Disadvantages**
  - High cost
  - Limited shape capability (e.g., plates)
  - Hard to machine (some)
  - Hysteresis
  - Galvanic corrosion for C/Al
  - Poor transverse strength for C/Al, C/Cu
- **Key matrix materials: Aluminum, Copper**
- **Key fibers; graphite (carbon), boron, silicon carbide**

HJN 6.12.92.9

Particle-Reinforced MMCs - Key Materials

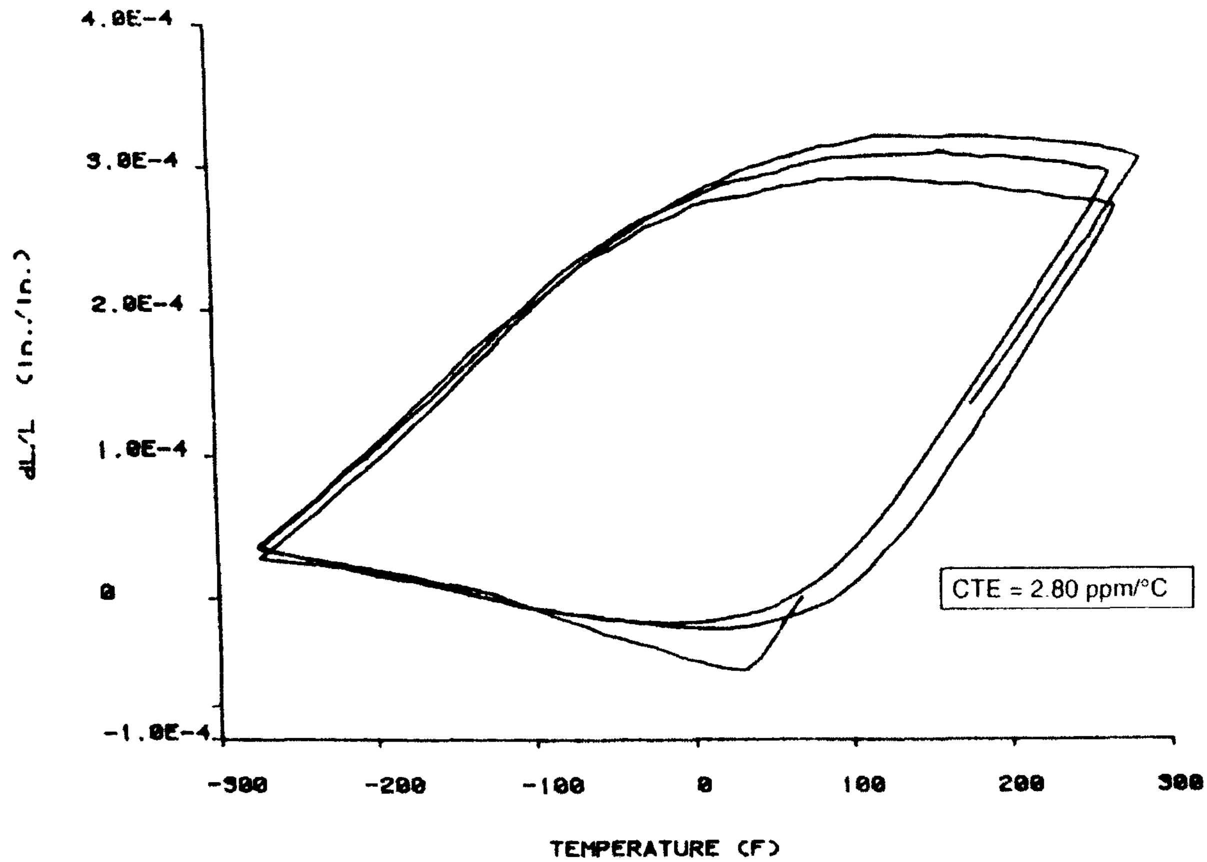
GE Aerospace

- **Aluminum reinforced with**
  - Silicon Carbide - (SIC)p/Al
  - Diamond - (Diamond)p/Al (experimental)
  - Aluminum Nitride - (AlN)p/Al (experimental)
- **Beryllia-reinforced Beryllium-(BeO)p/Be**
- **Diamond/Magnesium - (Diamond)p/Al (experimental)**
- **Many other systems possible**
  - e.g., copper matrix

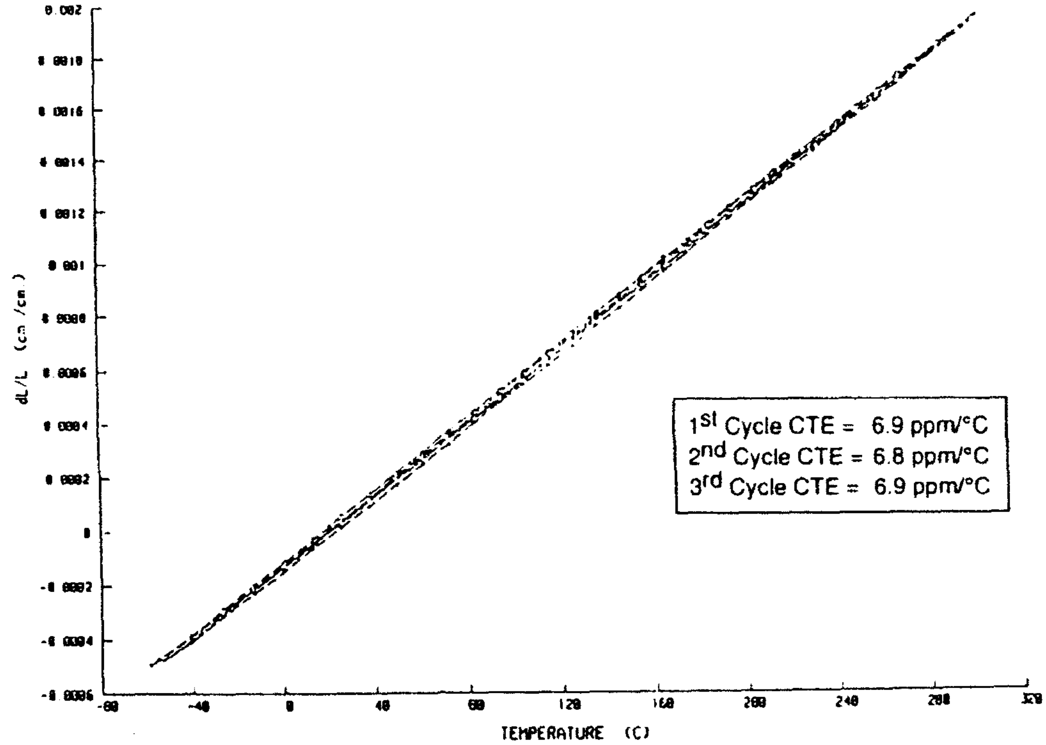
HJN 6/12/92 31

Gr-Al Cyclic Thermal Expansion - 3 Cycles

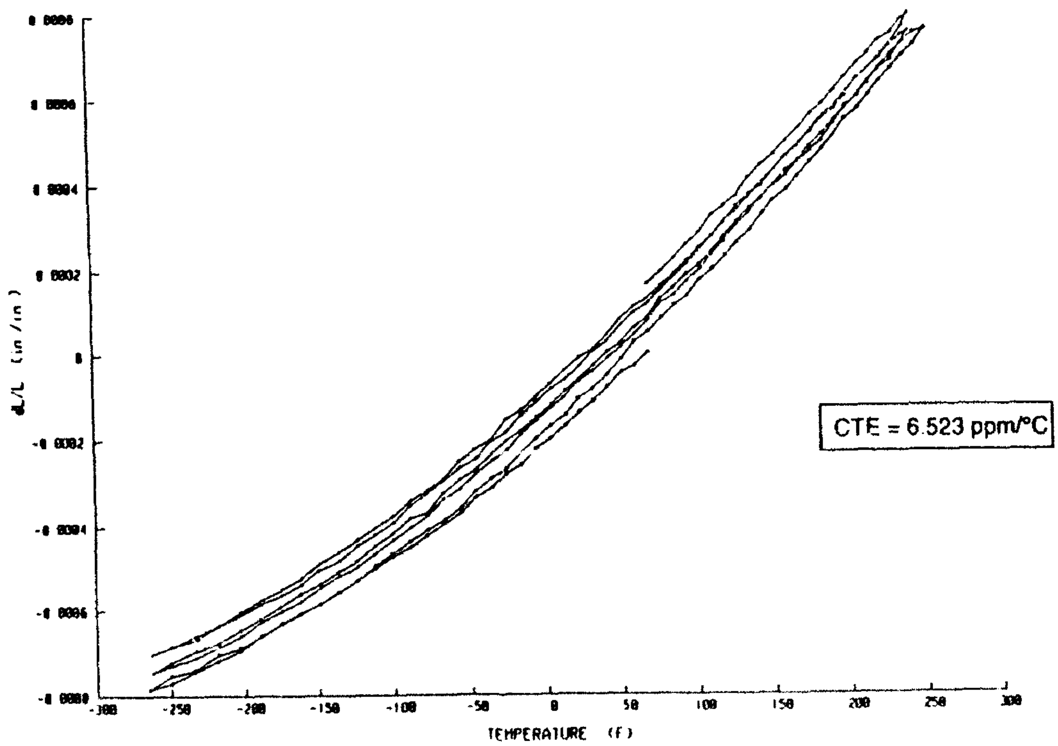
GE Aerospace



Tungsten/Copper Cyclic Thermal Expansion - 4 Cycles *GE Aerospace*

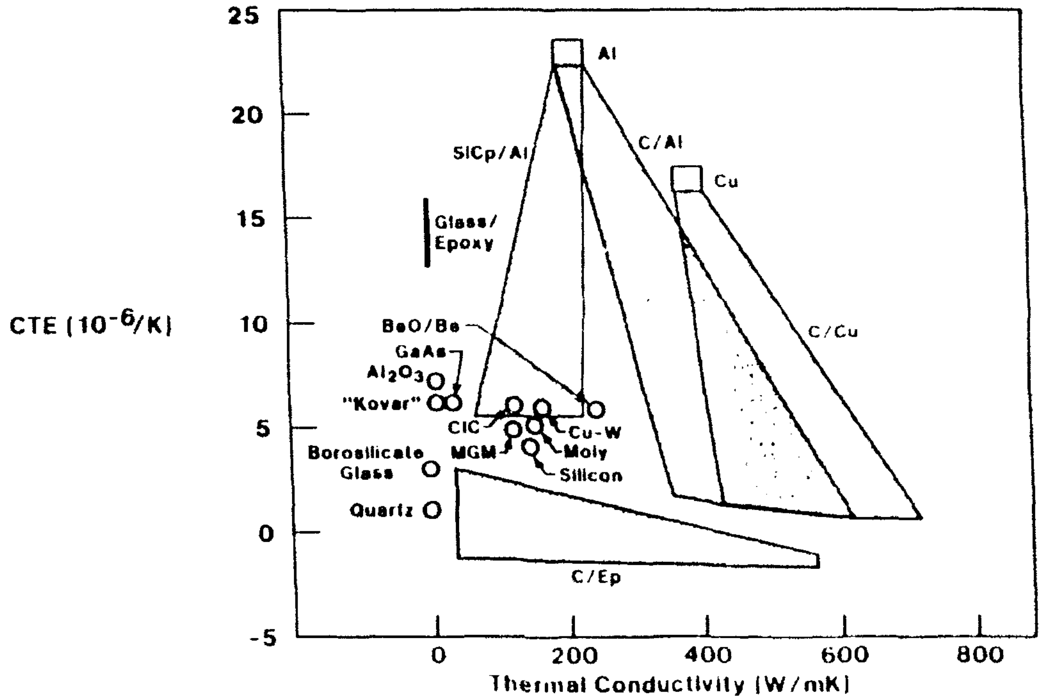


SiC(p)/Alumina Cyclic Thermal Expansion - 3 Cycles *GE Aerospace*



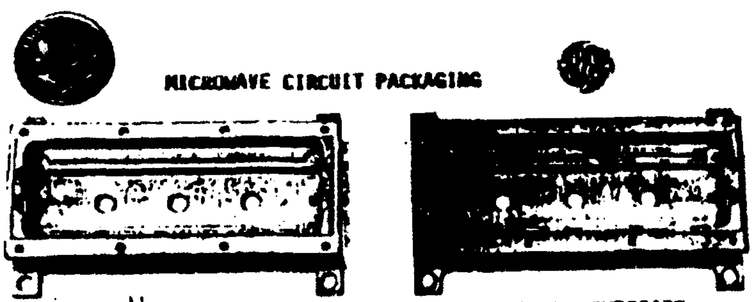
CTE of Electronic Materials

GE Aerospace



METAL MATRIX COMPOSITE AND "KOVAR" MICROWAVE PACKAGES

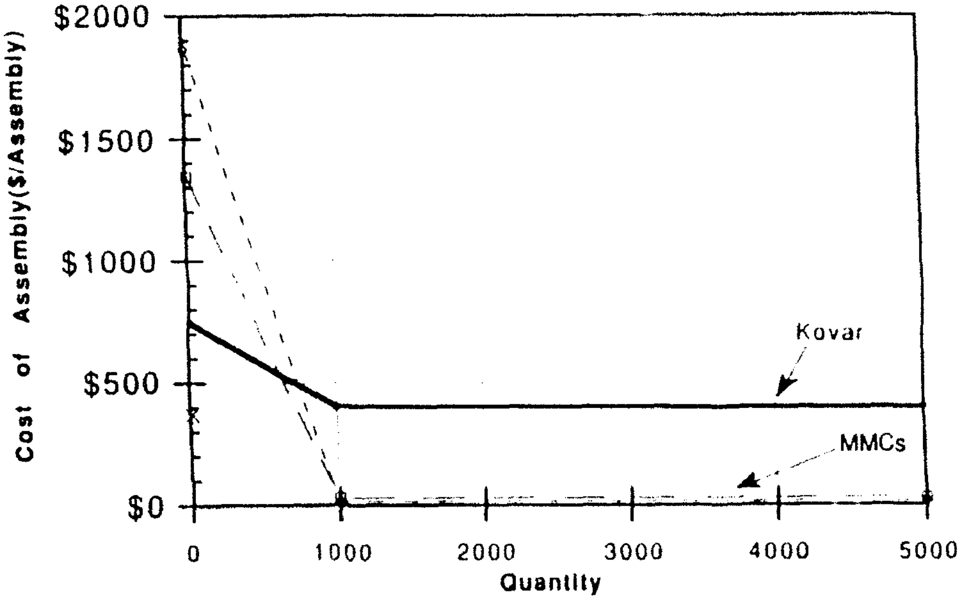
GE Aerospace



"KOVAR"	METAL MATRIX COMPOSITE
WEIGHT = 42 g	WEIGHT = 15 g
THERMAL CONDUCTIVITY = 9.6 BTU / HR-FT-°F	THERMAL CONDUCTIVITY = 74 BTU / HR-FT-°F

Kovar and Metal Matric Composite Package Costs

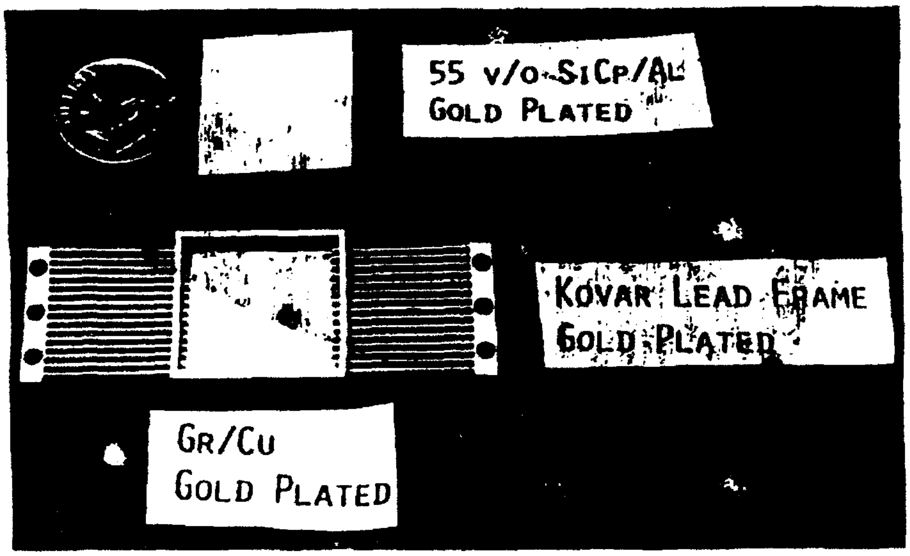
GE Aerospace



Materials & Structures

High-Thermal-Conductivity Multichip Module

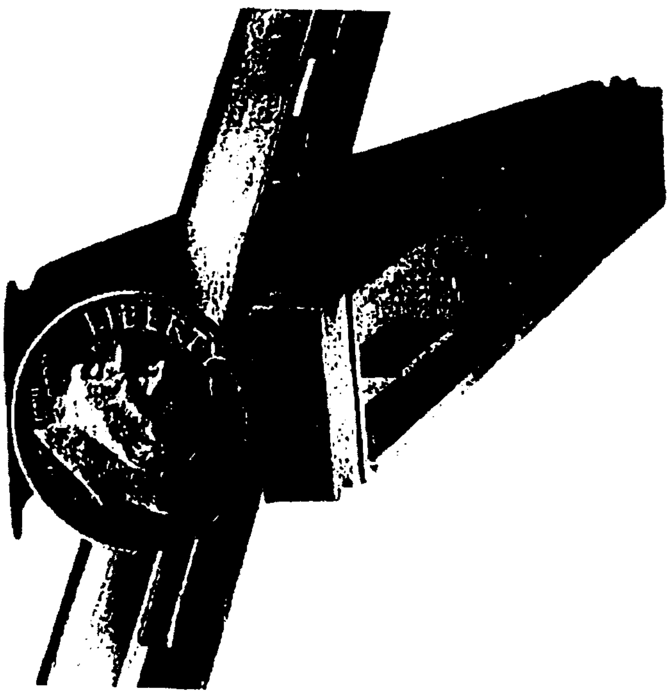
GE Aerospace
Astro Space Division



- P120 carbon fiber/copper base
- Tailored CTE matches alumina
- Advantages vs. molybdenum
  - 3 x thermal conductivity
  - 25% lighter

Pressure Infiltration Casting

- Form of liquid infiltration utilizing pressurized inert gas to force molten metal into a preform of reinforcement material
- Allows for inexpensive production of net-shaped composite materials with tailorable properties
- Pressure infiltration utilizes controlled pressurization - high infiltration pressures with low differential pressures inside and outside of mold
    - Reduces sealing problems
    - Lowers required wall strength
    - Minimizes thermal mass of molds
    - Lowers tooling costs
- Key characteristic - process does not rely on matrix wetting by the molten metal and is capable of high melt temperatures; therefore, many combinations of reinforcement and matrix alloys are possible
    - Aluminum silicon carbide
    - Graphite aluminum
    - Diamond gold
    - Graphite copper



Powder Injection Molding

- Form of powdered metallurgy where net shape formation of potentially inexpensive composite metal housings is possible
- Powder Injection Molding Process
  - Selected metals are milled to fine, uniform particle sizes
  - Fine metal powder is mixed with organic binders for adhesion
  - Pliable mixture is injection molded to shape
  - Shaped part is sintered in hydrogen furnace at very high temperatures
  - Multiple furnace firing occurs until the binders are removed and part density is achieved
- Process design characteristics include
  - Control of metal powder size to prevent agglomeration of metal particles during sintering
  - Control of heating rate during sintering to minimize shrinkage and warpage
  - Mold design to accommodate 20% shrinkage of part during firing

Conclusions

- **Low Cost (< $50) T/R Module Package Is Achievable In Large Quantities**
- **Metal Injection Molded Package Is Lowest Cost Solution for Packages With Features Like Septums, Grooves etc.**
- **Ring and Base Package Appears to Be Lowest Cost for Featureless Enclosures**
- **AlSiC Pressure Cast Packages Offer Minimum Weight at 10% - 20% Higher Cost (≤ $50)**

LTCC/HTCC Comparison

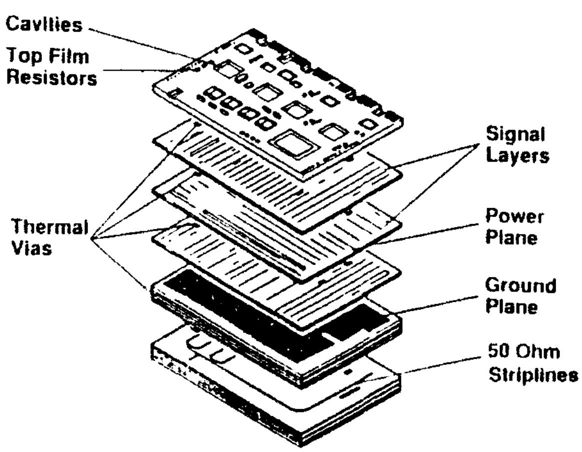
GE Aerospace

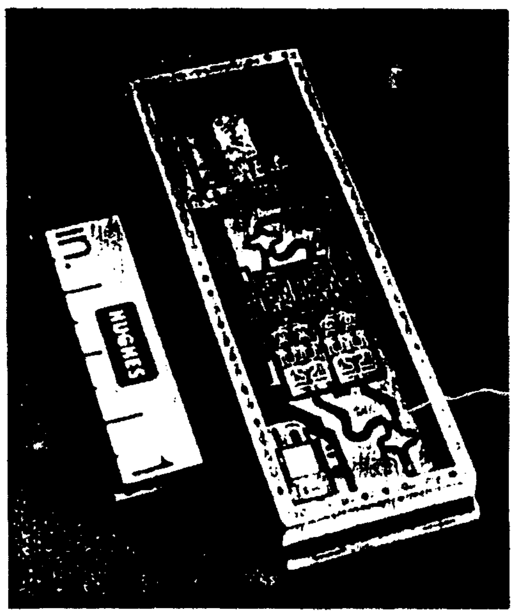
	LTCC Package	Thick Film on 96% Alumina	HTCC (92% Alumina)
Physical Properties			
CTE at 300°C (ppm/°C)	7.9	6.4	6.0
Density (g/cm^3)	2.9	3.7	3.6
Camber (mils/inch)	1-4	1-2	1-4
Surface smoothness (microinches)	8.7	14.5	20.0
Thermal conductivity (W/m K)	16-20	20	14-18
Flexural strength (kpsi)	22	40	46
Thickness/layer after firing (mils)	3.5-10.0	0.5-1.0	5-20
Dimensional Shrinkage Tolerances			
Length and width	± 0.2%	N/A	± 1.0%
Thickness	± 0.5%	N/A	+5.0%
Electrical Properties			
Insulation resistance (ohms at 100 VDC)	> 10^{12}	> 10^{12}	> 10^{12}
Breakdown field (volts/mil)	> 1,000	> 1,000	> 700
Dielectric constant (1 MHz)	7.1	9.3	8.9
Dissipation factor (%)	0.3	0.3	0.03
Buried conductor res. (mΩ/□)	5.0	—	10.0
Microstrip loss (dB/in @ 10 GHz)	0.8	—	16
Integrated res. & cap.	Yes	—	No

MIMIC | **Multi-Chip LTCC Package** | GE HUGHES

HARRIS · CASCADE MICROTECH · EEsof · E-SYSTEMS · AT&T · M/A-COM

Basic Construction





Single Channel X-Band LTCC Module

<u>Advantages</u>

- Integration of Transmission Structures
- Complete Hermetic Package
- Compact Size for Complex Circuitry
- Low Cost in High Volume

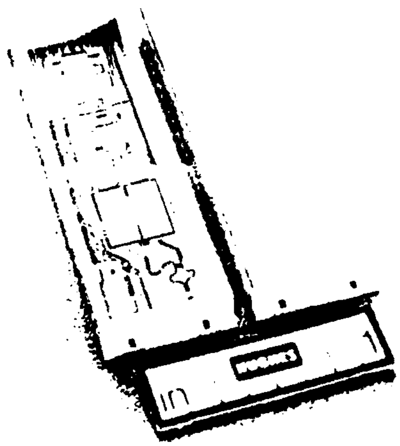
G11005002 08/05 01 91

MIMIC

LTCC PACKAGING FOR X-BAND RADAR MODULE

HUGHES

HARRIS | CASCADE MICROTECH | EE/OF | E-SYSTEMS | AT&T | M/A-COM



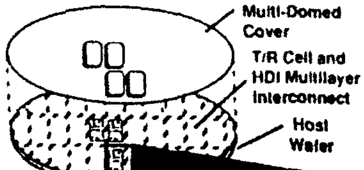
FEATURES

- 15 3.5 mil CIRCUIT LAYERS
- 10 10 mil SEAL RING LAYERS
- 4 MICROSTRIP TO STRIPLINE TRANSITIONS
- 2 ISOLATED AND SHIELDED STRIPLINES
- 4 THERMAL ELECTRICAL GROUND VIA FIELDS
- ISOLATION AND MODE SUPPRESSION VIAS THROUGH ALL 15 LAYERS
- GROUND PLANES IN ALL LAYERS
- EMI SHIELDING IN SEAL RING SIDEWALLS
- SHRINKAGE CONTROL ±0.2%
- LOSS AS LOW AS 0.2 dB/INCH (Al_2O_3= 0.2dB/INCH)

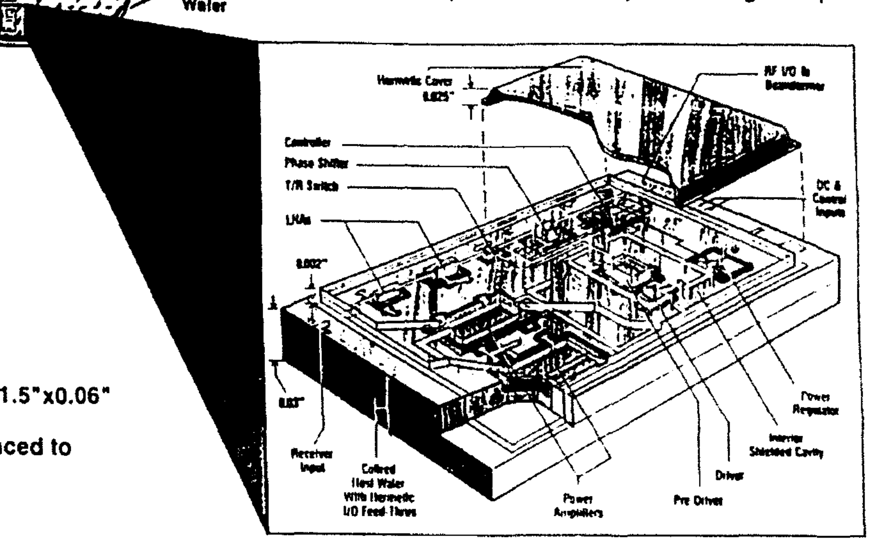
G0100504618

MPATT Microwave Packaging and Interconnect Technology for Phased Arrays (WL)

GE Aerospace



Module cost is reduced by
- Semiconductor-based processes and equipment
- Denser packaging which increases batch size (40 per 6-inch wafer)
- Improved module yield through adaptive lithography



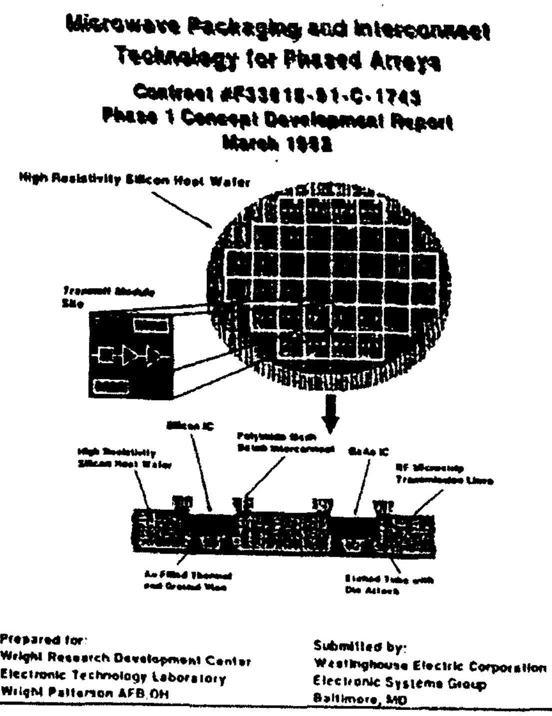
Size: 0.55"x1.5"x0.06"

Weight reduced to 2 grams

Technology Development

- Host wafer
- DC/RF Interconnect
- RF transmission media
- Wafer-level fabrication and test
- Cooling
- Hermetic seal

Microwave HDI results in significant reduction in module size, weight, and cost



Key MPIT Program Elements

Requirement	Westinghouse Approach	Benefits
Host Wafer Selection	High Resistivity Silicon	Low Cost Batch Processing Commercially Available Fine Line Geometries
Processing of RF/DC Interconnects & Passive Components	Precision Thin Film on Si motherstrate	Batch Processing Reduced Parts Count
GaAs/Si Component Attach & Interconnects	Reduced Stress Die Attach with Metal Shims TRW COmpliant INterconnect WEC Auto- Wirebonding	Batch Processing Enhanced Reliability
RF Transmission Media	Microstrip	Single Layer, High Density Supports Multiple Interconnect Processes
Wafer Level Test	RF Wafer Probing Automated Module Test	Fully Automated Improved Yield, Low Cost
Thermal Management	Thermal Spreaders Filled Thermal Vias	Improved Reliability Integrated Approach
Hermetic Coatings	WEC/Industry Initiatives Organic/Inorganic Coatings	Reduced Cost & Weight

MICROWAVE PACKAGING & INTERCONNECT TECHNOLOGY

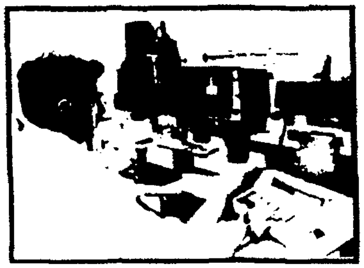
RJN 8/12/92-22

MPAIT Development Plan

GE Aerospace

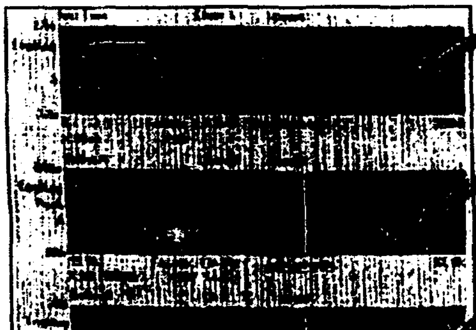
• Host Wafer	— AlN used for high thermal conductivity and excellent mechanical properties. Thermal expansion coefficient is matched to GaAs by copper deposition.
• DC/RF Interconnect	— Thin film metallization on Kapton defined by laser lithography allows face-up die attach.
• Die Attach & Interconnect	— Process compatible with standard eutectic, epoxy, and thermoplastic resins. — MMICs fill 80% of module area — 3:1 module size reduction
• RF Transmission Media	— High density thin film microstrip interconnect compatible with MMICs increases RF density by 10:1 — Microstrip lines are adaptively adjusted for MMIC misalignment — Shielded RF crossovers — RF feedthroughs buried in cofired AlN — Low ohmic and mismatch loss
• Wafer-Level Characterization, Dicing, and Test	— T/R modules fabricated on 6 inch wafers — Standard cassette-to-cassette handling — RF autoprobing at wafer level
• Cooling	— Face-up bonding and 4-mil MMICs provide best thermal path — Conventional cooling possible to 4 watts — Microchannel cooling in or external to host wafer allows output power to increase to 15 watts
• Hermetic Seal	— Integral hermetic package without walls — Near term batch processed metal cover — *Longer term uses thin film conformal coating*

PICK AND PLACE AUTOMATION DEVELOPMENT REDUCES VARIATION AND LOWERS COST

DEM/VAL	MANTECH PHASE 2	<$400 MODULE
• 124 COMPONENTS/MODULE • 5 SUBASSEMBLIES	• 41 COMPONENTS/MODULE • 3 SUBASSEMBLIES	• 17 COMPONENTS/MODULE • NO SUBASSEMBLIES
		INTEGRATED AUTOWORK CELL
• SEMI-AUTOMATIC PROCESS • +/-.007 INCH/LIMITED FEEDERS • 70 - 95% YIELD (COMP) • 10 MODULES/SHIFT/MACHINE • $40/MODULE (PLUS REWORK)	• FULLY AUTOMATIC PROCESS • +/-.003 INCH/MULTI-FEEDERS • 99.9% YIELD (1000 ppm) • 78 MODULES/SHIFT/MACHINE • $8/MODULE (PLUS REWORK)	• INTEGRATED MFG PROCESS • +/-.0005 INCH/MULTI-FEEDERS • 99.99% YIELD (100 ppm) • 200 MODULES/SHIFT/MACHINE • <$3/MODULE (NO REWORK) @ 1000 MODULES/DAY

Mantech for T/R Modules

Wirebond Ultrasonic Signal Analysis



Current Envelope
- Time Record of V/S Pulse
- Rise Time, Duration
- Basis for Frequency Response

Frequency Response-Current
- Fourier Transform of Current Envelope
- Mechanical Resonant Frequency
- Shape, Magnitude Relate to Bond Quality

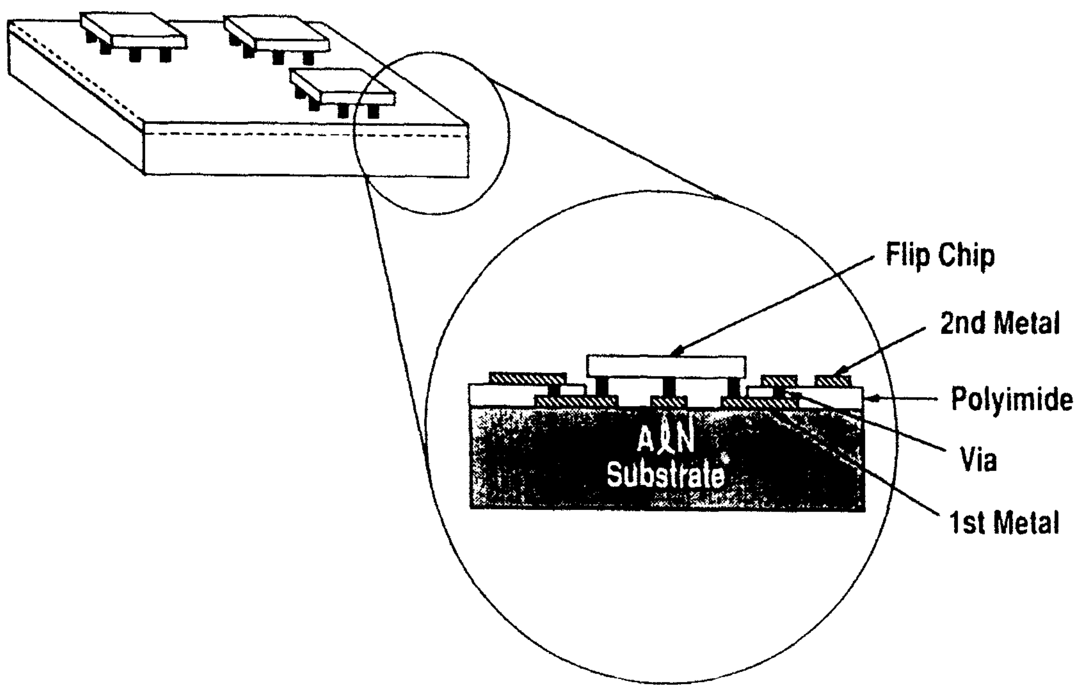
Frequency Response - Impedance
- Voltage/Current
- Depends on Bond Geometry
- Relates Directly to Bond Quality

Ultrasonic Monitors for Wirebonding
- Bond Characteristics Measured in Realtime (2 Wires/4 Bonds per Second)
- Measurements Relate to Bond Quality (Strength, Visual) with Neural Network
- Bond Quality Relation Enables On-Line Statistical Process Control, Defect Detection

Texas Instruments/Westinghouse Mantech Joint Venture

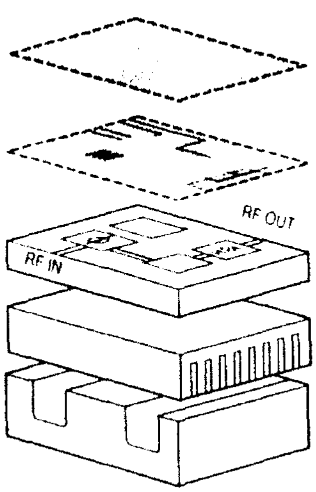
Silicon Wafer Processing Provides the Technology to Batch Process T/R Modules

HUGHES



4 Watt Transmit Module Will Demonstrate Feasibility of Wafer Fabrication of T/R Modules

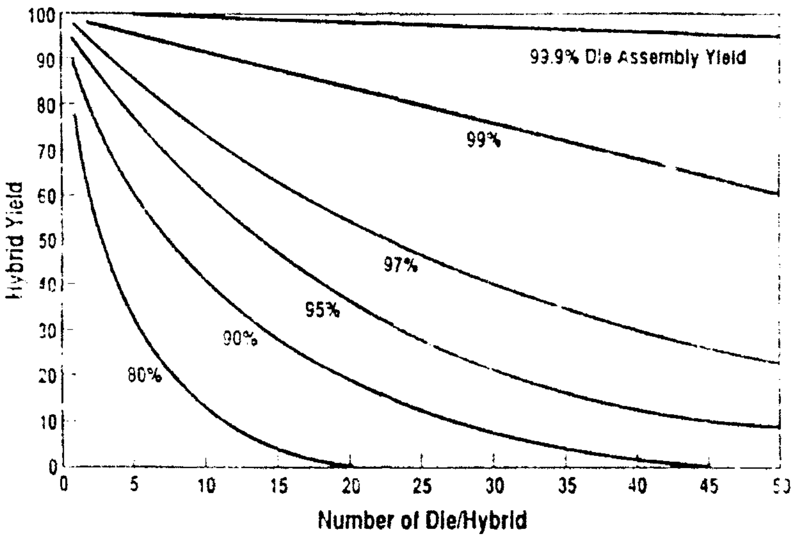
HUGHES



Designing for Manufacturing Yield

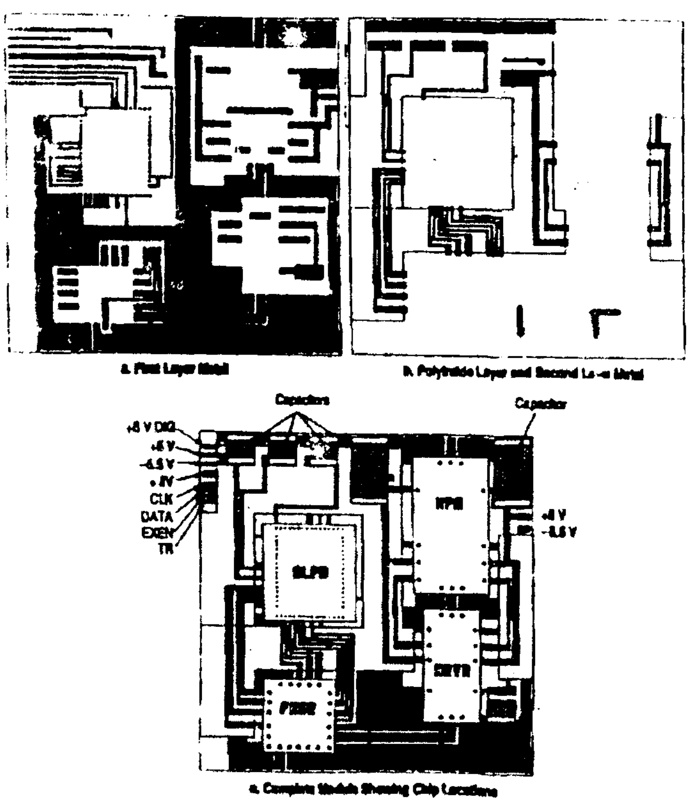
Die Yield After Attachment and Number of Die Per Hybrid Will Determine the Hybrid Yield

HUGHES



Four Areas to Address to Achieve Desired Hybrid Yield:

1. Partitioning, to Reduce the Number of Die Per Hybrid
2. Die Test, to Start With a Higher Percentage of Good Die
3. Assembly Improvements, Design for High Assembly Yields
4. Rework, Initial Design Must Allow Cost Effective Rework



HUGHES

A Transmit Module Has Already Been Designed for MCM Manufacturing

RJN 6/12/92-5

Future Microwave Packaging Requirements - 2000

GE Aerospace

- **High Density Integration**
  - High Density Integration of microwave and digital electronics to increase radar performance through improved calibration, adaptive nulling, digital beam forming, distributed signal processing, etc.

- **Improved Heat Removal**
  - Additional heat removal capacity to handle thermal load of higher power transmitters and increased module integration.

- **Opto-electronics Integration**
  - Integration of opto-electronic components for mating with fiber optic beamformer and control harnesses.

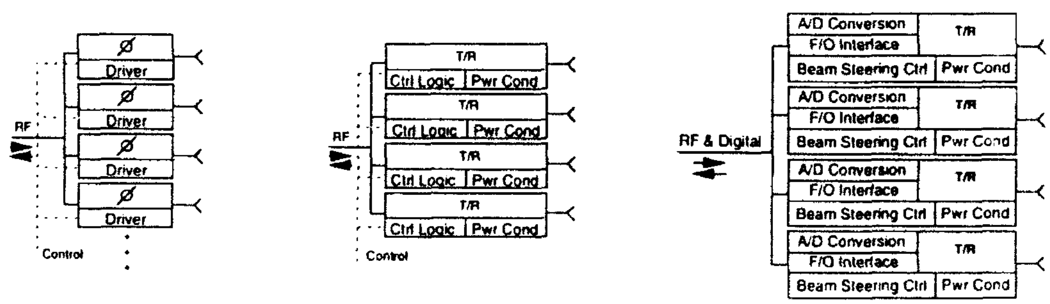
- **Multi-layer Packaging**
  - Multi-layer packaging for increased volume integration and insertion into thin conformal array structures.

RJN 6/4/92-6

Phased Array Thrust

GE Aerospace

1980 *1990* *2000*

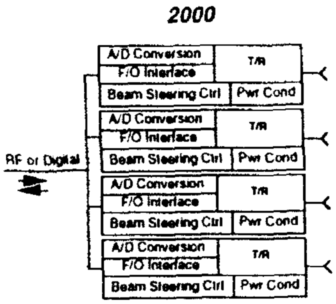


	1980	1990	2000
Elemental Electronics	• Phase Control (Silicon)	• Phase & Gain Control (GaAs) • Transmitter (GaAs) • Receiver (GaAs) • Control Logic (GaAs) • Power Conditioning (Silicon)	• Phase & Gain Control • Transmitter (GaAs) • Receiver (GaAs) • Control Logic (GaAs) • Power Conditioning (Silicon) • Beam Steering (Silicon) • Performance Monitoring • Calibration • Space Time Adaptive Processing • Digital Beamforming • Signal Processing
Centralized Electronics	• Transmitter (Tube/Silicon) • Receiver (GaAs) • Power Conditioning • Beam Steering Computer • Performance Monitoring • Calibration • Signal/Data Processing • Display	• Beam Steering (Silicon) • Performance Monitoring • Calibration • Adaptive Nulling • Signal/Data Processing • Display	• Data Processing • Display

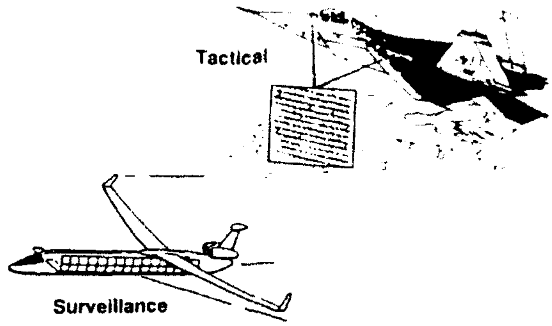
Conformal Airborne Arrays

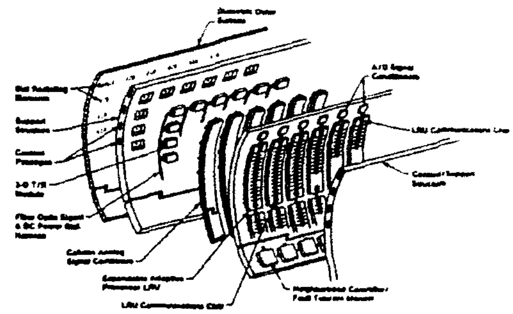
GE Aerospace

Airborne integration places extraordinary demands on packaging, interconnects, thermal control, and mechanical structure.



- **Distributed Processor**
- **Integrated Active Antenna Structure**





For future airborne radar, advanced packaging and photonic technology will reduce radar weight and cost and add new performance capability.

RJN 2/27/92-2

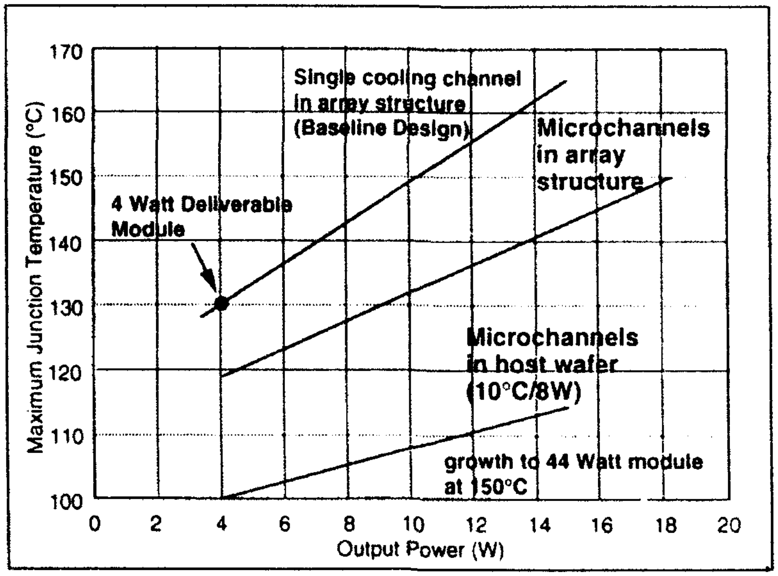
Microwave/Digital Integrated Packaging

GE Aerospace

Issue	Microwave	Digital	Needs
Frequency/ Clock Rate	1-100 GHz	30 MHz-200 MHz-2 GHz	
Average Power Consumption	5-50 Watts	20-200 Watts	
Die	•GaAs •Thickness - 4 mils •Ground Plane Metallization Solder on Epoxy Attachment	•Silicon and GaAs •Thickness ≈ 20-25 mils •Eutectic/Epoxy Attachment	
Substrate	•CTE match with GaAs (5.8 ppm/°C) •CTE (BeO) ≈ 6.7 k=6.3 W/in°C •CTE (Al_2O_3) = 6.7 k = .9 W/in°C	•CTE match with Si (3.2 ppm/°C) •CTE (AlN) = 4.1 ppm/°C k = 4.3 W/in°C	Develop compatible substrate/ adhesive system for GaAs/Si •AlN •Metal matrix (SiCAl)
Interconnect System	•Low loss transmission line •Low inductance RF grounding •Low coupling (<60 dB) •L, C, R lumped element matching •High power	•High density •Low crosstalk	High density/high isolation multilayer interconnect system
Packaging	•Efficient heat removal •Multilevel packaging for tight antenna element grid spacing	•Efficient heat removal	High thermal conductivity/CTE matched metal matrix packages

Microchannel Cooling Effect on T_j(max) and P_o

GE Aerospace

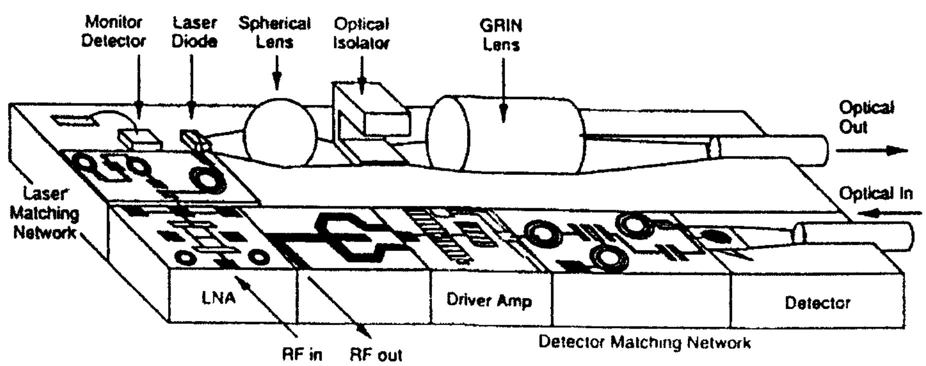


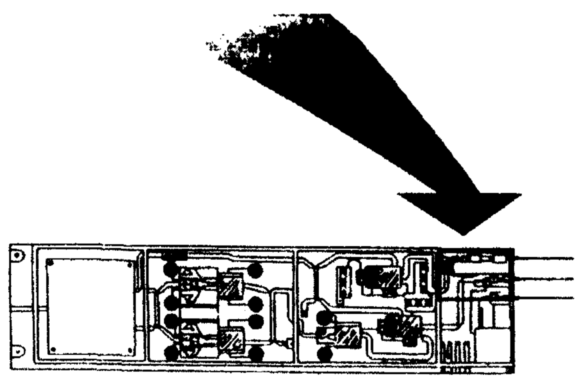
Transmit power can be reliably increased to 44 watts with AlN and microchannel cooling.

RJN 6/12/92-19

Fiber-Optic Microwave/Optical Interface

GE Aerospace





Microwave Packaging — Summary

GE Aerospace

- **Improved packaging and interconnect systems are required**
  Packaging material compatibility with GaAs and silicon
  - Thermal coefficient of expansion
  - High thermal conductivity

  Higher Density Interconnects
  - Uncompromised microwave performance
  - High isolation for reduced microwave/digital coupling (crosstalk)
  - Top level "flying lead" replacement

  Feedthrough Connections
  - Low microwave loss
  - High power DC
  - High density control

  Low-Cost
  - Materials
  - Automated assembly and test
  - Wirebond replacement

- **Advanced Technology needed for future higher power/highly integrated systems**
  - Multilevel packaging
  - Lightweight/low cost metal matrix materials
  - Optical component insertion for microwave and high speed digital interconnects

Millimeter-Wave Multi-Chip Module Packages

Barry R. Allen

Microwave Packaging Technology Workshop
Atlanta, Georgia
June 18, 1992

Millimeter Wave Packaging Topics

- Requirements
- Challenges
- Examples
- Comments and conclusions

Millimeter-Wave Packaging Requirements

TRW

- Extension of microwave requirements
- Unique challenges
  - external RF interfaces less standardized
  - dimensional tolerances decrease with frequency
  - dielectric based packages exhibit many resonance modes
  - conductor losses increase rapidly, ($L \sim f^{3/2}$ for optimum single-mode line)
  - arrays require dense RF, DC and control packing
- And opportunities
  - passive components smaller for higher level of integration in package
  - integrated package and antenna more practical
  - dielectric interconnects possible in some cases
  - quasi-optical systems for improved performance

Millimeter-Wave Packaging Requirements

TRW

Package Function	Millimeter Wave Requirement
External RF interfaces	Low loss, low VSWR Low unwanted radiation
Internal RF interfaces	Repeatable chip-to-chip connections
Internal signal distribution	Low loss, low VSWR Low unwanted coupling
Internal and external signal isolation	High isolation, no mode coupling
DC/Control distribution	No RF degradation
Hermeticity	Required at present
Thermal management	Minimize temperature rise for reliability
Low cost	Required in relatively low volume
Small size	Key requirement in arrays
Light weight	Required in arrays and munitions

Millimeter-Wave Packaging Challenges

Package Function	Millimeter Wave Challenge
External RF interfaces	Likely to be waveguide or antenna Few standards
Internal RF interfaces	Radiation and repeatability
Internal signal distribution	Microstrip or stripline plus others
Internal and external signal isolation	Isolation difficult in non-metallic package
DC/Control distribution	Constricted space
Hermeticity	Usually adds significant loss
Thermal management	Higher power density for transmit
Low cost	Difficult with precision dimensions
Small size	All dimensions not scaled equally
Light weight	Limited by thermal requirements

Millimeter-Wave Packaging Challenges

- Millimeter wave MMICs relatively new technology
- Usually machined metal housings and single layer substrates at present
- Present fabrication limits restrict multi-layer substrates to about 40 GHz
- DoD (and eventual commercial) needs require lower cost packaging
- Millimeter packaging for low cost requires:
  - Accurate CAD for EM, thermal, and mechanical simulation
  - Improved, repeatable mechanical and electrical properties
  - Reliable, available package suppliers

Millimeter-Wave Packaging Approach

TRW

- Most packaging approaches use four main elements:

  1 - Package base
  2 - Package walls
  3 - Internal Interconnects
  4 - Package interface

- Each major package element is somewhat independent, resulting a number of configurations.

- The lowest cost packaging approaches provide batch or automated processing of all package elements.

Millimeter-Wave Packaging Electrical Limits

TRW

Approximate dimensional limits for mode-free multilayer alumina microstrip ($\varepsilon_r = 9.9$)

Frequency (GHz)	Maximum Via Spacing (mils)	Maximum Substrate Thickness (mils)	Maximum Feedthrough Diameter
10	170	50	150
30	57	17	50
60	28	8	25
90	19	6	17
120	14	4	13

Dimensions scale approximately as $\frac{1}{\sqrt{\varepsilon_r}}$

Millimeter-Wave Package Base

TRW

Implementation	Characteristics
Metal - Kovar, CuMo, CuW, AlSi, etc.,	- Excellent shielding and grounding - Several precision fabrication methods - Low thermal resistance except Kovar
Metal matrix - AlSiC	- Excellent shielding and grounding - Less dimensional precision than metal - Low thermal resistance
Co-fired ceramic	- High dielectric constant - Combined interconnect and base - Metallized for shielding and grounding - Refractory thick-film metallization - High thermal resistance without vias
Low temperature co-fired ceramic	- Lower dielectric constant - Combined interconnect and base - Metallized for shielding and grounding - Low resistance thick-film metallization - High thermal resistance without vias

Millimeter-Wave Package Base

TRW

Implementation	Characteristics
Polished ceramic	- High dielectric constant - Combined interconnect and base - Metallized for shielding and grounding - Low-loss thin-film metallization - High thermal resistance without vias
Polished fused silica	- Lowest dielectric constant - Combined interconnect and base - Metallized for shielding and grounding - Low-loss thin-film metallization - Poor thermal resistance without vias - Requires glass frit for package

Millimeter-Wave Package Walls

TRW

Implementation	Characteristics
Metal - Kovar, CuMo, CuW, AlSi, etc.,	- Excellent shielding - Several precision fabrication methods
Metal matrix - AlSiC	- Excellent shielding and grounding - Less dimensional precision than metal
Co-fired ceramic	- High dielectric constant - Metallized for shielding - Refractory thick-film metallization - Many vias needed for mode suppression
Low temperature co-fired ceramic	- Lower dielectric constant - Metallized for shielding - Low resistance thick-film metallization - Many vias needed for mode suppression
Fused silica	- Lowest dielectric constant - Metallized for shielding - Requires glass frit for package - Vias needed for mode suppression

Millimeter-Wave Package Interconnect

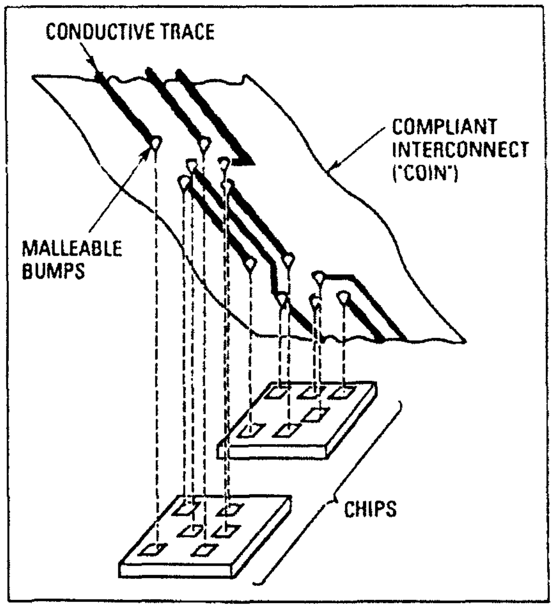
TRW

Implementation	Characteristics
Co-fired ceramic	- High dielectric constant, high loss - Refractory thick-film metallization
Low temperature co-fired ceramic	- Lower dielectric constant, lower loss - Low resistance thick-film metallization
Polished ceramic	- High dielectric constant - Low-loss thin-film metallization - Requires glass frit for multilayer
Fused silica	- Lowest dielectric constant, lowest loss - Low-loss thin-film metallization - Requires glass frit for multilayer
Combined flexible thin-film and ceramic	- Thin-film multilayer for control and DC - Ceramic over thin-film used for RF
High resistivity Si	- Acceptable loss for many applications - Complex bias and interconnect
Flexible membrane (COIN)	- CPW interconnect - Combines interconnect and bonding

Compliant Interconnect (COIN) Concept

TRW

- Self-adapting to MCM
- Unhampered heat dissipation from below
- Connects chip pad directly to chip pad
- Shortest signal path routing
- Tap signal anywhere over the chip surface
- Inexpensive and disposable
- Pressure or permanent contacts
- Easy to test, burn-in
- Matches high density interconnect attributes
- Need not customize chips

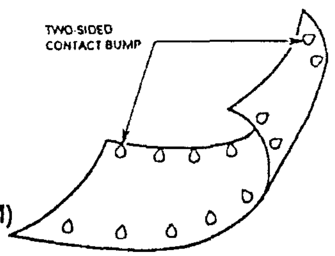


COIN is a multilayer structure built on flexible stock, bearing malleable bumps on one or both sides, to make contact to the chip pads, and/or the substrate traces, and/or the outgoing leads.

COIN Applications

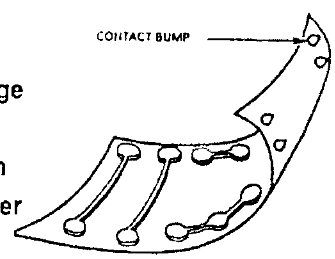
TRW

A) Board-to-Board Connector
- 3D: MCM-to-MCM
- 3D: Chip-to-Chip
- 3D:Board-to-Board
- Wafer Probe
- Chip-to-Board (MCM)



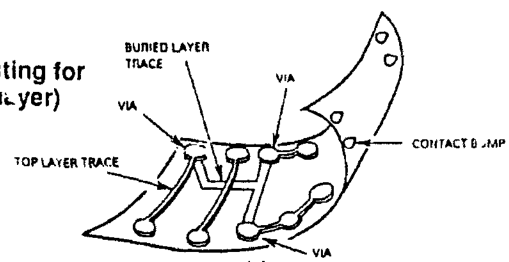
(a)

B) Wire/Ribbon Replacement
- Wire Bond-to-Package
- Chip-to-MCM
- GaAs-to-Silicon
- Carrier-to-Carrier



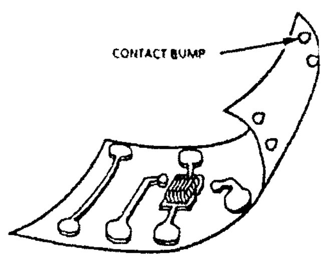
(b)

C) Complex Routing for MCMs (Multilayer)
- Digital
- A/D
- RF
- MMIC
- WSI
- Power Distribution



(c)

D) Simple MCM Substrate
- 3D MCM
- WSI



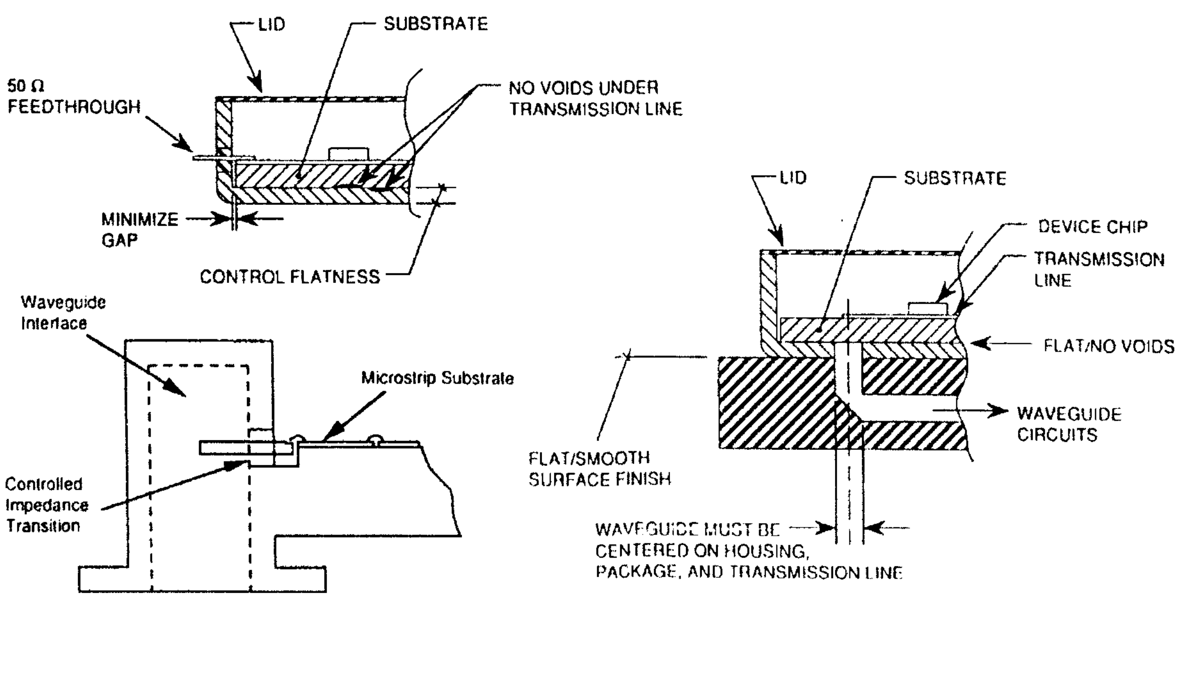
(d)

Millimeter-Wave Package Interface

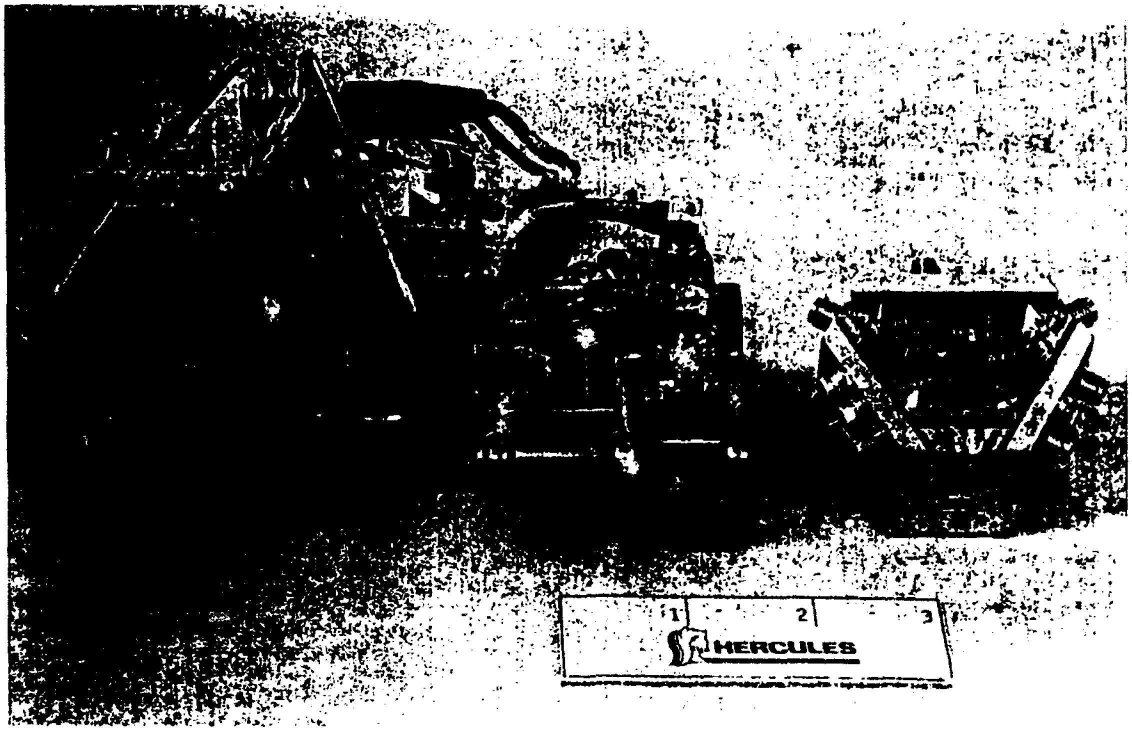
Implementation	Characteristics
Stripline transition to microstrip	- Ceramic feedthrough - Radiation and coupling - High loss
CPW transition to CPW	- Ceramic feedthrough - Radiation and coupling - High loss
Microstrip to slot coupled waveguide	- Narrowband - Waveguide back short desirable
Microstrip E-plane probe	- Hermetic with separate feedthrough - Waveguide back short required
Glass feedthrough E-plane probe	- For metal or metal matrix package - Can be wideband - Waveguide back short required
Glass feedthrough coax connector	- For metal or metal matrix package - Wideband - Presently limited to 65 GHz

Millimeter-Wave Packaging

Low loss, low VSWR transitions that are essential for low noise and high power applications require precision fabrication.

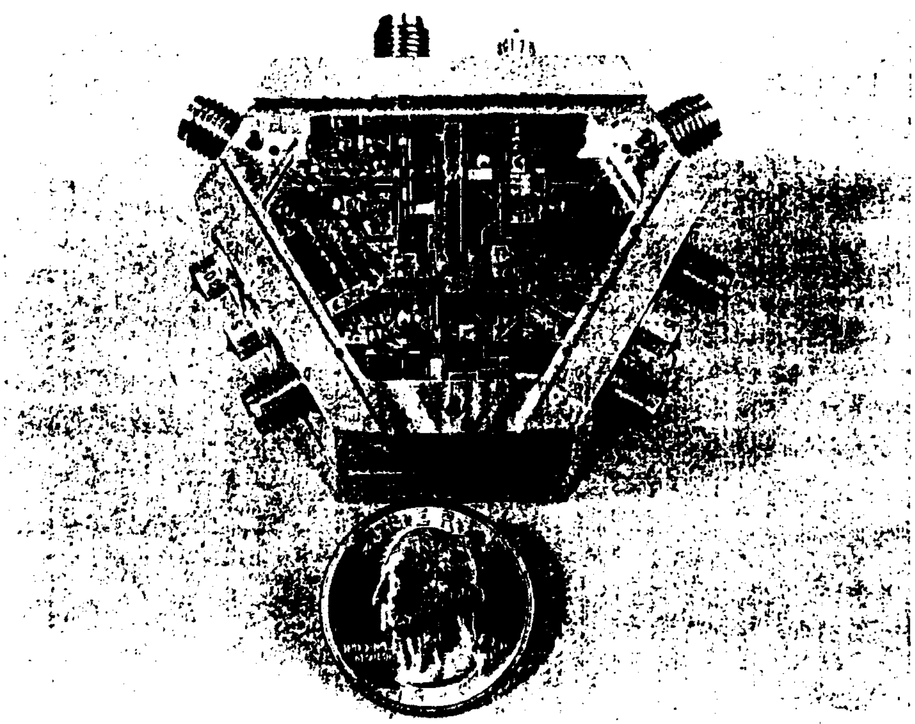


Ka-band FM-CW Transceiver Comparison



HERCULES

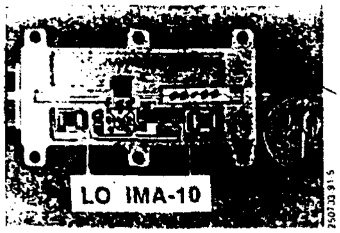
Ka-band MMIC FM-CW Transceiver



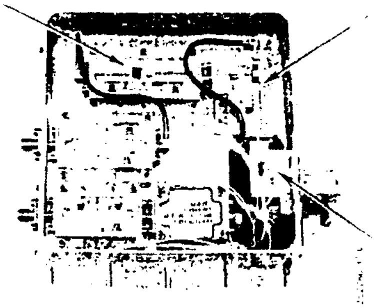
HERCULES

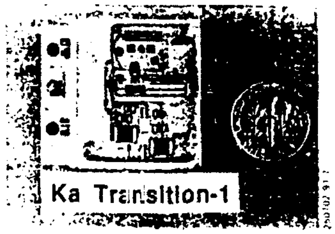
Modular Packaging of MMIC Downconverter

TRW



Ka-band Low Noise Downconverter

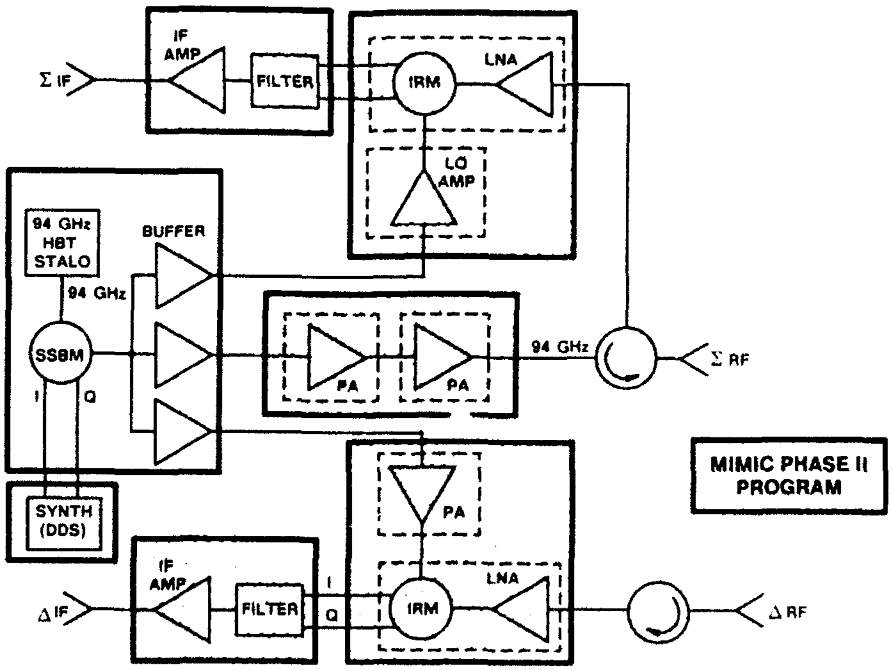




Packaging Features

- Standardized hermetic coaxial and waveguide interfaces
- No carriers
- No separate internal covers
- Most machining with single setup; no EDM required
- Operation through 50 GHz with alumina substrates, through 65 GHz with fused silica substrates

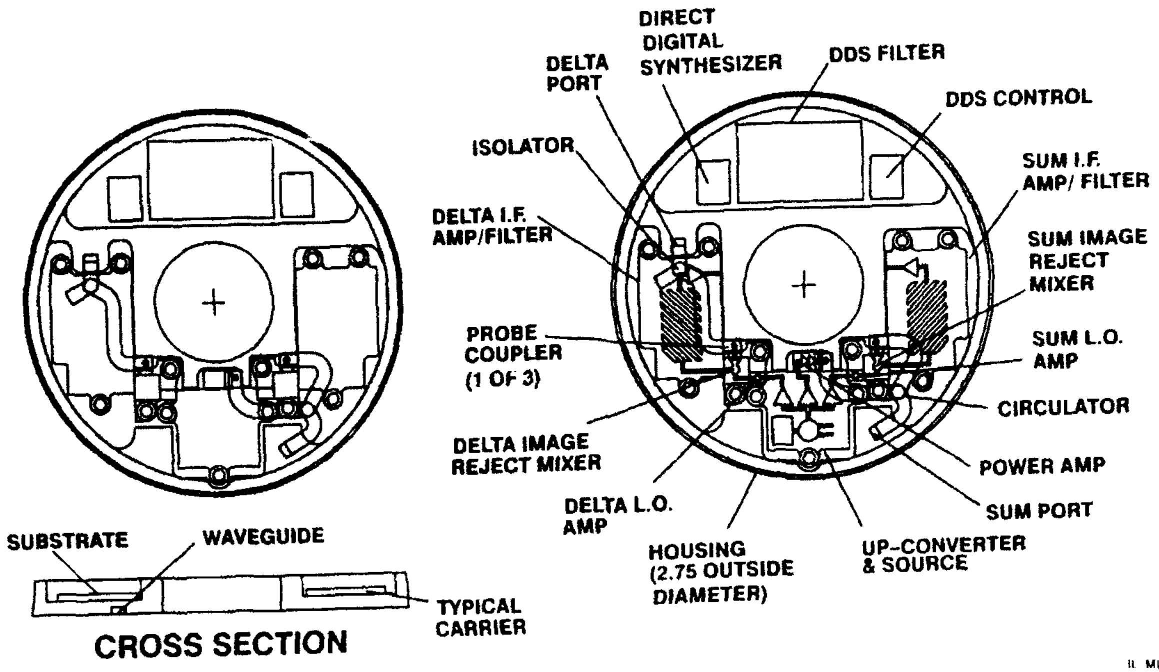
TRANSCEIVER BLOCK DIAGRAM



IL 900920C MG

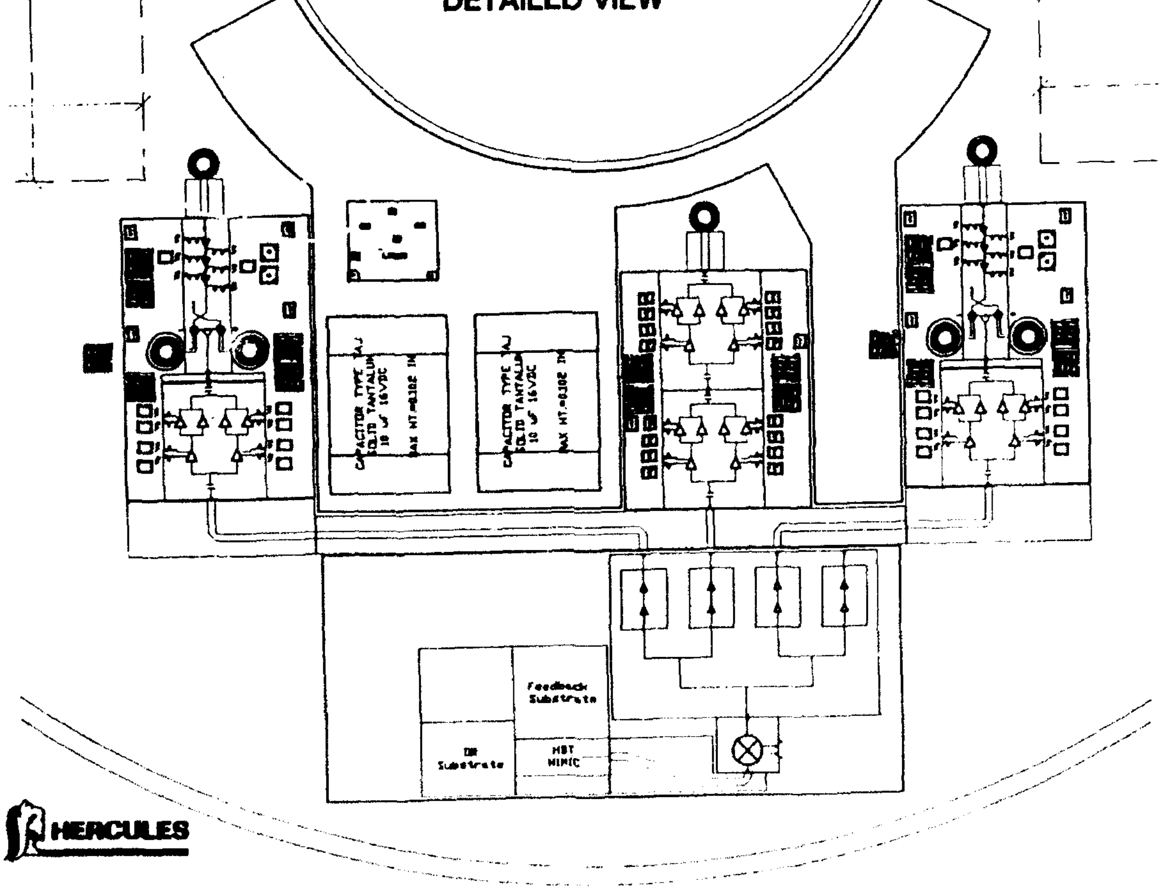
HERCULES

W-BAND GaAs MIMIC TRANSCEIVER



HERCULES

MIMIC BRASSBOARD TRANSCEIVER
DETAILED VIEW

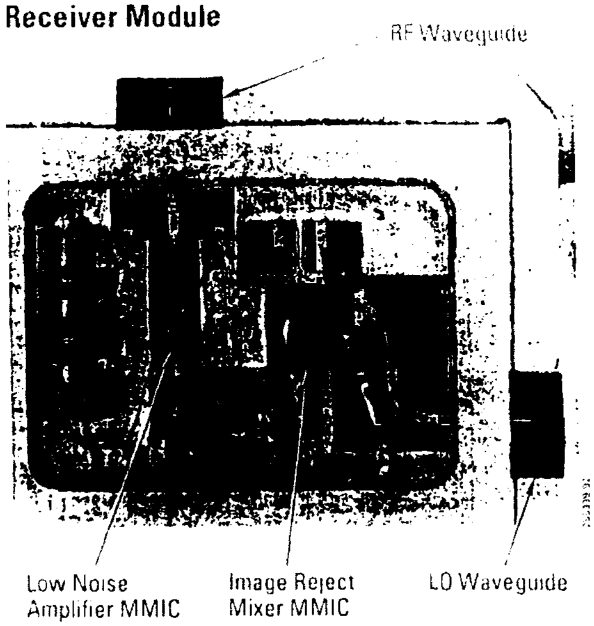


HERCULES

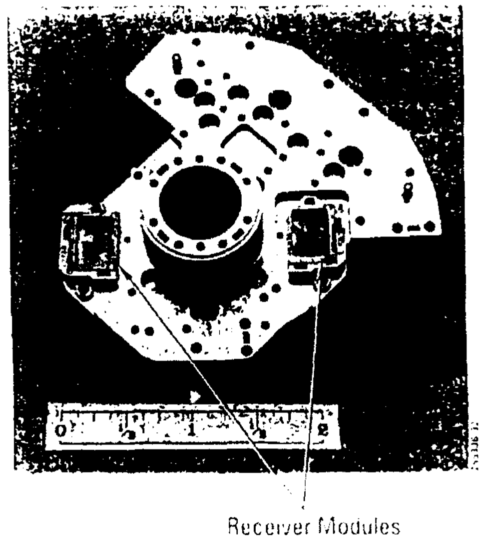
W-band MMIC Receiver Module

TRW

Receiver Module



Transceiver Housing

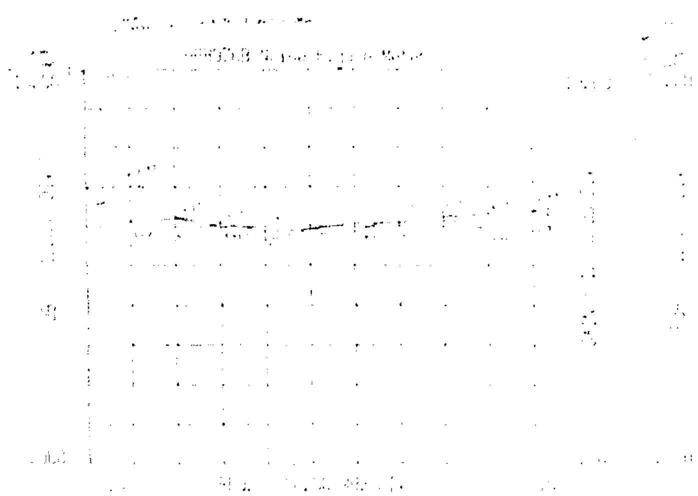


W-band MMIC Receiver Module

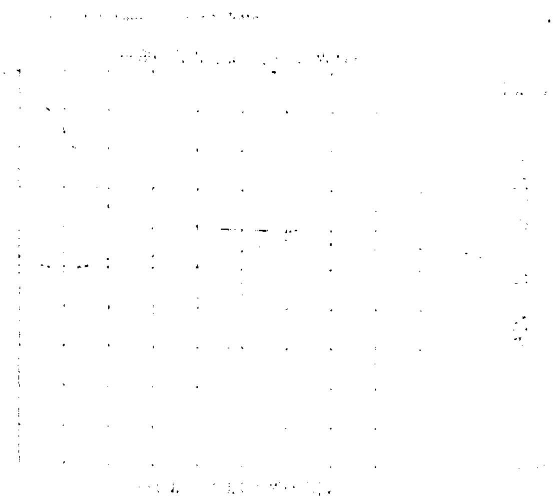
TRW

Package degrades noise figure and gain of the module over 1 dB.

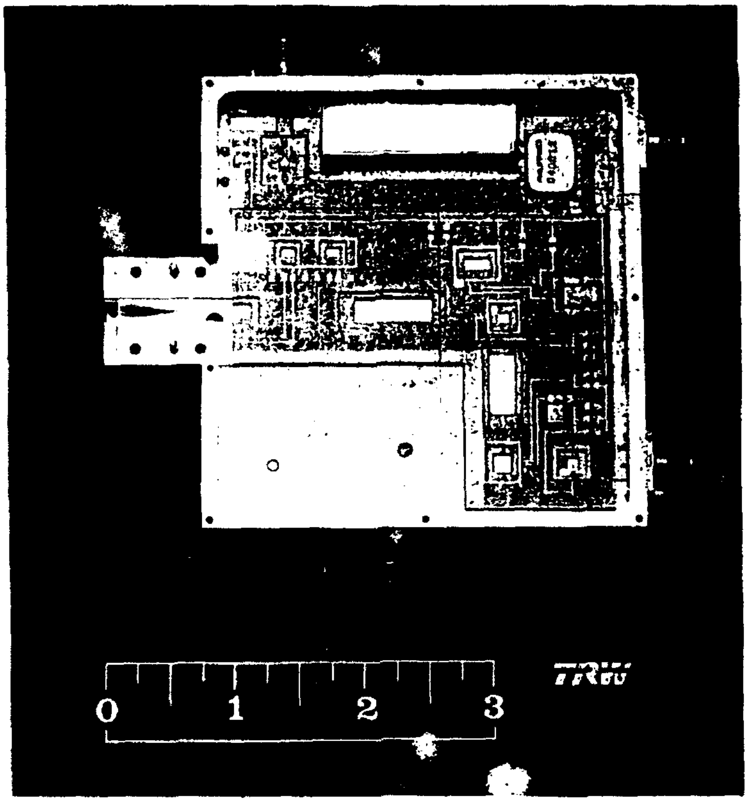
Noise figure and gain of I-channel of I-Q mixer



Noise figure and gain of Q-channel of I-Q mixer

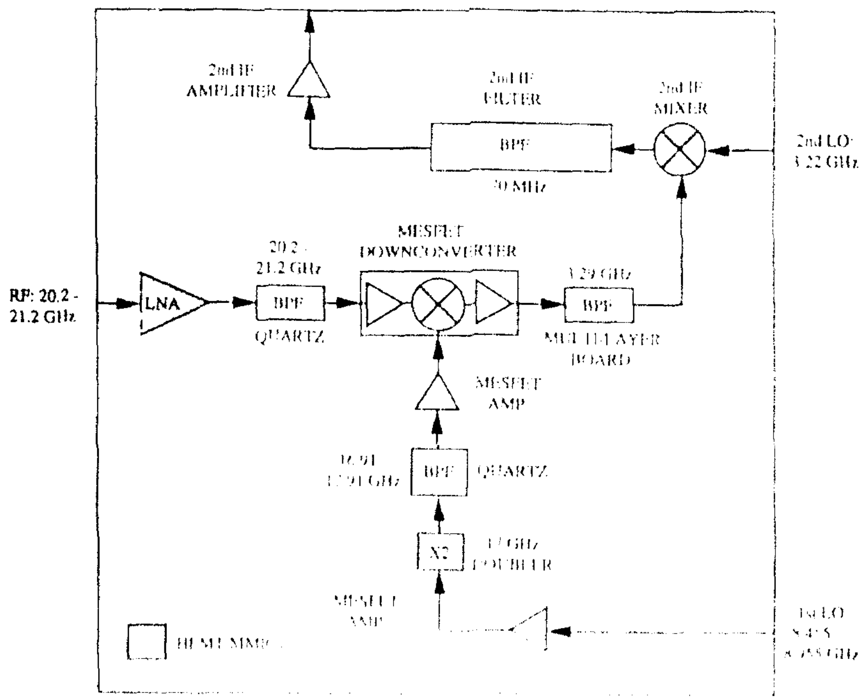


K-band LNA/DC Using LTCC Interconnects



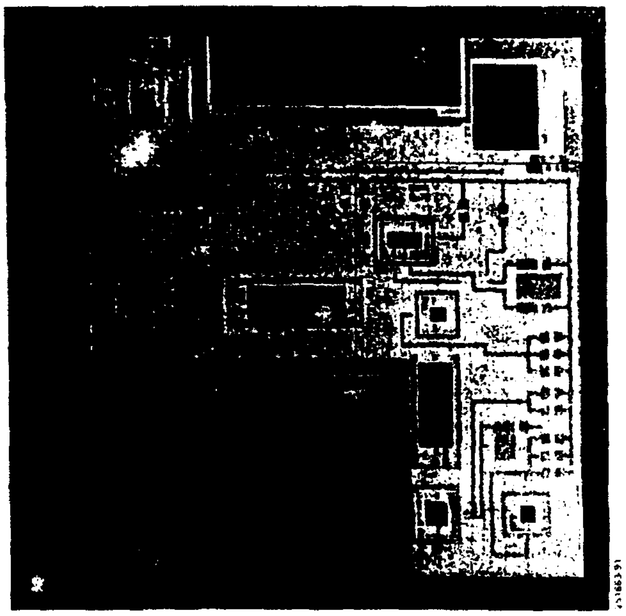
K-band Integrated LNA/DC Block Diagram

LTCC includes embedded filters all RF and DC connection paths



K-band LNA/DC LTCC Interconnect

TRW



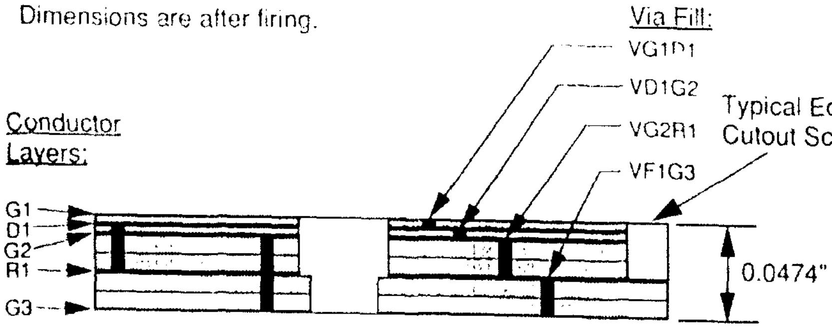
- Low temperature co-fired ceramic
- Good electrical properties
  - $\varepsilon_r = 7.25$
  - $\tan(\delta) \sim 0.008$
  - Thick film gold (5 mΩ/sq)
- Stripline RF interconnect
- Two levels for dc and control
- Cut-outs for mounting RF chips and filters

K-band Low Temperature Co-fired Ceramic

TRW

TAPE Stackup: One 0.0037" + Four 0.010"

Dimensions are after firing.



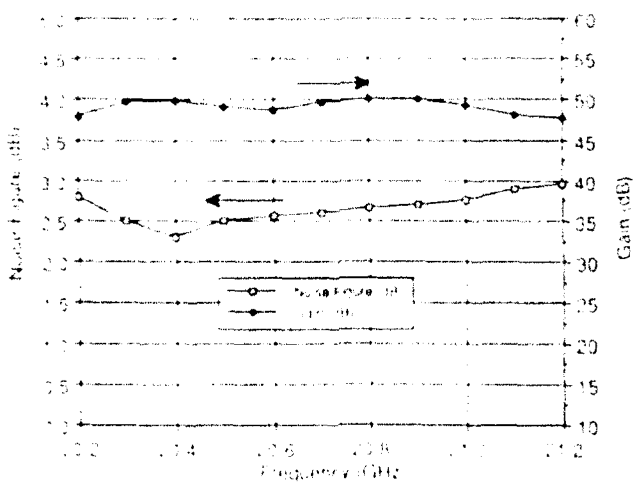
MASK DESIGNATIONS

G1: Top Ground
D1: DC Bias #1
G2: Stripline Top Ground
R1: RF Stripline Layer
G3: Stripline Bottom Ground

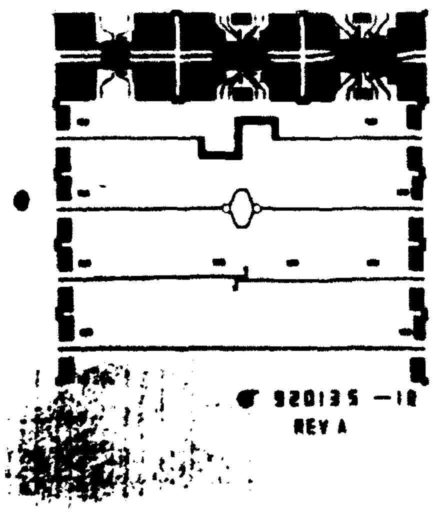
K-band Integrated LNA/DC Performance

The LTCC loss was too high to use for waveguide transition and K-band filters; separate fused silica substrates used to maintain low loss.

Receiver Noise Figure and Associated Gain



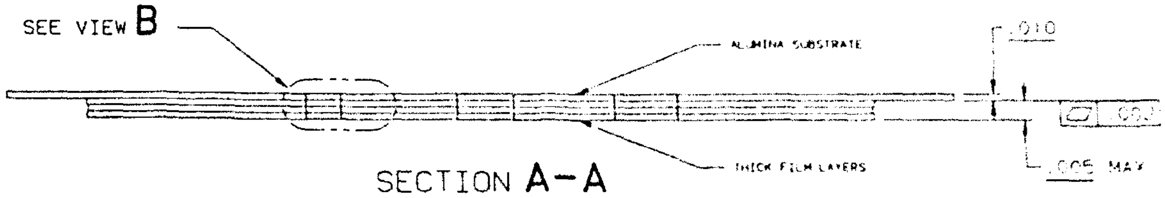
Ka-band Low Temperature Co-fired Ceramic



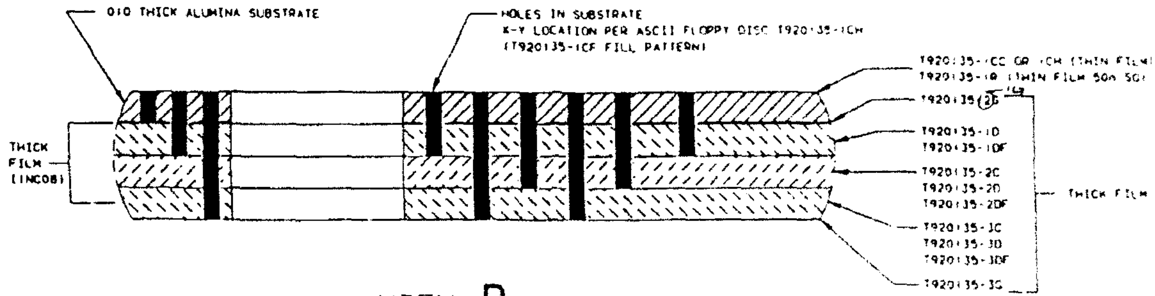
- Multilayer LTCC test structures for 35 GHz
- Transmission loss equivalent to alumina ~0.8 dB/inch
- No resonance problems observed

Ka-band Low Temperature Co-fired Ceramic

TRW



SECTION A-A
MULTILAYER SUBSTRATE CROSS-SECTION
-2 ONLY



VIEW B
SCALE 20/1
-2 ONLY

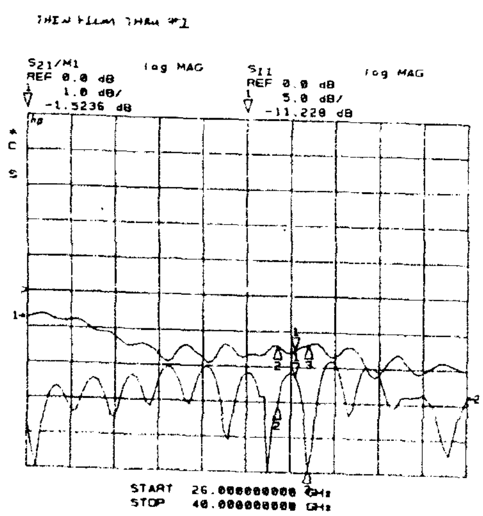
Ka-band Low Temperature Co-fired Ceramic

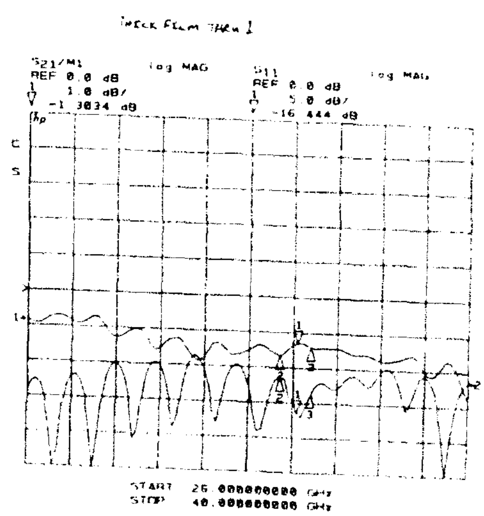
TRW

Loss of LTCC and thin-film alumina nearly identical

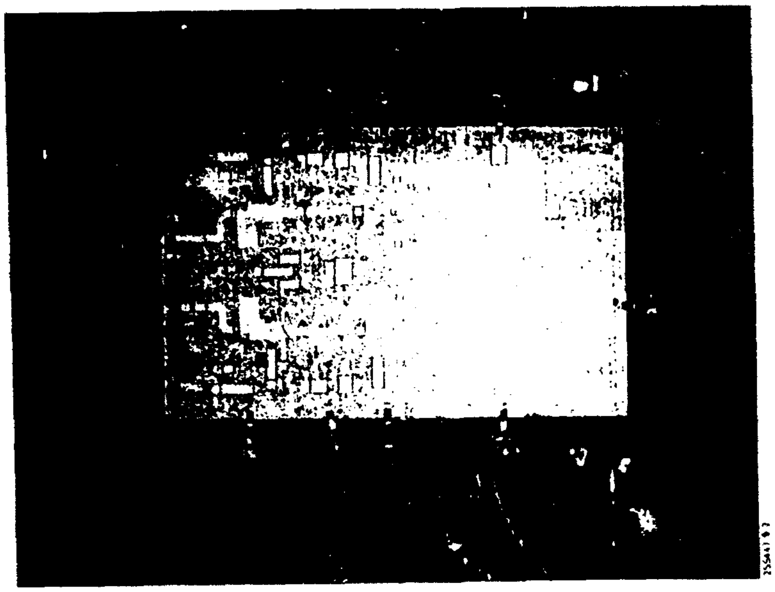
Thin-film alumina through

LTCC through





Ka-band Low Temperature Co-fired Ceramic

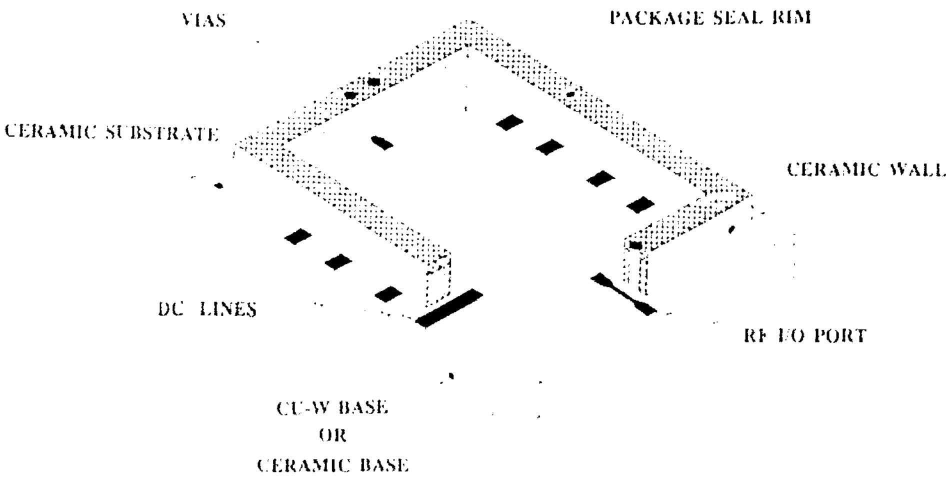


- 35 GHz power MMIC test structure
- Through substrate chip mounting for low thermal resistance
- RF performance equivalent to alumina

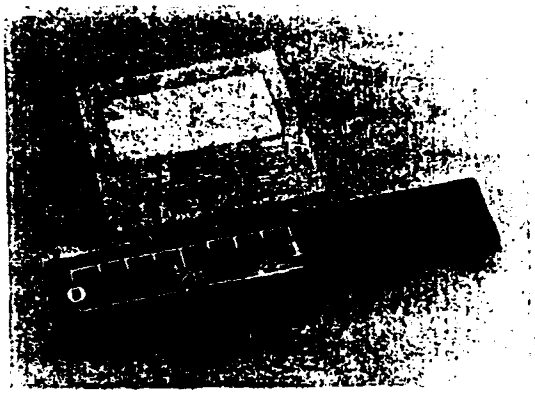
Ka-band Ceramic Package

Investigating both LTCC and transfer tape on thin-film substrate.

Loss intentionally added to reduce dielectric resonance Q.



Transfer Tape Q-band Feedthroughs



Thin-film alumina test pattern before addition of transfer tape

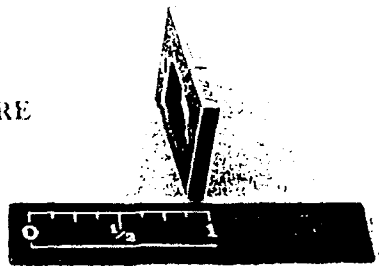
Completed transfer tape feedthroughs, loss <1.5 dB through 50 GHz

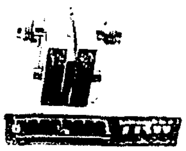
Transfer Tape Q-band Feedthroughs

- ADVANCED CERAMIC MULTIPLE HIGH DENSITY PACKAGE TRANSITIONS.
- OUTSTANDING PERFORMANCE TO 40 GHz.
-

	14GHz	19GHz	32GHz	40GHz
INSERTION LOSS:	-.66db	-.54db	-1.9db	-1.0db

- MODULAR MILLIMETER WAVE COAXIAL TEST FIXTURE





Millimeter-Wave Package Comments

- Resonances in ceramic wall package limit the frequency to about 40 GHz.
- Metal or metal-matrix packages are capable of operation through 100 GHz.
- Precision low cost fabrication of package walls and base is needed
- Either ceramic or glass feedthroughs can provide wideband interfaces at 1-2 dB loss.
- More work is needed on combined hard and soft substrate multilayer to apply the work in digital MCMs to millimeter wave packages.
- A technique for attaching a single cover to thin internal walls during sealing would reduce the size and weight of complex millimeter wave packages.

Millimeter-Wave Package Conclusions

- Millimeter wave packaging relatively immature
- More work needed to apply low cost fabrication to millimeter wave packaging
- CAD needed to model electrical performance and manufacturing process for conductor loss, dimensions, and material properties to eliminate iterations.
- More development needed in non-metal packaging approaches for millimeter waves, especially for low cost fabrication of strong, thin, accurately patterned dielectric layers with low resistance metallization

Microwave Packaging Technology Workshop

Addendum to AGED Electronics Packaging Technology STAR

June 18-19, 1992

Georgia Institute of Technology

Atlanta, GA

mptw6192.ptp

Microwave and Millimeter-wave Package Design, Modeling & Simulation

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Major Issues for MW/MMW Package CAE

- o Packages are part of a hierarchical design: integrate the package simulator into a design environment that includes chip, PCB and system simulators.
- o Enhance/Develop database to cover package and PCB design and simulation
- o Trend is toward higher density & complexity
- o Intelligent programs: design synthesis/compaction, PCB routers

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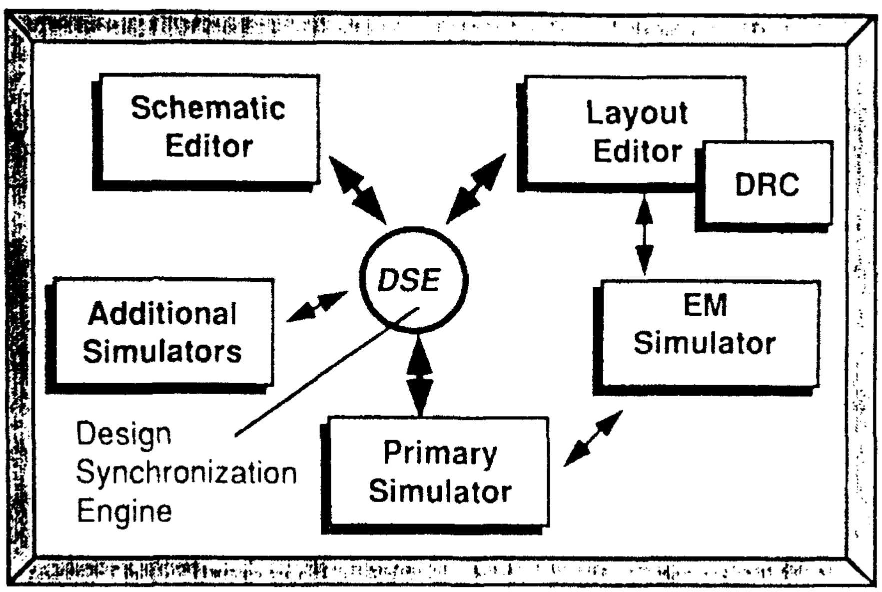
The Ideal Open EDA Framework



Interchangeable tools that remain fully integrated

Issues for Package EM Simulators

- o Pick an EM analysis method that fits the problem
- o Develop algorithms that yield acceptable accuracy and speed
- o Target the engineers desk (workstations, networks) or massively parallel computers

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EEsof EM Simulator Product - 1992

- o EMSim, based on Spatial Domain, Method of Moments
- o Target Application: Simulation of complete passive MMIC structure, with acceptable speed and accuracy
- o Level of geometrical complexity: quasi-planar -- ground plane, plus two dielectrics and two additional metals
- o No walls, lids; vias are modeled
- o S-parameters model insertion
- o Input: GDSII or ACADEMY drawing file
- o Output: S-, Y- or Z-parameters

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mptw619: ptp

Watkins-Johnson 0.5 - 3.0 Ghz Two-stage Amplifier

- o M. M. Meehan, T. Wandinger, D. A. Fisher, "Accurate Design Centering and Yield Prediction Using the 'Truth Model'," IEEE International Microwave Symposium, pp. 1201-1204, Boston, MA, June 10-14, 1991.
- o P. J. Draxler, G. E. Howard, Y. L. Chow, "Mixed Spectral/Spatial Domain Method Simulation of Components and Circuits," 21st European Microwave Conference, pp. 1284-1289, Stuttgart, Germany, Sept. 9-12, 1991.
- o Simulation time 6m 10s (1m 45s) on HP 700

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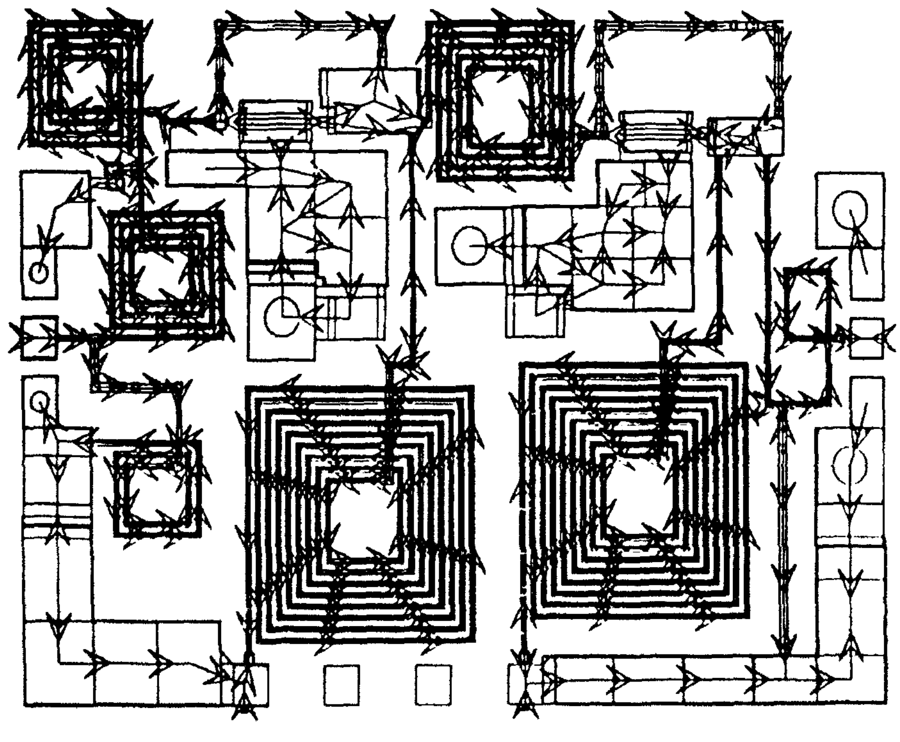
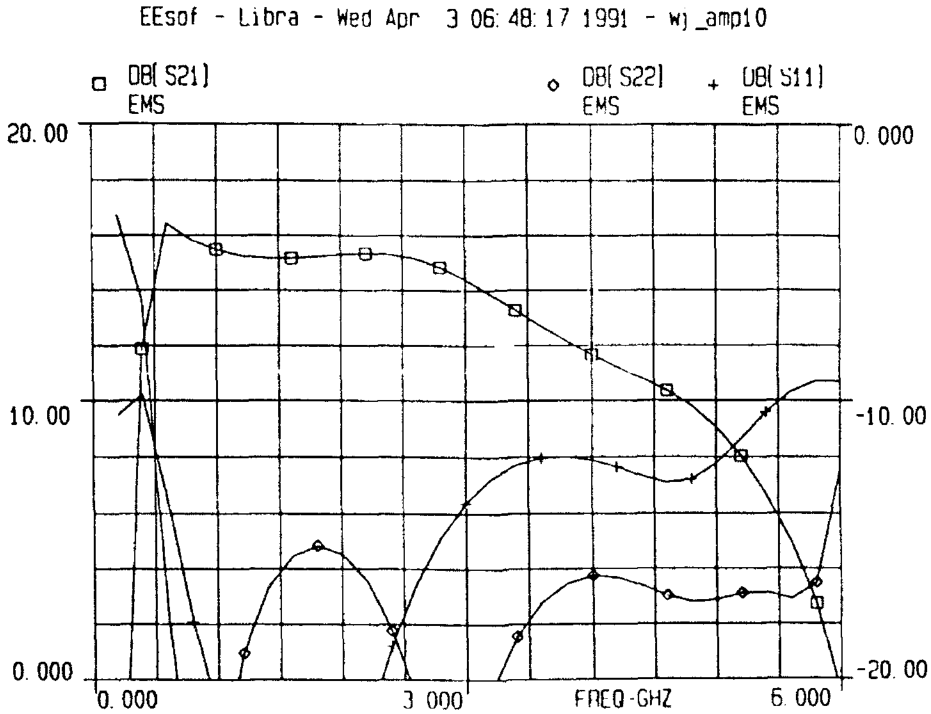
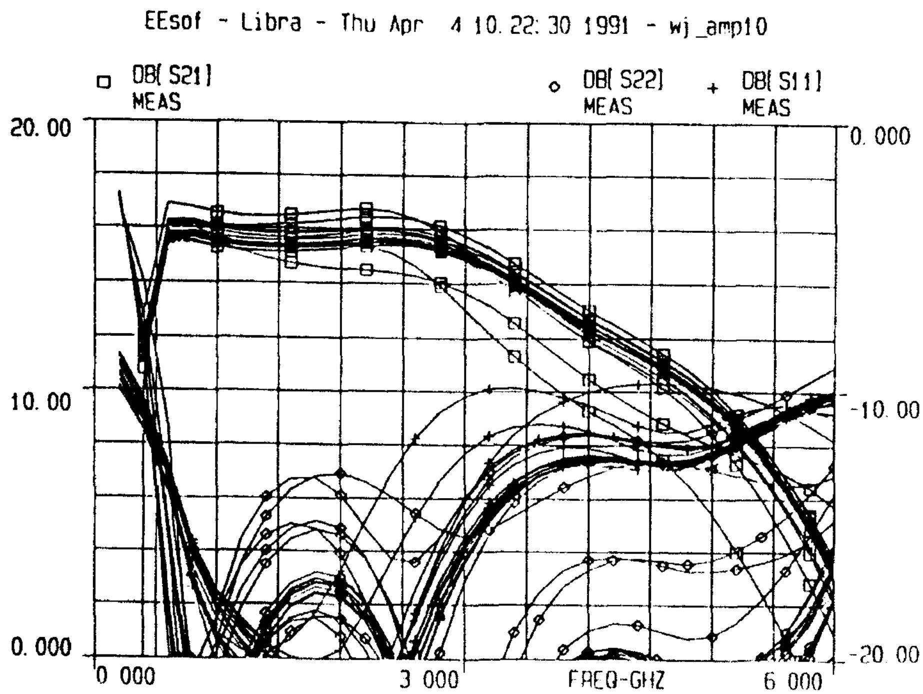
Patched Amplifier in EMSim



EMSim Simulation of MMIC Amplifier



Measured Data for MMIC Amplifier



Future Product Challenges

- o Seamlessly integrate EM simulation into Design Environment
  - Enhanced design database
  - EM simulation as another "simulator socket"
- o Analysis of more complicated PCB geometries
  - At least five metal and dielectric layers
  - Dielectrics of limited extent in transverse dimensions
  - Arbitrary angles in transverse dimensions
  - Controlled impedance vias
  - Walls and lids
  - Arbitrary angles
  - Arbitrary port locations and de-embedding

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Future Product Challenges (cont'd)

- o Improved algorithm efficiency
  - Multi-level techniques
  - Circle of influence (impedance matrix localization)
  - Alternatives to LU-decomposition
- o Graphical Display
  - S-parameters, Y-parameters, etc.
  - Electric field, current densities, magnetic field, etc.
  - User-defined

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Microwave Packaging Technology Workshop

MW/MMW Package Design - Modeling and Simulation

Sponsored by

Wright Patterson Airforce Base

Georgia Institut of Technology - June 18, 1992

Achim Hill

Ph: (201) 881 1200
Fax: (201) 881 8361
E-Mail: Achim@resq.fidonet.org

Compact Software inc.

1

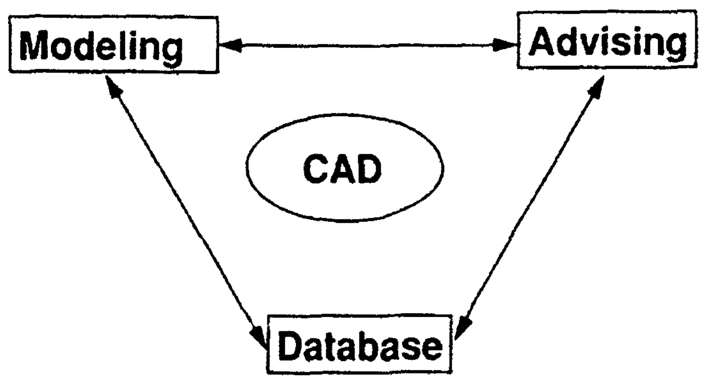
CAD Needs for MW/MMW Package Design

- Modeling
  - Interconnects - chip, module and array level
  - Transitions - MS -SL - MS, CPW - MS, WG - MS, Coax- MS
  - Ground bounce
  - Housing
- Package Design Advisor (PDA)
  - Package material fit
  - Design-manufacturing trade-offs
  - Packaging influence at design level
- Database support
- Concurrent electromechanical design tools

Compact Software Inc.

2

CAD Support Areas



Modeling

- Circuit/nodal and system simulators
- Measurement/Parameter extraction techniques
- Electromagnetic simulators
  - 2D, 2.5D, 3D
- Mechanical simulators
  - thermal and structural parameters
- Support modules
  - package specific applications

Measurement/Parameter Extraction Techniques

- Chip-level package theoretical modeling is difficult and not well understood
- Hardware which facilitates package measurement and calibration techniques widely used with VNAs
- Incorporation of data into existing simulation programs provides ability to describe device and package behavior

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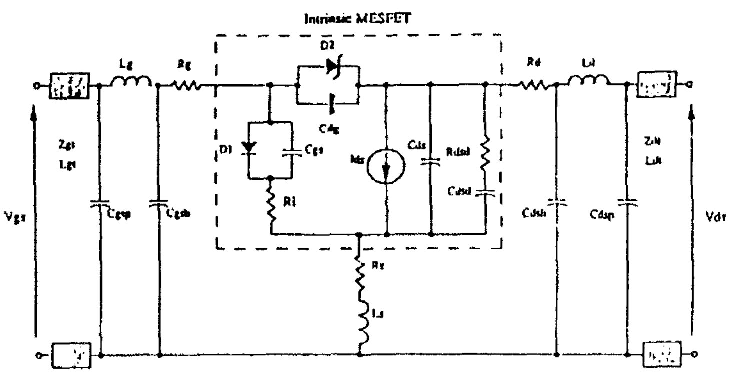
Chip-Level Package Model



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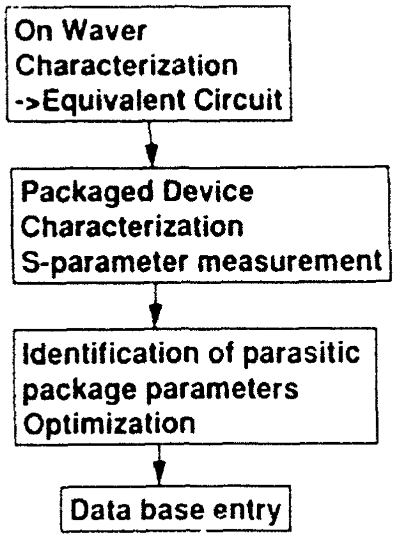
Chip-Level Package Characterization - Procedure

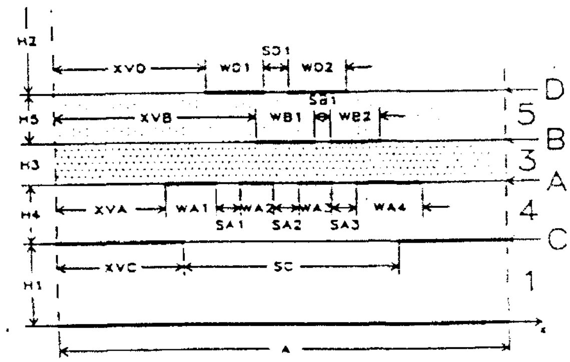


Chip-Level Package Characterization - Problems

- Frequency limit for the validity of the model
- Statistical variations of device performance and package geometries
- ☞ Make model available and accessible to the user
- ☞ Provide optimization software for package parasitics to the user and assure compatibility of database and software packages

Electromagnetic Simulators - 2D

2 D - Interconnects
Module level, System level



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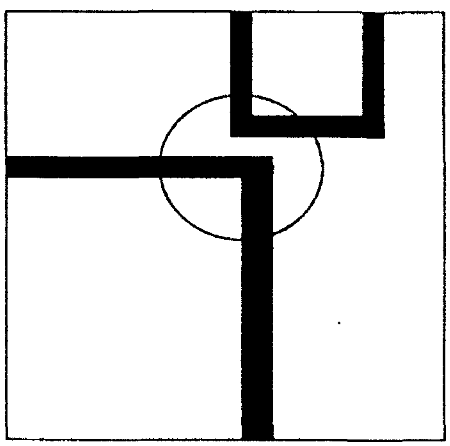
Electromagnetic Simulator 2 1/2 D

2 1/2 D - High density spots, chip level



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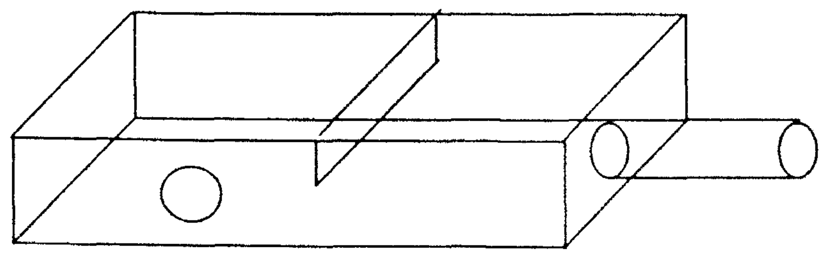
Electromagnetic Simulator - 3D

3D - Connectors, Transitions, Housing effects
Chip level, module level , system level



Support Modules

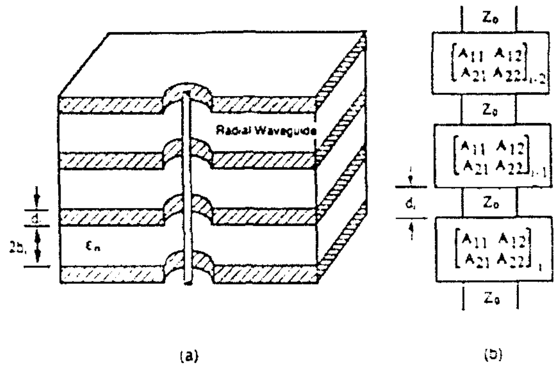
- **Package specific simulation tools**
  - Circuit model for vias through multiple substrate layers
  - Identification of package resonance modes
  - Ground bounce:

    Chip level: Lumped circuit model

    Module, System Level: 2D EM and circuit techniques

Support Module - Example_1

- Hybrid EM/Circuit technique

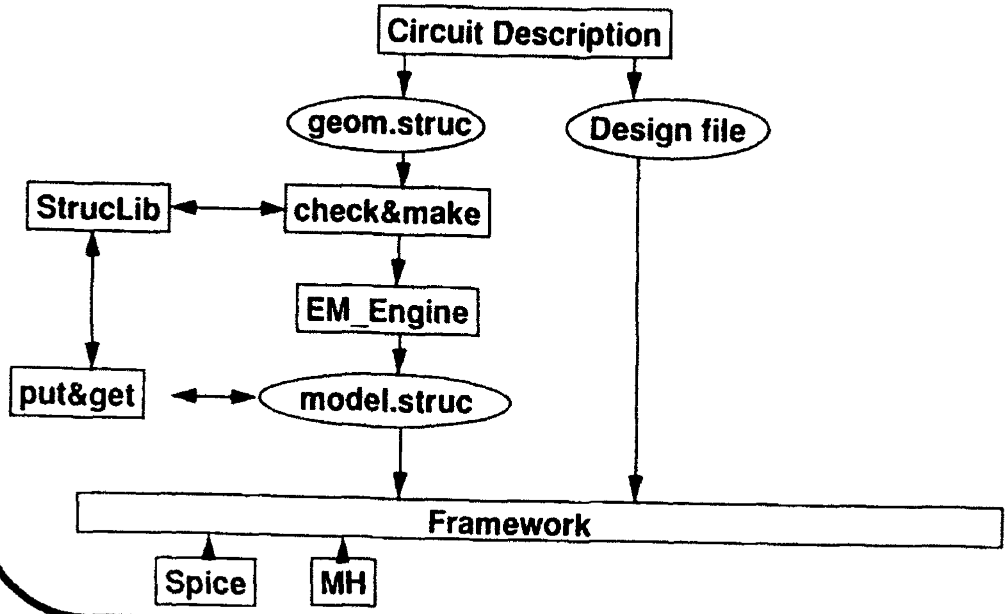


Electromagnetic Simulation

- Accurate results
- Long runtimes
- ☞ Generate Structure Library for common geometries such as transitions and interconnects

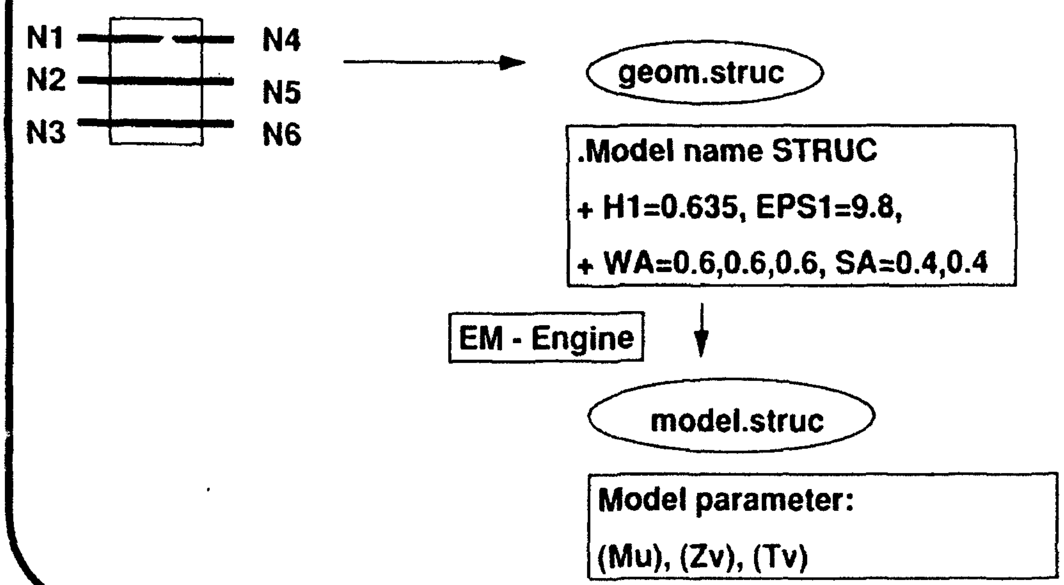
Electrical characteristics of typically encountered interconnect/package structures are computed only if they cannot be located in the Structure Library. Once computed, the parameters can optionally be entered into the library and will be available for subsequent fast simulations. The implementation of interpolation schemes makes real time optimization possible.

Structure Library



Structure Library - Example

Coupled Lines



Modeling - Summary

- Accurate fullwave electromagnetic modeling of complex circuits consisting of passive and active components together with the consideration of the influence of all package effects is currently not feasible within acceptable time frames.

- A combination of circuit simulation, electromagnetic simulation and system simulation which are used independently to model the entity consisting of circuits and package should be utilized at the current stage of developments.

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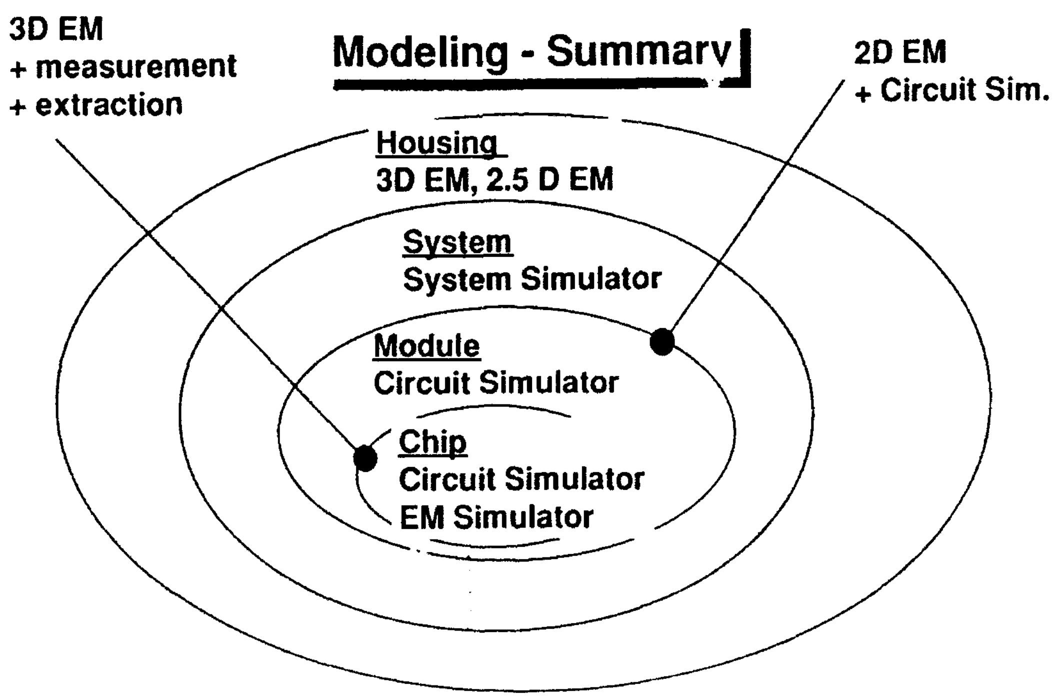
Modeling - Summary



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Database

PROPERTIES	PROCESS	SWITCHES	EXPERIENCE	REQUIREMENT
mechanical	statist data	hierarchy	measurem.	packages
electrical	standard	security	document.	geometries
optical	compatibility			cooling
geometry	manuf. data			size, weight
symbol	cost			perform.

Inter-relationship:

- Material-Process
- Design-Manufacturing
- Cost-Benefit

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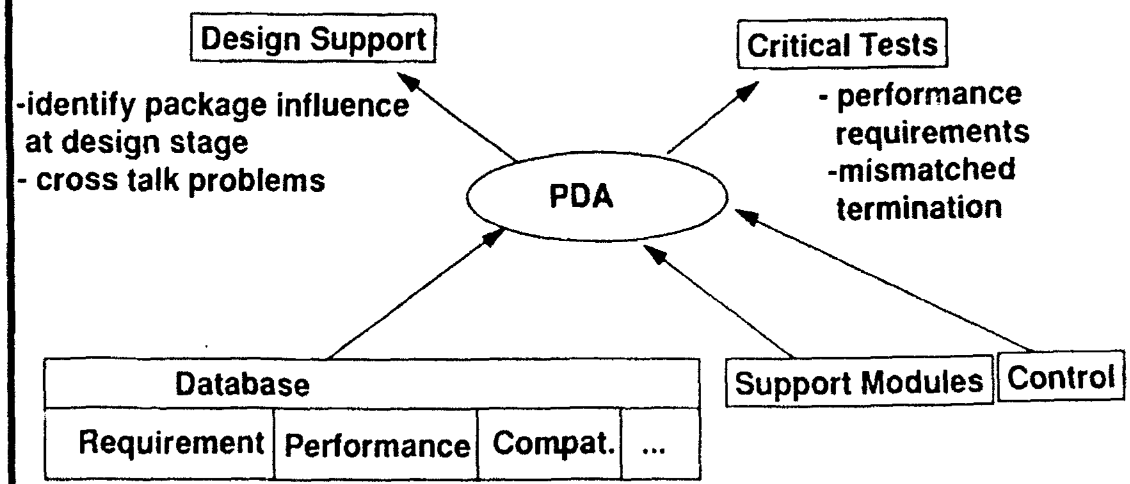
Package Design Advisor



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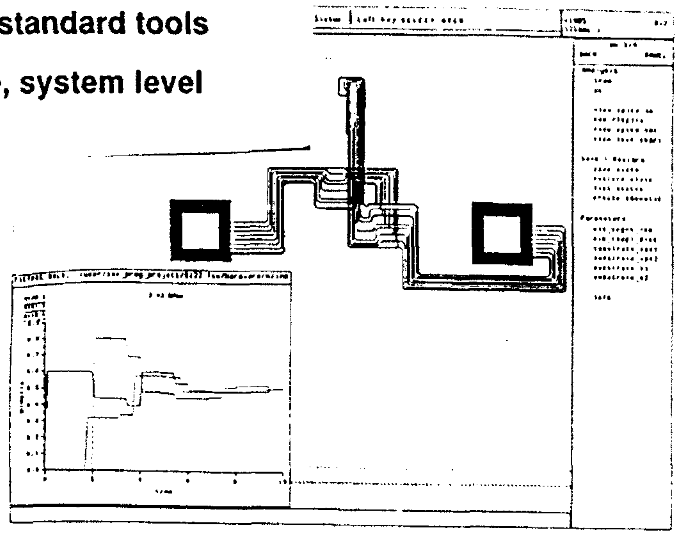
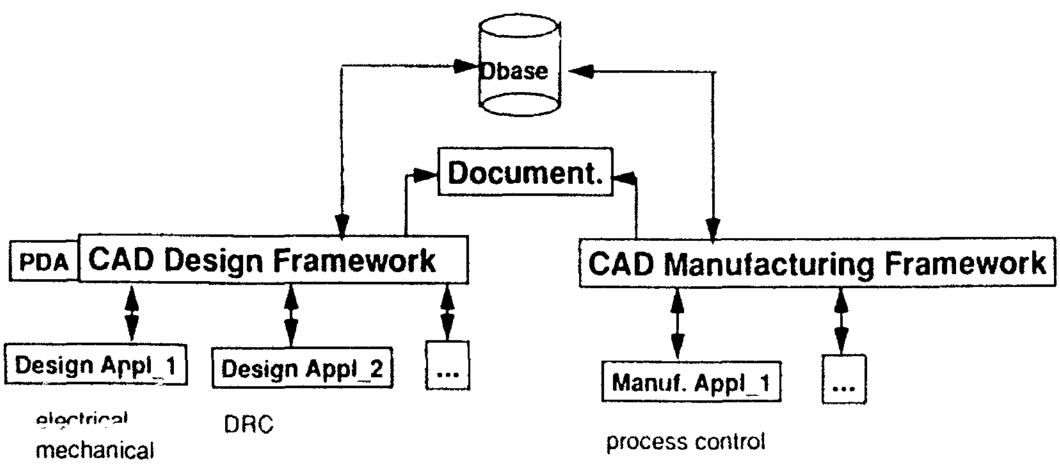
Package Design Advisor - Example

- Effect of interconnect (or transitions,...) is integral part of the design
- Use of standard tools
- Module, system level

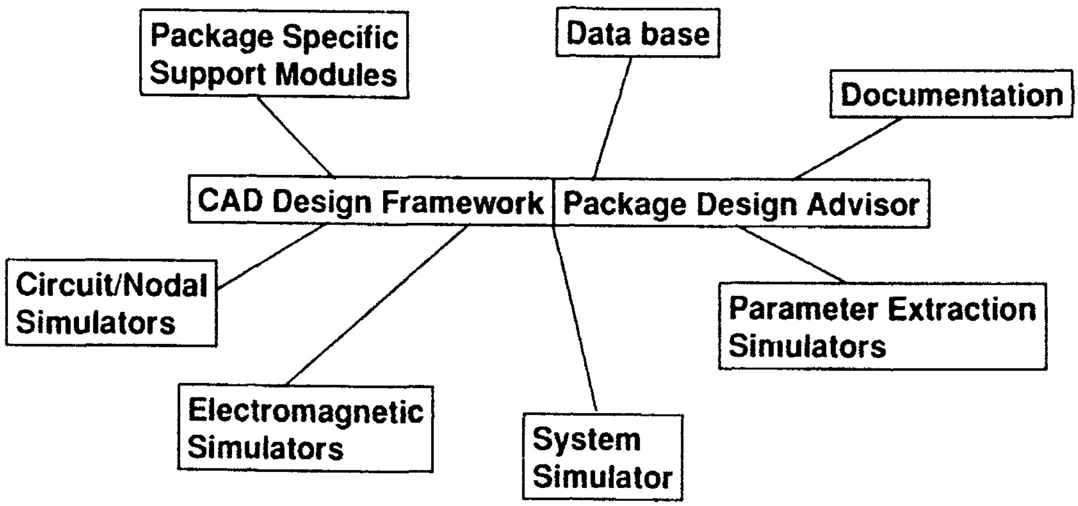


CAD Environment with PDA



- Can electrical, mechanical and manufacturing environment be integrated within a framework?

CAD Environment - Design



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Summary

- Modeling of package specific transitions, interconnects and grounding are modeled primarily using existing programs. Additional modeling/electromagnetic development is required to analyze certain transitions. Programs must be easily accessible and must be integrated in design environment.
- A database which captures electromechanical, optical, process, standard, compatibility and experience information should be developed. This database can be used as bases for a Package Design Advisor, process-design trade-off analysis, benefit-cost analysis.
- The package design environment is embedded in a CAD framework. Mechanical and electrical tools should be integrated within one framework.

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AGENDA

PACKAGING MANUFACTURING TECHNOLOGY

- DEVELOPMENT OF HIGH VOLUME/MULTIPLE PRODUCT MULTICHIP MODULE PACKAGING CAPABILITY
- MANUFACTURING TECHNOLOGY IMPROVEMENTS
  - MODULE
  - SUB-ARRAY
  - ARRAY
- MICROWAVE VERSUS MILLIMETER WAVE REQUIREMENTS
- PACKAGING EVALUATION AND CHARACTERIZATION

PACKAGING MANUFACTURING TECHNOLOGY

- STRONG MANUFACTURING TECHNOLOGY BASE ESTABLISHED FOR ACTIVE APERTURE X-BAND MODULE PRODUCTION THROUGH:
  - MANTECH FOR T/R MODULES - WR & DC
  - MIMIC - DARPA
- MODULE PERFORMANCE, COST, RELIABILITY THROUGHPUT CAPABILITY DEMONSTRATED USING INDUSTRY STANDARD CHIP AND WIRE TECHNOLOGY AND COMPOSITE PACKAGE WITH PLANAR RF/DC FEED-THROUGHS.
  - ROBUST DESIGN AND MANUFACTURING CAPABILITIES ESTABLISHED
  - EXCELLENT THERMAL MANAGEMENT
  - PROVEN RELIABILITY AND COST
  - HIGHLY AUTOMATED
  - INDUSTRY STANDARD
  - APPROACH BROADLY APPLICABLE THROUGH 20 GHz

PACKAGING MANUFACTURING TECHNOLOGY

PERFORMANCE DRIVEN REQUIREMENTS REQUIRING IMPROVED MULTICHIP MODULE PACKAGING CAPABILITY.

- BROADBAND ACTIVE APERTURE SYSTEMS
  - INCREASED FREQUENCY AND DECREASED MODULE TO MODULE SPACING REQUIRES LOW COST, HIGH PERFORMANCE MULTILAYER RF/DC DISTRIBUTION NETWORK CAPABILITY.
  - INCREASED EMPHASIS ON LIGHT-WEIGHT PACKAGING
  - IMPROVED MODULE TEST CONNECTION PROBES AND PROCEDURES
- CONFORMAL ARRAY ACTIVE APERTURE SYSTEMS
  - THIN SKIN REQUIREMENTS REQUIRE 3-D RF/DC PACKAGING APPROACH
  - AFFORDABILITY IS KEY ISSUE
  - LIGHTWEIGHT AND STRUCTURAL INTEGRITY REQUIRED AS WELL

Advanced Technology

MANUFACTURING TECHNOLOGY ISSUES AND PROPOSED SOLUTIONS

1.) IMPROVED ELECTRICAL MODELING AND SIMULATION CAPABILITIES.

- TO ACHIEVE INCREASED PACKAGING DENSITIES AND HIGHER PERFORMANCE FOR MULTILAYER PACKAGING STRUCTURES, IMPROVED EM SIMULATION, DESIGN GUIDELINES AND DESIGN RULE CHECKING CAPABILITIES. EM SIMULATION TO ADDRESS IMPROVED ISOLATION AND VSWR FOR HIGH DENSITY THREE DIMENSIONAL PACKAGING STRUCTURES AND HIGH DENSITY MIXED MICROWAVE/DIGITAL PACKAGING STRUCTURES.
- IMPROVED MODELING TOOLS FOR COPLANAR WAVEGUIDE AND STRIPLINE STRUCTURES

2.) STATISTICAL AND ROBUST DESIGN METHODOLOGIES

- APPLICATION OF DESIGN AND STATISTICAL PROCESS CONTROL METHODOLOGIES TO ACHIEVE HIGH PERFORMANCE, LOW COST AND FIRST PASS DESIGN SUCCESS THROUGH DEVELOPMENT AND APPLICATION OF STATISTICAL DESIGN AND ROBUST DESIGN TECHNIQUES, SUCH AS: DESIGN OF EXPERIMENTS AND RESPONSE SURFACE DESIGN APPLIED TO ELECTRICAL, MECHANICAL AND FABRICATION, AND ASSEMBLY PROCESSES.

3.) SYSTEM LEVEL ANALYSIS AND APPROACH

- INTEGRATED SYSTEM ANALYSIS AND APPROACH FROM CHIP DESIGN TO ARRAY DESIGN IN CONJUNCTION WITH FOCUSED TECHNOLOGY EFFORTS.

MANUFACTURING TECHNOLOGY ISSUES AND PROPOSED SOLUTIONS (CONT.)

4.) HIGH DENSITY PACKAGING CONCEPTS

- THREE DIMENSIONAL, FULLY ISOLATED, LOW LOSS RF/DC PACKAGING STRUCTURES CAPABLE OF HIGH INTERCONNECT DENSITIES AND HIGH POWER DISSIPATING CAPABILITIES AND APPLICABLE TO CONFORMAL ARRAYS.
- HIGHER FREQUENCY AND LARGE ARRAYS REQUIRE INCREASED DENSITY AND IMPROVED DISPERSION AND LOSS ACHIEVABLE THROUGH FIBER OPTIC INTERCONNECTS
- ISSUES INCLUDE FIRST, SECOND AND THIRD LEVEL OPTICAL INTERCONNECT TECHNOLOGIES
- IMPROVED COOLING CAPABILITIES FOR BOTH SILICON AND GaAS COMPONENTS-MULTICHANNEL COOLING, THINNED DEVICES, INTEGRAL HEAT SINKS

5.) IMPROVED PROPERTIES, CHARACTERIZATION, CONTROL AND UNDERSTANDING OF THE INTERRELATIONSHIP BETWEEN AND AMONG RAW MATERIALS AND THE PACKAGE STRUCTURE

METAL CONDUCTORS

IMPROVE MATERIALS-AG, CU FOR LOWER LOSS
IMPROVED EDGE CONTROL-SHAPE AND POROSITY FOR LOWER LOSS
ESPECIALLY LOW TEMPERATURE COFIRED CERAMIC

CERAMICS

HIGH THERMAL CONDUCTIVITY,MATCHED GaAS AND SILICON SUBSTRATE MATERIALS

MANUFACTURING TECHNOLOGY ISSUES AND PROPOSED SOLUTIONS (CONT.)

INORGANIC COATING

LOW TEMPERATURE, POLYMER FILM COMPATIBLE MATERIALS TO PROVIDE
MOISTURE PROTECTION AND ELIMINATE NEED FOR SEPARATE HERMETIC HOUSING/LID

POLYMER FILMS

TAILORABLE COEFFICIENT OF THERMAL EXPANSION (CTE)
LOWER DIELECTRIC CONSTANTS
TAILORABLE DIELECTRIC CONSTANTS
PHOTO DEFINABLE POLYMIDE WITH SLOPED EDGES

ADHESIVES

TAILORABLE CTE
ADJUSTABLE CURE TEMPERATURES
TAILORABLE DIELECTRIC CONSTANTS

SOLDER

TAILORABLE CTE
FLUXLESS, LEAD FREE MATERIALS

IMPROVED PACKAGES/SUBSTRATE MATERIALS

HIGHER THERMAL CONDUCTIVITY
PRECISION MOLDING CAPABILITY
TAILORABLE/MATCHED CTE

MANUFACTURING TECHNOLOGY ISSUES AND PROPOSED SOLUTIONS (CONT.)

6.) HIGHER CHIP FUNCTIONAL DENSITY

SYNERGISTIC PACKAGING/CHIP DEVELOPMENT APPROACH

MIXED DIGITAL/MICROWAVE-HBT TECHNOLOGY
- TTL/CMOS CONTROL CIRCUITS FOR GaAS MICROWAVE MONOLITHIC INTEGRATED CIRCUITS
- LOW NOISE AMPLIFIERS, POWER AMPLIFIERS, MIXERS AND SWITCHES

COUPLERS, BIAS NETWORKS, MULTILAYER STRUCTURES

7.) HIGH SPEED FULLY FUNCTIONAL TESTING OF DIGITAL, ANALOG AND MICROWAVE COMPONENTS

INEXPENSIVE, HIGH FREQUENCY LARGE AREA HIGH SPEED PROBES

8.) HIGH SPEED INTELLIGENT PROCESSING

HIGH SPEED FULLY AUTOMATIC, FABRICATION AND ASSEMBLY EQUIPMENT AND PROCESSES CAPABLE OF PRECISION PLACEMENT ACCURACIES WITH ADAPTIVE CONTROL THROUGH INTELLIGENT PROCESSING CAPABILITIES

9.) DEVELOPMENT OF AN INTEGRATED DESIGN, ASSEMBLY AND TEST DATA BASE FOR ANALYSIS, SIMULATION AND PRODUCT/PROCESS IMPROVEMENT.

INTEGRATED DATA BASE

- ESTABLISH APPROPRIATE HARDWARE AND SOFTWARE LINKS BETWEEN EXISITNG CAE/CAD SYSTEMS TO REDUCE DESIGN TO BUILD CYCLE TIME
- ESTABLISH APPROPRIATE HARDWARE AND SOFTWARE LINKS BETWEEN MANUFACTURING INFORMATION SYSTEMS AND EQUIPMENT SENSORS FOR SPC DATA COLLECTION.
- IMPLEMENT NEW DATA ANALYSIS SOFTWARE TO SUPPORT:
  - SPC, WHERE DATA IS INCORPORATED IN A REAL-TIME FEEDBACK LOOP FOR EITHER MACHINE ADJUSTMENT OR TO FLAG OUT-OF-SPEC CONDITIONS.
  - DATA ANALYSIS, WHERE DATA ARE ANALYZED AFTER THE FACT TO DISCERN CORRELATIONS AMONG INPUT PARTS AND MATERIALS, OPERATING CONDITIONS, AND THE PERFORMANCE AND COST OF END-ITEM MODULES.

INTEGRATED DATA BASE (CONT.)

- SYSTEM SIMULATION, WHERE PERFORMANCE PREDICTIONS AT THE MODULE LEVEL AND AT THE HIGHER SYSTEM LEVEL ARE MADE AND COMPARED TO MEASURED PERFORMANCE
- MACHINE SETUP OR OPERATOR INSTRUCTIONS, TO SIMPLIFY THE START-UP ACTIVITIES FOR AUTOMATED ASSEMBLY OPERATIONS BY PROVIDING NEEDED DATA ON PARTS AND MATERIALS
- QUALIFICATIONS, FOR RELIABILITY ASSURANCE AND TO PROVIDE AN ARCHIVAL RECORD FROM WHICH TO ANALYZE FIELD FAILURES
- COST MODELING, TO ALLOW REAL-TIME COST DATA TO BE USED TO OPTIMIZE ASSEMBLY LINE LOADING AND TO SUPPORT FORWARD PROJECTIONS OF COST IN HIGH-VOLUME PRODUCTION

MANUFACTURING TECHNOLOGY ARRAY AND SUB-ARRAY NEEDS

ARRAY AND SUB-ARRAY FABRICATION, ASSEMBLY AND TEST ISSUES REQUIRING MANUFACTURING TECHNOLOGY IMPROVEMENT OF MATERIALS, PROCESSES AND EQUIPMENT.

- AUTOMATED ASSEMBLY OF T/R MODULES INTO ARRAY/SUB-ARRAY
  - MODULE INTERCONNECTION AND ATTACHMENT
- AUTOMATED FABRICATION AND TEST OF DC AND RF MULTILAYER CIRCUITS
- AUTOMATED FABRICATION AND ASSEMBLY OF ANTENNA ELEMENTS INTO FACEPLATES
- AUTOMATED FABRICATION OF LIQUID COOLED COLDPLATES
- AUTOMATED TRANSFER OF 3-D DESIGN MODELS TO FABRICATION SHOPS
- ELIMINATION OF CFC's AND LEAD BASED SOLDER

PACKAGING MANUFACTURING TECHNOLOGY

- CONFORMAL ARRAY AND SMART/THIN SKIN REQUIREMENTS
  - AFFORDABILITY IS KEY ISSUE
  - THREE DIMENSIONAL PACKAGING CONCEPTS ESSENTIAL TO ACHIEVE THIN SKIN AND MEET WAVELENGTH DRIVEN MODULE TO MODULE SPACING REQUIREMENTS
  - PACKAGING CONCEPT MUST ELIMINATE SYSTEMATIC ERRORS ASSOCIATED WITH MODULE/SUB-ARRAY MISALIGNMENT
  - STRUCTURAL INTEGRITY AND LIGHTWEIGHT MUST BE MAINTAINED ACROSS ARRAY

Advanced Technology

PACKAGING MANUFACTURING TECHNOLOGY

REQUIREMENTS OF MICROWAVE VERSUS MILLIMETER WAVE

- INDUCTIVE AND CAPACITIVE PARASITICS MUST BE REDUCED WITH INCREASING FREQUENCY
  - SHORT RF BOND LENGTH, RIBBON OR MESH
  - HIGHER PLACEMENT ACCURACIES AND LINEWIDTH CONTROL
- WAVEGUIDE TO MICROSTRIP OR WAVEGUIDE TO COPLANAR CONNECTIONS/ TRANSITIONS TYPICALLY REQUIRED FOR RF I/O
- CONTROLLING THE INCREASING TRANSMISSION LINE LOSS WITH FREQUENCY REQUIRES MORE PRECISE CONTROL OF LINEWIDTH EDGE GEOMETRY AT MILLIMETER FREQUENCIES AND DECREASED SURFACE ROUGHNESS OF SUBSTRATE
- GREATER COUPLING WITH INCREASING FREQUENCIES DUE TO DECREASED CIRCUIT AND PACKAGE DIMENSIONS REQUIRES IMPROVED ISOLATION CONTROL

Defense Systems & Electronics Group

PACKAGING MANUFACTURING TECHNOLOGY

REQUIREMENTS OF MICROWAVE VERSUS MILLIMETER WAVE - (CONT.)

- CLOSER GRID SPACING WITH INCREASING FREQUENCY FOR PHASED ARRAY APPLICATIONS PUTS INCREASING DEMANDS ON HIGH DENSITY PACKAGING CONCEPTS.
  - OVERHEAD FUNCTIONS SUCH AS PACKAGE SIDEWALLS BECOME MAJOR ISSUE AT MILLIMETER WAVE FREQUENCIES
- BOTH MICROWAVE AND MILLIMETER WAVE APPLICATIONS REQUIRE MODULE MANUFACTURING TECHNOLOGY IMPROVEMENTS DESCRIBED PREVIOUSLY.

PACKAGING MANUFACTURING TECHNOLOGY

IMPROVEMENTS NEEDED TO EVALUATE AND CHARACTERIZE PACKAGE MATERIALS, SUBSTRATES AND HOUSINGS FOR MULTICHIP MODULES

- STANDARDIZED TEST STRUCTURES AND TEST METHODS
  - DEFINITION OF REQUIREMENTS VERSUS APPLICATION
  - IDENTIFICATION AND DEVELOPMENT OF TEST METHODS
  - DEVELOPMENT OF TEST STRUCTURES
- IMPROVED 3-D MODELING CAPABILITY FOR ELECTRICAL AND MECHANICAL ANALYSIS
- IMPROVED AND VALIDATED COST MODELING TOOLS

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MULTICHIP PACKAGING FOR
MICROWAVE COMPONENT APPLICATIONS.

Mil-Standard and Commercial Approaches.

Objectives:

1. To describe differences and common aspects of the two approaches.

2. To provide insight into the evolution of the microwave package in response to downward cost pressures.

3. To explore the QML concept for microwave packages and components.

4. To provide ideas for leveraged package development for low-cost microwave packaging.

John R. Tyler
June 18, 1992.

MANUFACTURING

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MULTICHIP MICROWAVE PACKAGING; AN OUTLINE

Mil Standard vs. Commercial:

1. Requirements of the Microwave Package.

2. Avantek Case Studies.

3. Standards and Standardization.

4. QML Issues.

5. Leveraged Microwave Package R&D.

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REQUIREMENTS OF THE MICROWAVE PACKAGE.

- THE ELECTRICAL INTERFACE.
- THERMAL STABILITY.
- THE MECHANICAL INTERFACE.
- ENVIRONMENTAL PROTECTION.
- D F X ——→ D T C.

HOW DO THESE CLASSICAL REQUIREMENTS DIFFER IN MIL-STANDARD AND COMMERCIAL PRODUCTS?

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ELECTRICAL PACKAGE REQUIREMENTS

Mil-Standard

- 0.1 - 0.2 dB insertion loss @ 10 GHz, VSWR = 1.2:1 typical.
- Coax-to-microstrip transitions.
- Microstrip-stripline-microstrip in ceramic.

Commercial

- 1 dB insertion loss, 1.5:1 VSWR acceptable.
- CPW, Microstrip surface-mount configurations.
- Advantages: Lighter, cheaper, high-volume.

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THERMAL REQUIREMENTS

Mil-Standard

- Greater operating and storage temperature range (ambient).
  -e.g., -55 to 95oC typ. operating range.
- More GaAs→more stringent package thermal requirements.

Commercial

- Higher package stresses due to materials.
- Lower-cost package elements can be thermally insulative (eg, soft-boards).
- Advantages: Low fabrication costs.

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MECHANICAL PACKAGE REQUIREMENTS.

Mil-Standard

- Custom or semi-custom installation (outline).
- 100% mechanical screening.

Commercial

- MCMs: Some standard footprints emerging by market.
- FCPs: Surface Mount, standard SOT, SOIC packages per EIA, EIAJ, JEDEC.
- Advantages: Open Tooling, Automated assembly, mechanical qualification by package.

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ENVIRONMENTAL PROTECTION

Mil-Standard

- Seal per 883, Method 1014.
- Finish: Noble metal or solderability per M-38510.

Commercial

- Product qualification to high capability (Cpk>1.33).
- Process qualification to high capability (Cpk>1.33).
- Open-package (cavity) qualification at supplier.
- Advantages: Higher product quality at lower cost.

MANUFACTURING

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DESIGN-TO-COST

Mil-Standard

- Parts count reduction (MANTECH).
- GaAs cost reduction (MIMIC).
- Custom designs → low non-recurring investment.

Commercial

- Typical $50K - 100K non-recurring tooling
  → low unit price (in volume).
  Eg, stampings, castings, moldings.
- Standardization of package outlines.
- Advantages: Open tooling, volume manufacturing.

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MILITARY ⟶ COMMERCIAL

COMPONENT TYPE:	TO	PLANAR-PAK	SMT W/CARRIER	SMT GULL-WING	LEADLESS
AMP	●	●	●	●	●
AGC	●	●			
VTO	●	●	●	●	
DET	●	●			
MIX	●	●		●	
ATT	●	●			
LIM	●				
SWT		●		●	●

MANUFACTURING

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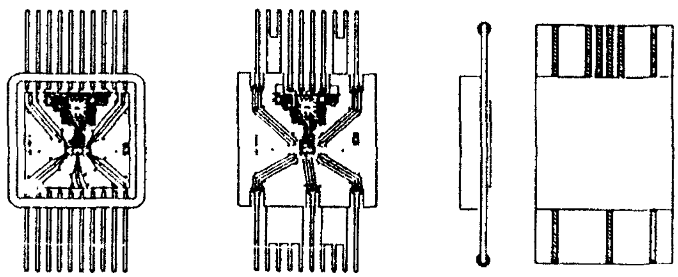
1992-

FURTHER COST REDUCTIONS
LEAD PROTECTION
TAPE & REEL
PACKAGE ALTERNATIVES
REDESIGN (SP7T)



MANUFACTURING

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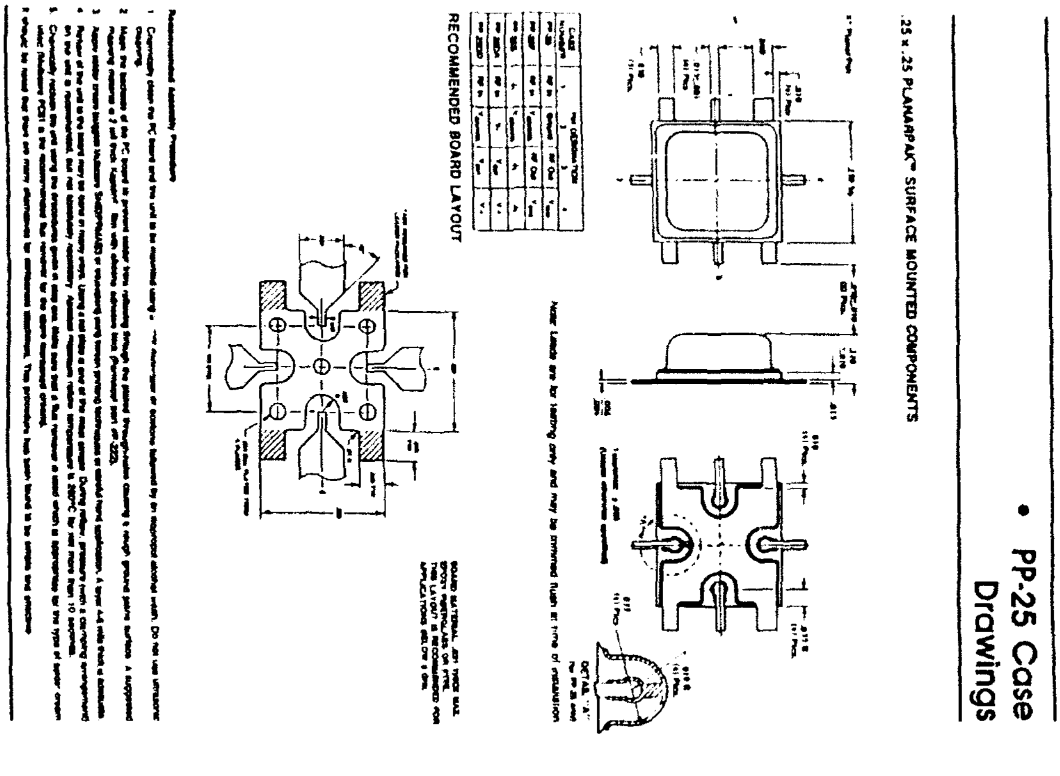

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POLYMERIC ENCAPSULANTS

MATERIAL DESCRIPTION	DIELECTRIC CONSTANT	DISSIPATION FACTOR@1MHZ	HARDNESS	LINEAR TCE (ppm/oC)
ABLEBOND 933-1.5	2.2	0.019	60D	30
DOW CORNING Q1-4939	2.8	0.001	44A	200
CHIPCOAT 2157	2.2	0.0036	9H	7
SUMITOMO BAKELITE NOVOLAK COMPOUND	4.7	0.015	65D	20

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ENCAPSULANT EFFECT @ 2.6 - 4 GHz

	Air	Encapsulated
Input R. L.	13.1	10.8
Gain	12.6	11.5
Noise Figure	0.98	1.13

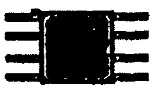
MANUFACTURING

AVANTEK Semiconductor Training

Ceramic & Glass - Metal Packages

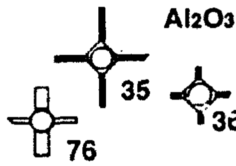
Commercial/Industrial Grade
PKG Codes 18, 35, 36, 72, 76

Surface Mount
Gold plated Kovar leads
Glass-Metal

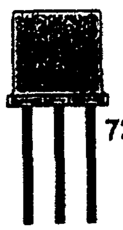


18

Surface Moumt
Tin plated Kovar Leads
Al_2O_3 ceramic



35 36 76



72

"TO-72" Metal Can
Gold plated Kovar leads

TXV, B and C Level Screening

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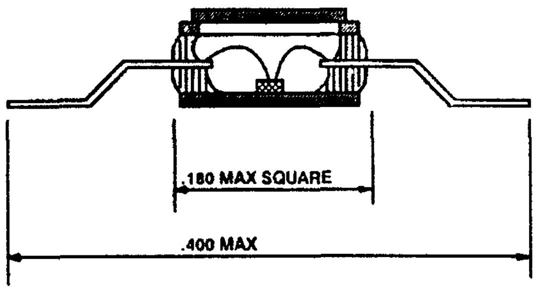
COMPARISON OF THE TWO TECHNOLOGIES

PACKAGE #18
OXIDE METAL BONDING

MECHANICAL INTEGRITY DEPENDS ON:

*WETTING CONTACT ANGLE
*TCE MATCHING
*STRESS PROPAGATION PROPERTIES OF GLASS STRUCTURE
*CORROSION PROPERTIES OF KOVAR

GLASS PACKAGE SECTION VIEW

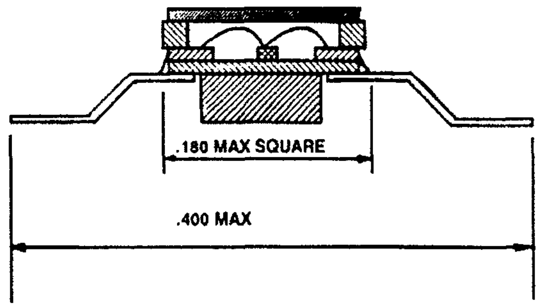


PACKAGE#28
COFIRED ALUMINA BONDING

MECHANICAL INTEGRITY DEPENDS ON:

*MONOLITHIC STRUCTURE OF CERAMIC LAYERS

CERAMIC PACKAGE SECTION VIEW



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ADVANCED BIPOLAR PRODUCTS

AVANTEK

COMMERCIAL PACKAGE STANDARDS

- JEDEC STANDARD No. 26 General Specification..."

  No. 26-A

  No. 22-B "Test Methods ..."

  JEP No. 95-1 "Registered and Standard Outlines..."

  JC11.5-91 Standards Committee.

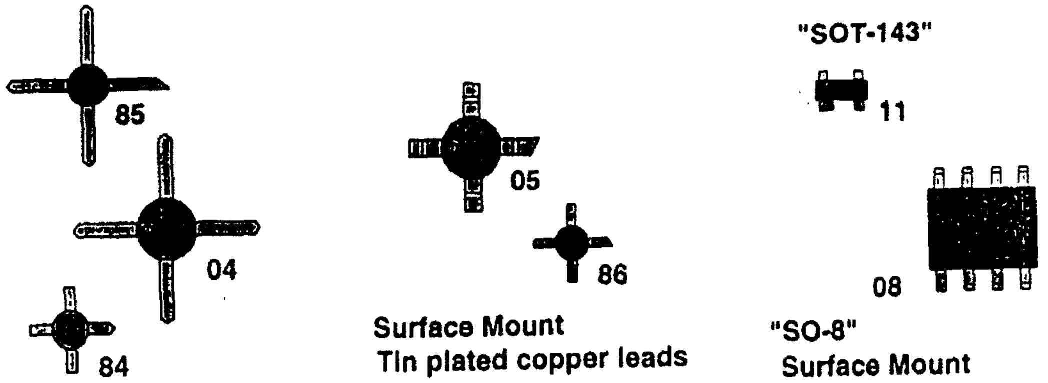
- EIAJ ⟷ EIA

- ISO 9000 Europe, Japan, Korea, Taiwan.

MANUFACTURING

Plastic Packages

Commercial/Consumer
PKG Codes 04,05,08,11,84,85,86



Surface Mount
Tin plated copper leads

"SO-8"
Surface Mount
Tin plated Kovar leads

Tin plated copper leads

AVANTEK

Reliability Qualification For Plastic Package

	Stress Test	Test Methods	Test Condition	LTPD	Duration
Life	Operating Life Test	JEDEC STD 22B M-A108	Tj/Tch temperature @ 150°C	5	2000 hours
Life	High Temperature Reverse Bias*	JEDEC STD 22B M-A108	Ambient temperature @ 150°C	5	1000 hours
Life	High Temperature Storage	JEDEC STD 22B M-A103	Ambient temperature @ 150°C no bias	5	1000 hours
Thermal	Thermal Shock	JEDEC STD 22B M-A106	Temperature from -65°C to 150°C	7	100 cycles
Thermal	Temperature Cycling	JEDEC STD 22B M-A104	Temperature from -65°C to 150°C	10	1000 cycles
Moisture	Temperature & Humidity	JEDEC STD 22B M-A101	85°C/85% Relative Humidity	10	1000 hours
Moisture	Autoclave	JEDEC STD 22B M-A102	2 ATM saturated steam +121°C and 100% Relative Humidity	10	96 hours

*Applicable only to Silicon Bipolar Products.

Appendix B

AVANTEK

QML SUPPLIER REQUIREMENTS

- Standard differentiation of processes by component or package type.
- Assured capability (Cpk) of each process.
- Product qualification, package qualification.
- Circuit topology and layout can be custom.
- Significant component cost-reduction to system-level contractors.

MANUFACTURING

AVANTEK

QML PROCESS CAPABILITY

QUESTION: WHAT IS THE CUSTOMER'S REQUIREMENT?
WHAT IS THE PRODUCT REQUIREMENT?

QML SPECIFICATION: DETERMINE MINIMUM PROCESS CAPABILITIES REQUIRED BY PACKAGE OR PRODUCT.

QUALIFY PRODUCT AND SHIP VOLUME.

MANUFACTURING

AVANTEK

QML PROCESS CAPABILITY

883, METHOD 2011:	DESTRUCTIVE BOND PULL IS THE BEST METHOD TO DETERMINE PROCESS CAPABILITY OF WIRE-BONDING. SPECIFICATION LIMITS ARE NOT SCALED TO AVERAGE BOND STRENGTHS BY WIRE DIAMETER OR BONDING PROCESS.
METHOD 2019:	THERE IS NO CORRELATION BETWEEN DIE SHEAR STRENGTH AND ELECTRICAL RESISTIVITY FOR AuSi EUTECTIC OR EPOXY DIE ATTACH. DIE SHEAR TESTING IS NOT SUFFICIENT FOR HIGH DIE ATTACH PROCESS CAPABILITY.
METHOD 2017:	FILLET REQUIREMENTS ARE NOT SUFFICIENT FOR GaAs POWER.
NEW STATISTICAL "KEY MEASURES:"	ELECTRICAL RESISTIVITY. THERMAL RESISTANCE BY IR SCAN. TRANSIENT THERMAL AND ELECTRICAL RESPONSES. "Q" CIRCUIT FOR WIREBOND AND DIE ATTACH QUALITY. RADIOGRAPH, SAM NON DESTRUCTIVE TESTS.

MANUFACTURING

AVANTEK

PACKAGE DEVELOPMENT PRIORITIES

- STANDARD, LOW-COST, SURFACE-MOUNT COMPONENTS
  -PACKAGE QUALIFICATION.
- STANDARDIZED PACKAGE OUTLINES → TOOLING INVESTMENT → PACKAGE COST REDUCTION.
  -INCLUDE TEST FIXTURING AS PART OF STANDARD PACKAGE DEVELOPMENT.
- PARTS COUNT REDUCTION → INTEGRATE ADVANCED MATERIALS WITH LOW COST MATERIALS.

Examples: Aluminum MMC → A356 Al, Cast.
Ceramic-Metal Composites → Al, Cu.
Polymer-Polymer Composites → Epoxy Resins, Molded.

USE EXPENSIVE MATERIALS ONLY ALONG THE CRITICAL PATH.
-ELECTRICAL, THERMAL, MECHANICAL.
FAVOR LESS DEGREES OF FREEDOM IN FABRICATION.

MANUFACTURING

AVANTEK

PACKAGE DEVELOPMENT PRIORITIES

- GaAs FLIP CHIP BONDING - CPW TRANSMISSION LINES.
- POLYMERIC ENCAPSULANTS.
- LOW-COST CERAMIC INTERCONNECT STRUCTURES.
- ORGANIC MATERIALS FOR PACKAGING, INTERCONNECT AND BONDING.

MANUFACTURING

AVANTEK

LEVERAGED MICROWAVE PACKAGE R&D

- SHAREHOLDERS (INDUSTRY) TO DRIVE EXISTING CONSORTIA IN MICROWAVE PACKAGE R&D.
  -UNIQUE REQUIREMENTS → UNIQUE PROGRAM.
- GOVERNMENT/INDUSTRY TEAMS TO DEFINE R&D OBJECTIVES.
- STANDARDIZED QPL COST ROADMAP: 5 - 10 FORM FACTORS BY '93.
- FUNDING THROUGH CONSORTIA TO KEEP PACKAGING OPEN, STANDARD AND NON PROPRIETARY.

MANUFACTURING

M/A-COM

Packaging: Commercial vs. Military

OUTLINE

- Packaging Objectives
- Baseline Packaging
    - Military
    - Commercial
    - Conclusions
- Recent Trends in Packaging
- Possibilities for the Future
- Recommendations

Rick Perko
June 18, 1992

M/A-COM

Packaging Objectives

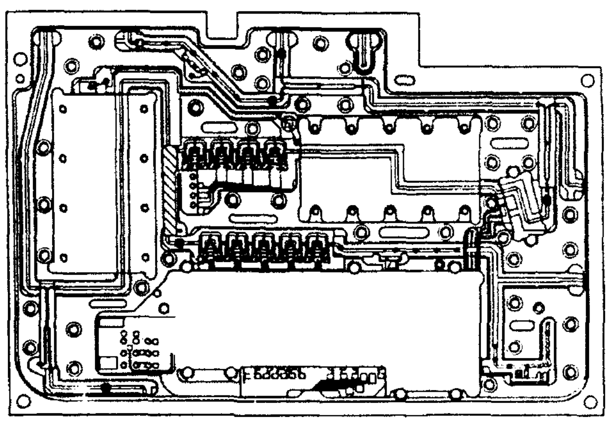
- MILITARY
    - Reliability (MTBF & Shelf Life)
    - Moderate Cost (Low - Medium Volume)
    - High Perfomance (Thermal & RF Characteristics)
    - Size (Highly Integrated)
- COMMERCIAL
    - Low Cost (High Volume)
    - Quality (Uniform Performance)
    - Standardized Interface

M/A-COM Baseline Technologies / Military

- Hermetic Metal Enclosures
  - Coax Glass-fired Feedthroughs
  - Welded Covers
- Ceramic Packages
  - Co-fired "Planar" Feedthroughs
  - Covers Welded, Soldered or Glass Sealed

M/A-COM Metal Package

Cost $50.00 - $200.00



Extremely Adaptable
- Material Choices for:
  - Weight
  - Thermal Conductivity
  - TCE
- Complex Partitioning for Isolation
- Excellent RF Performance

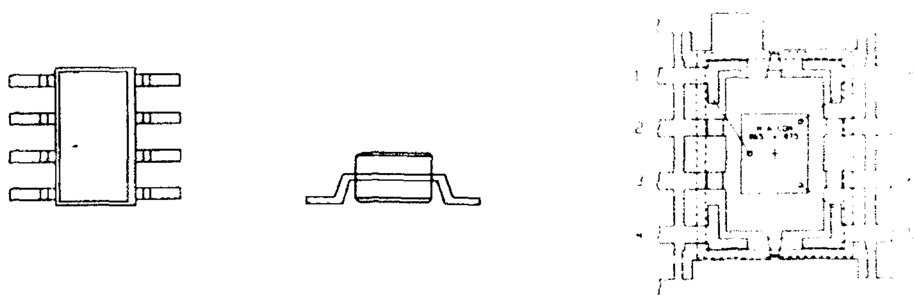
Advances
- Matrix Metals
- Powdered Metallurgy

M/A-COM Baseline Technologies / Commercial

- Plastic Injection Molded
  - 3 GHz Frequency Limit
  - Non-Hermetic
- Plastic Premolded
  - Non-Hermetic
  - Performance Limits Undefined
  - Applies to Chip on Board
- Mini-Ceramic
  - Hermetic
  - Higher Performance / Cost
- Discrete on PCB
  - Depends on Cheap Labor
  - Integration Potential Limited

M/A-COM Injection Molded Package

Unit Cost (Korea): Dice Wafer, Die Attach, Wire Bond, Injection Mold } < $0.25



Four Bit Attenuator

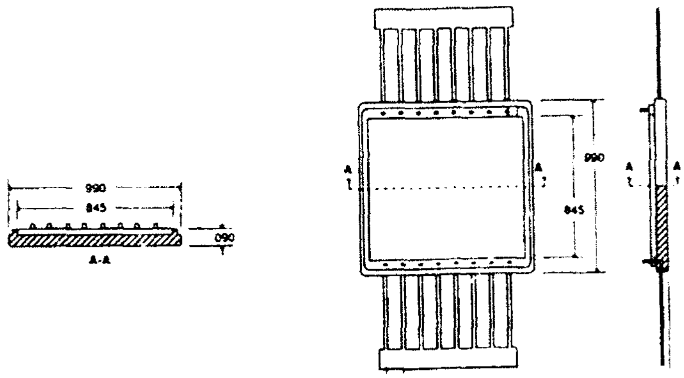
3GHz Limit

Technical Advances: Low Inductance Lead-frame Design.
Multiple Die / Package.

M/A-COM

Premolded Package

Circuit Size .8"X.8" Cost < $1.00



Useful for Chip-on-Board Assemblies.
Non-hermetic.
No Microwave Optimized Standard Packages.

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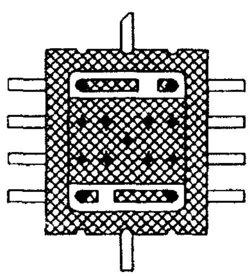
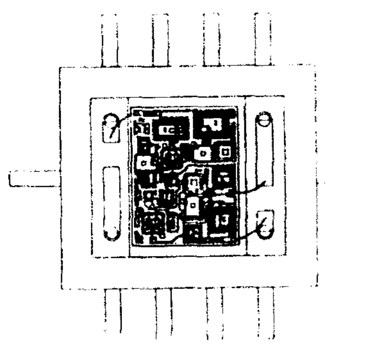
Mini-Ceramic Package

Cost: $1.25
Package Size: .250" X .215" X .050"
Circuit Size: .120" X .120"





GPS Low Noise Amplifier

Hermetic / Surface Mount
Limited to Smaller Circuits

M/A-COM Baseline Technologies / Conclusions

Plastic Commercial Packaging Does Not Meet Hermeticity or Performance Requirements of Many Military Applications.

Ceramic Packages Can be Cost Effective for Small Circuits but is Expensive for Larger High Performance Assemblies.

M/A-COM Current Trends

- Reliability Without Hermeticity
  - Better Focus on Actual Failure Mechanisms
  - Surface Passivation Options
- Lower Cost Hermetic Enclosures
  - Integrated Package / Circuit Functions
    LTCC
    Wafer Level Protection
  - Powdered Metallurgy
- Acceptance of Plastic?

M/A-COM

Plastic

Unreliable or Unappreciated?

- Injection Molding Technology is Evolving Rapidly
  - Compounds, Fillers & Methods Have Improved Dramatically in the Past 5 Years.
  - Reduced Moisture Intrusion
  - Improved RF & Thermal Performance
- Premolded Technology Also Holds Promise
  - High Strength Crystalline Material
  - Integrated Heatsinks
  - Metal Coatings
  - Complex Forms

THE COMPLEX WORLD OF PLASTICS REQUIRES CONTINUOUS EVALUATION TO DETERMINE THE IMPACT OF RECENT ADVANCES

M/A-COM

Microwave MCMs

Intermediate Motherboards (e.g. GMIC)
versus
Integrated Packaging (e.g. LTCC)

MCM

Strengths
- Partition for Yield Control
- Partition for Performance
- Increased Flexibility

Liabilities
- Requires Final Package
- Increased Parts Count

Integrated Package

Strengths
- Reduced Parts Count
- Includes Package

Liabilities
- Premium on Known Good Die
- Integ. Medium Dictated by Package Needs

M/A-COM

Possibilities

Hermetic MCMs

- Glass / Silicon (GMIC) Integration Medium
  - Wafer Level Protection
  - High Performance Potential
  - Compatible with Flip Chip & Thermal Pedestals

Plastic Enclosures

- Premolded Plastic Enclosures
  - Integrated Heatsinks
  - High Strength Crystalline Plastics
  - Complex Structures (Multiple Chambers)
  - Metallized for EMI

M/A-COM

Recommendations

- RWoH Programs
  - Microwave Applicability
  - Failure Mode Analysis
  - How to Qualify New Technologies
- Plastic Technologies Programs
  - Reliability Issues
  - High Frequency Transition Methods
  - Thermal Management
  - EMI Control
- Don't Bet on a Single Solution
  - A Broad Spectrum of Requirements Will Require Flexible Solutions.
- Technology Access
  - Second Tier Suppliers are Critical for Broad Leverage.

Microwave Packaging Technology Workshop
18-19 June 1992

Military vs. Commercial Packages
Multilayer Ceramic Package Technology

Michael Flanders
Coors Electronic Package Company

"Commercial vs. Military"

- Packaging has traditionally been down the supplier food chain; not as affected by "peripheral" requirements
- Increasing complexity/capability of packaging, plus recent Govt. focus brings opportunities/responsibilities
- Focusing only on technical requirements will no longer suffice; must address non-technical aspects when quoting
- Many package manufacturers will need some "education" as Primes or co-Primes

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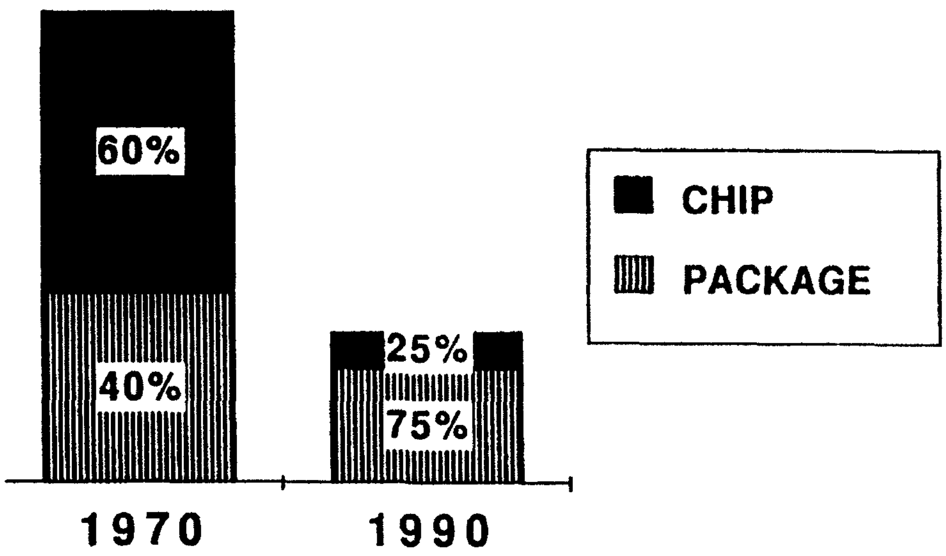
SIGNAL DELAY



MLC Technologies: MATERIAL

Material	Applications	Advantages	Disadvantages
Aluminum Nitride (AlN)	- High Performance Packages - High Power Applications - Large Chip Packaging	- 0.1% Shrinkage Control (hot-pressed)	- No metallized cavities (hot-pressed)
Low Temp. Cofired Ceramic (LTCC)	- High Performance Packages - Microwave Applications	- High-conductivity metals - Low K formulations - Adjustable TCE	- Poor heat dissipation
Alumina 99.5%	- Thin Film Interconnects - Microwave Applications	- Excellent Surface Finish - Low Loss	- No cofire metallization
Alumina 92%	- Low & Intermediate Performance Packages	- Low Cost - High Strength - Mature Technology	

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MLC Technologies: PROCESS

Process	Advantages / Applications	Disadvantages
Greenline transparency to ceramic materials	- Established technologies - Cost Control	
Hot-pressing	- Dimensional Control	- no metallized cavities (currently)
Continuous furnace firing	- High Volume - Low Cost	- Material-dependent Shrinkage Control

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MLC Technologies: PROCESS (cont.)

Process	Advantages / Applications	Disadvantages
Refire techniques	- Curved Ceramic ("smart skin")	
"Programmable grid" Via Technology	- Low Cost - Short Turn - Hole Quality	- Standard Grid limitations
Electroless Plating	- Design	- Not approved for some military applications
CuW Thermal Vias	- Lower Cost vs. CuW heatsink	

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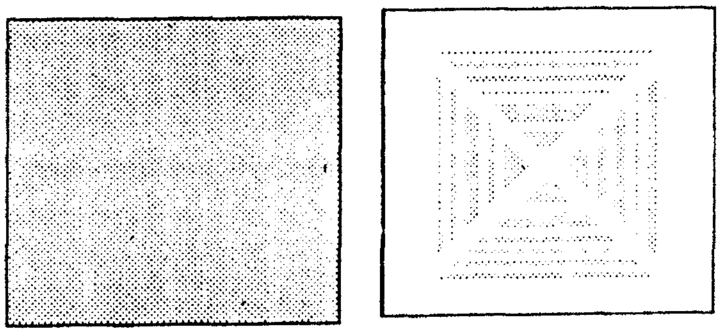
Programable Punch Tooling

- MCM interconnect design on a fixed grid will reduce tooling cost
- Increase appeal to ceramics in MCM applications through lower tooling costs



CEPCo

Coors Thermal Via Development

- Increases thermal dissipation in alumina
- Low cost alternative to Cu/W heat sinks

CEPCo

MLC Technologies: PART TYPES

Part Type	Applications
Feedthroughs	- High-Rel replacement for glass-to-metal seal - Controlled impedance
Double-sided boards / thru-board interconnects	- Reduced signal delay - Component consolidation

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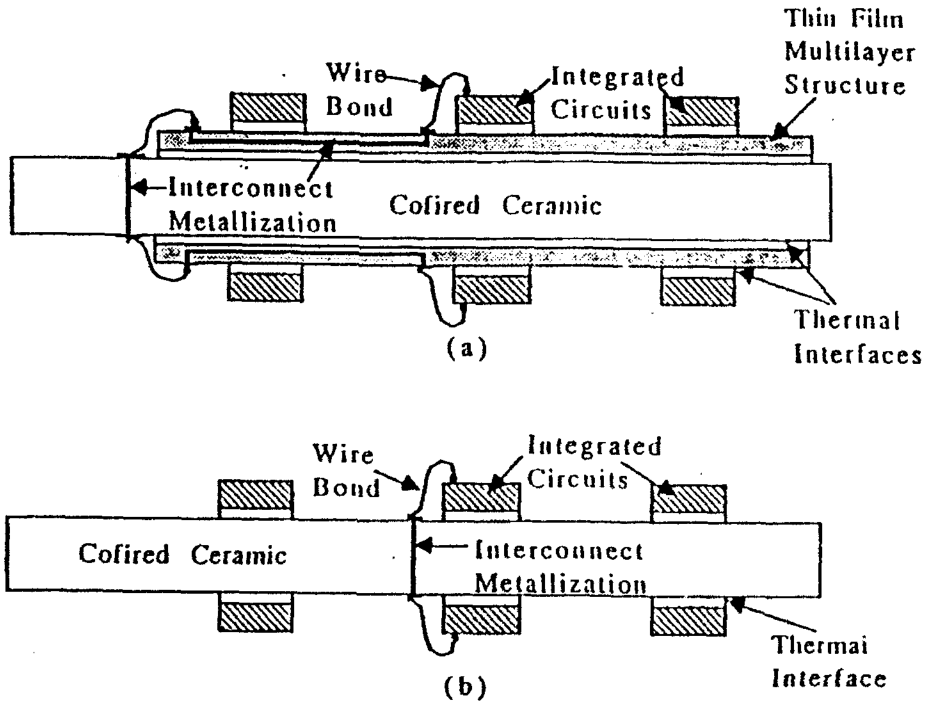

(a) Thin film multichip modules mounted on a double sided cofired ceramic carrier. (b) Double sided multichip module using the cofired ceramic as the interconnection.

MLC Technologies: PART TYPES
(cont.)

Part Type	Applications
Multichip Modules / Package	- Protection of MCM
Multichip Module / Substrate	- Base for Thin Film customization - Combines cost/conductivity advantages of MLC with pattern density advantage of Thin Film
Multichip Module / Interconnect Board	- Can combine substrate and package

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See June issue of Electronic Packaging + Production

"Selecting a Ceramic Substrate for Multichip Modules"

MLC Technologies: PART TYPES
(cont.)

Part Type	Applications
Brazed packages	- PGAs, leaded packages, housings, heatsinks
SLAM arrays	- Array processing (by customer)
Chip carriers	- Standard outlines
Crystal / oscillator packages	- Clock applications

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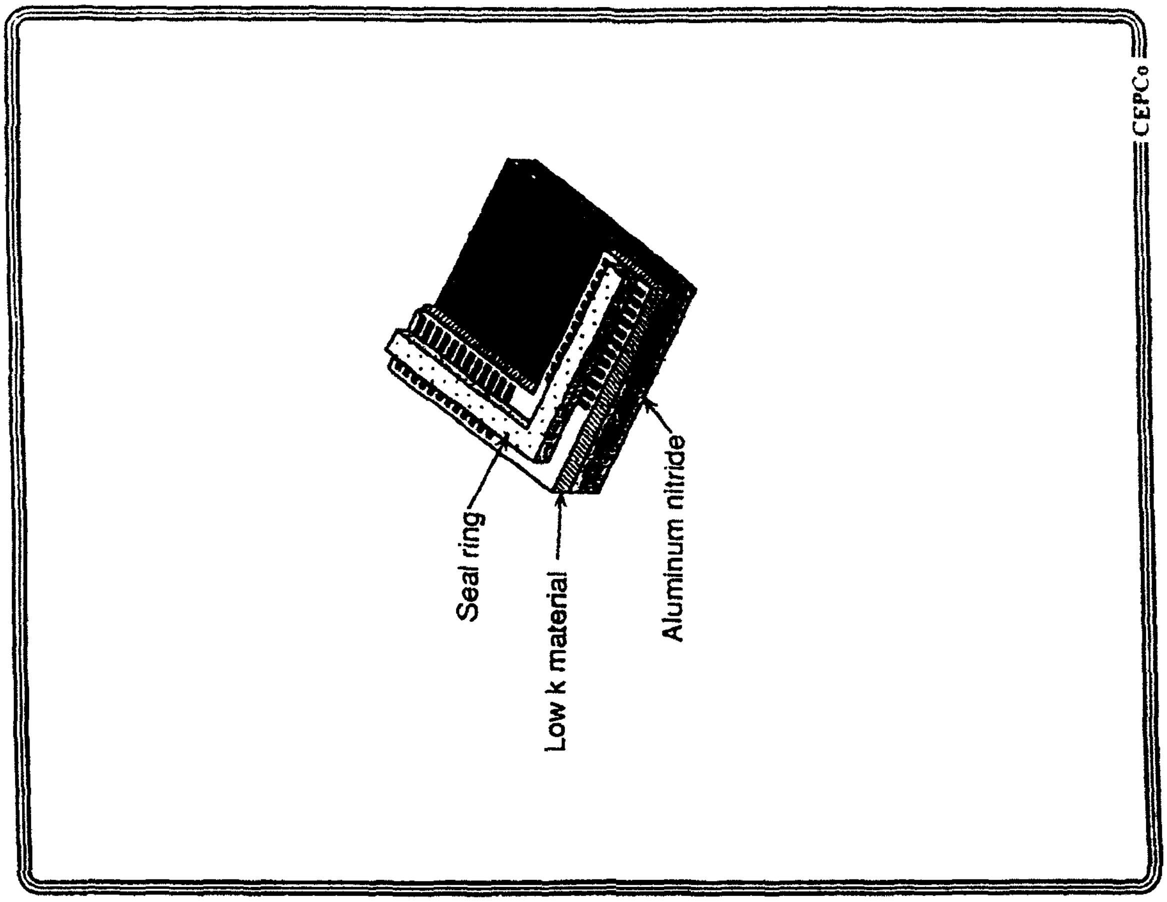
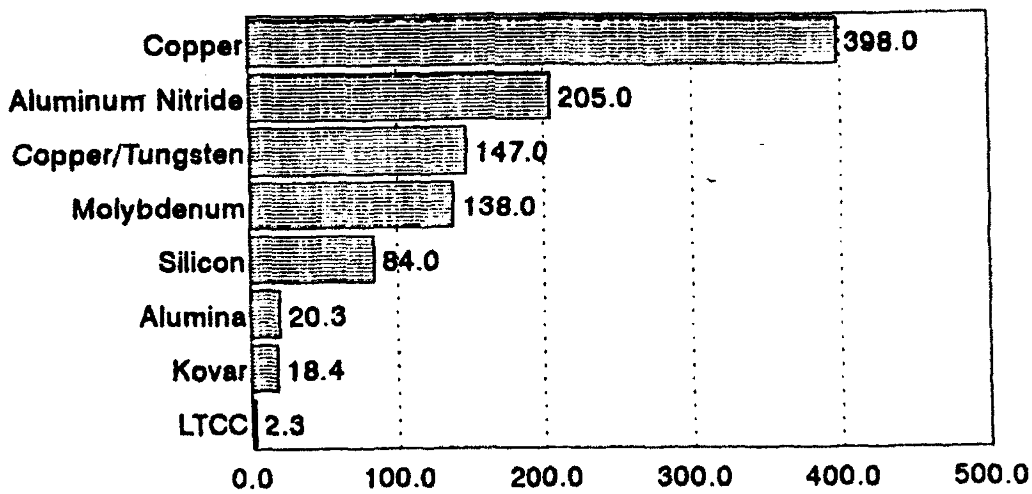
Areas for Investment

- Combining different ceramics in single structure (e.g. LTCC on AlN, high/low-K combined)
- Lower loss LTCCs
- Improved edge definition
- High-conductivity pattern metallization
- Higher conductivity internal metallization for high-alumina substrates
- Establishing via grid and lead pitch standards
- Economical methods for finer pitch vias (cost-controlled tooling)
- High-frequency testing techniques

Coors Electronic Package Company

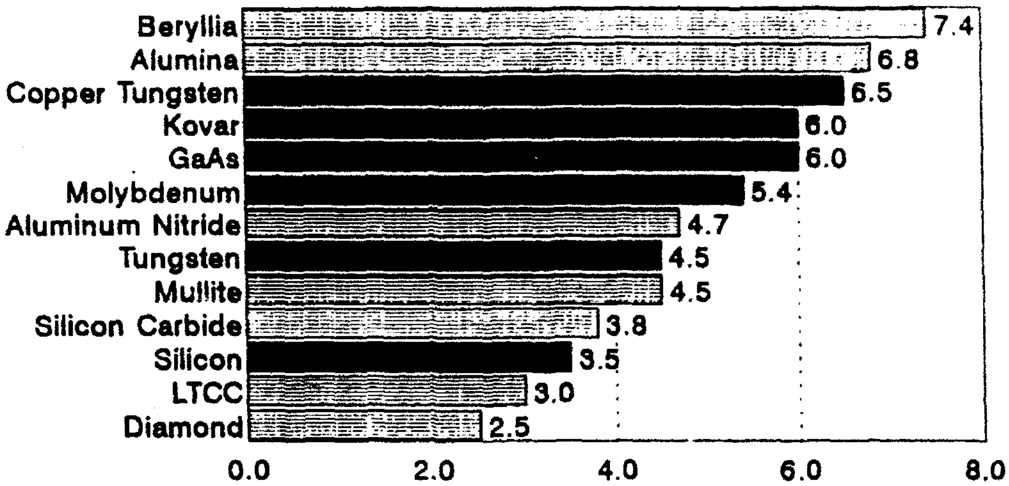


Thermal Conductivity
(W/m deg C)

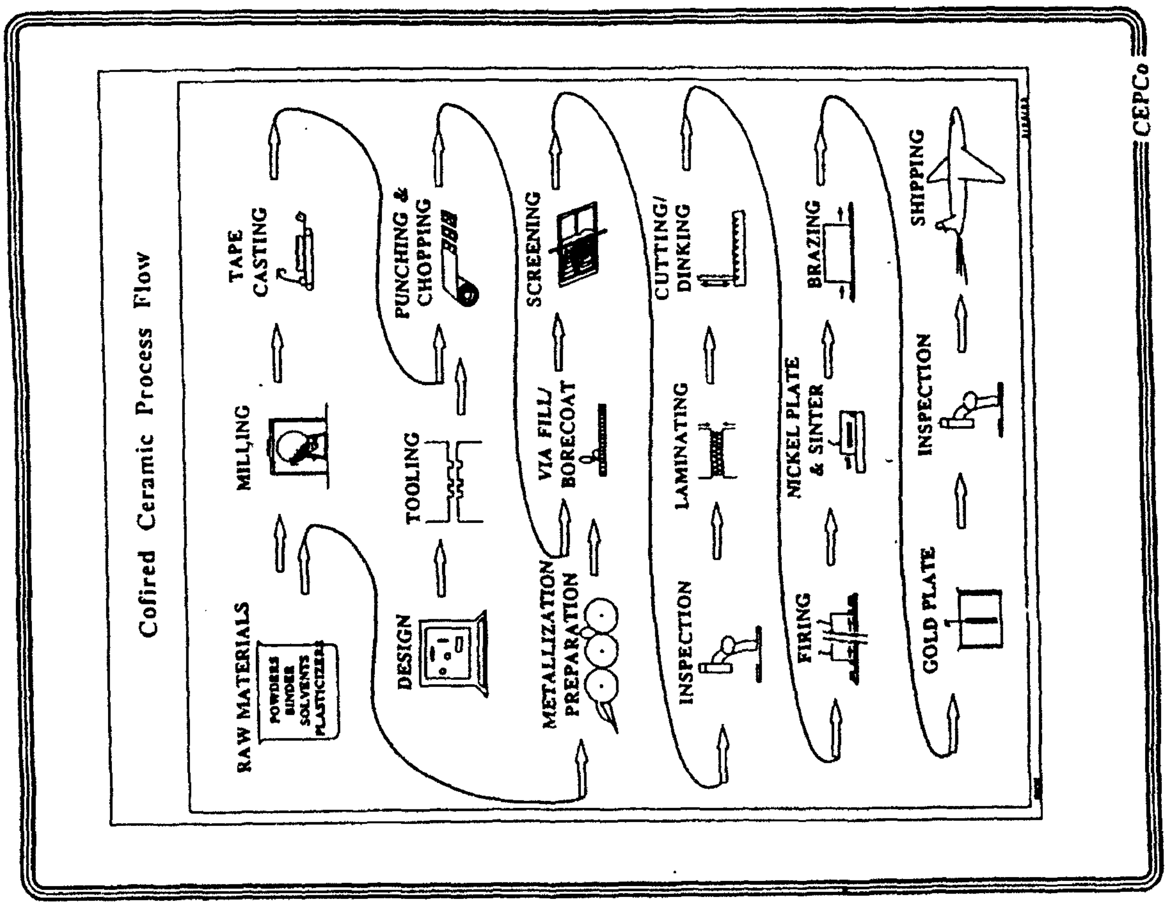


Coors Electronic Package Company

Thermal Expansion
(ppm/deg C)



Coors Electronic Package Company



MTT-12 Microwave and Millimeter Wave Packaging Committee

Purpose:

To Coordinate Technical Activities in Microwave and Millimeter Wave Packaging

Focus:

Emerging Areas, eg. MMIC Packaging for Military and Commercial Applications

Committee Membership:

Bert Berson*, Berson and Associates and Lehigh University

Terry Cisco, Hughes

Richard Decker, Lehigh University

Gary Holz, The Packaging Group

Doug Maki*, Maki and Associates

Jeanne Pavio, Texas Instruments

Dick Sparks, Raytheon

V. J. Tripathi, Oregon State University

* Co-Chairpersons, for information contact Bert Berson - (415) 968-2101

Activities

Packaging Standards Meetings:

1989 MTT-S MMIC Package Standards and Progress in Packaging 100 Attendees

1988 Standards in Microwave and Millimeter Wave Packaging 25 Attendees

Panel Sessions:

1990 MTT-S Symposium Panel: Is There a Need for Domestic Suppliers?

Workshops on Advances in Packaging:

1990 MTT-S Symposium Workshop: New Packaging Techniques for MMICs and Discrete Devices - 100 Attendees

1988 MTT-S Symposium Workshop: Packaging Hybrid and Monolithic Microwave and Millimeter Wave Components - 100 Attendees

1987 MTT-S Symposium Workshop: Planning and Packaging for the Next Generation of Integrated Circuits 100 Attendees

Sessions on Packaging:

1992 MTT-S Microwave and Millimeter Wave Packaging - 200 Attendees

1990 MTT-S Microwave Packaging and Manufacturing - 80 Attendees

Topical Meetings:

1992 IEEE Topical Meeting on Electrical Performance of Electronic Packaging: Co-Sponsored with IEEE Components,Hybrids, and Manufacturing Technology Society - 105 Attendees

Planned Activities for 1993

1993 MTT-S Workshop on Low Cost Packaging

Special Issue of the MTT Transactions on Packaging - 1993/1994

1993 MTT-S Packaging Session at the MTT-S Symposium

Recommendations

<u>Central Source of Information Needed:</u>

Broad Industry Access without Proprietary Considerations is Necessary

- Materials Properties
- Models
- Sources of Packages, Parts, Materials, ...
- Standards
- Design Rules

<u>Standards and Standardization:</u>

Standards are a Necessary Precondition to Standardization which is a Prerequisite to Cost Reduction

Standards are Needed in:

- Test
- Modeling and Design
- Manufacturing
- Environmental Requirements
- Ruggedness

Standards Activities Need to Proceed More Quickly

- Need Consistent Effort for Vendors and Users to Develop and Adopt Standards

<u>Packaging Design Rules:</u>

Vendors Function Primarily as "Machine Shops" and have No Microwave Design or Test Capability

Design Rule Compilations are Needed to Remove Barriers to Entry for Particular Packages and Ultimately Reduce Costs

Training in Microwave Package Design is a Necessity

AUTOMATIC RF TECHNIQUES GROUP

Call For Papers

The Automatic RF Techniques Group will hold their 40th Conference in Orlando, Florida, December 3 and 4, 1992. The Conference theme is:

Measurement and Design of Packages and Interconnects

As microwave and digital designs increase in complexity and speed, while they decrease in size, the difficulty of realizing packages and interconnects is becoming a choke-point in design and measurement. The increased difficulty leads to lack of accurate data, which, in turn, can lead to catastrophic design costs and lead-time. Papers are invited which identify problems and/or solutions in this area. Potential topics include (and are not limited to) measurement of large, high speed, high frequency systems; analysis of such systems; trouble-shooting or validating fabricated systems (both during manufacture and during design); and application of microwave techniques to high speed digital systems. In addition, papers concerning all other areas of microwave measurement and design are welcome.

Technical presentations shall be informal twenty-five minute talks using viewgraphs or 35-mm slide illustrations. Authors are requested to submit a one-page abstract and a 500 to 1000 word summary with attachments containing illustrations, etc., providing sufficient technical content to enable proper evaluation and explaining the contributions's usefulness to the conference attendees. Please refer to "ARFTG Instructions to Authors" for further information. All accepted papers will be published in the post-conference digest. Two copies of the abstract and summary should be sent to Bert Berson, Technical Program Chairman, and should be received no later than October 5, 1992. Papers received on or before September 7, 1992, will be considered for early acceptance and pre-conference publicity. Manufacturers interested in exhibiting at the conference should contact the Exhibit Chairman for information and an application and agreement form.

Submit papers to:

Mr. Bert Berson
Berson and Associates
~~655 Castro Street, Suite 3~~
445 Castro ST, Suite 2
Mountain View, CA 94041
(415)968-2101

For Exhibit Applications or further information contact the conference chairman:

Mr. James C. Rautio
Sonnet Software, Inc.
135 Old Cove Road, Suite 203
Liverpool, NY 13090-3746
(315)453-3096

The materials data in this section was taken from data sheets and other literature from vendors, including published articles. Article references are identified by a code in brackets, for example [NOV91], the corresponding references are also compiled near the end of this Handbook.

Most numerical values are from tables, but some were obtained from graphs. Where necessary, numerical values have been converted to the standard units used in this Handbook, usually SI ("metric"); vendors' original values are shown in braces { }. For explanations and conversion factors for units refer to *Units & Conversions* at the end of this Handbook (page ?). Data given for room temperature, 25°C or 30°C are combined on the same row in the tables.

The data included here are usually the most recent and best available, and in many cases (as indicated) have been reviewed by the vendor. However, caution is warranted in using this data. Usually, values represent typical characteristics rather than specification limits. Variability in the values is seldom indicated, and frequently data values do not agree even among a single vendor's literature. In most cases, the values must be regarded as typical values, because of lot-to-lot variations. If a property is critical, evaluation of the particular material lot, or agreement on specification limits with the manufacturer, may be warranted.

Non-magnetic means not *ferro*magnetic.

Data for the following materials are included in this section:

Generic Names	Brand Names
	Alloys
Fe-Ni 42% to 50% Ni	—
Fe-Ni-Co ASTM F-15	Kovar®, Sealvar®
	Metal Matrix Microcomposites
Ag/Invar®	Silvar™
Al/Si	CMSH A-40
Al/SiC	DWAL 20™; SiC40 MCM, SiC50 MCM, SiC55 MCM; PRIMEX™; MCX-622™, MCX-693™, NX-201™, NX-5221™, NX-5251™, EPX-100™, EPX-200™
Cu/Al_2O_3	GlidCop® AL-15
Mo/Cu	AMC 7525, AMC 8020, AMC 8515; Thermkon®: 70M, 65M; CMSH: CM-10, CM-15, CM-20
W/Cu	Thermkon®: 83, 76, 68, 62; CMSH: W-10, W-15, W-20
	Laminates/Clad Materials
Cu/Mo/Cu	CMC13, CMC20
Mo/graphite/Mo	MGM
Ni/Mo, Ni/Mo/Ni	—
	Ceramics
Alumina, Al_2O_3	—
Aluminum nitride, AlN	—

Alloys: Fe-Ni and Fe-Ni-Co

Generic name/description: **Fe-Ni alloys, 42-50% Ni**

Brand name/varieties: **Carpenter Low Expansion "45" [1] and Carpenter Glass Sealing "46" Gas Free [2]**

Vendors: Carpenter Technology Corporation

Parmatech Corporation

Multimaterial Molding (this vendor is no longer in business; data is included for comparison).

Type: Carpenter: Alloys of two metal elements. Parmatech & Multimaterial Molding: Microcomposite of metallic powders.

Primary: Controlled/matched thermal expansion.

Applications: Direct semiconductor chip and substrate attach; glass or ceramic feedthru sealing; flanges & carriers, package bases, machined packages.

[1] Carpenter also supplies High Permeability "45" with a similar composition.

[2] ASTM F-30

B. Mechanical

Vendor	Carpenter		Parmatech		Multimaterial
Material	Low Expansion "45" [1]	Glass Sealing "46"	42% Fe-Ni	50% Fe-Ni	50% Fe-Ni
Tensile strength MPa (ksi)	550 (80)	565 (82)	440-470 (64-68)	415-460 (60-67)	420 (61)
Yield strength MPa (ksi)	280 (40)	230 (34)	280 (40)	150-170 (22-25)	170 (25)
Elongation %	30	27	31	31-35	21
Modulus of elasticity GPa (Mpsi)	145 (21)	160 (23)	140 (20)		
Specific stiffness GPa-cm³/g	17 7	19 6	17 9		
Hardness	75 R_B	76 R_B	49 R_B	58-60 R_B 54-58 R_B HIP'ed [2]	

[1] Annealed

[2] Hot isostatic pressed

A. Metallurgical

Vendor	Carpenter		Parmatech		Multimaterial
Material	Low Expansion "45"	Glass Sealing "46"	42% Fe-Ni	50% Fe-Ni	50% Fe-Ni
Fabrication method	Typically vacuum melted alloying		Powder injection molding (PIM)		Powder injection molding (PIM)
Composition weight %	Fe: balance (~54) Ni: 45.00 ± 0 5	Fe: balance (~53) Ni: 46 00	Fe: balance (~58) Ni: 41 0-42.0	Fe: balance (~50) Ni: 50 0-51 0	Fe: balance Ni: 50%
Primary impurities/ minor constituents	C: 0 05% Mn: 0.50% Si: 0 25%	C: <0 05% Mn: 0 50% Si: 0 25% Ti: 0 20% Nb: 0 20%	C: 0 01% max as sintered Si: 0 17% maximum	C: 0 01% max Si: 0.15% max	
ASTM grain size				4 2 HIP'ed [1]	
Density g/cm³	8 17	8.17	7 80	8 10 (7 95 min) 8 30 ± 0 05 HIP'ed	8 04 96% of full density

[1] Hot isostatic pressed.

C. Thermal & Thermomechanical

Vendor		Carpenter [1][2]		Parmatech		Multimaterial
Material		Low Expansion "45"	Glass Sealing "46"	42% Fe-Ni	50% Fe-Ni	50% Fe-Ni
Melting point		1425°C	1425°C			
Thermal expansion 10^{-6}/K	25°C			4 0		
	25 - 100°C	7 81	7 10			
	25 - 200°C	7 49	7 37			
	25 - 300°C	7 23	7 50			
	25 - 350°C	7 19	7 44			
	25 - 400°C	7 19	7 43			
	25/30 - 450°C	7 78	7 91		9 35 9 56 HIP'ed	
	25/30 - 500°C	8 47	8 68		9 19 9 38 HIP'ed	
	25 - 600°C	10 41	10 02			
	25 - 700°C		10 99			
	25 - 800°C		11 82			
CTE inflection point [3]		≈ 420°C	≈ 430°C			
Specific heat J/g-K (BTU-lb/°F)		0 50 (0 12)	0 50 (0 12)			

[1] Thermal expansion test method ASTM E 228

[2] Thermal conductivity and thermal expansion are isotropic

[3] Due to magnetic effects, there is a change in the rate of thermal expansion around the Curie point

D. Electrical & Magnetic

Type: Conductor; ferromagnetic.

Vendor	Carpenter		Parmatech		Multimaterial [1]
Material	Low Expansion "45"	Glass Sealing "46"	42% Fe-Ni	50% Fe-Ni	50% Fe-Ni
Electrical resistivity μΩ-cm	55 @ RT	46 @ RT		50-60	
Electrical conductivity % IACS	3.1	3.7		3.4-2.9	
Curie Temperature	≈ 420°C	≈ 430°C			

[1] Multimaterial Molding 50% Fe-Ni, magnetic data: remanence Br 4.2 kgauss, saturation Bs 12.6 kgauss, ratio Br/Bs 0.3, coercive field Hc 0.2 oersted.

E. Forms & Sizes Available

Vendor	Carpenter		
Material	Low Expansion "45" and Glass Sealing "46"		
Forms	Strip (including deep-drawing, stamping, and coining; photo-etch quality available) and sheet	Plates	Wire, rod, bar (rectangular, square or round) or billets
Thickness	Typical ≈ 0.010" to ≈ 0.100	Up to ≈ 1"	0.010" diameter to 7" diameter or square
Width	Typical ≈ 1 foot	Up to ≈ 2 feet	
Length	Strip: continuous coil; sheet: ≈ 10 foot	Up to ≈ 8 to 10 feet	Wire continuous coil; other: up to 12 to 16 feet

Sizes given depend on product and are typical of standard products, a wider range is available.

Vendor	Parmatech	Multimaterial
Material	Fe-Ni	50% Fe-Ni
Forms	Net shape/near net shape	No longer in business
Thickness	< 0.5 inch (from economical considerations)	
Width	Weight from less than 0.1 gram up to a couple of hundred grams	
Length		
Surface finish	Mold surface finish: 16-32 RMS	

H. Post-Processing, Machining, Forming & Assembly

Machining or forming: Standard machining operations: milling, shaping, turning, boring, drilling, tapping and grinding. Carpenter: forming, deep drawing, stamping, coining; chemical milling (photoetching) possible (special grades available).

Plating: Ni; (Ni)/Au.

Feedthru installation types & methods: Carpenter Glass-Sealing "46" is suitable for direct glass sealing; see vendor's data sheets regarding procedures.

Lid/cover sealing materials & methods: Can be sealed by resistance seam welding.

I. Environmental properties

Carpenter Low Expansion "45" and Glass Sealing "46"are not considered corrosion resistant.

J. Other

Sources of data: Carpenter: vendor's data sheets, dated 3/63 and undated, vendor's brochure, ©1991; data has been reviewed by vendor. Parmatech: vendor's data sheets, undated. Multimaterial Molding: data sheet ©1987

Generic name/description: **ASTM F-15 Fe-Ni-Co alloy**

Brand name/varieties: **Sealvar™, Kovar®**

Vendors: Ametek, Specialty Metal Products Div. (brand name Sealvar™), UNS K94610; ASTM F-15-78; MIL-I-23011C, Class 1

Carpenter Technology Corporation (brand name Kovar®), UNS K94610; ASTM F-15-78; MIL-I-23011C, Class 1

Parmatech Corporation, ASTM F-15

Type: Alloy of three metal elements.

Primary features: Controlled/matched thermal expansion; glass and ceramic sealable.

Applications: Direct semiconductor chip and substrate attach, glass feedthru sealing, Flanges & carriers, package bases, machined packages.

A. Metallurgical

Vendor	Ametek	Carpenter	Parmatech
Material	Sealvar™ [1]	Kovar®	F-15 Fe-Ni-Co
Fabrication method	Wrought powder metallurgy, roll compaction	Vacuum melted alloying	Powder injection molding (PIM)
Composition weight %	Fe: balance (~54) Ni: 31.00 Co: 15.00	Fe: balance (~54) Ni: 29.00 Co: 17.00	Fe: balance (~54) Ni: 31.00 Co: 15.00
Primary impurities/ minor constituents %	C: 0.01 Zr: 0.001 Mg: 0.001 Ti: 0.001 Si: 0.05 Cu: 0.05 Mn: 0.07 Cr: 0.05 Al: 0.001 Mo: 0.001 all max	C: 0.02 max Mn: 0.30 Si: 0.20	C: 0.01 max Si: 0.2 max
Density g/cm^3	8.2	8.359	7.9

[1] Material is fully dense, no porosity even as thin as 0.002"

B. Mechanical

Vendor	Ametek	Carpenter	Parmatech
Material	Sealvar™ [1][2]	Kovar® [3]	F-15 Fe-Ni-Co
Tensile strength MPa (ksi)	505 (73)	517 (75)	
Yield point MPa (ksi)	345 (50) 0.2% offset	345 (50)	
Elongation %	30-35	30	
Modulus of elasticity GPa (Mpsi)	125 (18)	138 (20)	
Specific stiffness GPa-cm^3/g	15.2	16.5	
Hardness	150-160 HV DPH	68 R_B	70 R_B

[1] Specimen description: annealed to ASTM #8.0-9.5 grain size

[2] See vendor's data sheets for work hardening and temperature softening curves

[3] Specimen description: strip tested parallel to direction of rolling, annealed 999°C for 30 min FC
All data for room temperature.

C. Thermal & Thermomechanical

Vendor		Ametek	Carpenter	Parmatech
Material		Sealvar™ [1][2][3]	Kovar® [3][4][8]	F-15 Fe-Ni-Co
Melting point		approx. 1450°C	approx. 1450°C	
Thermal conductivity W/m-K (BTU-in/hr-ft²-°F)	25°C		17.3	
	38°C	21.3 (148)		
	200°C	21.9 (152)		
	300°C	23.5 (163)		
	400°C	25.2 (175)		
	500°C	27.4 (190)		
Thermal expansion 10^{-6}/K [5]	25/30 - 100°C	6.2	5.86	
	25/30 - 200°C	5.6	5.20	
	25/30 - 300°C	5.3	5.13	
	25/30 - 350°C		4.89	
	25/30 - 400°C	5.0 [6]	5.06	5.06
	25/30 - 450°C	5.4 [6]	5.25	5.25
	25/30 - 500°C	6.0	6.15	
	25/30 - 600°C	7.6	7.80	
	25/30 - 700°C	9.1	9.12	
	25/30 - 800°C	10.2	10.31	
	25/30 - 900°C	11.2	11.26	
Specific heat J/g-K (cal/gm/°C)	0°C	0.44 (0.105)		
	25°C		0.46 (0.11)	
	430°C	0.65 (0.155)		

[1] See vendor's data sheet for additional data on thermal conductivity and thermal expansion.

[2] Thermal expansion data for sample annealed in H at 900°C for 1 hour and cooled from 900°C to 200°C at a rate not exceeding 5°C/min.

[3] Thermal conductivity and thermal expansion are isotropic.

[4] Thermal expansion data for sample annealed in H at 900°C for 1 hour and at 1099°C for 15 min, and cooled to room temperature within 1 hour; test method is ASTM E-228

[5] Due to magnetic effects, there is a change in rate of thermal expansion around the Curie point, approx 435°C.

[6] Conforms to ASTM F-15-78 (83) specification for CTE within 4.60 to 5.20 for 30 - 400°C and within 5.10 to 5.50 for 30 - 450°C

D. Electrical & Magnetic

Type: Conductor; ferromagnetic [1].

Vendor		Ametek	Carpenter	Parmatech
Material		Sealvar™ [2]	Kovar® [1]	F-15 Fe-Ni-Co
Electrical resistivity μΩ-cm	RT/25°C	45.7	49	55
	200°C	72		
	300°C	86		
	400°C	95		
	480°C	102		
Curie temperature		~435°C	~435°C	

[1] See vendor's data sheet for details on magnetic properties of Kovar®

[2] See vendor's data sheet for additional data on electrical resistivity

E. Forms & Sizes Available

Vendor	Ametek	Parmatech
Material	Sealvar™	F-15 Fe-Ni-Co
Forms	Strip, coiled	Net shape/near net shape
Thickness	0.002 inch to 0.060 inch	< 0.5 inch (for economical considerations)
Width	Up to 12 inch	Weight from less than 0.1 gram up to a couple of hundred grams
Length	Continuous coil	
Flatness/camber	As required	
Surface finish	Rolled finish as specified, from mirror (<=1-2 microinch) up, standard ≈5-10 microinch	

Vendor	Carpenter		
Material	Kovar®		
Forms	Strip (including deep-drawing, stamping, and coining; photo-etch quality available) and sheet	Plates	Wire, rod, bar (rectangular, square or round) or billets
Thickness	Typical ≈ 0.010" to ≈ 0.100	Up to ≈ 1"	0.010" diameter to 7" diameter or square
Width	Typical ≈ 1 foot	Up to ≈ 2 feet	
Length	Strip: continuous coil, sheet: ≈ 10 foot	Up to ≈ 8 to 10 feet	Wire: continuous coil, other: up to 12 to 16 feet

Sizes given depend on product and are typical of standard products, a wider range is available.

F. Post-Processing, Machining, Forming & Assembly

Machining or forming: Standard machining operations: milling, shaping, turning, boring, drilling, tapping and grinding. Kovar® & Sealvar™: forming, deep drawing, stamping, coining, chemical milling (photoetching) possible (Kovar® is available in special photoetching grades). Parmatech: coining, grinding & stamping.

Plating: Ni; (Ni)/Au: Kovar® & Sealvar™ can be readily plated.

Feedthru installation types & methods: Sealvar™ and Kovar® are suitable for direct glass sealing; see vendor's data sheets regarding procedures.

Lid/cover sealing materials & methods: Can be sealed by resistance seam welding.

Feedthru installation types & methods: See vendor's data sheet regarding procedures.

G. Environmental properties

Kovar® is not considered corrosion resistant.

H. Other

Sources of data: Ametek: vendor's data sheets, ©1988; data has been reviewed by vendor. Carpenter: vendor's data sheet, dated 1991; data has been reviewed by vendor. Parmatech: vendor's data sheet, undated.

Metal Matrix Microcomposites

Generic name/description: **Ag/Invar®** metal-matrix microcomposite.

Brand name/varieties: **Silvar™**

Vendor: Texas Instruments, Metallurgical Materials Division

Primary features: Controlled/matched thermal expansion with high thermal conductivity.

Applications: Direct semiconductor chip and substrate attach. Flanges & carriers, heat spreaders, package bases, machined packages.

A. Metallurgical

Material	Silvar™
Fabrication method	Powder metallurgy; Ag is infiltrated into a sintered Invar® sponge
Composition volume %	Invar® balance Ag: 30 ± 1% [1]
Primary impurities/ minor constituents	Fe Ni. 0.5% max
Density g/cm^3	8.77

[1] Other compositions possible.

B. Mechanical

Material	Silvar™
Tensile strength MPa (ksi)	500 (73)
Yield strength MPa (ksi)	480 (70)
Elongation %	2.0
Modulus of elasticity GPa (Msi)	110 (15.9)
Specific stiffness GPa-cm^3/g	12.5
Hardness	55-60 R_B

C. Thermal & Thermomechanical

Material	Silvar™
Melting point	960°C
Maximum allowable temperature during processing (short term)	935°C
Maximum continuous use temperature	935°C
Thermal conductivity W/m·K	130 @ RT [1]
Thermal expansion 10^{-6}/K average 30°C to 150°C	5.6
Specific heat J/g·K	0.431 @ RT [2]

[1] Test method: laser flash diffusivity, ASTM C714

[2] Test method: drop calorimetry

Specimen for both tests: disk 0.5 inch diameter by 0.118 thick

D. Electrical & Magnetic

Type: Conductor; ferromagnetic.

Material	Silvar™
Electrical resistivity µΩ·cm	56 @ RT
Electrical conductivity % IACS	30 @ RT

E. Forms & Sizes Available

Material	Silvar™
Forms	Machined into finished parts
Thickness	Starting blank is 3/4" by 2" by 7" maximum.
Width	
Length	
Surface finish	8 microinch

F. Post-Processing, Machining, Forming & Assembly

Machining or forming: Standard machining operations: milling, shaping, turning, boring, drilling, tapping and grinding. Drawing, stamping, machining and forming are possible. Can be stress relieved.

Plating: Easily plated with Ni, Cu, Ag, Au by rack or barrel plating.

Brazing: Easily brazed at 800°C to 900°C, using BT braze.

Lid/cover sealing materials & methods: Easily machined or stamped into lids; laser weldable to Kovar®.

G. Environmental properties

Corrosion: a Ni diffusion barrier is recommended to prevent oxidation of Invar® constituent.

H. Other

Sources of data: Vendor's preliminary data sheet, revision A, dated 16 December 1991; additional data directly from vendor; information has been reviewed by vendor.

Generic name/description: **Al/Si matrix microcomposite**

Brand name/varieties: **CMSH; A-40**

Vendor: Sumitomo Electric U.S.A., Inc.

Type: Microcomposite.

Primary features: Reduced thermal expansion with high thermal conductivity. Low-density.

Applications: Direct semiconductor chip and substrate attach where good thermal conductivity is needed; high-power circuits. Flanges & carriers, package bases, machined packages, or heat sinks.

A. Metallurgical

Material	A-40
Fabrication method	Powder metallurgy, hot extruding or hot pressing
Composition weight %	Al: 60 Si: 40
Density g/cm^3	2.55 ± 0.03 [1]
Grain size	Si: 5–10 μm average

[1] ± indicates standard deviation.

B. Mechanical

Material	A-40 [3]
Fabrication method	Extruded or hot pressed
Tensile strength MPa	250
Modulus of elasticity GPa	100
Hardness	110 HV

[3] Thermal conductivity measured by laser flash method (specimen 10 mm diameter by 2 mm), thermal expansion per ASTM E 228-85 (specimen 3 x 3 x 19 mm).

C. Thermal & Thermomechanical

Material		A-40	
Fabrication method		Extruded	Hot pressed
Melting point temperature		577°C	
Maximum temperature during processing (short term)		530°C	
Thermal conductivity W/m·K [1][2]	25°C	126	
	100°C	138	
Thermal expansion 10^{-6}/K [3]	RT - 100°C	13.5	12.7
	RT - 200°C	14.2	13.8
	RT - 300°C	14.8	
	RT - 400°C	15.4	
Specific heat J/g·K		0.88	

[1] *For thermal conductivity data over the range 20°C to 400°C refer to vendor's data sheet*

[2] Thermal conductivity measured by laser flash method (specimen 10 mm diameter by 2 mm)

[3] Thermal expansion per ASTM E 228-85 (specimen 3 x 3 x 19 mm)

D. Electrical & Magnetic

Type: Conductor; non-magnetic.

Material	A-40
Electrical resistivity μΩ·cm	8.1
Electrical conductivity % IACS	21

E. Forms & Sizes Available

Material	A-40 [1][2]		
Forms	Billet	Rod	Round, hot pressed
Thickness	5, 5.5, 10 mm	35, 42, 55 mm diameter	150 mm diameter
Width	35, 70, 60 mm		
Length	250 mm	250 mm	140 mm

[1] Other sizes are available, contact vendor.

[2] Note: extruded A40 is encased in an Al skin parallel to the extrusion direction

F. Post-Processing, Machining, Forming & Assembly

Machining or forming: see vendor's data sheets regarding machining.

Note: pieces made by extrusion have residual stress; it can be relieved by annealing at 500°C for 1 hour followed by a slow cooldown.

Plating: Ni; Ni/Au; Ni/Ag; Cu
Pretreat with HNO_3, plate Zn, electroless zincate, 0.3-0.5 μm, followed by Ni (electro or electroless).

Soldering: possible after Ni plating; temperature must be below 530°C.

Lid/cover sealing materials & methods: an A-40 lid may be sealed directly using low-temperature glass frit, or it may be soldered after Ni plating; a Fe-Ni or Fe-Ni-Co lid may be welded if a similar seal ring is soldered to the housing.

G. Environmental properties

Corrosion is the same as Al.

H. Other

Source of data: Vendor's data sheets, dated 1990 and undated, data has been reviewed by vendor.

Generic name/description: **Aℓ/SiC matrix microcomposites**

Brand names/varieties: DWA: SiC40 MMC, SiC50 MMC, SiC55 MMC;
Lanxide: **PRIMEX™: MCX-622™, MCX-693™, NX-5201™, NX-5221™, NX-5251™, EPX-100™, EPX-200™**

Vendors: DWA Composite Specialties, Inc.

Lanxide Electronic Components L. P.

Primary features: Controlled/matched thermal expansion with high thermal conductivity. Low density.

Applications: Direct semiconductor chip and substrate at'.ch where good thermal conductivity is needed; high-power circuits. Packages, package bases, flanges & carriers, heat spreaders and sinks; machined or net-shape.

A. Metallurgical

Vendor	DWA		
Material	SiC40 MMC	SiC50 MMC	SiC55 MMC
Fabrication method	Powder metallurgy, hot pressing, followed by extrusion, rolling or forging		
Composition volume %	SiC: 40 ± 2 [1] Aℓ: balance	SiC: 50 ± 2 [1] Aℓ: balance	SiC: 55 ± 2 [1] Aℓ: balance
Material characteristics	Aℓ is 6061 or 6063	Aℓ is 6063	
Density g/cm^3	2 9	2 9	3 0

[1] Standard deviation.

Vendor	Lanxide PRIMEX™				
Material	NX-5201™	NX-5251™	MCX-693™	NX-5221™	MCX-622™
Fabrication method	Powder metallurgy; pressureless metal infiltration				
Composition volume %	SiC: ~60 Aℓ: balance	SiC: ~60 Aℓ: balance	SiC: 65 Aℓ: balance	SiC: ~70 Aℓ: balance	SiC: 70 Aℓ: balance
Density g/cm^3	2 95	3 0	3 0	3 00	3 0

B. Mechanical

Vendor	DWA		
Material	SiC40 MMC	SiC50 MMC	SiC55 MMC
Modulus of elasticity GPa (Msi)	140 (20)	170 (25)	190 (28)
Specific stiffness GPa-cm^3/g	46	59	63

Vendor	Lanxide PRIMEX™				
Material	NX-5201™	NX-5221™	MCX-693™	MX-5251™	MCX-622™
Tensile strength MPa (ksi)	210 (30 5)			234 (34)	
Yield strength MPa (ksi)				460 (66) 0 2% compressive	
Elongation %				0 3	
Flexural strength MPa (ksi)		210 (30 5)	300		300
Poisson's ratio			0 24		0 22
Modulus of elasticity GPa (Msi)	200 (29 0)	220 (31 9)	235	190 (27 6)	265
Specific stiffness GPa-cm^3/g	68	73	78	63	88
Fracture toughness MPa-m$^{1/2}$ (ksi-in$^{1/2}$)	10 (9 1)	8 (7 3)	9	12 (11)	10

C. Thermal & Thermomechanical

Vendor	DWA DWAL 20™		
Material	SiC40 MMC	SiC50 MMC	SiC55 MMC
Thermal conductivity W/m-K	130 190 [1]	200 minimum	200 minimum
Thermal expansion 10^{-6}/K @ RT	12.1	10.5	8.8

[1] 130 W/m-K is for 6061 Al, not optimized for high thermal conductivity; 190 is for 6063 Al.

Vendor		Lanxide PRIMEX™				
Material		NX-5201™	NX-5221™	MCX-693™	NX-5251™	MCX-622™
Thermal conductivity W/m-K	RT/22°C	160	160'	180	150	170
	200°C					134
Thermal expansion 10^{-6}/K	RT	8.5	7.1	6.5	9.5	6.0
	RT - 100°C			7.0		6.5
	RT - 200°C			7.4		7.0
	RT - 300°C			7.7		7.4
	RT - 400°C			7.8		

D. Electrical & Magnetic

Type: *Conductor; non-magnetic.*

Vendor	DWA DWAL 20™			Lanxide PRIMEX™				
Material	SiC40 MMC	SiC50 MMC	SiC55 MMC	NX-5201™	NX-5221™	MCX-693™	NX-5251™	MCX-622™
Electrical resistivity µohm-cm								
Electrical conductivity % IACS								

E. Forms & Sizes Available

Material	DWA				
Forms	Billets	Forged plate	Rolled sheet (developmental)	Extrusions	Finished parts
Thickness	20 to 65 pounds	0.250" to 1"	SiC40 MMC: 0.010" up SiC50 and SiC55 MMC 0.020" up	1/2"	
Width				3"	
Length				24"	
Flatness		0.001"/inch	0.001"/inch		
Surface finish			16 microinch rms		

Vendor	Lanxide PRIMEX™			
Material	MCX-622™, MCX-693™		EPX-100™	EPX-200™
Forms	Plate	Net-shape parts	Net-shape package shells (with or without feedthrus)	Carrier plates/flanges/ heat spreaders from NX-5201™, NX-5221™ or NX-5251™
Thickness	0.062", 0.080", 0.125"	Parts from 0.05" x 0.08" x 0.04 to 5" x 9" x .125" have been made; other sizes possible		Standard 0.040" thick, to 4" x 4". 0.060 to 0.250 thick to 6" x 6"
Width	6.5"/7.0"			
Length	7.0"/7.5"			
Flatness/ camber	0.001"/inch to 0.003"/inch depending on thickness, parallelism 0.0005"/inch			
Surface finish	As molded, typically 32 Ra, same when plated			

F. Post-Processing, Machining, Forming & Assembly

Machining: Aℓ/SiC is very abrasive; standard machining can be done using carbide or diamond tools or EDM (*wire or plunge/sinker*). DWA: Sheet can be stamped and cut with abrasive water jet or laser. Near-net shape forging is possible and squeeze casting is under development.

Plating: DWA: Iridite Ni/Au anb Ni/Sn. Lanxide: Ni (electroless); Ni/Au; Cu; Sn. Ni meets MIL-C-26074, Au meets MIL-G-45204. Anodizing or chromate conversion is possible.

Soldering: DWA: Plated Aℓ/SiC can be soldered with In alloy solders or Au/Sn, Au/Ge.

Feedthru installation types & methods: Lanxide: Ceramic and glass coaxial feedthrus (with eyelet) and planar cofired ceramic feedthrus have been installed by soldering (with appropriate plating). *Feedthrus integrated as part of the fabrication* (MCX-622™ *and* EPX-100™) *are a future possibility*. Contact vendor for further information.

Lid/cover sealing materials & methods: Welding of lids to Aℓ/SiC is still on an experimental basis. Lanxide: With appropriate plating, Fe-Ni lids have been soldered with Au/Sn. An Aℓ sealing band (free of SiC) can be formed on top of the sidewall *during fabrication* (EPX-100™), sufficiently thick to allow laser welding, rework and reseal; however, fabricating packages with this sealing band has not been economical.

G. Environmental properties

Corrosion: Lanxide MCX-622™ passes MIL-STD-883 salt-fog corrosion testing.

H. Other

Sources of data: DWA: vendor's data sheets, reference [BER--]. Lanxide: vendor's data sheets, *some copyrighted* 1989 *and* 1990, *some undated*; [WHI90] D. White, S. Keck, I. Smith and A. Silzars: "New High Ground in Hybrid Packaging" **Hybrid Circuit Technology**, Dec. 1990

Generic name/description: **Dispersion strengthened Cu**; AL-15 (UNS: C15715) grade is recommended for hybrid circuit package components.

Pure Cu matrix with fine aluminum-oxide particles dispersed throughout.

Brand name: **GlidCop®**

Vendor: SCM Metal Products, Inc.

Features: High strength, resistance to softening from high-temperature exposure, high electrical and thermal conductivities.

Applications: Where high strength after high temperature exposure (e.g. brazing) is required, or high strength with high electrical and/or thermal conductivity.

For applications requiring brazed joints and/or high temperature exposure in hydrogen containing atmospheres or vacuum, (LOX) GlidCop®, a low oxygen grade is also available and recommended.

A. Metallurgical

Material	GlidCop® AL-15
Fabrication method	Powder metallurgy, followed by hot consolidation and cold forming
Composition weight %	Cu: balance, 99.7 Al_2O_3: 0.3 [1]
Primary impurities/ minor constituents weight %	O: typical 0.04% low-oxygen grade available [2]
Density g/cm^3	8.90

[1] At determined by wet chemical analysis of atomized powder prior to internal oxidation; B determined by induction coupled plasma technique on finished product.

[2] Low-oxygen GlidCop® contains nominally 250 ppm B (the "free" oxygen is tied up as B_2O_3). Low-oxygen test: *SCM Metal Products Hydrogen Embrittlement Test* on finished product, modified ASTM F68 section 10.5

B. Mechanical

Material	GlidCop® AL-15 [1]
Tensile strength MPa	365-661 [2]
Yield strength MPa	255-613
Elongation %	1-27
Modulus of elasticity GPa	130 [3]
Specific stiffness $GPa\text{-}cm^3/g$	14.6
Hardness	62-72 R_B [4]

[1] Values for typical products, depends on product, see vendor's data sheets.

[2] ASTM E8, specimen 12.5 mm wide, 50.0 mm gage length.

[3] Ultrasonic, specimen 12.5 mm diameter and 12.5 x 12.5 mm bars.

[4] ASTM E18, specimen 10 mm x 10 mm x 6 mm, measured on face transverse to extrusion direction

C. Thermal & Thermomechanical

Material		GlidCop® AL-15
Melting point		1083°C
Maximum allowable temperature during processing (short term)		1030°C [1]
Maximum continuous use temperature		980°C [2]
Thermal conductivity W/m·K	20°C	365 [3]
	100°C	352
	200°C	338
	300°C	330
	400°C	324
Thermal expansion $10^{-6}/K$	25 - 200°C	17.7
	25 - 300°C	18.1
[4]	25 - 500°C	19.0
	25 - 600°C	19.6
	25 - 800°C	20.4
	25 - 1000°C	21.2
Specific heat J/g·K		0.391 [5]

[1] Strength levels will be near the lower ends of the ranges shown in preceding table

[2] As long as stress levels are below the yield strength at temperature

[3] Measured by heating one end of a rod (16 mm diameter x 100 mm long) and measuring temperature gradient along the length

[4] ASTM E228-85, specimen 6.4 mm diameter x 50 mm long

[5] Perkin Elmer DSC2 Differential Scanning Calorimeter

D. Electrical & Magnetic

Type: Conductor, non-magnetic.

Material		GlidCop® AL-15
Electrical resistivity μΩ·cm		1.86
Electrical conductivity % IACS [(μΩ·cm)$^{-1}$]	20°C	93 (0.538)
	200°C	50
	400°C	38

E. Forms & Sizes Available

Material	GlidCop® AL-15 [1]				
Forms	Plate	Strip and strip reroll	Bar and rod	Wire and wire redraw	Rounds
Thickness	18-75 mm	0.10-20 mm	3-75 mm diameter	0.25-3 mm diameter	To 1000 mm diameter
Width					

[1] *Most forms available with or without oxygen-free Cu cladding*

F. Post-Processing, Machining, Forming & Assembly

Plating: Cu or Ni electroplating; a cleaning procedure is required for good adhesion; Cu strike is recommended prior to Ni plating. Recommended plating baths: Ni--acid Watts; Cu--acid Cu sulfate or Cu cyanide. For details see vendor's technical literature

Brazing: Brazing is possible with many braze materials; however, because GlidCop® has a finer grain structure than conventional Cu, diffusion of the braze material into the part is rapid (especially for Ag). Thus in many cases a Ni or Cu plating is recommended before brazing. However, for Au-based brazing plating may not be necessary; if wetting is a problem, Cu plating is recommended. Ni plating can cause brittle layers/joints. For brazing under reducing atmospheres, the low oxygen grade is recommended. See vendor's technical literature for details and recommended brazing practices.

G. Environmental properties

H. Other

Special safety precautions: None

Sources of data: Vendor's data sheets dated 1 August 1989, 10 May 1989, 10 January 1990, brochure ©1988, Material Safety Data Sheet dated 1 April 1989, data has been reviewed by vendor.

Generic name/description: **Mo/Cu composites and metal-matrix microcomposites**

Brand name/varieties: **AMC 8515, AMC 8020, AMC 7525; Thermkon®: Thermkon® 65M, *Thermkon® 70M*; *CMSH*: *CM-10, CM-15, CM-20***

Vendors: Ametek

CMW Inc.

Sumitomo Electric U.S.A., Inc.

Primary features: Controlled/matched thermal expansion with high thermal conductivity.

Applications: Direct semiconductor chip and substrate attach where good thermal conductivity is needed; high-power circuits. Flanges & carriers, package bases, machined packages, or heat sinks.

A. Metallurgical

Vendor	Ametek [1]			CMW Thermkon®		Sumitomo CMSH [2]		
Material	AMC 8515	AMC 8020	AMC 7525	65M [3]	70M [3]	CM-10	CM-15	CM-20
Fabrication method	Wrought powder metallurgy, roll compaction			Powder metallurgy, infiltration [4]		Powder metallurgy, infiltration		
Composition weight %	Mo: 85 Cu: 15	Mo: 80 Cu: 20	Mo: 75 Cu: 25	Mo: 85 Cu: 15	Mo: 80 Cu: 20	Mo: 89 Cu: 11	Mo: 85 Cu: 15	Mo: 80 Cu: 20
Density g/cm^3 [5]	10.01 (10.00 calc)	9.94 (9.94 calc)	9.90 (9.87 calc)	9.92	9.85	10.10	10.01	9.94

[1] Parts are fully dense and section as thin as 0.010" are hermetic.

[2] Mo grain size 5–10 μm average ; density 99.5% of theoretical; porosity is not connected—hermetic as thin as 0.5 mm

[3] Test methods. chemistry, ASTM E31, density, ASTM B311, room temperature

[4] Grain size and distribution: mixture of 1 μm to 10 μm particles. Porosity is nominally 0.75 volume percent of infiltrant.

[5] Density calculation based on Mo @ 10.22 g/cm^3, Cu @ 8.94 g/cm^3.

B. Mechanical

Vendor	Ametek			CMW Thermkon®		Sumitomo CMSH [1]		
Material	AMC 8515	AMC 8020	AMC 7525	65M	70M	CM-10	CM-15	CM-20
Tensile strength MPa ($\times 10^3$ psi)			570 (82.5)	725 (105)	690 (100)	480	540	490
Yield strength MPa ($\times 10^3$ psi)			535 (77.7)	655 (95)	620 (90)			
Elongation %			2			840	1,180	980
Flexural strength MPa ($\times 10^3$ psi)				1140 (165)	1100 (160)			
Modulus of elasticity GPa				250 (36 Mpsi)	240 (35 Mpsi)		284 (29×10^3 kg/mm^2)	275 (28×10^3 kg/mm^2)
Specific stiffness $GPa\text{-}cm^3/g$				25.2	24.4		28.4	27.7
Hardness				95 R_B	90 R_B	170 HV	150 HV	140 HV

[1] Specimen sizes: tensile strength, 6.25 mm diameter by 16 mm (parallel part) transverse rupture, 3 mm by 4 mm, length between fulcrums 20 mm; modulus of elasticity, 10 mm by 10 mm

C. Thermal & Thermomechanical

Vendor		Ametek [1][2]			CMW Thermkon® [3]		Sumitomo CMSH [3][4]		
Material		AMC 8515	AMC 8020	AMC 7525	65M	70M	CM-10	CM-15	CM-20
Melting point					1050°C				
Maximum temperature during processing (short term)							900°C	900°C	900°C
Thermal conductivity W/m·K	RT/25°C	165	175	185	135	145	170	160	170
	100°C						166	180	192
Thermal expansion $10^{-6}/K$	RT - 400°C						6.5	7.0	8.1
	30 - 150°C	6.5	7.1	7.7					
	-100 - 500°C				6.0 [5]	6.5 [5]			
Specific heat J/g·K (cal/g·K)							0.272 (0.065)	0.276 (0.066)	0.280 (0.067)

[1] Specimen for thermal expansion is 1/4" by 2"

[2] Thermal conductivity is isotropic to ±5, thermal expansion is isotropic to ±0.2

[3] Thermal conductivity and thermal expansion are isotropic

[4] Thermal conductivity measured by laser flash method (specimen 10 mm diameter by 2 mm), thermal expansion per ASTM E 228-85 (specimen 3 x 3 x 19 mm)

[5] Thermal expansion is close to linear over this range

D. Electrical & Magnetic

Type: Conductor; non-magnetic.

Vendor	Ametek			CMW Thermkon®		Sumitomo CMSH		
Material	AMC 8515	AMC 8020	AMC 7525	65M	70M	CM-10	CM-15	CM-20
Electrical resistivity μΩ-cm			5.1 @ 22°C	6.2 @ RT	5.4 @ RT	5	5.3	
Electrical conductivity % IACS			34 @ 22°C	28 @ RT	32 @ RT	34	33	

E. Forms & Sizes Available

Vendor	Ametek	CMW	Sumitomo	
Material	AMC 8515, AMC 8020, AMC 7525	Thermkon® 65M & 70M	CMSH CM-10	CMSH CM-15 and CM-20
Forms	Coupons or parts	Coupons/billets	Coupons/billets	
Thickness	1.5 mm (0.060 inch) max	From ~0.025" to ~1"	*1 mm to 5 mm max*	
Width	127 mm (5 inch) max	From 2 inch x 2 inch to 4 inch x 4 inch maximum, depending on part	2.3 inch x 2.3 inch maximum	4 inch x 4 inch maximum
Length	300 mm (12 inch) max			
Flatness/ camber	As required	0.0006 inch typical	10 μm/10 mm for thickness < 0.5 mm 5 μm/10 mm for thickness > 0.5 mm	
Surface finish	As required	As sintered, ~125 microinch rms, usually ground or machined as required	Rmax = 4 μm	

F. Post-Processing, Machining, Forming & Assembly

Machining or forming: Ametek & CMW: *Standard machining operations—milling, shaping, turning, boring, drilling, tapping and grinding.* Avoid notches and sharp corners if possible. See vendor's data sheets for additional information. Ametek: flat parts can be stamped, but forming is not possible due to lack of ductility. Sumitomo: *Can be machined with carbide tools, or ground with an alumina wheel.*

Plating: Ni; Ni/Au; Ni/Ag. Ametek: Mo/Cu can be plated. CMW can be electroless plated with Ni. Sumitomo: Can be plated with Ni, electro (Watt's) or electroless (Ni-P); refer to vendor's literature for recommended procedures.
Specifications/qualification testing: CMW: Au meets MIL-G-45204C for purity, thickness, hardness, and easy soldering and brazing; also passes 15 min @ 420°C bake after plating.

Brazing: Sumitomo: Ni plated CMSH can be brazed to metals or metallized ceramics, 72%Ag/28%Cu at 800-900°C suggested by vendor.

Feedthru installation types & methods: Sumitomo: Glass feedthrus may be directly fired in.

Lid/cover sealing materials & methods: Sumitomo. By soldering or brazing, with suitable plating (for example Ni/Au).

G. Environmental properties

Corrosion: CMW: same as Cu. Sumitomo: oxidation same as Cu alloy.

H. Other

Sources of data: Ametek: preliminary data sheet, undated; data has been reviewed by vendor. CMW: vendor's data sheet, ©1991; data has been reviewed by vendor. Sumitomo: vendor's data sheets, dated April 1988 and 1990, data has been review by vendor.

Generic name/description: **W/Cu metal-matrix microcomposites**

Brand name/varieties: **Thermkon®; Thermkon® 62, Thermkon® 68, Thermkon® 76, Thermkon® 83; CMSH: W-10, W-15, W-20**

Vendors: CMW Inc.

Sumitomo Electric U.S.A., Inc.

Primary features: Controlled/matched thermal expansion with high thermal conductivity.

Applications: Direct semiconductor chip and substrate attach where good thermal conductivity is needed; high-power circuits. Flanges & carriers, package bases, machined packages, or heat sinks.

A. Metallurgical

Vendor	CMW Thermkon® [1][2]				Sumitomo CMSH [3][4]		
Material	62	68	76	83	W-10	W-15	W-20
Fabrication method	Powder metallurgy, infiltration				Powder metallurgy, infiltration		
Composition weight %	W: 90 Cu: 10	W: 85 Cu: 15	W: 80 Cu: 20	W: 75 Cu: 25	W: 89 Cu: 11	W: 85 Cu: 15	W: 80 Cu: 20
Density g/cm³	17.17	16.31	15.56	14.84	17.00	16.40	15.65

[1] Test methods: chemistry, ASTM E31; density, ASTM B311; room temperature.

[2] Grain size and distribution: mixture of 1 μm to 10 μm particles. Porosity is nominally 0.75 volume percent of infiltrant.

[3] Hermetic as thin as 0.5 mm.

[4] W grain size 5–10 μm average; density 99.5% of theoretical.

B. Mechanical

Vendor	CMW Thermkon® [illegible]				Sumitomo CMSH [illegible]		
Material	62	68	[illegible]	83	W-10	W-15	W-20
Tensile strength MPa (ksi)	860 (125)	830 (120)	[illegible] (115)	690 (100)	560	530	490
Yield strength MPa (kpsi)	800 (116)	720 (105)	610 (89)	520 (76)			
Elongation % in 1 inch	0.5	0.5	1.5	1.5			
Modulus or rupture in bending GPa	1.24	1.21	1.17	1.03			
Transverse rupture strength MPa					1,060	1,200	1,330
Flexural strength MPa (ksi)	1240 (180)	1210 (175)	1170 (170)	1030 (150)			
Modulus of elasticity GPa (Mpsi)	255 (37)	250 (36)	240 (35)	235 (34)	330	310	280
Specific stiffness GPa-cm³/g	14.8	15.3	15.4	15.8	19.4	18.9	18.0
Hardness	27 R_C	25 R_C	103 R_B	98 R_B	300 HV	280 HV	260 HV

[1] Specimen sizes: tensile strength, 6.25 mm diameter by 16 mm (parallel part); transverse rupture, 3 mm by 4 mm, length between fulcrums 20 mm, modulus of elasticity, 10 mm by 10 mm by 10 mm.

C. Thermal & Thermomechanical

Vendor		CMW Thermkon® [1]				Sumitomo CMSH [1][2][3]		
Material		62	68	76	83	W-10	W-15	W-20
Melting point temperature or temperature limitation		1050°C						
Thermal conductivity W/m-K	25°C	157	167	180	190	180	190	200
	100°C					176	183	177
Thermal expansion 10^{-6}/K	25°C				8.3	6.5	7.2	8.3
	-100 - 500°C [4]	5.7	6.5	7.6	8.3			
Specific heat J/g-K (cal/g-K)		0.149	0.163	0.178	0.192	0.163 (0.039)	0.172 (0.041)	0.184 (0.044)

[1] Thermal conductivity and thermal expansion are isotropic

[2] For thermal conductivity data between 0°C and 300°C, see vendor's data sheet

[3] Thermal conductivity measured by laser flash method (specimen 10 mm diameter by 2 mm) thermal expansion per ASTM E 228-85 (specimen 3 x 3 x 19 mm)

[4] Thermal expansion of Thermkon® is close to linear (CTE is close to constant) over this temperature range

D Electrical & Magnetic

Type: Conductor; non-magnetic.

Vendor	CMW Thermkon®				Sumitomo CMSH		
Material	62	68	76	83	W-10	W-15	W-20
Electrical resistivity μΩ·cm	5.4	4.9	4.2	3.8	5.3		4.0
Electrical conductivity % IACS	32	35	41	45	33		43

E. Forms & Sizes Available

Vendor	CMW	Sumitomo
Material	Thermkon® 62, 68, 76, 83	CMSH W-10, W-15, W-20
Forms	Coupons/billets	Coupons/billets
Thickness	From ≈0.025" to ≈1"	1 mm to 5 mm max
Width / Length	From 2 inch x 2 inch to 4 inch x 4 inch maximum, depending on part	4 inch x 4 inch maximum
Flatness/camber	0.0006 inch typical	10 μm/10 mm for thickness < 0.5 mm 5 μm/10 mm for thickness > 0.5 mm
Surface finish	As sintered, ≈125 microinch rms, usually ground or machined as required	Rmax = 4 μm

F. Post-Processing, Machining, Forming & Assembly

Machining or forming: CMW: Standard machining operations—milling, shaping, turning, boring, drilling, tapping and grinding. Avoid notches and sharp corners if possible. See vendor's data sheets for additional information. Sumitomo: can be machined with carbide tools, or ground with an alumina wheel.

Plating: Ni; Ni/Au; Ni/Ag; Sumitomo: Can be plated with Ni, electro (Watt's) or electroless (Ni-P); *refer to vendor's literature for recommended procedures.*

Specifications/qualification testing: CMW: Au meets MIL-G-45204C for purity, thickness, hardness, and easy soldering and brazing; also passes 15 min @ 420°C bake after plating.

Brazing: Sumitomo: Ni plated CMSH can be brazed to metals or metallized ceramics, *72%Ag/28%Cu at 800-900°C suggested by vendor.*

Feedthru installation types & methods: Sumitomo: Glass feedthrus may be directly fired in

Lid/cover sealing materials & methods: Sumitomo: By soldering or brazing, with suitable plating (for example Ni/Au).

G. Environmental properties

Corrosion: CMW: same as Cu. Sumitomo: Oxidation like Cu alloy.

H. Other

Sources of data: CMW: vendor's data sheets, ©1984 and ©1991; data has been reviewed by vendor. Sumitomo: vendor's data sheets, dated April 1988 and 1990, data has been reviewed by vendor.

Generic name/description: **Cu/Mo/Cu** clad metal sheet

Brand name/varieties: **CMC13, CMC20**

Vendors: Climax Specialty Metals

Metallwerk Plansee GmbH/Schwartzkopf Technologies Corp.

Type: Metal; three layer sheet with Mo in center and clad with Cu on both sides (single-side cladding also available).

Features: Controlled/matched thermal coefficient of expansion (parallel to sheet), with good thermal conductivity, and a surface which is easily plateable and attachable.

Applications: Direct semiconductor chip and substrate attach where good thermal conductivity is needed; high power circuits. Flanges & carriers, package bases, heat spreaders.

A. Metallurgical

Vendor	Climax [1]					Plansee	
Material						CMC13	CMC20
Fabrication method	Lamination; hot roll bonding/cladding					Roll bonding/cladding	
Composition thickness % [2]	Cu: 5 Mo: 90 Cu: 5	Cu: 13 Mo: 74 Cu: 13	Cu: 20 Mo: 60 Cu: 20	Cu: 25 Mo: 50 Cu: 25	Cu: 33⅓ Mo: 33⅓ Cu: 33⅓	Cu: 13 Mo: 74 Cu: 13	Cu: 20 Mo: 60 Cu: 20
Material characteristics	Mo: 99.95% minimum; Cu: CDA101						
Density g/cm^3 [3]	10.09	9.89	9.71	9.58	9.37	9.87	9.69

[1] Standard compositions; custom compositions available.

[2] Cu percentage may vary ±2% (per side for Climax, total for Plansee) from these values.

[3] Calculated by rule of mixtures, using Cu @ 8.94 g/cm^3 and Mo @ 10.22 g/cm^3.

D. Electrical & Magnetic

Type: Conductor; non-magnetic.

Vendor		Climax					Plansee	
Material		5/90/5	13/74/13	20/60/20	25/50/25	33/33/33	13/74/13	20/60/20
Electrical resistivity μΩ-cm	-55°C		2.3	2.2	2.0	1.6		
	20°C		3.8	3.4	3.0	2.5	3.41 [1]	2.88 [1]
	125°C		5.2	4.7	4.0	3.2		
Ac surface resistance		Assumed to be that of Cu CDA101 subjected to processing					Assumed to be that of Cu subjected to processing	
Magnetic susceptibility		-2×10^{-6} to -10×10^{-6} cgs [2]					5.2×10^{-6} @ 20°C	

[1] Longitudinal

[2] See vendor's literature for details

B. Mechanical

Vendor	Climax					Plansee	
Material	5/90/5	13/74/13	20/60/20	25/50/25	33/33/33	13/74/13	20/60/20
Tensile strength MPa	760/785	660/690	565/600	495/525	345/365		
(ksi) [1]	(110/114)	(96/100)	(82/87)	(72/76)	(50/53) [2]		
Yield strength (0.2%) MPa	660/690	580/605	495/525	420/455	260/285		
(ksi) [1]	(96/100)	(84/88)	(72/76)	(61/66)	(38/41) [2]		
Elongation	13%/74%/13% data 0.020" thick: 11-15% longitudinal, 8-11% transverse 0.040" thick: 12-16% longitudinal, 9-12% transverse						
Modulus of elasticity GPa	303	269	241	220	186		228 [3][4]
Specific stiffness GPa-cm^3/g	30.2	27.3	24.7	23.0	19.7		23.5

[1] Lower value is transverse, higher value is longitudinal

[2] Extrapolated

[3] Longitudinal (Z), measured by ultrasonic technique

[4] It is recommended that the moduli of single components be used for modelling, Mo: 320, Cu: 135 @ 20°C; *see [KLE-]*.

C. Thermal & Thermomechanical

Vendor		Climax [1]					Plansee	
Material		5/90/5	13/74/13	20/60/20	25/50/25	33/33/33	13/74/13	20/60/20
Maximum use temperature		900°C						
Thermal conductivity W/m-K	X,Y	166	208	242	268	311	208	244
	Z	151	170	194	213	251	170	191
Thermal expansion coefficient 10^{-6}/K Average -55°C to +125°C		5.1 nearly constant	5.7 slight decrease with temp	6.5 decrease above 25°C	7.3 decrease above 25°C	8.6 decrease above 25°C	6.1/6.6 [2]	7.0/7.7 [2]
Specific heat J/g-K [3]		0.26	0.28	0.29	0.31	0.33	0.28	0.30

[1] For data over the temperature range 125°C to 900°C, refer to vendor's data sheets. CTE is fairly constant over this temperature range, ranging between approximately 5.2×10^{-6} K (for 5/90/5) to 6.4×10^{-6}/K (for 33/33/33)

[2] Longitudinal (Z), during thermal cycling; includes hysteresis, see [KLE-]

[3] Climax: Average -55°C to +125°C, Plansee: 20°C

E. Forms & Sizes Available

Vendor	Climax	Planseè [1]	
Material	Cu/Mo/Cu	CMC13, CMC20 Cu/Mo/Cu	
Forms	Sheet & foil	Standard foils	Foils and sheets
Thickness	0.001" to 0.250" [2]	13/74/13: 0.1, 0.15 ± 0.010 mm 20/60/20: 0.5, 0.6 ± 0.028 mm	13/74/13: 0.07, 0.10, 0.15, 0.5, 0.6 mm
Width	12" to 24" maximum, depending on thickness	240 x 320 mm	240 to 304.8 mm, depending on thickness
Length	8' to 35' depending on thickness		Approximately 6 to 10 m depending on material and thickness
Flatness	From 0.001"/inch to 0.010"/inch depending on product and size		
Surface finish	For thickness less than 0.010": 0.38 μm (15 microinch) maximum, for thickness 0.010" and above: 0.76 μm (30 microinch) maximum		

[1] Other dimensions by request; contact vendor.

[2] Thicknesses outside this range available on custom basis.

H. Post-Processing, Machining, Forming & Assembly

Machining or forming: Material may be drilled, stamped, sheared, drawn and bent. Care is needed to avoid delamination and excessive smearing of Cu. Chemical milling (photoetching) is also possible. See vendor' data sheets for detailed information on chemical milling of Climax materials.

Plating: Ni; (Ni/Au; Ni/Ag, ...). Assumed similar to Cu. Note: a different process will be used for plating exposed Mo (for holes or edges). See Climax data sheets for recommended processes.

Brazing: Cu/Mo/Cu has been successfully brazed to Al_2O_3, BeO, and Kovar®; for each material there is a recommended Cu to Mo thickness ratio. InCuSil is recommended, other braze materials can be used. Care is needed in the process to avoid bowing. See Climax data sheets for recommended processes.

Feedthru installation types & methods: Not applicable.

Lid/cover sealing materials & methods: Not applicable.

I. Environmental properties

J. Other

Sources of data: Climax: vendor's data sheets and brochure, some dated 1990, some undated, data has been reviewed by vendor. Plansee: vendor's data brochure, undated, data has been reviewed by vendor.

Generic name/description: **Mo/graphite/Mo**; three layer sheet with graphite in center and clad with Mo on both sides.

Brand name: MGM

Vendor: Texas Instruments, Industrial Materials Dept.

Plansee/Schwarzkopf Technologies Corp

Features: Controlled/matched thermal coefficient of expansion (parallel to sheet), with good thermal conductivity, high strength and low density.

Applications: Direct semiconductor chip and substrate attach where good thermal conductivity is needed; high-power circuits. Flanges & carriers, package bases, heat spreaders.

A. Metallurgical

Material	MGM Mo/graphite/Mo
Fabrication method	High-temperature vacuum brazing [1]
Composition thickness % [2]	Mo 10 to 25 C 80 to 50 Mo 10 to 25
Primary impurities/ minor constituents	Titanium carbides at brazed interfaces
Density g/cm^3	3.9 to 5.9

[1] Mo sheets are bonded to graphite using a high-temperature vacuum brazing process

[2] MGM is fabricated with total thickness from 0.040 inch to 0.100 inch; each Mo layer is 0.010 inch thick, thus the ratio ranges from 10/80/10 for 0.100 inch thick MGM to 25/50/25 for 0.040 inch thick MGM

B. Mechanical

Material	MGM Mo/graphite/Mo [1]
Tensile strength MPa	90 to 160
Yield strength MPa	80 to 120
Elongation %	<0.2 graphite [2] >5 Mo
Fatigue strength MPa	52 [3] 35 [4]
Modulus of elasticity GPa	79 at 20°C
Bending modulus GPa	220 @ 20°C
Specific stiffness $GPa\cdot cm^3/g$ $(MPa\cdot m^3/kg)$	20.8
Hardness	140 to 380 HV 10
Bonding strength MPa	25 [5]

[1] Measured mean values for 0.1" x 6" x 6" plate of 10/80/10 MGM

[2] During tensile testing graphite fractures near yield point

[3] Four-point bend test ($N_{max} = 1 \times 10^7$)

[4] Push-pull test ($N_{max} = 1 \times 10^8$)

[5] Tensile between Mo sheets and central graphite plate

C. Thermal & Thermomechanical

Material		MGM Mo/graphite/Mo [1]
Maximum allowable temperature during processing (*short term*)		1600°C
Maximum continuous use temperature		300°C in air, 1000°C in inert, non-oxidizing environment
Thermal conductivity W/m-K	X,Y	110
	Z	130
Thermal expansion 10^{-6}/K -180°C to +400°C		4 8
Specific heat J/g-K		0 61

[1] Measured mean values for 0.1" x 6" x 6" plate of 10/80/10 MGM

D. Electrical & Magnetic

Type: Conductor; non-magnetic.

Material	MGM Mo/graphite/Mo
Electrical resistivity μΩ-cm	24 4 @ 27°C
Electrical conductivity % IACS	7 1 @ 27°C
AC surface resistance	Assumed to be that of Mo subjected to processing

E. Forms & Sizes Available

Material	MGM Mo/graphite/Mo
Forms	Sheet & foil
Thickness	1 to 2 54 mm (0 040" to 0.1") ± 0 004"
Width	4", 6" or 9" ± 0 250"
Length	4", 6" or 7" ± 0 250"
Flatness	0 002"/inch
Surface finish	≤ 16 microinch

H. Post-Processing, Machining, Forming & Assembly

Machining or forming: Can be machined with standard carbide tools; consult the vendor for recommendations.

Plating: Assumed similar to Mo. Note: a different process will be used for plating exposed C (for holes or edges). Ni, Cr, Al, Cu can be deposited by electroplating, ion vapor deposition, or enhanced ion plating.

Feedthru installation types & methods: Not applicable

Lid/cover sealing materials & methods: Not applicable.

I. Environmental properties

Corrosion: Mo and graphite are galvanically compatible, thus corrosion protection (Ni plating, for example) is not necessary. Testing under MIL-STD-202F (method 101D and 106E) shows that MGM is compatible with salt fog and cyclic high temperature and humidity environments.

J. Other

Source of data. Vendor's preliminary data sheet, dated 1991; additional data directly from *vendor; data has been reviewed by vendor*

Generic name/description: **Ni/Mo or Ni/Mo/Ni** clad metal sheet

Vendor: Climax Specialty Metals

Type: Metal; Mo sheet clad with Ni on one or both sides.

Features: Low thermal coefficient of expansion (parallel to sheet) with good thermal conductivity and surface which is easily plateable and attachable.

Applications: Direct semiconductor chip and substrate attach where good thermal conductivity is needed; high-power circuits. Flanges & carriers, package bases, heat spreaders.

A. Metallurgical

Material	Ni/Mo	Ni/Mo/Ni	
Fabrication method	Lamination; roll bonding/cladding.		
Composition, thickness %	Ni: 5 Mo: 95	Ni: 2.5 Mo: 95 Ni: 2.5	Ni: 5 Mo: 90 Ni: 5
Material characteristics	Mo: high purity, Ni: commercially pure wrought.		
Density g/cm³ [1]	10.15	10.15	10.08

[1] Calculated, using Ni @ 8.85 g/cm³ and Mo @ 10.22 g/cm³

B. Mechanical

Material	5/95	2.5/95/2.5	5/90.5
Tensile strength MPa (ksi) [1]		760/800 (110/116)	
Yield strength (0.2%) MPa (ksi) [1]		620/690 (90/100)	
Elongation	20% longitudinal, 5% transverse		
Reduction of area	18% longitudinal, 7% transverse		
Modulus of elasticity GPa (x 10⁶ psi)		340 (49)	
Specific stiffness GPa-cm³/g		34	

[1] Lower value is longitudinal, higher value is transverse

C. Thermal & Thermomechanical

Material	5/95	2.5/95/2.5	5/90.5
Thermal expansion 10^{-6}/K Average -55°C to +125°C [1]		5.25	5.4

[1] CTE is fairly constant over this temperature range

D. Electrical & Magnetic

Type: Conductor.

Material	5/95	2.5/95/2.5	5/90/5
Electrical resistivity			
Electrical conductivity			
Ac surface resistance	Assumed to be that of Ni subjected to processing		

E. Forms & Sizes Available

Material	Ni/Mo and Ni/Mo/Ni
Forms	Sheet & foil
Thickness	0.038 mm (0.0015") to 6.35 mm (0.25")
Width	Thickness 0.127 mm (0.005") and less: to 305 mm (12") Thickness 0.127 mm (0.005") and above: to 610 mm (24")

H. Post-Processing, Machining, Forming & Assembly

Plating: Assumed to be the same as Ni. Note: a different process will be used for plating exposed Mo (for holes or edges).

Feedthru installation types & methods: Not applicable.

Lid/cover sealing materials & methods: Not applicable.

I. Environmental properties

J. Other

Sources of data: Climax: vendor's data sheet, undated; data has been reviewed by vendor

Ceramics

Generic name/description: **Aluminum Nitride, polycrystalline AlN ceramic**

Vendors: CeraTronics (brand names/varieties: K-70, K-170, K-200)

CPS

Coors/W.R. Grace & Company/Interamics

Kyocera

Sumitomo

Primary features: Matched thermal expansion; high thermal conductivity. A insulator/dielectric material that can be metallized.

Applications: Substrates, thin film networks, direct Si chip attach, package bases, cofired packages or cofired substrates.

A. Metallurgical

Vendor	CeraTronics	Coors	CPS	Kyocera	Sumitomo
Fabrication method	Tape casting and sintering		Injection molding; brand name Quicksel™		
Density g/cm^3	3.28	3.25-3.26	3.30	3.3	3.26
Color		Translucent grey	Light gray		
Alpha particle flux		<0.05 a/cm^2/hr		0.007±0.001 CPH/cm^2	

B. Mechanical

Vendor	CeraTronics	Coors	CPS	Kyocera	Sumitomo
Compression strength Mpa					2,260 (230 kg/mm^2)
Bending strength MPa	296			390-490 (40-50 kg/mm^2) (three point)	290 (30 kg/mm^2)
Flexural strength Mpa		280	365 (53 ksi)		
Modulus of elasticity GPa	303	340	310 (45 Mpsi)	315 (32 x 10^3 kg/mm^2)	335 (34 x 10^3 kg/mm^2)
Shear modulus GPa		140			
Poisson's ratio				0.24	
Hardness		1200 kg/mm^2			1200 HV

C. Thermal & Thermomechanical

Vendor		CeraTronics	Coors	CPS	Kyocera	Sumitomo [1]
Thermal conductivity W/m·K @ RT/25°C		K-70 70 K-170 170 K-200 200	115 170-190 [2]	>170 230 ± 21 (3 σ) (NOV91)	150 sheet 170 pressed	180 thick 200 thin (1 mm) substrate
Thermal expansion 10^{-6}/K	RT	4.5 (K170)				
	25 - 300°C		4.0	4.5		
	RT - 400°C	4.8				4.5
	40 - 400°C				4.7	
	25 - 500°C		4.5			
Specific heat J/g·K (cal/g·°C or K)					0.75 (0.18)	0.67 (0.16)
Thermal shock ΔT °C					350-375	

[1] See vendor's data sheets for additional information

[2] Values differ between data sheets

D. Electrical & Magnetic

Type: Insulator/dielectric; non-magnetic.

Vendor		CeraTronics	Coors	CPS	Kyocera	Sumitomo
Volume resistivity	RT/25°C	>10^{14}	>10^{14}	>10^{13}	>10^{14}	10^{13}
	300°C		7.9 x 10^{10}			
Ω-cm	700°C		1.0 x 10^{7}			
Te value °C [see ##...]			900			
Dielectric strength kV/mm		14	13.0		15.9	15
Dielectric constant	1 kHz		8.7			
	1 Mhz	8.8	8.5	8.5 @ 25°C	8.5	8.9
	10 MHz		8.5			
	9.3 GHz		8.3			
	10 GHz					7.5
Dissipation factor	1 kHz		0.2			
10^{-3}	1 MHz	~0.5-1.0	0.1 0.001 loss index	<1 @ 25°C	0.3	0.3
	10 MHz		0.1			
	9.3 GHz		1			
	10 GHz					

E. Forms & Sizes Available

Vendor	CeraTronics	Coors/Interamics	CPS	Sumitomo
Forms	Sheet	Packages		Sheet
Thickness	0.0125" to 0.0375" ±0.002" (0.025", 0.040" standard)			0.015", 0.025", 0.040" ±10%
Width and Length	Up to 4" x 4"	Up to >4" x 4"		Up to 2" x 2"
Flatness/camber	0.002"/inch	0.0005"/inch	3 σ tolerance ±0.058 mm (±0.023") (±0.5%) cavity size, ±0.061 mm (±0.0024") cavity center-to-center on cavity size of 11.43 mm x 11.43 mm (0.45" x 0.45")	0.003"/inch
Surface finish	Ra <30 microinches	<30 microinches (as low as 2 microinches with polishing)	<0.41 μm as molded, as sintered; <0.05 μm polished; defect sizes <25 μm at densities of <1/cm², typical for polished	Rmax 300 microinches typical

F. Post-Processing, Machining, Forming & Assembly

Machining or forming: Standard ceramic machining operations.

Metallization: Coors: Thin or thick-film metallizations, W or Mo. CeraTronics: DBC (direct bonded Cu), thick-film metallizations, including Au, Ni/Au, Ti/W/Au, Ta_2N, Cu, Ag-Pd, Au-Pt, Mo (can be Ni or Au plated) and cofired W.

Lid/cover sealing materials & methods: Not directly, requires seal ring or metallization.

G. Environmental properties

Note: For thermal operations, material is sensitive to oxidation with minute amounts of oxygen.

H. Other

Sources of data: CeraTronics: vendor's data sheet, undated. Coors/Interamics: vendor's data sheets, undated. CPS: [NOV91] B. E. Novich, C. A. Sundback and R. W. Adams: "Quickset™ Injection Molding of High Performance Ceramics" **1991 ACS Annual Meeting**, to be published in **Advances in Ceramics**; data sheet ©1989. Kyocera: vendor's data brochure ©1991. Sumitomo: vendor's data sheet, dated 1990. [BLU89] J. B. Blum "Aluminum Nitride Substrates for Hybrid Microelectronic Applications" **Hybrid Circuit Technology**, pp. 7-14, Aug. 1989.

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DATABASE:

Object Oriented:	Relational:
VBASE	INGRES
GEMSTONE	SQL SERVER
OBJECTIVITY/DB	INTERBASE
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THERM 2	THEAT	COMOS/M
ALGOR	ANSYS	

MECHANICAL SIMULATORS (Vibration, Stress):

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ANSYS	COMOS/M
ALGOR	
NISA	

DRAFTING:

CADDS	PERSONAL DESIGNER
AUTOCAD	CADKEY