EPII Level-to Level Analysis of MCMs
Contract No. F33615-91-K-1717
Final Report - Executive Summary
to the Electronics Laboratory at WPAFB;
supplemented by fourteen separate reports

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Overview

The objective of this project was to develop a leading-edge, computationally efficient software package for the thermal and thermo-mechanical analysis of multilayer multichip modules (MCM's). The need to explicitly consider the two physical scales of the MCM, the global scale, and the neighborhood of critical areas with features discretely represented, the local scale, dictated that new analysis methodologies be developed. To address this development effort, a three task project was performed. The goal of the first task was the development and seamless integration of the global/local heat conduction and thermo-mechanical analysis of MCM's. The goal of the second task was to develop measurement techniques for use in verifying the predictions of the analysis procedures. The goal of the third task was to link the software developed with leading-edge electromagnetic analysis procedures.

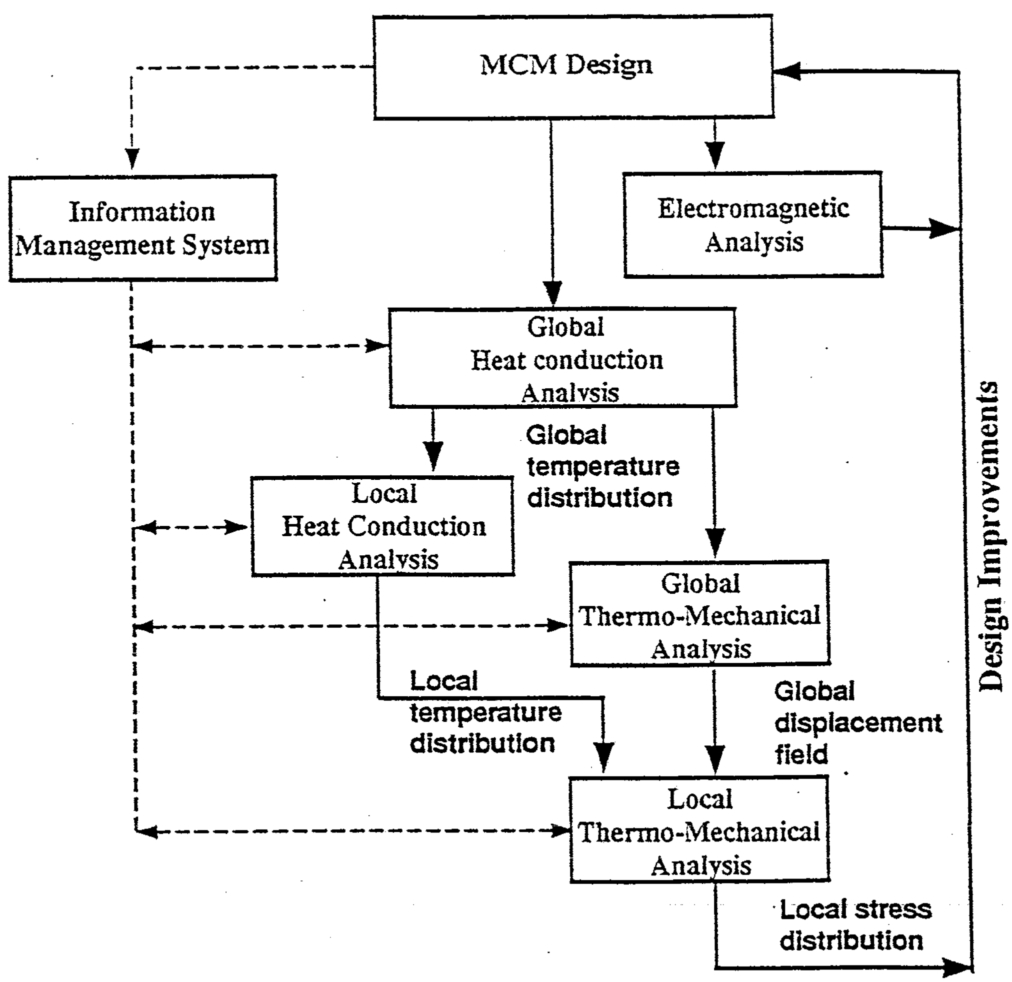

Figure 1: Overview of REPAS analysis components and their interactions.

Task 1 Summary

A multilayer multichip module (MCM) is characterized by having a number of layers containing wires and vias in various configurations, in conjunction with a general chip and cooling structure layout, typically on the outer surface. Although general purpose micromechanical level analysis procedures could be used to analyze MCM's, such an analysis representing all the features present in the MCM would be prohibitive. To address the deficiencies of the procedures currently available, a set of coordinated multiple scale heat conduction and thermo-mechanical analysis techniques, which include a number of new capabilities, were developed. The global analysis procedures employ averaging techniques to convert each layer into an equivalent homogeneous medium. Both the global heat conduction and thermo-mechanical analysis procedures are based on a new variational approximation in which the differential equations and certain interface and boundary conditions are satisfied exactly. Therefore, the numerical solution process must only perform area integrals, as opposed to full volume integrals and the number of unknowns in the procedure does not increase as the number of interconnect layers increases.

The local heat conduction analysis is performed using a highly efficient stochastic algorithm for solving Laplace's equation. The algorithm is based on the floating random-walk method. The algorithm derives from the Laplace solution on a scalable cubic domain, subject to arbitrary Dirichlet conditions. A boundary-integral solution is then found, from which an integral for temperature at the domain center is obtained. This integral is expanded as an infinite sum, and probability rules that statistically evaluate the sum are deduced. These rules define the algorithm, yielding temperature at a specific point within the windowed local heat conduction domain. The Dirichlet boundary conditions are obtained from the global heat conduction analysis over the window boundary.

Since the details of the local stress fields are critical to the prediction of failure quantities, the local thermo-mechanical analysis procedure must accurately represent the local geometric detail in an analysis which can ensure the accuracy of the analysis. An automated adaptive finite element methodology was developed to perform these analyses. The main components of the automated adaptive finite element procedure developed are:

(i) an automatic mesh generator capable of creating valid graded meshes in arbitrarily complex domains,

(ii) finite element analysis procedures for thermo-mechanical analysis,

(iii) a posteriori error estimation procedures to predict the mesh discretization errors and to indicate where it must be improved, and mesh enrichment procedures to update the mesh discretization.

Seamless integration is accomplished through the use of a single physical description from which all discrete analysis models are built. The simplest common physical description of the MCM

available to us is a CIF file. Although, this representation does lack a number of features desired in a complete physical description, an augmented version of it, combined with a specific knowledge-base, is an adequate physical description. The geometric model for the local automated adaptive finite element analysis must be a non-manifold solid model derived from the CIF file. Since available solid modelers are limited to two-manifold models, special extensions were developed to allow for the proper representation of the classes of non-manifold situations present in a multichip module.

As indicated in the attached documentation, this software system has been constructed and its application demonstrated on a 25 chip MCM.

Task 2 Summary

The definition of this task and its objectives was finalized during the project review on 6 January 1992 at the Wright Patterson Air Force Base. The prime objective is to experimentally verify the results of the thermo-mechanical modeling. The main thrusts were to survey the state of the art of measuring stress/strain over small areas—in the order of a micron—and, if available on campus, to use it on a hardware test vehicle designed and built to represent a multi-layer multichip module (MCM) structure suitable for the thermo-mechanical modeling.

Numerous measurement techniques were analyzed in depth, several actually tried out in laboratory. The evaluation results for the stress measurements vs. lateral resolution are summarized in Figure 5 on page 22. For the lateral resolutions greater than approximately 0.1 mm, the Moire fringe technique has the highest sensitivity. Below that, the ellipsometry offers the highest sensitivity. The limit of lateral resolution is wave length limited, while the stress sensitivity of approximately 10 MPa is probably sufficient for most applications.

The mapping of MCM surface temperature is another key requirement. Ideally, the same technique would do both. However, use of photoluminescence offers speedy mapping with the resolution vs. area dependency shown in Figure 6 on page 23.

Design of the hardware test vehicle had to satisfy several requirements. To be representative of a state-of-the-art MCM, it had to contain multiple copper or aluminum conductors 10 to 100 micron wide, about 5 micron thick, embedded in polymeric dielectric, preferably replicated in another set of wiring layer oriented perpendicularly to the first. It had to contain several representative IC chips. Representative here means an edge in the order of 10 mm and the power densities in the order of 5 to 50 W/cm^2 to induce additional thermo-mechanical stress representative of actual applications, measurable with the available instrumentation and amenable for modeling by satisfying model's boundary conditions. Such vehicle was designed, masks made and a simple (substrate, insulator, conductor, insulator) multi-layer structure built and distributions of stress and temperature measured using Raman scattering.

Initial modeling attempts were made as well by providing input to the models via CIF file. The initial results (example in Figure 7 on page 24) had highlighted some modeling idiosyncracies used to fine-tune the modeling algorithms. As of this writing, detailed measurements and model data are not yet available.

Task 3 Summary

The purpose of Task 3 was to link the thermo-mechanical analysis techniques to electromagnetic analysis to provide an interactive capability for examining the trade off between layout of the MCM wiring (including the variation of the design rules as well as the electrical issues such as terminator placement) and the temperature and stress predicted. As originally proposed, this effort focused on interfacing the thermo-mechanical software to the MagiCAD package which was graciously made available by workers at the Mayo Foundation. This tool was developed under DARPA sponsorship with a large team of 25 staff personnel over a period of many years, and had been demonstrated to provide the support required for MCM analysis. This support included extraction of parasitic capacitances and inductances from the wiring cross sectional geometry specifications, and the ability to simulate critical signal waveforms in a multichip package. The package also provided the ability to model chip bonding mechanisms at high frequency through the use of lumped parameter systems which could be measured experimentally. In addition Mayo's software provided a complete graphics interface. It therefore became the primary goal of this task to facilitate the interface of the thermo-mechanical tools and Mayo's tools.

The Mayo group was extremely cooperative and diligently provided many details concerning the MagiCAD data base and internal operation that proved invaluable in completing the project. The Mayo group even assisted with creating a unique compilation of their software which could activate the 90 MFLOPS floating point vector accelerator present on the VAX 6410 at RPI. Although not actually employed in the MagiCAD system, the group selected CIF or the Caltech Intermediate Form as the primary data base for exchange of information, and the appropriate translators were constructed. This data structure also had to be augmented by the vertical dimensions, and materials constants descriptive of each layer of material used in the process.

Throughout the contract period there was concern over the fact that the Mayo MagiCAD package was originally developed for DEC VAX architectures using the VMS operating system, whereas most of the new codes were developed on UNIX workstations. However, since the primary transfer of information used on this task is by an augmented CIF file, the interaction across system boundaries is still fairly seamless. The RPI group worked with the Mayo group to help insure that the codes developed under the VMS version would eventually be readily ported to any UNIX version of Mayo MagiCAD. At the time of this writing Mayo currently has a

POSIX (actually OSF) VMS and ULTRIX version ported to the DEC ALPHA. They are currently working on a HP UNIX version.

The work of Task 3 also included application of the software integrated under the project to the design of a specific multichip module. This was viewed as a means for driving the development of the codes toward a more realistic set of design capabilities. The module actually selected for analysis would, if constructed, support a GaAs/AlGaAs HBT design for a Fast RISC processor (F-RISC/G) the development of which was funded by (D)ARPA. This is a module which dissipates several hundred watts but produces a 1000 MIPS throughput. It is the initial design of a series of such explorations of the use of HBT technology for subnanosecond computers. The use of this software system led to the conclusion that the cache memory for the original design was too hot, and this would lead to overheating of the devices, and extraordinary stress and temperature deviations. This excessive heating would actually have resulted in slower HBT operation, causing the processor to fail to perform at the targeted speed.

One unanticipated side benefit derived from the work funded on the contract in local thermal analysis using Monte Carlo random walk methods was stimulated by the GaAs RISC application used to demonstrate the thermomechanical tools. It was discovered that the same method could be used to compute capacitance in complex 3D structures that are significantly larger than those handled by Mayo MagiCAD or other commercially available CAD tools for electromagnetic analysis. The techniques used in MagiCAD could not handle crossovers or rapid spatial variations in local geometric cross sections of the conductors. This technique was applied to calculate the complete capacitance matrix (suitable for SPICE simulations) for long nets and even complete macrocells in the GaAs/AlGaAs HBT circuits, as well as for chip to chip wiring in the MCM layouts. Once again only the CIF description augmented by 3D and materials information are required. An example of an HBT macrocell recently analyzed by this method is shown in the Figure 4 on page 18.

List of Contents

Overview 1
- Task 1 Summary 2
- Task 2 Summary 3
- Task 3 Summary 4

List of Contents 6

Program objective, its tasks and subtasks 7

Program investigators 8

Summary of Accomplishments 9
- Task 1 - General Accomplishments 9
- Task 1 - Technical Results 9
- Task 2 - General Accomplishments 9
- Task 2 - Technical Results 10
- Task 3 - General Accomplishments 11
- Task 3 - Detailed Accomplishments 11

Highlights of Attached Reports 12
- A High-Speed Floating Random-Walk Algorithm for Thermal Analysis 12
- Global/Local Analyses of Multichip Modules: Automated 3-D Model 12
- A Global-Local Procedure for the Thermoelastic Analysis 13
- A Global-Local Procedure for the Heat Conduction Analysis 15
- MCM Design and Integration with Electromagnetic Analysis 17
- REPAS—Rensselaer Electronic Packaging Analysis Software 19
  - User's Manual 19
  - Programmer's Manual 19
- Experimental Verification 20
- Other Program Documentation Supplied 24

List of other Pertinent Publications 25

Program objective, its tasks and subtasks

The over-all program objective has been to develop a leading-edge computationally efficient CAD/CAE package for three-dimensional analysis of multilayer MCM's.

This program had been organized into three tasks and several subtask as follows:

□ **Task 1**: Develop highly efficient thermo-mechanical analysis program for interconnect structures:

- *Subtask 1.1:* Global thermo-elastic analysis of layerwise volume-averaged structures based on variational procedure;
- *Subtask 1.2:* Local thermo-stress of detailed geometry based on automated adaptive finite element method;
- *Subtask 1.3:* Local thermal analysis of materially homogeneous sub-blocks based on floating random-walk method, along with surface splining;
- *Subtask 1.4:* An overall structure for the automatic generation of the analysis models from the generally used MCM representations;
- *Subtask 1.5:* Global thermal analysis of layerwise volume-averaged structures based on variational procedure.

□ **Task 2**: Seek empirical confirmation of the Task 1 model(s):

- Select, develop, and apply a set of measurement techniques to test critical aspects of the global and local simulation package.
- Develop a test vehicle which:
  - Fulfills the boundary condition and other requirements of analysis tools;
  - Enables measurement of temperature and strain distribution;
  - Has sufficient sensitivity and resolution to challenge the analysis tools.
- Provide to analysis tools/model information on:
  - Materials and structure used in the MCM test vehicle;
  - Physical and thermal properties information.
- Compare measured stress and temperature results to global/local model predictions.

□ **Task 3**: Install, upgrade and expand leading electromagnetic modeling program(s) and link it / them to the thermo-mechanical programs of Task 1.

Program investigators

Faculty / Postdocs	Students	1.1	1.2	1.3	1.4	1.5	2	3	Adm
Harry F. Tiersten		x				x			
	B. J. Lwo	x							
	Y. S. Zhou	x							
Ting-Leung (Sam) Sham			x			x			
	L.-Y. Song		x						
Yannick L. Le Coz				x					
	W. Snyder			x					
	M. Zierak			x					
Ralph. B. Iverson				x					
Mark S. Shephard			x		x				x
	V. S. Wong		x		x				
	R. Garimella (from Sept. 92)				x				
Peggy L. Baehmann (till Sept. 1992)			x						
Mark W. Beall (from Nov. 1992)					x				
Peter D. Persans							x		
Eugene J. Rymaszewski							x		x
	James Deacutis (from Sept. 92)						x		
John F. McDonald								x	
	Atul Garg							x	

Summary of Accomplishments

Task 1 - General Accomplishments

- ☐ Developed and implemented global/local analysis methodology for:
  - Heat conduction;
  - Thermo-mechanical analysis of MCM's.
- ☐ Employed efficient mix of analysis techniques for analysis methodology:
  - Global variational procedures;
  - Floating random-walk techniques;
  - Adaptive finite element methods.
- ☐ Automated analysis discretization generation from CIF file.

Task 1 - Technical Results

- ☐ Methods Development:
  - Unique variational analysis methodology;
  - Layer-based material property averaging procedures;
  - Generalized the floating random-walk method for local volumetric heat-conduction analysis;
  - Multi-material discretization error indicator;
  - Construction of valid non-manifold models from incomplete specs.
- ☐ Software Development:
  - Effective numerical implementation of variational procedure for global heat conduction and thermo-mechanical analyses;
  - Floating random-walk procedure for high-speed local heat conduction analysis;
  - Automated adaptive local stress analysis;
  - Automatic construction of analysis discretizations from a CIF file description of an MCM;
  - General attribute and information manager for integrating software components.
- ☐ Numerical Studies:
  - Accuracy assessment of the variational method for global analyses;
  - Accuracy assessment of the floating random-walk local analysis;
  - Accuracy assessment of the global/local solution methodology;
  - Example multichip modules.

Task 2 - General Accomplishments

- ☐ Surveyed the state of the art of the temperature and stress measurement techniques with respect to their spatial resolution and sensitivity.

- ☐ Selected a test vehicle structure:
  - – Can be rapidly manufactured;
  - – Measured results able to confirm/challenge the analysis program predictions.

Task 2 - Technical Results

- ☐ Several temperature measurement techniques were critically considered:
  - – Contact measurement↔direct thermocouple,
  - – Contactless measurement techniques:
    - • Raman line shifts in particle inclusions or the substrate,
    - • Photoluminescence,
    - • Photoelastic ellipsometry,
    - • Infrared imaging.
- ☐ Several strain/stress measurement techniques have been investigated:
  - – Large area average strain↔wafer curvature:
    - • X-ray;
    - • Optical;
  - – Laterally resolved strain:
    - • X-ray diffraction:
      - - probe layers vs. substrate,
      - - estimate of count rate with lateral resolution,
      - - estimate of strain resolution;
    - • Moire fringe,
    - • Photoelastic ellipsometry,
    - • Raman scattering,
  - – Three dimensional resolution of strain↔probe layers
    - • Photoluminescence,
  - – X-ray strain, and X -ray bending analysis.
- ☐ Photoelastic ellipsometry :
  - – The change in analyzer null position in polarized reflection ;
  - – Provides sufficient 10 MPa sensitivity;
  - – Possibility of down to 10 micron, or less, lateral resolution. ;
  - – A low resolution system has been prototyped.
- ☐ Photoluminescence from small particle (10-100 nm diameter CdSe) inclusions in the polymer insulator provides sufficient temperature resolution (< 5 K at room temperature) and spatial resolution (down to 1 micron) for the current tests.
- ☐ We have set up a 2-3 micron resolution microscope and manual translation stage on a luminescence system for these measurements.
- ☐ We have worked extensively with members of the Task 1 team to specify a test

vehicle on which our measurements will test the model predictions.

- Limitations in measurement techniques impose harsh limitations on chip power input, wiring pitch and thickness, and substrate thickness.
- Feedback on test vehicle design by the modeling group has been crucial in our vehicle development efforts.

Task 3 - General Accomplishments

- Mayo MagiCAD:
  - Obtained , installed, tested extensively, verified operational and adapted to RPI DEC VAX 6410 Vector Processor Hardware for Faster Operation;
  - Modified to include R_{dc} as well as R_{skin} for MCM work;
  - Extensively used to analyze interconnection geometries for MCM and Rockwell GaAs IC interconnection wiring.
- Interfacing Activities:
  - Input for the CIF file modifications for generalized 3D common physical specification for seamless interface to RPI thermo-mechanical suite.

Task 3 - Detailed Accomplishments

- Experimental Verification:
  - Used MagiCAD to verify measurements of IBM Cu/Parylene MCM test structures, including R_{dc} losses;
  - Established links with Ted Haller's work with Mayo on GE/HDI.
- Applications:
  - Integrated RPI-developed placement and routing programs to drive realistic design activity for MCM wiring structures;
  - Established link between MCM placement and routing structures to permit direct import to MagiCAD using this as a "pseudo-PCB" with DC loss in the wiring;
  - Created at least three Fast GaAs RISC MCM designs from ongoing ARPA/CSTO Fast RISC project for use by thermo-mechanical software as debugging examples;
  - Explored ultimate integration with CADENCE MCM tool suite;
  - In the process of acquiring a university license for CADENCE tools, including MCM suite;
  - Explored ultimate UNIX MagiCAD possibilities:

    (POSIX std MagiCAD is now available,
    but was not during the working span of the contract;
    and is still not available for the SUN or RS/6000 workstations at RPI).

Highlights of Attached Reports

A High-Speed Floating Random-Walk Algorithm for Thermal Analysis of Multichip Module Interconnects

This technical paper presents the theory and preliminary numerical results for a new random-walk algorithm that solves Laplace's equation subject to Dirichlet boundary conditions. Our focus is the steady-state thermal analysis of geometrically complex rectilinear domain boundaries and material interfaces--characteristic of multichip module (MCM) interconnects. We give a mathematical derivation of the surface Green's function for Laplace's equation over a square region. From it, we obtain an infinite multiple-integral series expansion yielding temperature at any space point in the problem domain. A stochastic floating random-walk algorithm is then deduced from the integral series expansion. To determine the areal thermal distribution within the domain, we introduce a unique linear, bilinear, and trigonometric splining procedure. It fits to random-walk point-temperature samples taken at corner and edge points of relatively large materially homogeneous rectangular sub-domains (sub-blocks). The splining functions are exact solutions to Laplace's equation inside the sub-domains. Numerical verification studies, in two dimensions, using finite-difference benchmark solutions have confirmed the accuracy and efficiency of our algorithm and splining procedure.

Global/Local Analyses of Multichip Modules: Automated 3-D Model Construction and Adaptive Finite Element Analysis

This paper first overviews an overall approach taken in the development of a set of global/local heat conduction and thermo-mechanical analyses of MCM's. Attention is then focused on the automatic construction, and adaptive finite element analysis of critical local 3-D regions.

Conceptually, each of the four analysis procedures considered is a two-step idealization process going from the physical description of the MCM to the analysis discretization. The simplest common physical description of the MCM available to us is a CIF file. The geometric model for the local automated adaptive finite element analyses must be a non-manifold solid model derived from the CIF file. The procedures required to interpret the CIF file in order to create commands to drive a solid modeling system, which create the solid model of the selected region, are discussed. Since available solid modelers are limited to 2-manifold models, special extensions were developed to allow for the proper representation of the classes of non-manifold situations present in a multichip module.

Given a complete geometric definition of the selected region of the multichip module, the automated adaptive finite element procedure invokes the Finite Octree mesh generator to, without user interaction, generate the initial mesh. Analysis of the initial mesh, using the capabilities of the ABAQUS finite element program, is then performed. As the analysis proceeds, a newly developed error estimation procedure that deals with multi-material objects determines where, and by how much, the mesh should be refined. This information is communicated to the automatic mesh generation procedures which carry out the required refinements. The paper describes the components of the automated adaptive finite element system, and presents the new error estimation procedures. Example results, like those in Figure 2, are given.

A Global-Local Procedure for the Thermoelastic Analysis of Multichip Modules

This paper describes the global thermoelastic analysis procedure developed to analyze MCM's and demonstrates its effectiveness in a global/local analysis process. In this procedure a simplified global problem is defined in which the layers containing wires are represented by a single material continuum with effective properties. This simpler problem is solved by means of a new variational approximation procedure. The displacement field obtained from this global solution is used as boundary data on the surface of a relatively small volumetric region surrounding a smaller critical region. The local solution is then found by means of a finite element method using that boundary data.

The above-mentioned variational approximation procedure has been used in obtaining static elastic deformation fields in a number of applications in the last few years by Tiersten and coworkers, in which it was shown to be very accurate, computationally efficient and convenient to use. Furthermore, it should be noted that the procedure is particularly well-suited to the treatment of multilayer configurations with a large number of layers, because it has the property that the size of the matrix that has to be inverted (decomposed) is independent of the number of layers.

In order to demonstrate the accuracy of the global-local approach and the variational approximation procedure, we consider a two-dimensional thermoelastic problem in which three layers are present with the middle one containing discrete wires. For the global analysis the middle layer is represented by one continuous medium having effective elastic and thermoelastic coefficients obtained through a newly developed averaging procedure. The solution for the global problem is obtained using the variational approximation procedure. The displacement field on the surface of a relatively small region surrounding a wire is taken from the global solution and used to find the local displacement fields by means of a finite element calculation that employs an adaptive mesh. The local displacement field found using the input surface data obtained from the variational approximation for the global solution and the complete finite element calculation are shown to be in excellent agreement.

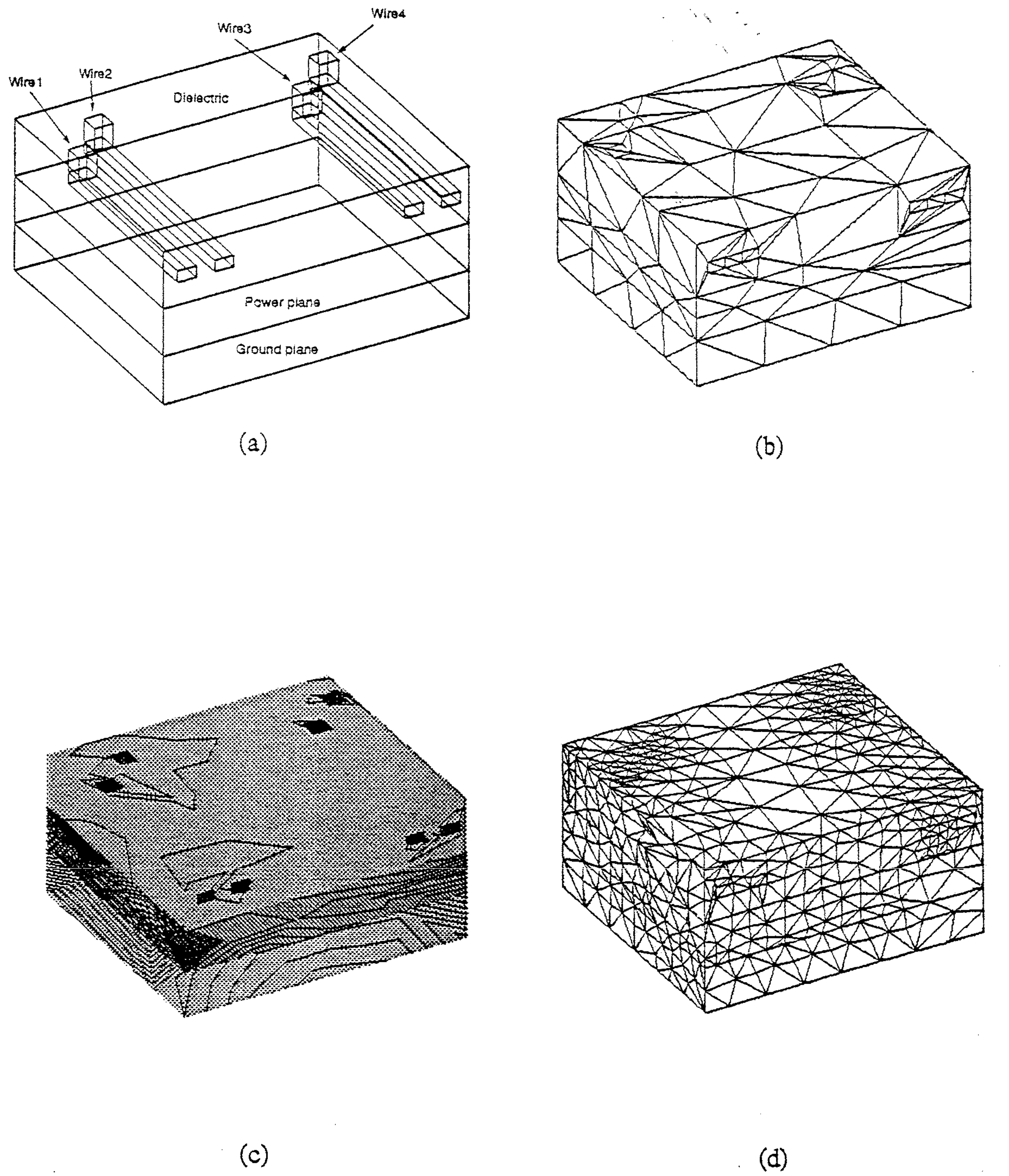

Figure 2: Three-dimensional example with initial and adaptively refined finite-element meshes:

(a) Geometric model of local window;

(b) Initial mesh of local model;

(c) Contour plot of mises stress after first analysis;

(d) Adaptively refined mesh.

A Global-Local Procedure for the Heat Conduction Analysis of Multichip Modules

This paper describes the global heat conduction analysis procedure developed to analyze MCM's. In this procedure a simplified global problem is defined in which the layers containing wires are represented by a single material continuum with effective properties. Since the interconnect in the multichip module contains many layers this simpler problem is solved by means of a new variational approximation procedure. The temperature field obtained from this global solution is used as boundary data on the surface of a relatively small volumetric region surrounding a smaller critical region. The local solution is then found by means of a finite element procedure or other fast algorithm using that boundary data.

The above-mentioned variational approximation procedure has been used in obtaining static elastic deformation fields in a number of applications in the last few years by Tiersten and coworkers, in which it was shown to be very accurate, computationally efficient and convenient to use. Furthermore, it should be noted that the procedure is particularly well-suited to the treatment of multilayer configurations with a large number of layers, because it has the property that the size of the matrix that has to be inverted (decomposed) is independent of the number of layers. It should also be noted that the application of this variational approximation procedure in the treatment of steady-state problems in linear heat conduction described in this paper is new.

In order to demonstrate the accuracy of the global-local approach and the variational approximation procedure, we consider a two-dimensional heat conduction problem in which three layers are present, with the middle one containing discrete wires. Prescribed temperatures and normal heat fluxes are imposed as boundary conditions. For the global analysis the middle layer is represented by one continuous medium having effective heat conduction coefficients, using a procedure that is somewhat different from the usual, because the ratio of the thermal conductivities of the wire and polymer materials is very large. The solution for the global problem is obtained using the aforementioned variational approximation procedure. The temperature field on the surface of a relatively small region surrounding a wire is taken from the global solution and used to find the local temperature field by means of a finite element calculation that employs an adaptive mesh. The entire two-dimensional problem is then solved for the local temperature field using the finite element procedure with an adaptive mesh. The local temperature fields found using the input surface data obtained from the variational approximation for the global solution and the complete finite element calculation are shown to be in excellent agreement.

The application of the global heat conduction analysis to a 25 chip MCM is demonstrated in Figure 3.

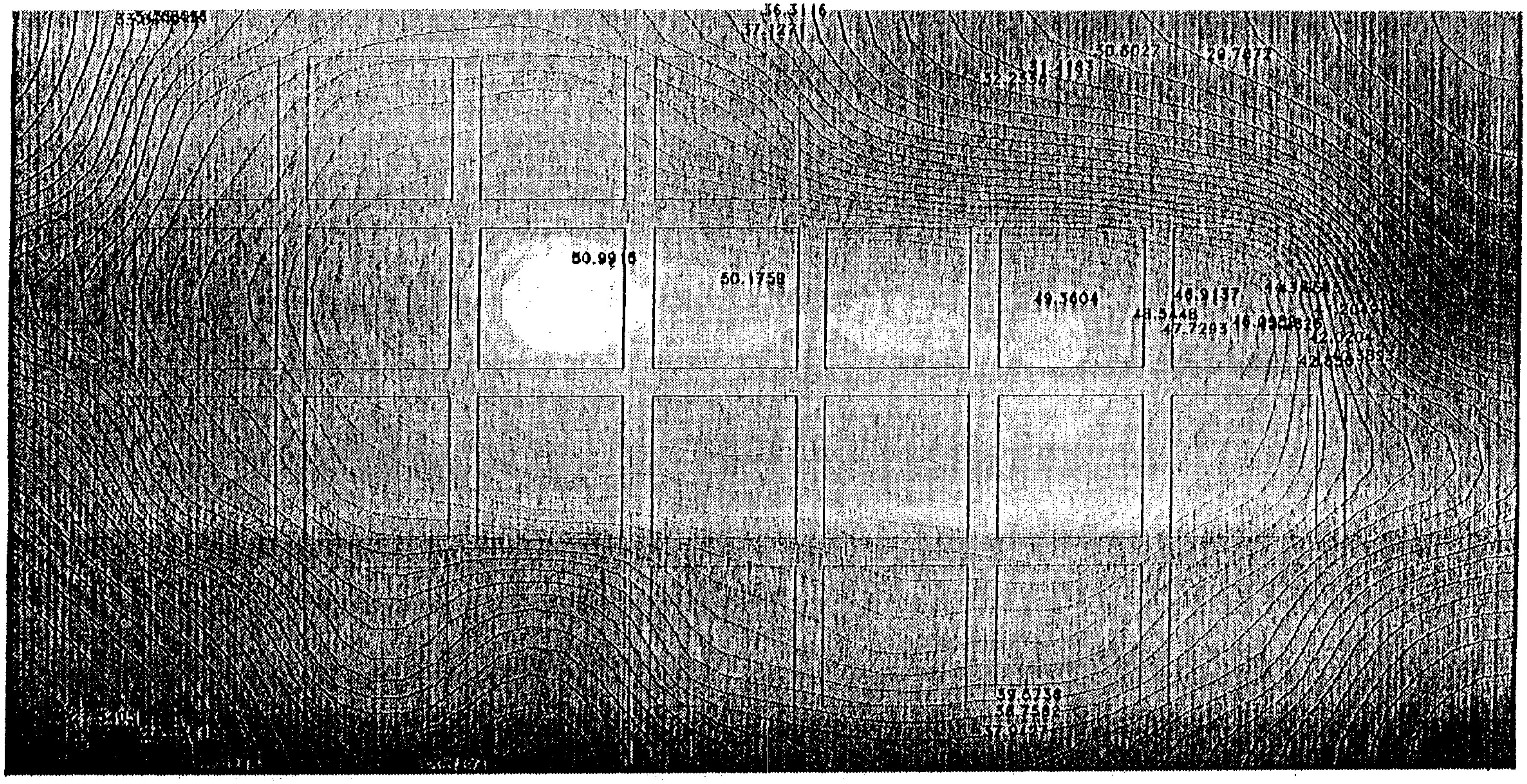

Figure 3: Temperature distribution in an interconnect layer as calculated by global heat conduction analysis.

MCM Design and Integration with Electromagnetic Analysis

In a multi-package system, the large inductance and capacitance associated with the pins in a conventional package limits high speed operation. A multichip module (MCM) avoids the delay associated with the individual packages by packing a number of individual dies in a single package. An MCM needs to provide dense interconnection and packing to ensure smaller time-of-flight of signals for high speed operation.

Dense packing generates more heat per unit area, which can burn the chips, making the system inoperable or the resultant stress can break the interconnects again making the system inoperable. Therefore the MCM should also be capable of dissipating more heat per unit area.

Hence, in order to design a high speed digital system, it is necessary to keep under consideration all aspects of a package design, namely, electromagnetic, thermal and thermo-mechanical. This report deals with the electromagnetic modeling part of an MCM design. The package and interconnect model can be combined into a simulation program for a CAD environment to predict the severity of transmission effects and to evaluate system performance.

The simulation procedure includes the extraction function which extracts circuits and interconnect information from layout data stored in a CAD database and a simulation function which simulates the system performance at high frequency using both models.

MagiCAD (Mayo Graphical Integrated Computer Aided Design) is a VAX/VMS based package which provides a comprehensive design environment for the development and fabrication of VLSI chips (especially GaAs chips). Its electromagnetic (EM) analysis tools assist a designer in design and analysis of high speed packaging interconnect. Any signal net can be extracted from a common CIF (Caltech Intermediate Format) database using Extractor, a program developed at RPI, and input into the MagiCAD for simulation. The CIF database is generated by an MCM router and associated tools developed at RPI. MagiCAD can do the analysis in both time and frequency domain.

This report describes the development of a methodology for designing multichip modules, electromagnetic analysis using MagiCAD, and its integration with the thermal and thermo-mechanical analysis tools.

An example of an HBT macrocell recently analyzed by this method is shown in the Figure 4, next page.

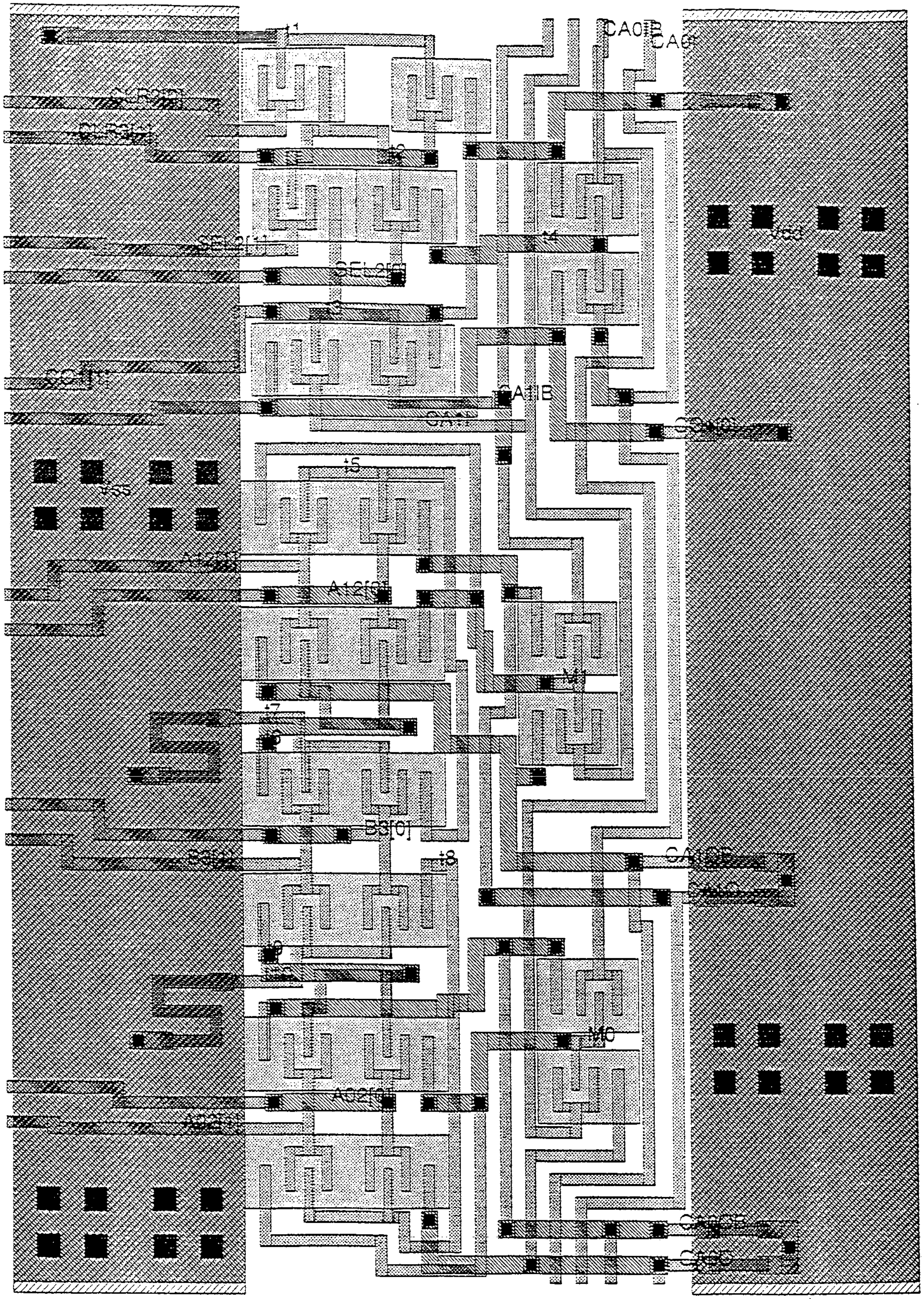

Figure 4: An example of HBT macrocell recently analyzed.

REPAS—Rensselaer Electronic Packaging Analysis Software—User's Manual

This document contains information needed to run the global/local heat conduction and thermo-mechanical analysis software. It also includes information on the software used to construct the analysis models for a CIF file description of the MCM and to specify the analysis attributes for the analyses.

Contents of the manual include:

1. software overview
2. installation instructions
3. software license information for all system components
4. MCM physical description
5. input required for the construction of the global analysis models
6. use of the global heat conduction software
7. use of the global thermo-mechanical software
8. use of the local heat conduction software
9. use of the local thermo-mechanical software
10. use of the MCM router
11. how to link to electromechanical analysis
12. how to run a complete analysis
13. control script descriptions
14. software capabilities and limitations
15. example results

REPAS—Rensselaer Electronic Packaging Analysis Software—Programmer's Manual

This document contains information needed to install and modify the global/local heat conduction and thermo-mechanical analysis software. It also includes information on the software used to construct the analysis models for a CIF file description of the MCM and to specify the analysis attributes for the analyses.

Contents of the manual include:

1. an introduction to the system components
2. a description of the software used to construct the analysis models from the CIF file
3. a description of the analysis attribute software
4. a description of the global heat conduction software
5. a description of the global thermo-mechanical software
6. a description of the local heat conduction software

7. a description of the local thermo-mechanical software
8. a description of the MCM router and link to electromechanical analysis

The description of each major software component includes at least a base description of the procedure, information on the source code, input/output procedures, and compiling information.

Experimental Verification

The definition of this task and its objectives were finalized during the project review held at the Wright Patterson Air Force Base on 6 January 1992. The prime objective was to experimentally verify the results of the thermo-mechanical modeling. The main thrusts were to survey the state of the art of measuring stress/strain over small areas—in the order of a micron—and attempt to make it available on campus and then use it on a hardware test vehicle designed and built to represent a multi-layer multichip module (MCM) structure suitable for the thermo-mechanical modeling.

Numerous measurement techniques were analyzed in depth, several actually tried out in laboratory. The evaluation results for the stress measurements vs. lateral resolution are summarized in Figure 5. For the lateral resolutions greater than approximately 0.1 mm, the Moire fringe technique has the highest sensitivity. Below that, the ellipsometry offers the highest sensitivity. The limit of lateral resolution is wave length limited, while the stress sensitivity of approximately 10 MPa is probably sufficient for most applications.

The mapping of MCM surface temperature is another key requirement. Ideally, the same technique would do both. However, use of electroluminescence offers speedy mapping with the resolution vs. area dependency shown in Figure 6.

As part of this program we completed many important preliminary tasks. We upgraded a Raman and photoluminescence system for microprobe analysis and established practical limitations for this system. We developed an ellipsometer for strain measurement and made progress on establishing the limitations of this system. We performed double crystal x-ray diffraction measurements on Si crystals to establish the signal limitations for conventional high flux in-house x-ray tubes. We developed a method for doping thin polymer films with semiconductor microcrystals for use as robust and high resolution temperature probes and we performed preliminary measurements with this system.

Design of the hardware test vehicle had to satisfy several requirements. To be representative of a state-of-the-art MCM, it had to contain multiple copper or aluminum conductors 10 to 100 micron wide, about 5 micron thick, embedded in polymeric dielectric, preferably replicated in another set of layers with the conductors perpendicular to the first set of conductors. It had to contain several representative IC chips. Representative here means an edge in the order of 10 mm and the power densities in the order of 5 to 50 W/cm^2 to induce additional

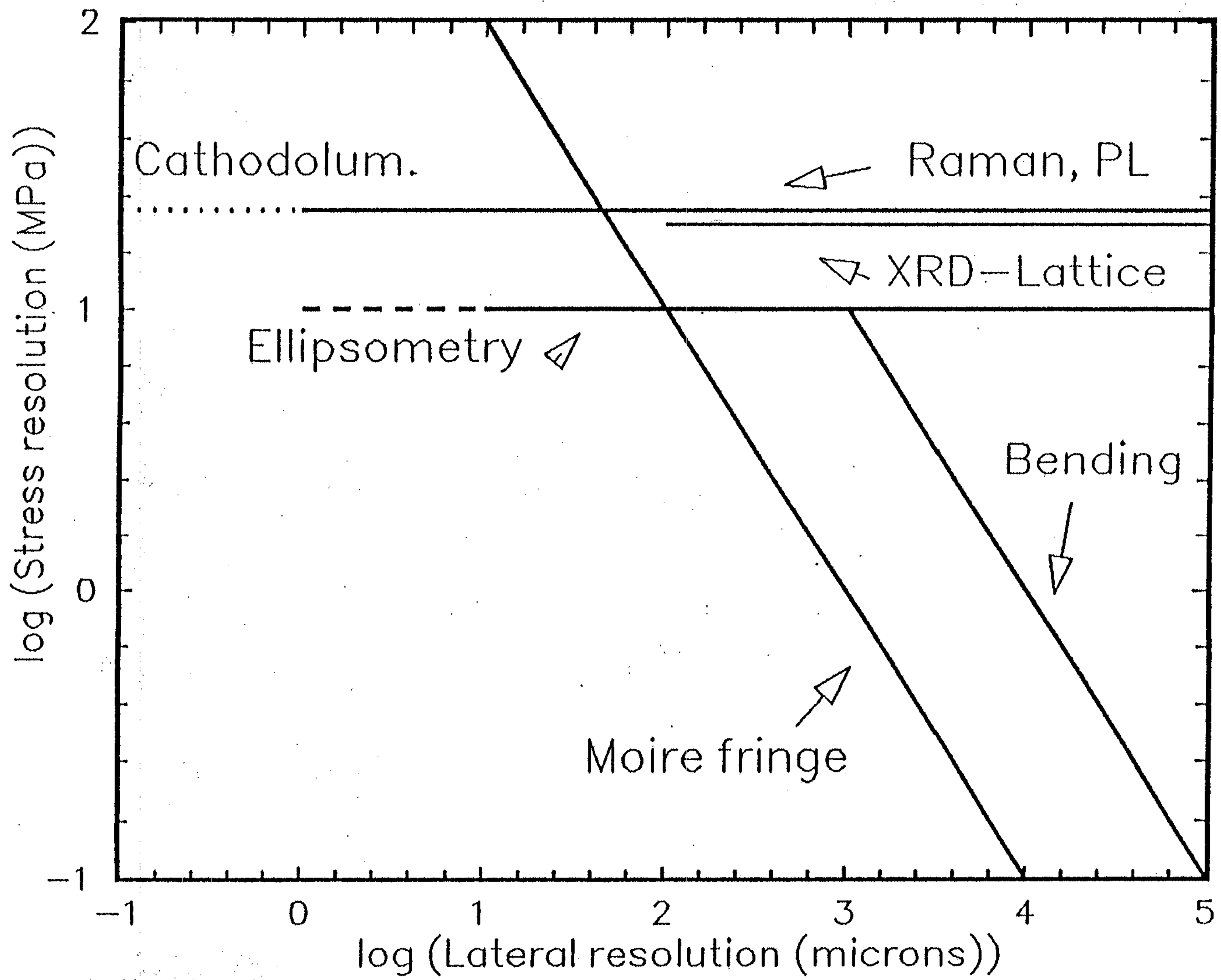

Figure 5: Lateral resolution and stress resolution of various techniques.

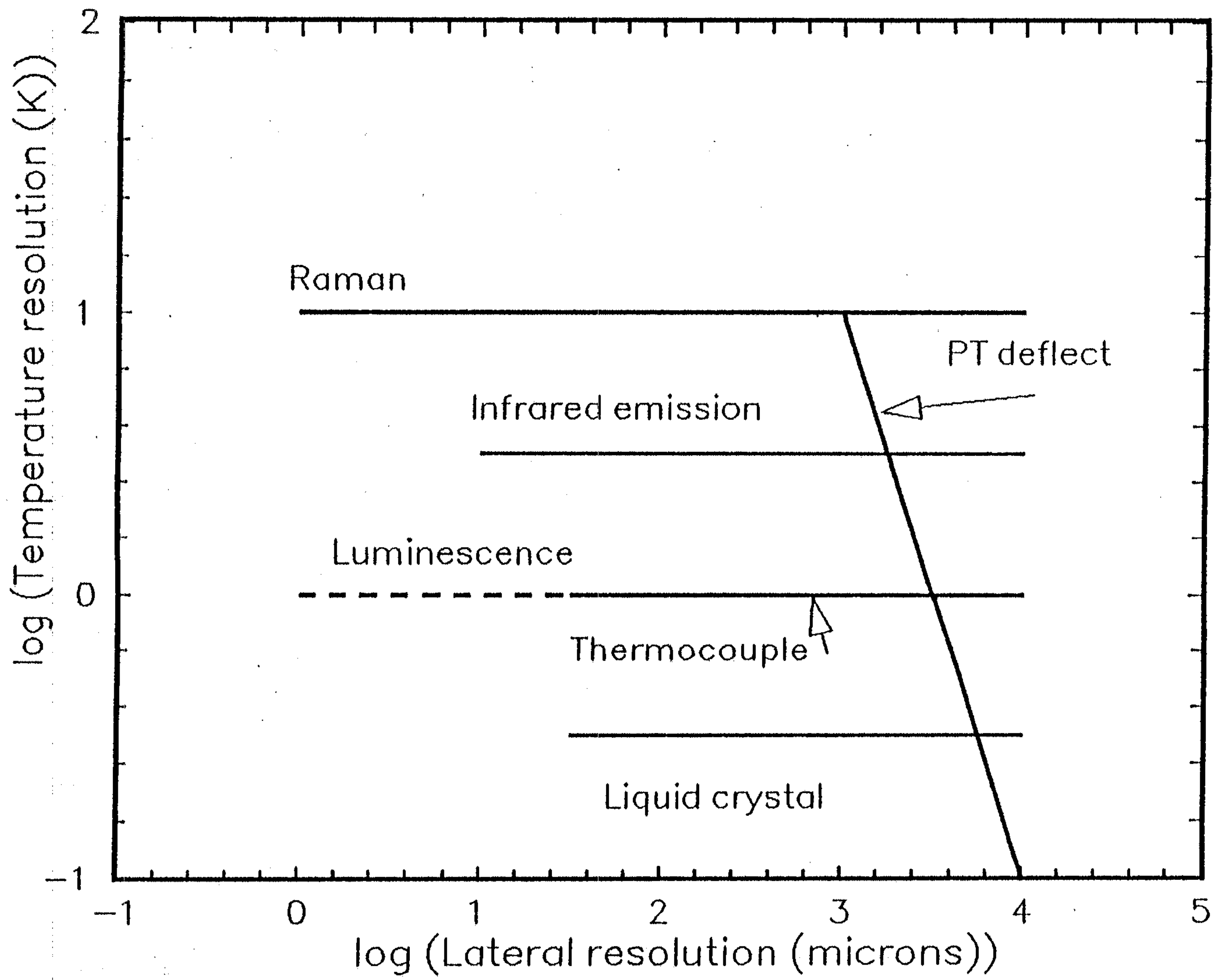

Figure 6: Lateral resolution and temperature resolution of various techniques.

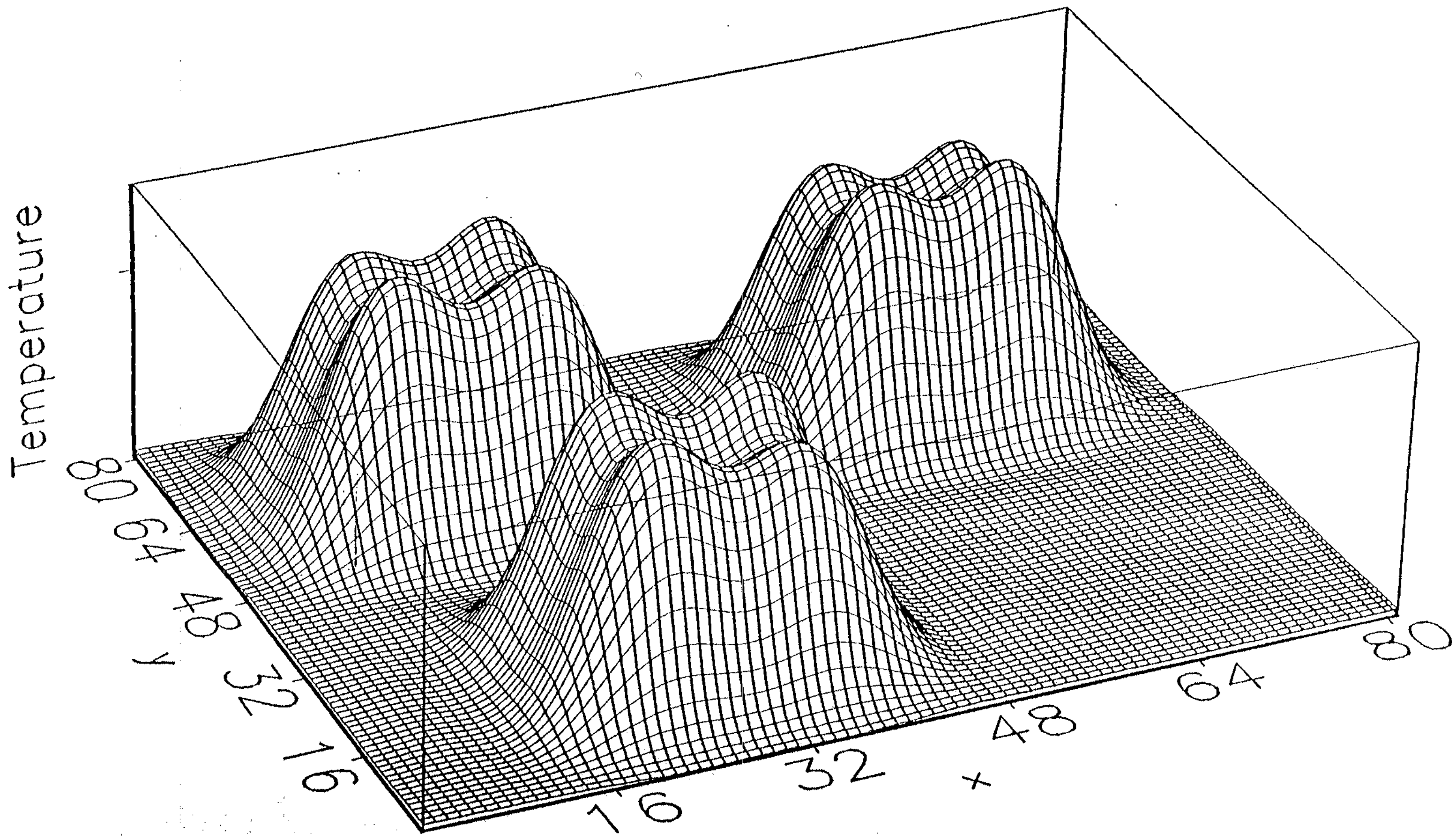

Figure 7: Contour plot of temperature profile in Model II; first run.

thermo-mechanical stress representative of actual applications, measurable with the available instrumentation and amenable for modeling by satisfying model's boundary conditions. Such vehicle was designed , masks made and relatively simple multi-layer structure (substrate with insulating, patterned conducting and another insulating layers) built and in it stresses were measure by Raman scattering.

Initial modeling attempts were made as well by providing input to the models via CIF file. Figure 7 (on previous page) shows the fist-pass modeling of temperature profile.

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