10:01:22 OCA PAD AMENDMENT - PROJECT HEADER INFORMATION 07/17/95

Active

Project #: E-19-677 Cost share #: Rev #: 13
Center # : 10/24-6-R7357-0A0 Center shr #: OCA file #:
Work type : RES
Contract#: 37556K Mod #: 07 Document : PO
Prime #: 91-C-7425 Contract entity: GTRC

Subprojects ? : Y CFDA: N/A
Main project #: PE #:

Project unit: CHEM ENGR Unit code: 02.010.114
Project director(s):
KOHL P CHEM ENGR (404)894-2893

Sponsor/division names: E-SYSTEMS INC /
Sponsor/division codes: 204 / 001

Award period: 911016 to 950731 (performance) 950731 (reports)

Sponsor amount	New this change	Total to date
Contract value	4,000.00	258,548.09
Funded	4,000.00	258,548.09
Cost sharing amount		0.00

Does subcontracting plan apply ?: N

Title: HIGH TEMPERATURE SUPERCONDUCTOR MULTICHIP MODULES

PROJECT ADMINISTRATION DATA

OCA contact: Robert D. Simpkins 894-4820

Sponsor technical contact	Sponsor issuing office
MR. J.J. YAVULLA	MR. DANIEL J. QUANTRILLE
(703)849-1688	(703)849-1688
E-SYSTEMS, INC.	E-SYSTEMS, INC
MELPAR DIVISION	MELPAR DIVISION
7700 ARLINGTON BOULEVARD	7700 ARLINGTON BOULEVARD
FALLS CHURCH, VIRGINIA 22046	FALLS CHURCH, VIRGINIA 22046

Security class (U,C,S,TS) : U ONR resident rep. is ACO (Y/N): N
Defense priority rating : N/A N/A supplemental sheet.
Equipment title vests with: Sponsor X GIT

Administrative comments -
MOD #07 ADDS $4,000 FOR FINAL REPORT AND EXTENDS PERIOD OF PERFORMANCE TO
7/31/95.
S:

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 08/01/95

Project No. E-19-677 Center No. 10/24-6-R7357-0A0

Project Director KOHL P School/Lab CHEM ENGR

Sponsor E-SYSTEMS INC/

Contract/Grant No. 37556K Contract Entity GTRC

Prime Contract No. 91-C-7425

Title HIGH TEMPERATURE SUPERCONDUCTOR MULTICHIP MODULES

Effective Completion Date 950731 (Performance) 950731 (Reports)

Closeout Actions Required:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	Y	
Final Report of Inventions and/or Subcontracts	Y	
Government Property Inventory & Related Certificate	Y	
Classified Material Certificate	N	
Release and Assignment	Y	
Other	N	

Comments

Subproject Under Main Project No.

Continues Project No.

Distribution Required:

Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Managment	Y
Research Security Services	N
Reports Coordinator (OCA)	Y
GTRC	Y
Project File	Y
Other	N
	N

NOTE: Final Patent Questionnaire sent to PDPI.

MONTHLY STATUS REPORT

SUBMITTED BY: Paul A. Kohl
FOR: October, 1991
SUBMITTED: November 9, 1991

1. PROGRESS SUMMARY

We have initiated work on discussing and defining objectives in three areas:

*Yield
*Processing and Design
*Testing

2. ISSUES

Technical Issues: We will proceed by taking the limited information on short term and long term program system goals and work back toward "yield, processing and testing" objectives. Some of the technical issues will become more defined by this analysis.

Organizational Issues: We are working through "how to most effectively interact". Some of this involves understanding each other's strengths and needs.

3. COST AND SCHEDULE

We had projected $50k for calendar year 1991, but now expect to spend about 60% of that amount ($30k) in calendar 1991, due to the late start of the program. The excess funds are expected to be spent in calendar 1992,

4. COORDINATION REQUIREMENTS

We are working with STI and Conductus to establish working groups. See attached letter.

No help is needed at this moment.

5. FOLLOW-ON PLANS

We plan to visit STI and hopefully Conductus during the week of November 18, 1991.

6. CORRESPONDENCE LOG

Several phone conversation took place with STI in addition to the attached letter.

MONTHLY STATUS REPORT

SUBMITTED BY: Paul A. Kohl
FOR: November 1991
SUBMITTED: December 9, 1991

1. PROGRESS SUMMARY

Our activities were focused on developing a specific list of tasks for which we can contribute to the program goals. We have identified specific items with STI and Conductus (see exhibit A). These tasks were identified because of their need and the expertise at Georgia Tech (Professors Bidstrup, Hertling and Kohl)

Optimum Conventional Materials. This can be done in an advisory capacity as well as an experimental program.

Electrical Modeling and Measurement. This includes helping in the design of electrical structures, the establishment of experimental procedures, the execution of experimental programs, and the modeling of results. Advisory and experimental aspects were discussed.

Processing and yield. This includes advisory and experimental work in the design, processing and evaluation of structures and demonstrations. A specific suggestion as to a one-year demonstration using "dummy ICs" was made (see exhibit B).

2. ISSUES

(A) During our visits and phone conversations, we discussed 15 issues (see exhibit C). Specific assignments for many of these issues appear clear, however, numerous issues do not appear covered. For example, in-process and post-process fault testing is very challenging, and it appears that in-process fault repair will be necessary.

(B) The experimental work discussed with STI and Conductus far exceeds our funded experimental program at Georgia Tech.

3. COST AND SCHEDULE.

We are within our calendar year 1991 funds.

4. COORDINATION REQUIREMENTS.

We have had significant interactions with STI and Conductus. We would like to define the specific interactions with the other organizations, especially MIT and E-Systems.

5. FOLLOW-ON PLANS.

The plans will be discussed (modified) at the December 10, 1991 meeting.

6. CORRESPONDENCE LOG

Visits were made to STI on November 18, 1991 and Conductus on November 19, 1991. A second visit is planned for December 9, 1991. At least 6 substantiative phone conversations occurred with STI (Hertling, Bidstrup and Kohl), two with Conductus, two with n-Chip and 3 with the University of Arkansas.

MONTHLY STATUS REPORT

SUBMITTED BY: Paul A. Kohl
FOR: December, 1991
SUBMITTED: January 10, 1992

1. PROGRESS SUMMARY

We have had technical interchanges with STI, and Conductus for the purpose of:

*evaluating measurement procedures and capabilities at STI
*identifying most important experimental program(s) to undertake.

2. ISSUES

Technical Issues: We have proposed numerous experimental programs which we can pursue. These were transmitted to STI and Conductus. We hope to crystalize the exact experimental program as soon as possible.

3. COST AND SCHEDULE

We are within the established budget.

4. COORDINATION REQUIREMENTS

We anxiously look forward to feed back from STI and Conductus as to the precise work programs for 1992 (as per Quantrille memo, 3 January 1992).

5. FOLLOW-ON PLANS

We plan to host a visit by STI concerning testing and processing in January (exact date has not been set), and by M. Cima (exact date not set).

6. CORRESPONDENCE LOG

Several phone conversation took place with STI and David Hertling as to test procedures and have discussed the possibility of building a high speed probe station at 77 K at Georgia Tech. Also, attended the December working meeting in Sunnyvale, California.

MONTHLY STATUS REPORT

SUBMITTED BY: Paul A. Kohl
FOR: January 1992
SUBMITTED: February 10, 1992

1. PROGRESS SUMMARY

Technical input and discussions took place concerning

*Testing at high speed and at low temperatures
*Low temperature mechanical properties
*Ion milling of HTSC materials

A mechanical-electrical test structure will be designed for evaluating the HTSC and gold properties.

2. ISSUES

Technical Issues: We understand that the 1992 demonstration module has been agreed to and look forward to details of the specific work program.

3. COST AND SCHEDULE

We are within the established budget.

4. COORDINATION REQUIREMENTS

We are starting work in three areas with STI being the coordinating partner. The next coordination needs are to obtain feedback on the electrical-mechanical test structure, mechanical properties testing at low temperature, and ion milling. We expect these will take place over the next 6 weeks.

5. FOLLOW-ON PLANS

We will lay out the mechanical-electrical test structure within 2 weeks and have it reviewed by STI. We will begin mechanical testing of insulators at low temperature in February.

6. CORRESPONDENCE LOG

Numerous conversations took place with STI and Lincoln Bourne visited Georgia Tech on February 10, 1992.

E 19-677

MONTHLY STATUS REPORT

SUBMITTED BY: Paul A. Kohl
FOR: February 1992
SUBMITTED: March 12, 1992

1. PROGRESS SUMMARY

We are designing a mask set which has a series of test structures to be used for; (1) electrical characterization of HTSC MCMs (including fine-line structures), (2) process development (including fine-line HTSC features, and (3) characterization of yield and materials.

We are installing and characterizing a low temperature stress measurement capability.

We are in the process of more precisely defining the scope of the experimental program.

2. ISSUES

The major issue this month is the design and detail of the test features for the new mask set.

3. COST AND SCHEDULE

We are within the established budget.

4. COORDINATION REQUIREMENTS

We are working on the mask set and defining the experimental program with STI (and Conductus).

5. FOLLOW-ON PLANS

We plan to complete the design of the mask set within three weeks and have the experimental program defined this month.

6. CORRESPONDENCE LOG

Lincoln Bourne visited Georgia Tech on February 10, 1992 and there have been several conversations with STI concerning the experimental program. The second version of the program definition document is attached.

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MONTHLY STATUS REPORT

SUBMITTED BY: Paul A. Kohl
FOR: March 1992
SUBMITTED: April 13, 1992

1. PROGRESS SUMMARY

We have designed a mask set for testing, evaluating and performing fine-line process development for HTSC MCMs. The mask set (95% complete) was sent to Micro Phase Inc. for fabrication of the chrome masks in late March. A paper copy of the design is overdue and the new date for us to receive the paper prints is April 15, 1992. The mask contains 6 die which have features as small as 2 μm. The start of the documentation is attached (much more will be written). The paper prints of the mask are expected to be sent to STI on 4/15/92.

We have started the ion etching experiments using the two samples from STI. We will compare oxygen, chlorine, fluorine and nitrogen to the more established argon ion etching. The criteria will involve etch rate, undercutting, and electrical effects. The electrical effects will use the above mentioned mask. Some experiments will be done in April, however, the etching work will increase in activity in May and June.

We have started looking at the most appropriate methods for low temperature measurements. The wafer deflection system (CTE and stress measurements) is being calibrated at low temperatures.

2. ISSUES

We have two technical issues to discuss (primarily with STI). The first is the review of the test mask. The second issue is the parameters on argon ion etching of HTSC materials.

3. COST AND SCHEDULE

We are within the established budget.

4. COORDINATION REQUIREMENTS

We have had adequate coordination with STI in these early phases. No additional actions are needed.

5. FOLLOW-ON PLANS

We will sent STI paper print of test mask and will modify and document the design as appropriate. Etching experiments will ramp up in the next months as we are in the process of getting students up to speed.

6. CORRESPONDENCE LOG

Several conversations took place with STI.

F-19-692
H-7

MONTHLY STATUS REPORT

SUBMITTED BY: Paul A. Kohl
FOR: April 1992
SUBMITTED: May 9, 1992

1. PROGRESS SUMMARY

Electrical Characterization. We have completed the design of the HTSC test structures and have sent the blow-ups of the layout to STI for review. Several minor changes have been made including the addition of a 5 GHz resonator. The next step will be to fabricate the structures in HTSC and gold for comparison. A copy is attached.

Polymer characterization. We have been able to modify equipment so as to measure residual stress near 77 K. Attached is a plot of temperature vs residual stress for a Ciba 200 polyimide. We plan to measure the stress, CTE, and other parameters of a series of pre-imidized polyimides processed at various temperatures in order to quantify trade-offs.

Ion Milling. We have begun ion milling experiments using oxygen as the milling source. However, due to equipment problems, we have not been able to try other experiments yet. The etch rate for oxygen at 610 eV, 600 W, 50 mTorr, and 50 sccm was 100-125 A/min. We plan to measure the rates and electrical properties of etched samples.

2. ISSUES

We have no issues.

3. COST AND SCHEDULE

We are within the established budget.

4. COORDINATION REQUIREMENTS

We plan to initiate a meeting with STI (and others if appropriate) within the next 4-8 weeks to discuss results.

5. FOLLOW-ON PLANS

We plan to continue with the experiments in the three areas above.

6. CORRESPONDENCE LOG

Numerous conversations took place with STI. Dr. Simon Ang from the University of Arkansas has visited Georgia Tech.

MONTHLY STATUS REPORT

SUBMITTED BY: Paul A. Kohl
FOR: May 1992
SUBMITTED: June 10, 1992

1. PROGRESS SUMMARY

Electrical Characterization. A copy of the test structure write-up and 8.5x11 plot of the structures is attached. The order for the masks has been placed and delivery of the glass plates is expected this month. A set will also be purchased by STI (opposite tone on the metal). The structures will be fabricated in HTSC (at STI) and gold (at Georgia Tech) for comparison.

Polymer characterization. We are proceeding ahead on measuring mechanical properties of selected polymers at low temperatures, near 77K.

Ion Milling. We have not made much progress this month due to equipment problems.

2. ISSUES

In the next 1-2 months we hope to meet with STI (and others as appropriate) concerning the results and future plans on the electrical and polymer investigations.

For information, there will be a DoD sponsored (Special Technology Area Research) "Microwave Packaging Technology Packaging Workshop" at Georgia Tech on June 18 and 19. Information is attached and attendance is limited.

3. COST AND SCHEDULE

We are within the established budget.

4. COORDINATION REQUIREMENTS

We plan to initiate a meeting with STI in the near future

5. FOLLOW-ON PLANS

We plan to continue with the experiments in the three areas above.

6. CORRESPONDENCE LOG

We have had several conversations with STI, particularly Lincoln Bourne and Boo Nilsson concering the details of the test structure.

E 19-677

MONTHLY STATUS REPORT

SUBMITTED BY: Paul A. Kohl
FOR: June 1992
SUBMITTED: July 10, 1992

1. PROGRESS SUMMARY

Electrical Characterization. The electrical test structure has been completed. Parallel plate capacitor structures were added at the last minute. The masks have been ordered and should arrive within two weeks. STI will purchase a complete mask set and will process the structure in HTSC.

Polymer characterization. We measuring mechanical properties of Ciba Probamide 200 and 400 series polymers processed under different conditions at low temperatures, near 77K.

Ion Milling. We have milled HTSC material with N, F and O ions. The measurement of the rates is difficult because of the roughness of the starting material.

2. ISSUES

We have no technical issues which need to be addressed at this time. The equality of the experimental data occupying our time.

3. COST AND SCHEDULE

We are spent our M&S finds on the mask set and have asked permission to shift a small amount of funds into M&S. We hope that the additional funds will be provided so that the test structures can be fabricated and measurements can be made.

4. COORDINATION REQUIREMENTS

None at this time.

5. FOLLOW-ON PLANS

We plan to continue with the experiments in the three areas above.

6. CORRESPONDENCE LOG

We have had several conversations with STI, particularly Lincoln Bourne and Boo Nilsson concerning the details of the test structure.

#11

Monthly Status Report

Submitted By: Paul A. Kohl and Sue Ann Bidstrup
For: July 1992
Submitted: August 3, 1992

1. PROGRESS SUMMARY

Electrical Characterization

Electrical test structures are currently being fabricated at Georgia Tech. The purpose of these test structures is to evaluate high frequency electrical properties of superconducting MCM Interconnection, and to evaluate yield in forming HTSC and level to level interconnection.

Polymer Characterization

The effect of processing conditions on electrical properties and sub-ambient stress is being investigated for a series of polymer dielectrics. Preliminary data indicates that polyquinoline may be superior to Ciba Geigy Probimides. Advantageous properties include: lower dielectric constant; low residual stress; better solvent resistance.

Ion Milling

Ion milling is being explored using a variety of etching species including oxygen, CHF_3 and $CHCl_3$. The etching rate for each of these species has been determined. The effect of type of etching species on electrical performance and selectivity is currently being evaluated.

2. ISSUES

There has been an increase in requests to Georgia Tech for the electrical characterization of wafers. Funding has not been made available for testing on this magnitude.

3. COST AND SCHEDULE

We are within the established budget and schedule.

4. COORDINATION REQUIREMENTS

E-Systems will contact DuPont to evaluate the possibility of interactions with Georgia Tech.

5. FOLLOW-ON PLANS

We will continue with the experiments in the three areas listed above.

6. CORRESPONDENCE LOG

We have had over eight detailed discussions with STI, Conductus, Cornell and MIT. On July 31, Paul Kohl visited STI and representatives of Conductus to review current work. A visit with Dr. Robert Buhrman at Cornell is also planned during August.

MONTHLY STATUS REPORT

SUBMITTED BY: Paul A. Kohl
FOR: August 1992
SUBMITTED: September 9, 1992

1. PROGRESS SUMMARY

Electrical Characterization. The test structure designed with STI to evaluate the transmission line effects of HTSC interconnects has been completed and is being fabricated in gold at Georgia Tech. It will be fabricated in HTSC at STI. DuPont also plans to fabricate the same structure.

A second test structure for the purpose of yield evaluation has been designed and is being reviewed by the other sub-contractors. Details have been sent to all the parties concerned.

Polymer characterization. We have met with STI concerning characterization of insulators and have selected several materials to investigate. The mechanical and electrical properties will be evaluated at Georgia Tech at low temperature. The effect on HTSC interconnects will be evaluated at STI. We have also expanded the insulators to include silicon dioxide which will be deposited at Georgia Tech and sent to STI for evaluation.

Ion Milling. We are continuing to investigate the ion milling of HTSC materials.

2. ISSUES

The yield testing of HTSC materials is a major issue. The immediate problem is the quantity of samples to be processed for yield measurements. The long term problem is the availability of test equipment at 77 K. An independent test facilility to measure the product from multiple sources is important. In the long term, each vendor should have a facility.

In general, the yield testing is a good sign for this project. It will assit the development of a reasonable product home and will help to focus the project.

In the next 1-2 months we hope to meet with DuPont and others concerning the results and future plans on the electrical and polymer investigations.

3. COST AND SCHEDULE

We have nearly expended our budget and had to shift money into M&S (with approval) to buy photo masks.

4. COORDINATION REQUIREMENTS

We plan to visit DuPont in the next quarter and coordinate this with E-Systems and other on the east coast.

5. FOLLOW-ON PLANS

We plan to continue with the experiments in the three areas above.

6. CORRESPONDENCE LOG

P. Kohl visited STI on July 30 and met with STI and Conductus. Numerous phone conversation have taken place the M. Burnes (Conductus), D. Face (DuPont), B. Nilsson (STI), B. Burman and M. Cima concerning testing and design of structures. Several conversation with B. Nilsson have taken place concerning insulators and etching. Samples for insulator evaluation and specific polymer samples have been exchanged the STI.

E 19-697
-4-4

MONTHLY STATUS REPORT

SUBMITTED BY: Paul A. Kohl
FOR: September 1992
SUBMITTED: October 16, 1992

1. PROGRESS SUMMARY

Electrical Characterization. The test structure for yield evaluation has been completed and information has been sent to all parties. Once the masters have been purchased and inspected, copies can be purchased.

Polymer characterization. The work on evaluating the low temperature properties of a select number of polymers and SiO_2 is continuing. The results for SiO_2 as a passivation layer on HTSC is interesting, and will be concluded by STI. Several polymers are being investigated.

Ion Milling. We are investigating the reactive ion etching of HTSC materials in chlorine plasmas as an alternative to ion milling. Chlorine plasma can be used to etch HTSC and substrates at the rate of >500A/min. however, masking is always a problem with chlorine.

2. ISSUES

The yield testing of HTSC materials is a major issue which appears to be under control because of the involvement of E-Systems.

3. COST AND SCHEDULE

Our funding of $114K through 10/31/92 has been expended. The new funding on 11/1/92 and plus up funds are needed.

4. COORDINATION REQUIREMENTS

We will distribute information on testing.

5. FOLLOW-ON PLANS

We plan to continue with the experiments in the three areas above.

6. CORRESPONDENCE LOG

Numerous e-mail, FAX and phone conversations have taken place with DuPont, STI, and Conductus on the subjects of testing and insulators.

F-19-677

MONTHLY STATUS REPORT

SUBMITTED BY: Paul A. Kohl
FOR: October 1992
SUBMITTED: November 12, 1992

1. PROGRESS SUMMARY

Electrical Characterization. The test structure designed with STI to evaluate the transmission line effects of HTSC interconnects has been fabricated in gold and will be constructed in HTSC st STI.

The second test structure for the purpose of yield evaluation has been ordered from Microphase Labs. The paper drawing has been viewed by E-Systems and us. Approval was to fabricate the masks was sent. Details have been sent to all the parties concerned and copies have been ordered by several groups. A proposal on how the data will be analyzed has been sent out with Conductus and E-Systems replying.

Polymer characterization. The mechanical and electrical properties are being evaluated at low temperature. The effect on HTSC interconnects will be evaluated at STI.

Ion Milling. We are continuing to investigate the ion milling of HTSC materials.

2. ISSUES

The next major task is to evaluate the yield of various HTSC processes and foundries.

3. COST AND SCHEDULE

We have expended out funds through October 31, 1992 and are spending the plus-up funds.

4. COORDINATION REQUIREMENTS

We have communicated by phone and FAX to all the foundries and have coordinated the mask purchased. Communication back and data generation for yield is expected this month and into December.

5. FOLLOW-ON PLANS

Continue with the above projects.

6. CORRESPONDENCE LOG

Two meetings were held concerning materials, testing, and evaluation (SanDiego and Wilmington). There were many FAX and phone conversations concerning the test structures and measurements with the foundries, E-Systems and SBRC.

E19-617
#17

MONTHLY STATUS REPORT

SUBMITTED BY: Paul A. Kohl
FOR: November 1992
SUBMITTED: January 7, 1993

1. PROGRESS SUMMARY

Electrical Characterization. The test structure for yield evaluation have been purchased and inspected. Copies have been purchased. The electrical transmission line structures have not been fabricated as yet.

2. ISSUES

The test program is being developed and coordinated.

3. COST AND SCHEDULE

Our funding of $114K through 10/31/92 has been expended. The new funding on are needed.

4. COORDINATION REQUIREMENTS

None.

5. FOLLOW-ON PLANS

We will put together the data analysis for the test program when the format has been defined.

6. CORRESPONDENCE LOG

Numerous e-mail, FAX and phone conversations have taken place with DuPont, STI, and Conductus on the subjects of testing and insulators.

E19-677

MONTHLY STATUS REPORT

SUBMITTED BY: Paul A. Kohl
FOR: December 1992
SUBMITTED: January 7, 1993

1. PROGRESS SUMMARY

Electrical Characterization. The testing format has been determined for the yield evaluation. The fabrication is in progress at Conductus and DuPont.

Ion Milling. We have investigated the reactive ion etching of HTSC materials in $CHCL_3$, BCl_3, O_2 and CHF_3 plasmas as an alternative to ion milling. The etch rates in BCl_3 are YSZ:0A/min, CeO_2:120 A/min, sapphire:195A/min. In $CHCL_3$ YSZ:0A/min, Sapphire:243A/min, CeO_2:245 A/min, Th HTSC:600A/min. In O_2 Th HTSC:70A/min. We will be reproducing these results as well as etching all the HTSC related materials.

The intention is to expand the processing techniques, looking particularly at selectivity and stop etches.

2. ISSUES

None

3. COST AND SCHEDULE

Our funding of $114K through 10/31/92 has been expended. We have requested the next increment.

4. COORDINATION REQUIREMENTS

None at this time

5. FOLLOW-ON PLANS

We plan to continue with the experiments in the three areas above.

6. CORRESPONDENCE LOG

We have been in communication with Conductus, DuPont and STI concerning testing. We have visited DuPont in December and met with Dean Face. We have worked with STI concerning the etching of materials.

E 19-677

MONTHLY STATUS REPORT

SUBMITTED BY: Paul A. Kohl
FOR: January 1993
SUBMITTED: February 18, 1993

1. PROGRESS SUMMARY

Electrical Characterization. The testing format has been determined for the yield evaluation. We have been working on the most appropriate method of analyzing the data. We have discussed this with Mike Jack (SBRC). The test structures for the high frequency measurements are nearly complete at STI.

Ion Milling. We are continuing the planned experiements.

2. ISSUES

None

3. COST AND SCHEDULE

We are within the schedule and budget.

4. COORDINATION REQUIREMENTS

None at this time

5. FOLLOW-ON PLANS

We plan to continue with the experiments in the areas above.

6. CORRESPONDENCE LOG

We have been in communication with STI and SBRC concerning testing and have sent SBRC additional memos concerning test structures.

E19-677

#2

MONTHLY STATUS REPORT
A001 for subcontract 37556K

SUBMITTED BY: Paul A. Kohl
FOR: February 1993
SUBMITTED: March 15, 1993

1. PROGRESS SUMMARY

Electrical Characterization. The method of analysis for the yield data analysis has been proposed and is outlined on the attached sheets.

Ion Etching. Preliminary results for the ion etching experiments are shown on the attached summary sheet. The motivation for these experiments is (1) selective etch materials (etch stops), (2) planarization techniques, and (3) substrate removal.

2. ISSUES

Review of the timing and distribution list for yield data is needed.

3. COST AND SCHEDULE

We are within the schedule and budget.

4. COORDINATION REQUIREMENTS

None at this time

5. FOLLOW-ON PLANS

We plan to continue with the experiments in the areas above.

6. CORRESPONDENCE LOG

We have been in communication with STI and SBRC concerning testing and have sent SBRC additional memos concerning test structures.

HTSC YIELD ANALYSIS: Opens

Data Analysis	Plot Basis	Comments
1A. Frequency Distribution (Yield vs. line-width histogram) Assume 1 Ω threshold?	1/Wafer 1/Lot	Basic yield summary for wafer to wafer, and lot to lot.
1B. Visual Inspection	1/Wafer (a few wafers)	Defect Size (inferred) Defect size and type
2A. Defect Density Calculation	1/Wafer 1/Lot	Comparison of yield
2B. Defect Density Histogram (Do vs. Wafer number for each linewidth)	1/Organization	History of Do for each line width.
2C. Defect Density vs. linewidth	1/Organization	
3A. Yield vs. circuit area for each linewidth	1/Wafer 1/Lot	
3B. Fit to best model for each organization		
4A. Yield vs. wafer position (Yield vs. X,Y) (12 positions)	1/Wafer 1/Lot	Defect clustering

HTSC YIELD ANALYSIS: Shorts

Data Analysis	Plot Basis	Comments
1A. Frequency Distribution (Yield vs. line-width histogram)	1/Wafer 1/Lot	Yield summary
1B. Visual Inspection	Selected Wafers	Type of defect

HTSC: Parameters

Data Analysis	Plots	Comments
1. Critical Current vs. Linewidth	1/Wafer 1/Lot	
2. Resistance vs. current for each circuit at given linewidth	Selected sample	

DISTRIBUTION

Compile frequency distributions, defect density:

- Distribute within 48 hours receipt of data
- Reduce to paper copy (several/page)
- All organizations (plus E-Systems) receive all data with organization identified.

Fit to best model:

- On-going to be distributed weekly to biweekly.

Critical current data:

- Within 48 hours.

Questions

1. Name, e-mail, address, conformation number of contact person.
2. Electronic copy?
3. Other analysis?

			ETCH RATE (A/min)						
SUBSTRATE	CHCl3	BCl3	Cl2	SiCl4	O2	CHF3	N2	CH4	"Br"
LaAlO3 (3)	340		34						
Sapphire	243	195							
SrTiO3									
MgO									
YSZ	0	0	30						
Buffer La.									
CeO2	245	120	111						
YSZ									
HTSC									
TBCO (3)	650				70				
OTHER									
Photoresist					3000	0			
SiO2					0	375			
BCB					650				

E19-677

MONTHLY STATUS REPORT
A001 for subcontract 37556K

SUBMITTED BY: Paul A. Kohl
FOR: March 1993
SUBMITTED: April 23, 1993

1. PROGRESS SUMMARY

Electrical Characterization. The transmission line characteristics have not been measured yet. We anticipate they will be measured in the near future.

Ion Etching. We have been working through the survey of RIE etching studies and have found the etch rates in CHF_3 at 300W to be YBCO: 27A/min., TBCCO: 0 A/min., YSZ: 10 A/min., Al2O3: 15A/min., LaAlO3:10A/min. The etch rate of Al in Cl_2-BCl_3 is 2000A/min.

The most favorable etching conditions is still in Cl_2-BCl_3. We will continue to survey the rates. We have obtained adequate samples from STI.

Yield Analysis. We have considered various additional ways to extract data from the yield test, and await data.

2. ISSUES

None

3. COST AND SCHEDULE

We have expended all but $10k on this project. Incremental funds are required to continue working.

4. COORDINATION REQUIREMENTS

None at this time

5. FOLLOW-ON PLANS

We plan to continue with the experiments in the areas above.

6. CORRESPONDENCE LOG

We have been in communication with STI and SBRC concerning testing.

E-19-677

MONTHLY STATUS REPORT
A001 for subcontract 37556K

SUBMITTED BY: Paul A. Kohl
FOR: April 1993
SUBMITTED: June 17, 1993

1. PROGRESS SUMMARY

Electrical Characterization. A practice run of making measurements on HTSC transmission lines was made with two graduate students using the RF/microwave probe station and software.

Ion Etching. We are attempting to eliminate inconsistencies in the substrate and film etching. Control samples (aluminum and silicon) are run with each HTSC sample.

*Yield Analysis.*No work has been performed because of lack of data.

*Polymer Analysis.*Stress measurements at low temperature (-150 C) were obtained for Ciba's 293 preimidized polyimide and 412 photodefinable material for materials cured at 200 C to 350 C.

2. ISSUES

Program development in terms of products and development of hybrid structures would seem to be very dependent upon the yield (microstrip and via). The collection and distribution of this data is encouraged.

3. COST AND SCHEDULE

We are within budget.

4. COORDINATION REQUIREMENTS

None at this time

5. FOLLOW-ON PLANS

We plan to continue with the experiments in the areas above.

6. CORRESPONDENCE LOG

We have been discussing yield, structures and etching results with STI.

E19-6?7

MONTHLY STATUS REPORT
A001 for subcontract 37556K

SUBMITTED BY: Paul A. Kohl
FOR: May 1993
SUBMITTED: June 17, 1993

1. PROGRESS SUMMARY

Electrical Characterization. Electrical modeling of the multilayer HTSC structures was started which relate physical parameters to crosstalk, Zo etc. The purpose is to assist in the decision as to the best hybrid approach.

Ion Etching. We have attempted to lower the RIE power (200W to 500W) in order to achieve etching without mask removal. The results will be summarized in a future report.

Yield Analysis. No work has been performed because of lack of data.

Polymer Dielectrics. The dielectric constant of Ciba 293 and 412 was measured at room temperature for materials cured at 200-350C. The measurement of the dielectric constant at low temperature will be made.

2. ISSUES

None

3. COST AND SCHEDULE

We are within budget.

4. COORDINATION REQUIREMENTS

None at this time

5. FOLLOW-ON PLANS

We plan to continue with the experiments in the areas above.

6. CORRESPONDENCE LOG

Regular communications with STI have taken place.

E19-6-7

MONTHLY STATUS REPORT
A001 for subcontract 37556K

SUBMITTED BY: Paul A. Kohl
FOR: June 1993
SUBMITTED: June 29, 1993

1. PROGRESS SUMMARY

Electrical Characterization. The HTSC microstrip structures are being measured starting with the capacitor structures. Modeling is being performed on the polymer interlayer dielectrics. Results will be included in next month's report.

Ion Etching. We are in measuring the etch rates of HTSC materials and substrates. Data will be summarized shortly.

Yield Analysis. No work has been performed because of lack of data.

Polymer Dielectrics. The dielectric constant and stress measurements will be summarized at the end of July. The focus of the work is on (1) low temperature measurements, (2) rapid processing (see attached paper), and (3) photodefinable materials.

2. ISSUES

We would like to present the attached material at future technical conferences and publish the results. They would be submitted to ISHM or similar publications. This project has provided some of the support (low temperature aspects). Please inform us if there is any problem.

3. COST AND SCHEDULE

We are within budget.

4. COORDINATION REQUIREMENTS

None at this time

5. FOLLOW-ON PLANS

We plan to continue with the experiments in the areas above.

6. CORRESPONDENCE LOG

The attached information has sent to STI and Conductus. If further distribution is desirable, please inform us, or distribute yourself.

MONTHLY STATUS REPORT
A001 for subcontract 37556K

SUBMITTED BY: Paul A. Kohl
FOR: July 1993
SUBMITTED: September 30, 1993

1. PROGRESS SUMMARY

We have performed work in the following three areas: Electrical Characterization of HTSC microstrip structures, Ion Etching of HTSC materials and substrates, Yield Analysis, and Polymer Dielectrics for dielectric constant and stress measurements at low temperature.

We have detailed RIE experiments with STI. See details in quarterly report.

2. ISSUES

We have no issues at this time.

3. COST AND SCHEDULE

We are within budget.

4. COORDINATION REQUIREMENTS

We have obtained samples and needed information on our own.

5. FOLLOW-ON PLANS

We plan to continue with the experiments in the areas above.

6. CORRESPONDENCE LOG

P.A. Kohl visited STI in the month and discussed polymer processing, high frequency measurements and modeling.

MONTHLY STATUS REPORT
A001 for subcontract 37556K

SUBMITTED BY: Paul A. Kohl
FOR: August 1993
SUBMITTED: September 30, 1993

1. PROGRESS SUMMARY

The work has continued on Electrical Characterization of HTSC microstrip structures, Ion Etching of HTSC materials and substrates, Yield Analysis, and Polymer Dielectrics for dielectric constant and stress measurements at low temperature.

Of particular development this past month has been hybrid approaches to HTSC MCMs. We are performing calculations and experiments on a hybrid approach.

2. ISSUES

We look forward to the next coordination meeting concerning test structures, demonstrations, and particularly the hybrid approach.

3. COST AND SCHEDULE

We are within budget.

4. COORDINATION REQUIREMENTS

We have obtained samples and needed information on our own.

5. FOLLOW-ON PLANS

We plan to continue with the experiments in the areas above.

6. CORRESPONDENCE LOG

We have had numerous conversations with STI concerning test structures and measurements.

MONTHLY STATUS REPORT
A001 for subcontract 37556K

SUBMITTED BY: Paul A. Kohl
FOR: September 1993
SUBMITTED: October 8, 1993

1. PROGRESS SUMMARY

The work has continued on Electrical Characterization of HTSC microstrip structures, Ion Etching of HTSC materials and substrates, Yield Analysis, and Polymer Dielectrics for dielectric constant and stress measurements at low temperature.

Of particular development this past month has been hybrid approaches to HTSC MCMs. We are performing calculations and experiments on a hybrid approach.

2. ISSUES

We look forward to the next coordination meeting concerning test structures, demonstrations, and particularly the hybrid approach.

3. COST AND SCHEDULE

We are within budget.

4. COORDINATION REQUIREMENTS

We have obtained samples and needed information on our own.

5. FOLLOW-ON PLANS

We plan to continue with the experiments in the areas above.

6. CORRESPONDENCE LOG

We have had numerous conversations with STI concerning test structures and measurements.

E-19-677
31

MONTHLY STATUS REPORT
A001 for subcontract 37556K

SUBMITTED BY: Paul A. Kohl
FOR: October 1993
SUBMITTED: November 12, 1993

1. PROGRESS SUMMARY

HTSC work in October 93 has centered around modeling of multilayer HTSC structures. We have been modeled multi-layer hybrid structures and have looked at characteristic impedances of the signal lines and crosstalk between them. A major goal of this modeling effort is to be able to evaluate and compare hybrid HTSC structures using different materials and geometries. We have also been using our models to look at the trade-offs of using conventional metal instead of superconductors for power and ground planes.

We have completed the survey of Reactive Ion Etching (RIE) of HTSC films and substrate materials. There does appear to be a RIE enhanced etching effect, as compared to ion milling, the source of which is unknown. The next phase will be to etch Jc text structures to evaluate electrical properties.

We have preliminary results on Jc as a function of polymer type and have seen some improvement in performance. The results are going to be repeated.

2. ISSUES

We look forward to beginning the yield evaluation aspects of the program.

3. COST AND SCHEDULE

We are within budget.

4. COORDINATION REQUIREMENTS

none

5. FOLLOW-ON PLANS

We plan to continue with the experiments in the areas above.

6. CORRESPONDENCE LOG

A visit from Mike Eddy to Georgia Tech took place after the review in Arlington, VA on 26 October. David Hertling and Gary May attended the meeting.

E-19-677
-34

MONTHLY STATUS REPORT
A001, Deliverable #34 for subcontract 37556K

SUBMITTED BY: Paul A. Kohl
FOR: December 1993
SUBMITTED: February 22, 1994

1. PROGRESS

(A) Low Temperature Dielectrics. A select group of polymers have been selected for further investigation. The parameters to be varied are the polymer and its processing temperature. Degradation of the HTS during polymer processing is a major concern.

(B) Electrical Modeling. Attempts to model HTS microstrips have

2. ISSUES

We look forward to the next coordination meeting concerning test structures, demonstrations, and particularly the hybrid approach.

3. COST AND SCHEDULE

We are within budget.

4. COORDINATION REQUIREMENTS

We have obtained samples and needed information on our own.

5. FOLLOW-ON PLANS

We plan to continue with the experiments in the areas above.

6. CORRESPONDENCE LOG

coordinating input on hybrids

MONTHLY STATUS REPORT
A001, Deliverable #35 for subcontract 37556K

SUBMITTED BY: Paul A. Kohl
FOR: January, 1994
SUBMITTED: February 22, 1994

1. PROGRESS

(A) Polymers and HTS. A series of experiments have been designed with Conductus to examine the interaction of several polymers with YBCO. A series of 12 samples from the same wafer will be fabricated by Conductus. We will then deposit a series of different polymers on the samples and in a controlled way examine the interactions.

(B) Modeling. Calculations of characteristic impedance and inter-layer cross talk have been made and are being compared with STI and Conductus.

2. ISSUES

None at this time.

3. COST AND SCHEDULE

We are within budget but have expended more than 70% of the authorized funds.

4. COORDINATION REQUIREMENTS

A concise set of requirements and specifications is desirable.

5. FOLLOW-ON PLANS

We plan to continue with the experiments in the areas above.

6. CORRESPONDENCE LOG

Numerous discussions on hybrids and crosstalk have taken place.

F-19-?-?

37
35

MONTHLY STATUS REPORT
A001, Deliverable #37 for subcontract 37556K

SUBMITTED BY: Paul A. Kohl
FOR: February, 1994
SUBMITTED: March 5, 1994

1. PROGRESS

(A) Polymers in HTS. We have processed a set of eight samples for Conductus examining the effect of processing temperature and material on HTS properties. Experiments have been performed with Conductus, examining specific polymers for HTS applications. The surface resistance of 12 samples will be measured followed by temperature cycling experiments.

(B) Modeling. We have performed specific calculations looking at crosstalk. Dave Hertling is trying to put the numbers together with those of the other team members.

2. ISSUES

We look forward to the next coordination meeting concerning test structures, demonstrations, and particularly the hybrid approach.

3. COST AND SCHEDULE

We are within budget but have expended more than 70% of this year's authorized funds which are below the contract value.

4. COORDINATION REQUIREMENTS

The specific electrical requirements concerning HTS MCMs should be refined and distributed.

5. FOLLOW-ON PLANS

We plan to continue with the experiments in the areas above.

6. CORRESPONDENCE LOG

Samples and data have been exchanged on polymers on HTS.

F-17-671
4

QUARTERLY STATUS REPORT

SUBMITTED BY: Paul A. Kohl
FOR: October 16, 1991 to January 31, 1992
SUBMITTED: February 10, 1992

1. PROGRESS SUMMARY

In the past quarter, we have identified numerous areas where work should occur in order for HTSC MCMs to become a reality. We have agreed to start working in three areas:

1. Electrical testing
2. Processing
3. Materials testing

We anticipate that future activities will involve yield and process evaluations, and assistance in test modules.

2. ISSUES

The major issue has been the formulation of a meaningful experimental and consultation program. We have made considerable progress in understanding our respective role in this program.

3. COST AND SCHEDULE

We are within the cost and schedule of the program.

4. COORDINATION REQUIREMENTS

We are working with STI on coordinating projects and are pleased with their help.

5. FOLLOW-ON PLANS

Design, measurement and processing work will begin this quarter.

6. CORRESPONDENCE LOG

Several trips and interactions have taken place as documented in the Monthly Reports. Briefings of technical discussions have been sent to E-Systems as they occurred.

E-19-677
#5

QUARTERLY STATUS REPORT

SUBMITTED BY: Paul A. Kohl
FOR: February 1, 1992 to April 30, 1992
SUBMITTED: May 11, 1992

1. PROGRESS SUMMARY

In the past quarter, we have identified three areas of work in HTSC in which we will perform experiments.

1. Electrical testing: have designed a test structure.
2. Polymer processing: pre-imidized polymers.
3. Ion Milling: comparison to argon.

We have started work in each of these three areas.

2. ISSUES

The major issue has been the formulation of a meaningful experimental and consultation program. We have made some progress, however, we look forward to increasing our participation and interaction.

3. COST AND SCHEDULE

We are within the cost and schedule of the program.

4. COORDINATION REQUIREMENTS

We are working with STI on coordinating projects and are pleased with their help.

5. FOLLOW-ON PLANS

We plan to continue the experiments and will be reviewing the results with STI and others.

6. CORRESPONDENCE LOG

Several trips and interactions have taken place as documented in the Monthly Reports.

E-17-677

Quarterly Status Report

Submitted By: Paul A. Kohl and Sue Ann Bidstrup
For: May 1, 1992 to July 31, 1992
Submitted: August 3, 1992

1. PROGRESS SUMMARY

-- Electrical test structures have been designed and are currently being fabricated.
-- Ion milling with oxygen, CHF_3 and $CHCl_3$ has been investigated. The etch rate for each of these etching species has been determined.
-- The effect of processing conditions on dielectric constant and stress at low temperatures is being investigated for Ciba-Geigy Probimides and Maxdem polyquinolines. Preliminary data indicates that polyquinolines may be superior to the Probimide 200 series, in terms of the electrical properties, stress and solvent resistance.

2. ISSUES

There has been an increase in requests to Georgia Tech for the electrical characterization of wafers. Funding has not been made available for testing on this magnitude.

3. COST AND SCHEDULE

We are within the established budget and schedule.

4. COORDINATION REQUIREMENTS

None at this time

5. FOLLOW-ON PLANS

-- Continue to explore the trade-off between low cure temperature and final electrical properties for polymer dielectrics
-- Evaluate sub-ambient stress and coefficient of thermal expansion for Probimide 200 and 400 series, polyquinolines and benzocyclobutenes
-- Use the fabricated test structures to evaluate high frequency dielectric properties and yield
-- Evaluate the effect of etching species type for ion milling on electrical performance and selectivity

6. CORRESPONDENCE LOG

Several detailed discussions have occurred with STI, Conductus, Cornell and MIT. Paul Kohl visited STI to review current work. Dr. Simon Ang of University of Arkansas visited Georgia Tech.

E-19-677

QUARTERLY STATUS REPORT

SUBMITTED BY: Paul A. Kohl
FOR: August 1, 1992 to October 31, 1992
SUBMITTED: November 16, 1992

1. PROGRESS SUMMARY

In the past quarter, we have been working in three areas.

1. Electrical testing: have designed a second test structure for yield. The masks have been designed, checked and fabricated. Comments from all parties concerning evaluation procedures has been requested.

2. Insulator processing: pre-imidized polymers, and oxides. We have deposited SiO2 for STI on HTSC structures for evaluation, and have sent material to STI for their testing.

3. Ion Etching: comparison to argon milling. Etch rates in Cl_2 RIE are under way.

2. ISSUES

We anticipate that the major issue may become yield of HTSC small features and quality across large areas. At that point, an infusion of processing technology will be appropriate.

3. COST AND SCHEDULE

We have expended our first year's funds, as planned.

4. COORDINATION REQUIREMENTS

The coordination and communication on this project are important and efforts should be taken to sustain them.

5. FOLLOW-ON PLANS

We plan to continue the above work as planned.

6. CORRESPONDENCE LOG

Two were taken to coordinating meetings and many calls, FAXs and copies of the written reports were sent.

F-19-6 / / 24

QUARTERLY STATUS REPORT
A002

SUBMITTED BY: Paul A. Kohl
FOR: May, 10 1993
SUBMITTED: July 1, 1994

1. PROGRESS SUMMARY

Electrical Characterization. Electrical modeling of the multilayer HTSC structures was started which relate physical parameters to crosstalk, Zo etc. The purpose is to assist in the decision as to the best hybrid approach.

Ion Etching. We have attempted to lower the RIE power (200W to 500W) in order to achieve etching without mask removal. The results will be summarized in a future report.

Yield Analysis. No work has been performed because of lack of data.

Polymer Dielectrics. The dielectric constant of Ciba 293 and 412 was measured at room temperature for materials cured at 200-350C. The measurement of the dielectric constant at low temperature will be made.

2. ISSUES

None

3. COST AND SCHEDULE

We are within budget.

4. COORDINATION REQUIREMENTS

None at this time

5. FOLLOW-ON PLANS

We plan to continue with the experiments in the areas above.

6. CORRESPONDENCE LOG

Regular communications with STI have taken place.

QUARTERLY STATUS REPORT

SUBMITTED BY: Paul A. Kohl
FOR: May 1, 1993 to July 1, 1993
SUBMITTED: September 8, 1993

1. PROGRESS SUMMARY

In the past quarter, we have been working in three areas.

1. Electrical testing: Measurement of transmission line properties of STI's HTSC. Results are awaiting their fixtures.

2. Insulator processing: pre-imidized polymers, and oxides. We are depositing several polymers under different conditions to look at the resulting quality of the HTSC.

3. Ion Etching: We have compared substrates and superconductors etch rates in oxygen, chlorine and fluorine. There does appear to be an enhancement in etching in the RIE mode over ion milling. Further, there is a very significant selectivity difference between HTSC and substrates. We have designed a series of experiments testing the electrical quality of the RIE etched samples with STI.

2. ISSUES

We have made preparations for the yield test analysis and look forward to the program starting.

3. COST AND SCHEDULE

No issues

4. COORDINATION REQUIREMENTS

None.

5. FOLLOW-ON PLANS

We plan to continue the above work as planned.

6. CORRESPONDENCE LOG

A considerable level of communications has occurred with STI and some with E-Systems and Conductus.

F-10-577
36
34

QUARTERLY STATUS REPORT
A002, Deliverable #36 for subcontract

SUBMITTED BY: Paul A. Kohl
FOR: November 1, 1993 to January 31, 1994
SUBMITTED: February 25, 1994

1. PROGRESS SUMMARY

In the past quarter, we have been working in two areas.

(A) Low Temperature Dielectrics. A select group of polymers have been selected for further investigation. The parameters to be varied are the polymer and its processing temperature. Degradation of the HTS during polymer processing is a major concern. A series of samples have been made by Conductus and sent to Georgia Tech. The samples have been processed and returned to Conductus for surface resistance testing.

(B) Electrical Modeling. Attempts have been made to model HTS microstrips using existing simulators so as to add realism to the different hybrid approaches. The effort will be focused onto targeted structures in the future. The application of this work is for hybrid approaches to MCMs. A report on hybrids has been issued.

2. ISSUES

The most important issue in these topics is to focus the efforts on products and applications where electrical and yield results can be made to meet the match the application to the technology

3. FOLLOW-ON PLANS

We plan to continue the above work as planned.

E-19-677
#36
Final Rpt.

HTSC PROCESSING AND MEASUREMENTS

Authors: Sue Ann Bidstrup
David Hertling
Paul Kohl
Gary May

Performing Organization: Georgia Institute of Technology

Publication Date: June 1, 1995

Sponsoring Organization: E-Systems, Inc.
Contract #37556K

HTSC PROCESSING AND MEASUREMENTS

Sue Ann Bidstrup
David Hertling
Paul Kohl
Gary May

Georgia Institute of Technology
Pettit Microelectronics Research Center
Atlanta, GA 30332

June 1, 1995

Contract Number: 37556K
Prime Number: 91-C-7425

Sponsoring Organization: E-Systems, Inc.
Melpar Division
7700 Arlington Boulevard
Falls Church, VA 22046
Attention: Daniel J. Quantrille

ABSTRACT

The purpose of this project was to develop polymeric dielectrics to be used with HTSCs. The emphasis has been on state-of-the-art materials available from commercial suppliers (readily available materials), and modify the processing so as to optimize the quality of the HTSC. Of particular concern is the degradation of the HTSC while at a high temperature needed for processing the polymer.

Several interesting results have been obtained which shows that the resulting HTSC quality can be enhanced through process development.

The second topic is the characterization of HTSC as a transmission line structure. A mask set has been designed and fabricated to evaluate the electrical characteristics. The mask set is available through a third party mask making house for members of the team to purchase.

TABLE OF CONTENTS

FIGURE AND TABLES LISTS

SYMBOLS, ABBREVIATIONS, ACRONYMS

A	area of the capacitor plates
C	capacitance
E	Young's modulus of substrate
h	thickness of substrate
R_{coated}	radius of curvature of silicon substrate after polymer deposition
$R_{uncoated}$	radius of curvature of silicon substrate before polymer deposition
t	thickness of the polymer film
Y	admittance
Z	impedance
ε	complex permittivity of the polymer
ε'_r	measured permittivity of the polymer
ε''_r	measured dielectric loss factor
ε_0	permittivity of free space
ν	Poisson's ratio of the substrate material
ω	frequency
ρ_{tan}	loss tangent
σ	residual stress of the polymer film

Task 1: LOW TEMPERATURE PROPERTIES OF POLYMER DIELECTRICS

The goal of this study is to measure the low temperature properties of polymer films, with the intent of identifying those compatible with HTSC materials, as well as a set of processes which produce the highest quality insulators in terms of cost, processing, reliability, yield and electrical performance. Seven polymer systems were selected for evaluation as interlevel dielectrics in HTSCs. Since superconducting layers are sensitive to temperatures in excess of 200°C, the effect of processing temperatures on important performance properties was explored. Residual stress measurements were made over a temperature range from -150 to 25°C. In addition, the dielectric constants were measured. Based on this study, two polymer systems were selected for evaluation on YBCO devices, which have been provided by STI.

1.1 Introduction

The goal of Task 1 is to investigate several different polymer systems for use as interlevel dielectrics in HTSCs. Requirements for this application are:

- low dielectric constant
- no delamination or cracking of the films during multiple thermal cycles to liquid nitrogen temperatures (i.e. low residual stress)
- low processing temperature and low moisture uptake (superconducting layers are sensitive to the presence of moisture at temperatures > 200°C)
- solvent resistance

Polymer systems were selected for investigation include:

Dow Benzocyclobutenes (BCBs)
Ciba-Geigy Probimide 293 pre-imidized polyimides
Ciba-Geigy Probimide 412 pre-imidized, photo sensitive polymide
DuPont PI 2545 PMDA-ODA polyimides
DuPont PI2566 Fluorinated polyimides

BCBs and pre-imidized polyimide were selected for analysis because of their low processing temperature and because no water is evolved during processing. The PMDA-ODA polyimides were chosen as a standard polymer used in interlevel dielectric applications. Fluorinated polyimides have lower moisture uptake and a lower dielectric constant than PMDA-ODA polyimides.

In this investigation, sub-ambient residual stress and the dielectric constant were measured for each of these polymers at a variety of processing conditions. Based on this evaluation, two of the most promising systems were selected for further evaluation as interlevel dielectrics in HTSCs.

1.2 Methods, Assumptions and Procedures

The polymer test films were fabricated by spin coating low viscosity polymer solutions on four inch silicon wafers. The film thicknesses were measured using a Metricon model 2010 Prism Coupler. The thicknesses of the polymer films ranged from two to six microns.

The residual stress was determined for spin-coated films on 100 mm diameter silicon substrates using a Flexus F2320 wafer curvature system (Tencor Instruments Co., Sunnyvale, CA). The radius of curvature of the silicon substrate was measured before and after polymer deposition ($R_{uncoated}$ and R_{coated}, respectively). The residual stress of the films, σ, was calculated from the difference of the wafer curvature knowing the Young's modulus of the substrate, E, the Poisson's ratio of the substrate material, ν, the thickness of the substrate, h, and the thickness of the polymer film, t,

$$\sigma = \frac{1}{6}\frac{E}{(1-\nu)}\frac{h^2}{t}\left(\frac{1}{R_{uncoated}} - \frac{1}{R_{coated}}\right) \qquad (13)$$

Typical values for the Young's modulus and Poisson's ratio for silicon are 1.9×10^{11} N/m^2 and 0.27, respectively. The Flexus instrument was modified with a liquid nitrogen source to provide cooling down to -150°C; the cooling rate was 2°C/minute.

1.3 Stress Results and Discussion

All polymer systems and cure conditions examined in this study survived thermal cycling from room temperature to -150°C without film cracking or delamination. The results of residual stress data are shown in Figures 1.1 - 1.5. Curve fitting parameters for these figures are given in Tables 1.1 -1. 4.

6FDA/ODA:

PI2566 was spin coated onto two 380 micon thick silicon wafers. The average thickness of the films were measured using a Metricon Prism Coupler and were determined to be 2.3690 ± 0.010 microns and 5.7250 ± 0.057 microns. The following scans were performed on the thinner film using continuous temperature ramping: two experiments from -165 to 175°C and one from -110 to 25°C with a hold at -105°C. The linear linear stress-temperature response of this film is shown in Figure 1.1 (continuous ramping scan from -165° to 175°C). Figure 1.2 shows an example of -165 to 175°C scan for the thicker film. The linear dependence between temperature and stress indicates that the coefficient of thermal expansion (CTE) is independent of temperature. By extrapolation of the data to 77K, a stress of 75 MPa for the 2.37 micron film and a stress of 79 MPa is predicted.

PMDA/ODA:

PI2545 was spin coated on two silicon wafers. The film thicknesses were 4.3689 ± 0.012 microns and 3.9153 ± 0.021 microns. The stress was again calculated using the radius of curvature which was obtained from the Flexus at a variety of temperatures using both methods of heating and cooling describe above. A representative scan is shown in Figure 1.3. All data collected on this system show nonlinearity in stress as a function of temperature, indicating that the CTE changes with temperature. The curve fit parameters are shown in Table 1.2. The second order polynomial coefficients are used to predict a film stress at 77K of 59 MPa for the 4.37 micon film and a stress of 50 MPa for the 3.92 micron film.

Probimide 293 (preimidized):

Probimide 293 was spin coated on a silicon wafer with a thickness of 4.5298 ± 0.052 microns. The stress-temperature data are found in Figure 1.4. These results show that the slope is independent of temperature. The linear regression parameters are shown in Table 1.3. These parameters are used to predict a film stress of 82 MPa at 77K.

Probimide 412 (preimidized, photodefinable):

Probimide 412 was spin coated on a silicon wafer with a thickness of 2.0307 ± 0.016 microns. The results were similar to those obtained with the Probimide 293 with a slope of 0.184 ± 0.020 MPa/°C.

Benzocyclobutenes

BCB was spin coated onto a silicon wafer with a thickness of 1.0683 microns. Data from a -110 to 25°C with a hold at -105°C experiment is shown in Figure 1.5. The curve fitting parameters are given in Table 1.3. A stress of 71 MPa is predicted at 77K.

1.4 Conclusions and Recommendations

Through this study, we are now able to develop a short list of polymers to be considered for interconnect applications in HTSC's: benzocyclobutenes and pre-imidized polyimides. BCB polymers have the potential of curing at temperatures less than 200°C. In addition, the dielectric constant, moisture uptake and solvent resistance are independent of cure temperature and superior to other systems examined in this study. Although the measured residual stress at 77K is higher than PMDA-ODA, BCB films survived several quench cycles without curing or delaminating. Further work is required to determine whether BCBs have the long term reliability required for the HTSC application.

Pre-imidized polyimides, like BCBs, have low processing temperatures. However, the dielectric constant, stress and moisture uptake is significantly higher than BCB. Pre-imidized polyimides also have lower solvent resistance than BCB.

Benzocyclobutenes

BCB was spin coated onto a 375 μm thick silicon wafer at a thickness of 1.0683 μm. Experiments were done using both methods of temperature ramping and control. The ramp and hold experimental results are shown in Figure 1.5 to be linear. The complete set of regression data can be found in Table 1.4.

Table 1.1 Regression data for experiments performed on 6FDA/ODA in the form of y=mx+b.

Film thickness (μm)	m (MPa/°C)	b (MPa)	R^2
2.37	-0.1398	41.354	0.9949
2.37	-0.1583	44.100	0.9831
2.37	-0.1506	42.829	0.9956
average	-0.1496	42.761	---
standard dev.	0.0093	1.374	---
5.73	-0.1794	44.176	0.9988
5.73	-0.1557	44.382	0.9959
5.73	-0.1596	45.334	0.9983
5.73	-0.1483	—	—
average	-0.1608	44.631	—
standard dev.	0.0133	0.619	—

Table 1.2 Regression data for experiments performed on PMDA/ODA in the form of $y=ax^2+bx+c$.

Film thickness (μm)	a (MPa/°C²)	b (MPa/°C)	c (MPa)	R^2
4.37	$9x10^{-5}$	-0.0905	25.588	0.9949
4.37	0.0002	-0.1138	26.025	0.9961
4.37	0.0002	-0.1181	28.185	0.9956
average	0.0002	-0.1075	26.599	—
standard dev.	0.00006	0.0149	1.391	---
3.92	0.0001	-0.0878	26.524	0.9960

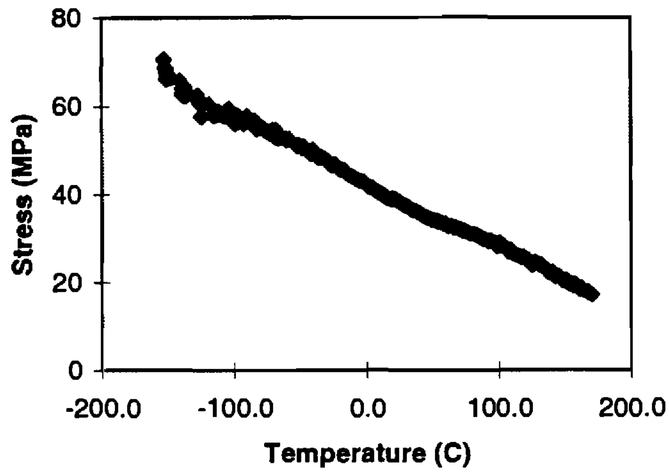
Table 1.3 Regression data for experiments performed on Probimide 293 in the form of y=mx+b.

Film thickness (μm)	m (MPa/°C)	b (MPa)	R^2
4.53	-0.1593	46.447	0.9939
4.53	-0.1619	47.811	0.9957
average	-0.1606	47.129	—
standard dev.	0.0018	0.964	---

Table 1.4 Regression data for experiments performed on BCB in the form of y=mx+b.

Film thickness (µm)	m (MPa/°C)	b (MPa)	R^2
1.07	-0.1678	31.321	0.9927
1.07	-0.1890	33.972	0.9845
average	-0.1784	32.647	—
standard dev.	0.0150	1.875	—

Fig. 1.1 2.37 micron 6FDA/ODA Film on Silicon



5.73 micron 6FDA/ODA Film on Silicon

Fig. 1.2

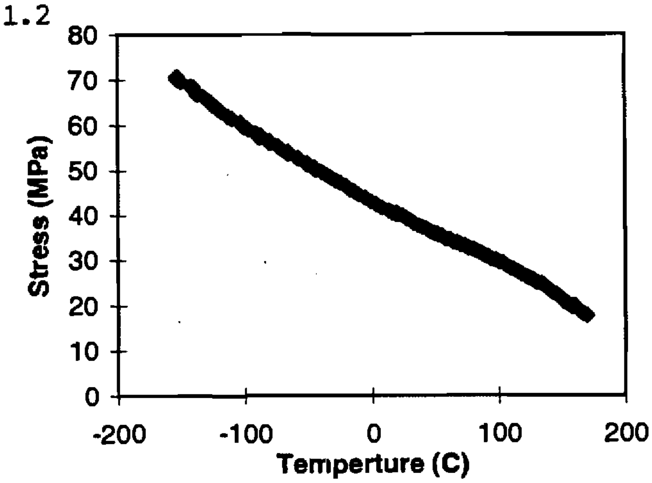


Fig. 1.3

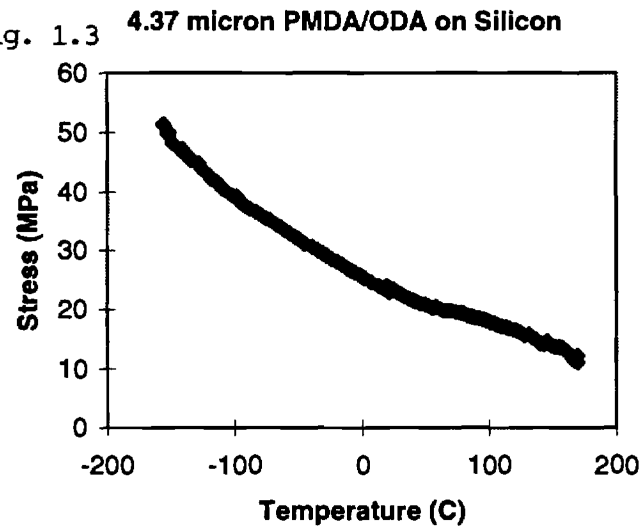


Fig. 1.4

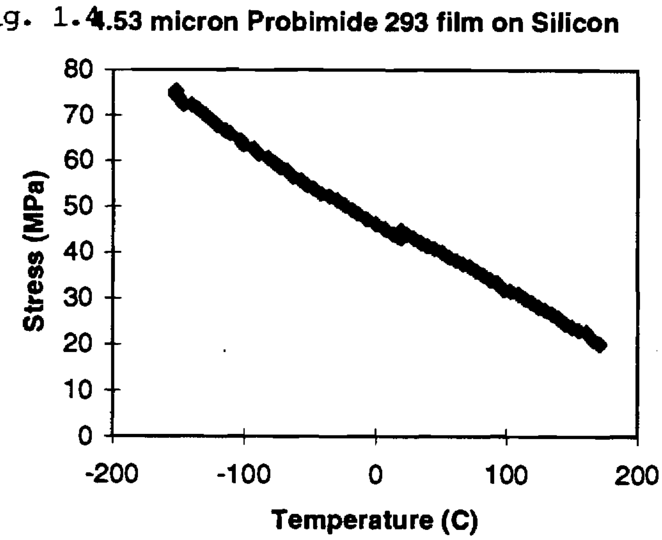
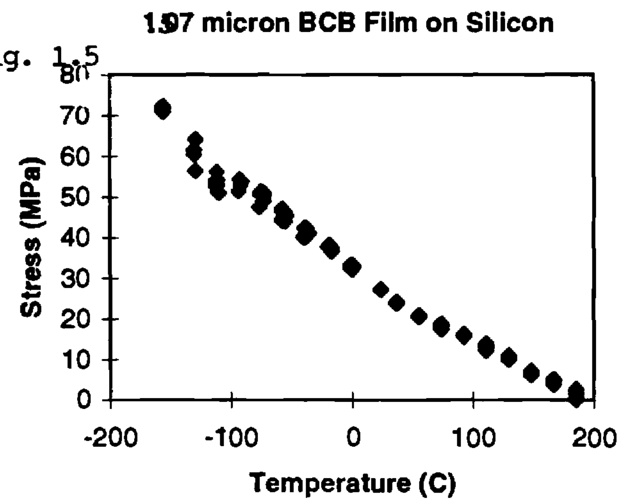


Fig. 1.5



2.1: Summary of Task 2

The goal of Task 2 is to investigate the properties of HTSC transmission lines, including characterization of simple discontinuities and coupling between adjacent transmission lines. Georgia Tech and STI jointly designed test structures for HTSC MCM's. The HTSC test vehicle includes test structures to measure material parameters, transmission line properties, and defect analysis. The artwork for the mask set was prepared at Georgia Tech. Mask sets were purchased to make test samples. Based on the success of this test pattern, other mask sets were designed and fabricated for the purpose of yield analysis. The yield test structure was funded under other programs.

2.2: Test Structures.

HTSC5 contains three capacitors with areas of 0.1225, 0.0225, and 0.001225 cm^2 for electrical characterization of the dielectric material. The capacitors are modeled by an ideal parallel plate capacitor with a dielectric which has a complex permittivity

$$\varepsilon = \varepsilon_o (\varepsilon_r' - j\varepsilon_r'') \qquad (2.1)$$

The capacitance is determined mathematically by using the permittivity of the dielectric, ε, and the dimensions of the physical capacitor (the area of the capacitor plates, A, and the thickness of the dielectric, t).

$$C = \frac{\varepsilon A}{t} \qquad (2.2)$$

The equivalent admittance of this capacitor is :

$$Y = j\omega C = \frac{\varepsilon_o A \omega}{t}(\varepsilon_r'' + j\varepsilon_r') = G + jB \qquad (2.3)$$

The HP 8510A network analyzer is used to measure the impedance, Z = R+jX ohms, of the physical capacitor at various frequencies. This impedance can be transformed into an admittance Y = G+jB such that

$$Y = G + jB = \frac{1}{Z} = \frac{R}{R^2 + X^2} + \frac{-jX}{R^2 + X^2} \qquad (2.4)$$

Equating the real and imaginary parts, and solving for the complex permittivity of the dielectric in terms of the physical dimensions of the capacitor, the radian frequency ω, and the measured quantities R and X, we have

$$\varepsilon'_r = \frac{-Xt}{\omega\varepsilon_o A(R^2 + X^2)} \tag{2.5}$$

$$\varepsilon''_r = \frac{-Rt}{\omega\varepsilon_o A(R^2 + X^2)} \tag{2.6}$$

The loss tangent of the dielectric is defined as

$$\rho_{tan} = \frac{\varepsilon''}{\varepsilon'} = \frac{-R}{X} \tag{2.7}$$

HTSC1 and HTSC2 contain three different kinds of transmission lines. These are straight lines, straight lines with one via, and a line in the shape of a square wave. The square wave structure has a second line in metal 2 traverse straight across the square wave and is intended to simulate layer to layer cross talk. The intersection of the two lines is typical of the crosstalk geometries in MCM's. Each of the three kinds of structures are fabricated in seven line widths, 2, 4, 10, 15, 20, 30, and 35 microns. Each line is terminated with ground-signal-ground (150 micron pitch) connections for direct probing. However, a low temperature, high frequency probe station was not funded in this project and therefore, wire bonding and packaging are necessary.

Transmission through the transmission lines is measured to determine the characteristic impedance and the complex propagation constant. Accurate determination of these transmission line parameters, however, is difficult with lines of such short length.

The characteristic impedance of the transmission lines is determined by measuring the impedance of both an open-circuited and short-circuited line.

$$Z_{sc} = Z_{in}\ (Z_L{=}0) \tag{2.8}$$

$$Z_{oc} = Z_{in}\ (Z_L{=}\infty) \tag{2.9}$$

$$Z_o = \sqrt{Z_{sc} Z_{oc}} \tag{2.10}$$

The characteristic impedance can also be expressed in terms of the line parameters per unit length, R, L, G, and C:

$$Z_o = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \tag{2.11}$$

Knowing the line parameters, the complex propagation constant can be determined.

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} = \alpha + j\beta \tag{2.12}$$

where α = loss per unit length and β = phase shift per unit length.

A limited number of materials were examined using these test structures. The results of these tests have been held by the companies because they relate to proprietary issues. It was intended that these test structures would be used to evaluate new innovations in HTSC materials and dielectrics. The program did not achieve that level of maturity.

2.3 Description of the HTSC test vehicle

There are four different 1cm by 1cm die, called HTSC1,HTSC2,HTSC3, and HTSC4. In addition HTSC11 and HTSC22 are exact copies of HTSC1 and HTSC2, respectively, with the HTSC layer overcoated with a layer of first gold. Fig.1 shows how the four different designs are distributed around the two inch wafer.

HTSC1 and HTSC11 (Fig.)

Pads 1-14, at the bottom of the die, cover seven different sized HTSC transmission lines running the width of the die, which comes out to 0.8980cm.

Pad #'s	Size(μm)
1-2	35
3-4	30
5-6	20
7-8	15
9-10	10
11-12	4
13-14	2

Just above the transmission lines are similar structures, but instead of running the full length of the die in HTSC, they go half way across in HTSC and the remainder of the way in gold2. The total length of the lines are .8980cm. The via exactly divides the line in half, the exact length of each segment is listed below.

Pad #'s	LineWidth(μm)	HTSC(cm)	Gold2(cm)
15-16	35	0.4453	0.4473
17-18	30	0.4455	0.4475
19-20	20	0.4460	0.4480
21-22	15	0.4468	0.4490
23-24	10	0.4475	0.4490
25-26	4	0.4484	0.4496
27-28	2	0.4485	0.4497

The top half of HTSC1 are transmission lines in the shape of square waves. A straight gold2 line runs directly over the top of the HTSC

Figure 2.1 Die Distribution

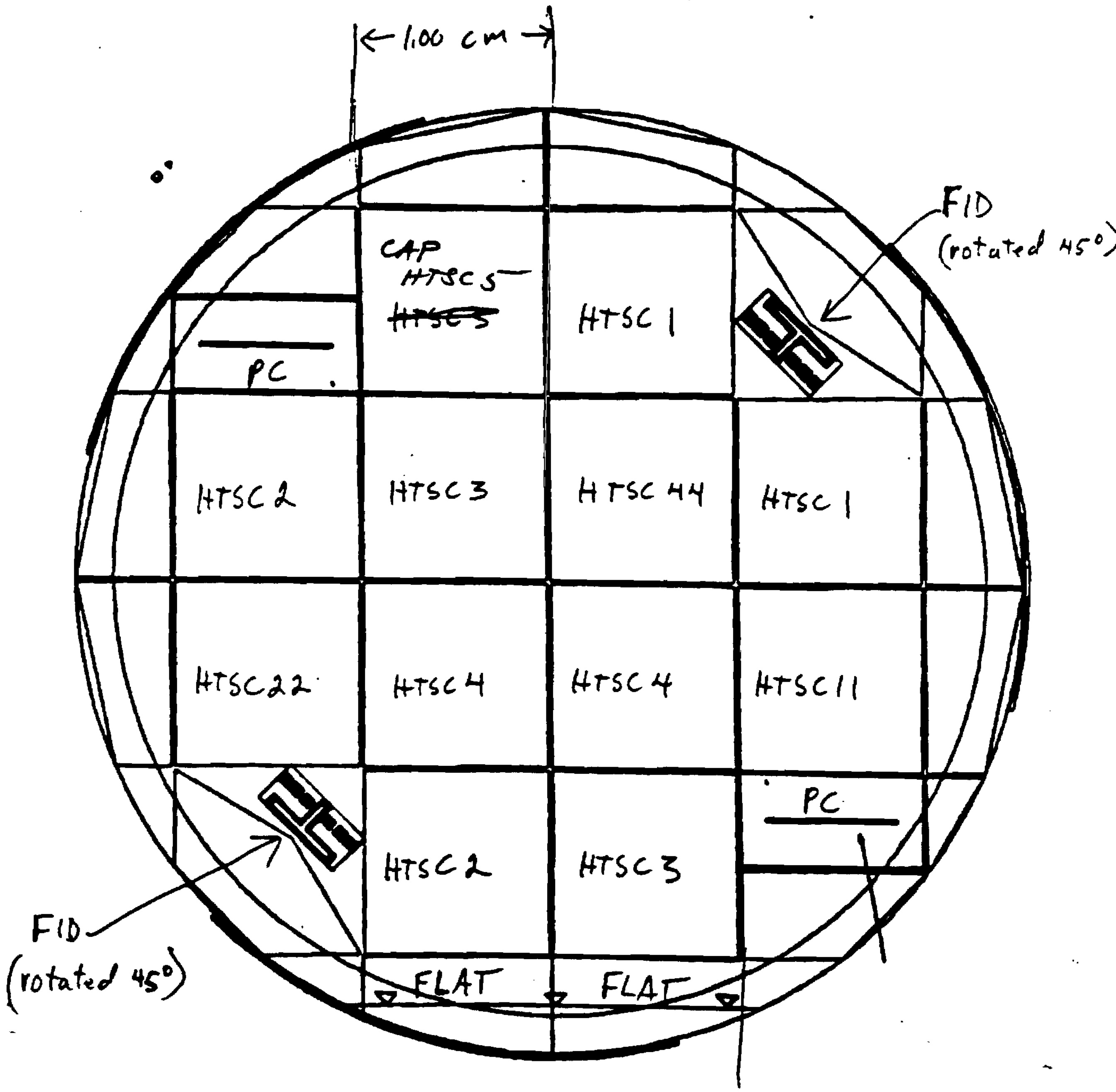
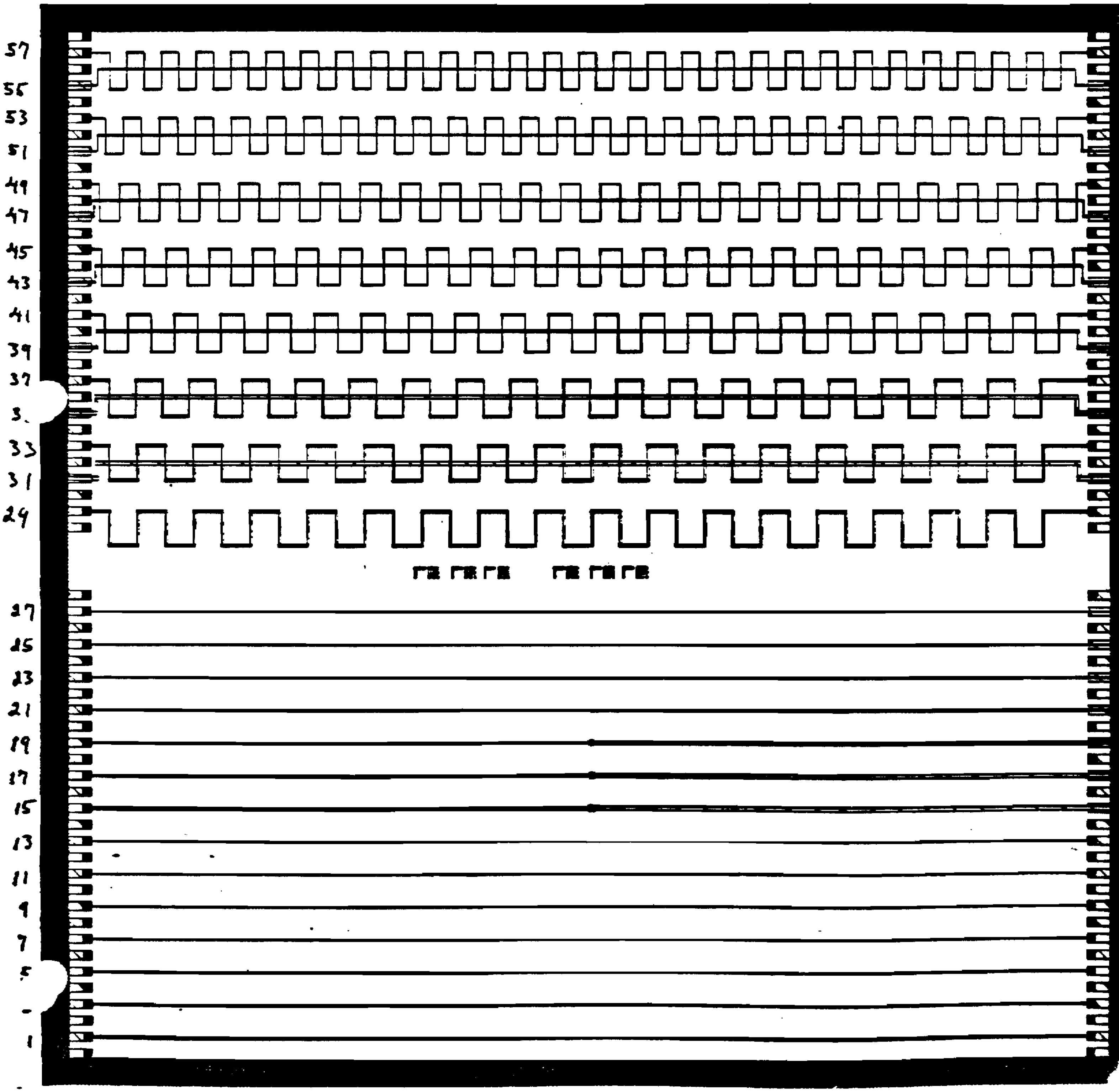


Figure 2.2 HTSCl



square wave to simulate cross talk from level to level. The widest one is duplicated without the gold2 line. The length is described by the sum of the straight line segments plus the number of corners. The number of squares is defined as the length divided by the width.

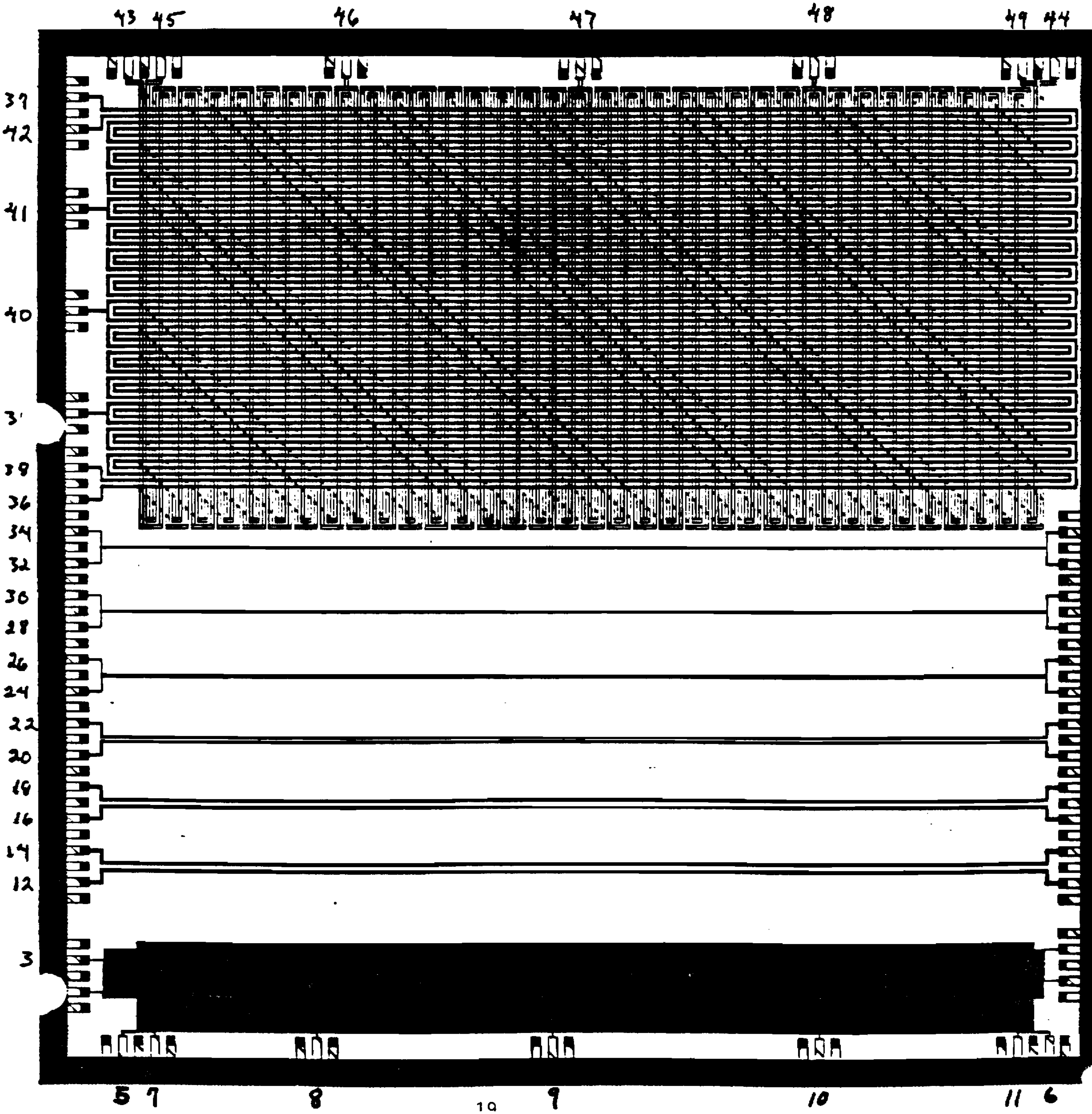
Pad #'s	Linewidth(μm)	Layer	Length(cm)	Length(squares)	Corners
29-30	35	HTSC	1.692	483.83	68
31-32	35	gold2	0.9140	261.14	4
33-34	35	HTSC	1.692	483.83	68
35-36	30	gold2	0.9180	306	4
37-38	30	HTSC	1.870	623.33	72
39-40	20	gold2	0.9220	461	4
41-42	20	HTSC	2.158	1079	84
43-44	15	gold2	0.9240	616	4
45-46	15	HTSC	2.278	1518.67	92
47-48	10	gold2	0.9260	926	4
49-50	10	HTSC	2.498	2498	100
51-52	4	gold2	0.9272	2318	4
53-54	4	HTSC	2.6044	6511	108
55-56	2	gold2	0.9168	4584	4
57-58	2	HTSC	2.7572	13786	112

There are some alignment marks and patterning structures in the middle of the die. The alignment marks use 20μm boxes and lines. The right angle pattern test structures are 100μm in their longest dimension, and come in two sizes, 2μm line/spaces and 20μm line/spaces.

HTSC2 and HTSC22 (Fig.)

This die has two different types of structures on it. The first is a pair fo serpentine lines in both HTSC and gold2. This is to look at both intra-level and inter-level crosstalk, as well as processing yield. Pads 1-11 cover the 4μm linewidth pair of serpentine lines, and pads 36-49 cover the 30μm linewidth version. Pads 39-41 and 46-48 are intermediate taps. The second type of structure on this die are long, straight parallel transmission line pairs to examine crosstalk, and are accessed by pads 12-35. The linewidths are 2,4,10,20,30, and 35 μm.

Figure 2.3 HTSC2



Linewidth(μm)	Level	Pads	Length(μm)	Squares	Corners
4	HTSC	1-2	253,328	63,322	62
4	HTSC	3-4	253,348	63,337	62
4	gold2	5-6	433,004	108,251	1044
4	gold2	7-11	433,004	108,251	1044
4	gold2	7-10	327,856	81,964	788
4	gold2	7-9	199,728	49,932	480
4	gold2	7-8	86,576	21,644	208
30	HTSC	36-37	269,420	8981	64
30	HTSC	38-42	269,420	8981	64
30	HTSC	38-41	197,720	6591	46
30	HTSC	38-40	125,960	4199	30
30	HTSC	38-39	54,200	1807	14
30	gold2	43-44	287,970	9599	144
30	gold2	45-49	287,970	9599	144
30	gold2	45-48	214,020	7134	108
30	gold2	45-47	140,040	4668	72
30	gold2	45-46	66,060	2202	36

The parallel transmission line pairs are described by the length of the parallel section and then by the total length, which is slightly longer since the short section out to the pad is included.

		Parallel Section		Total Length		
Linewidth(μm)	Pads	(μm)	Squares	(μm)	Squares	Corners
35	12-13,14-15	8735	250	9070	259	4
30	16-17,18-19	8740	291	9090	303	4
20	20-21,22-23	8740	437	9160	458	4
10	24-25,26-27	8740	874	9220	922	4
4	28-29,30-31	8756	2189	9256	2314	4
2	32-33,34-35	8756	4378	9268	4634	4

HTSC3(Fig.)

HTSC3 has three via chains on it, with the via diameters of 4μm, 20μm and 35μm. The 35μm chain consists of 16 rows of 80 vias each for a total of 1280 vias from pad 1 to pad 31. The 20μm diameter via chain consists of 10 rows of 111 vias each for a total of 1110 vias from pad 33 to pad 51. The 4μm via chain has 4 rows of 557 vias each for a total of 2228 vias from pad 53 to pad 59.

HTSC4 and HTSC44(Fig.)

HTSC4 has three long lines in HTSC at three different linewidths, 10μm, 4μm, and 2μm, with intermediate taps. The table below gives the total length for each linewidth, and the length between two consecutive pads.

Size(μm)	Pads	(μm)	Squares	Corners
10	1-36	2,071,650	207,165	420
10	1-2	59,190	5919	12
4	37-57	2,532,080	633,020	560
4	37-38	126,604	31,651	28
2	58-68	2,620,960	1,310,480	600
2	58-59	262,096	131048	60

Figure 2.4 HTSC3

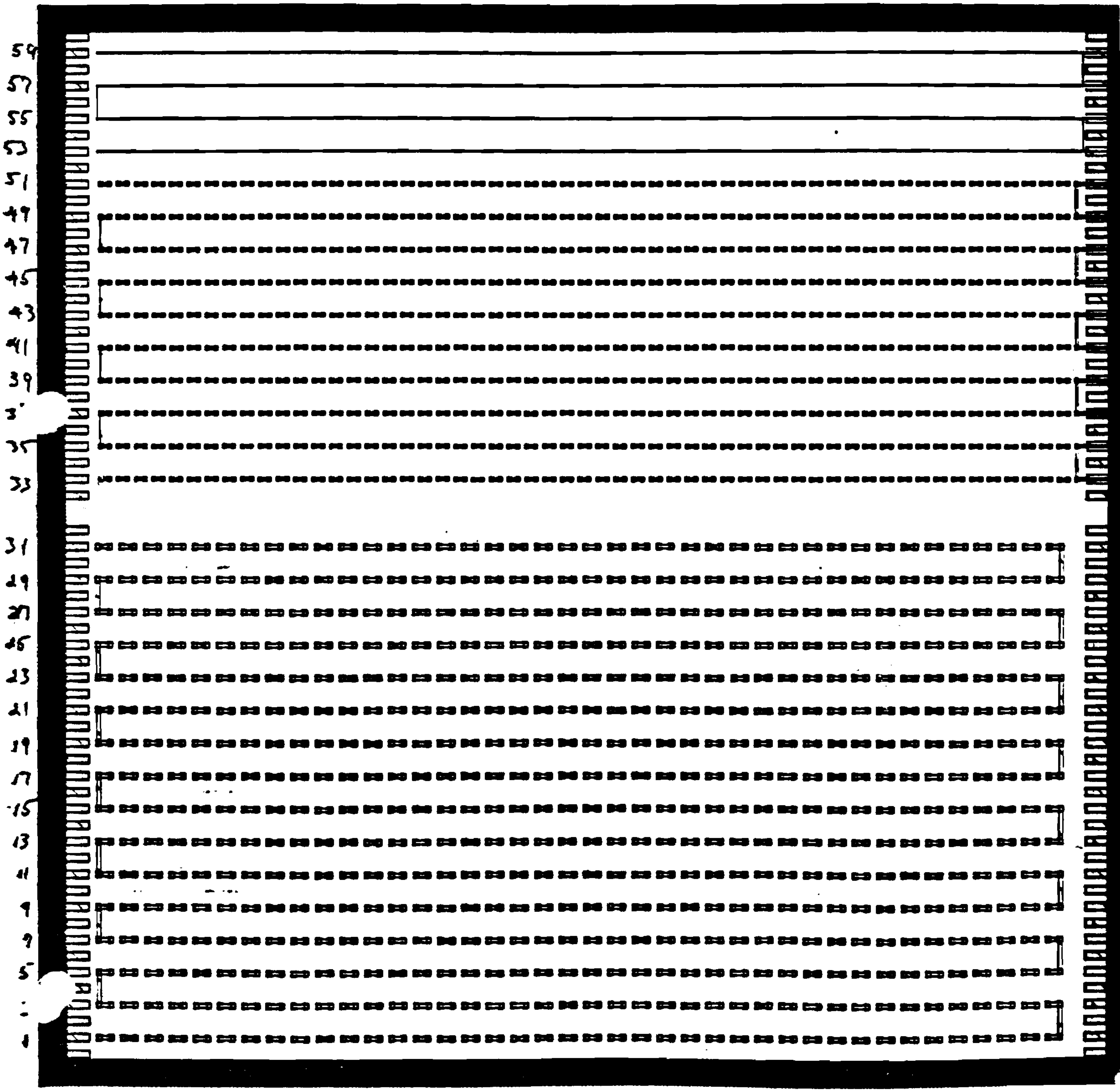
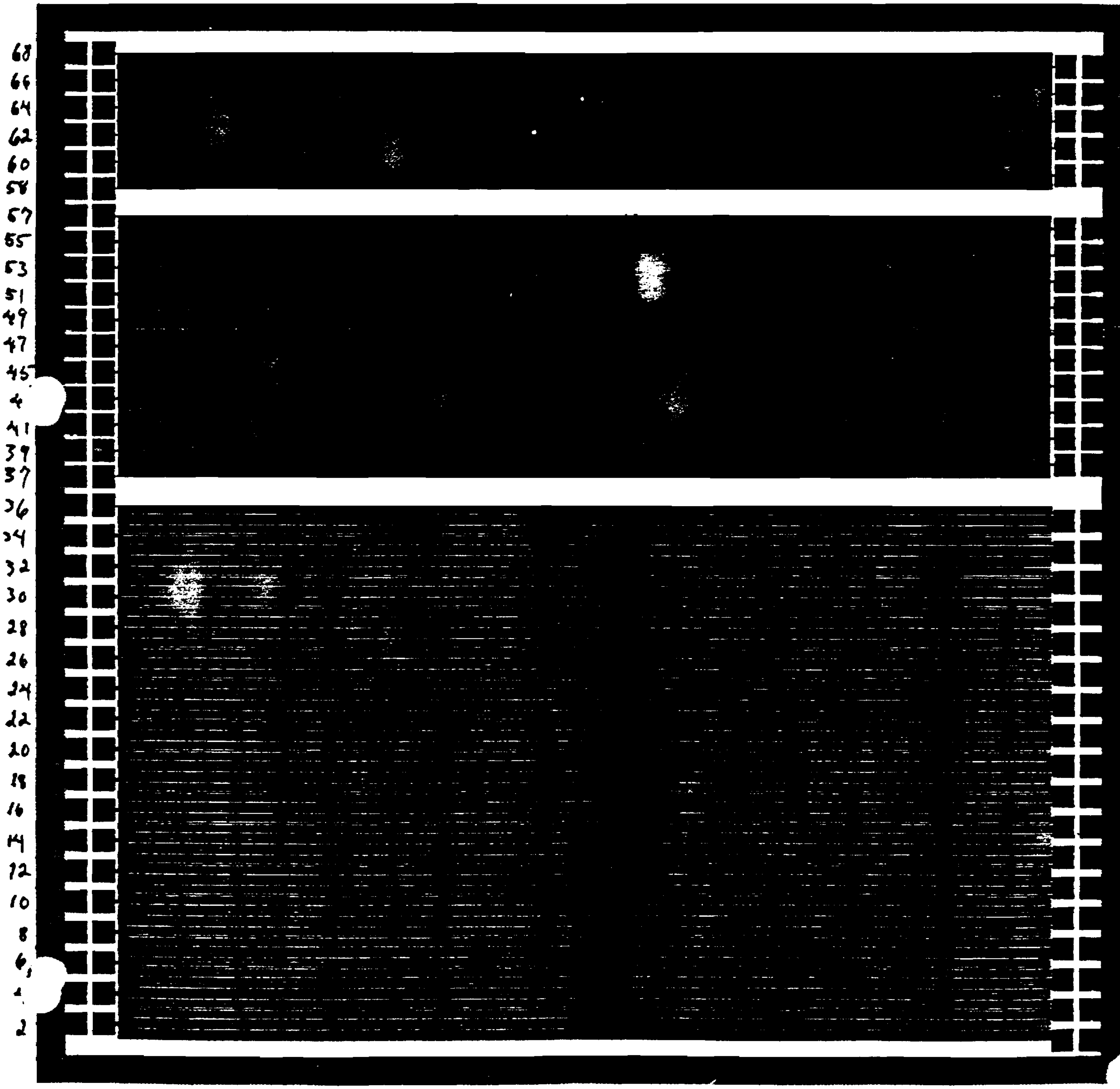


Figure2.5 HTSC4



2.4 Conclusions:

The characterization of HTSC materials an dielectrics is an efficient way to evaluate materials, processes and program progress for device related technologies. These test sructures were used to stimulate work in specific areas. The distribution of mask sets through a third party fabrication house is an effective way for all team members to obtain common information.