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PRESPUTTER SURFACE PREPARATION
FOR RTG THERMOPILES

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MASTER

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FOR RTG THERMOPILES

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ABSTRACT

The results of development studies leading to cleaning procedures for production processing are reviewed. The recommended procedures include lapping and polishing the thermopile surfaces to a $1/4 \mu$ finish; with a final ultrasonic cleaning sequence using isopropyl alcohol, detergent solution, water, and a final alcohol rinse just prior to sputtering. A hydrofluoric acid etch is probably desirable to provide a consistent surface oxide for subsequent tungsten contact deposition.

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INTRODUCTION

Intraconnections between the p and the n doped, silicon-germanium wafers in the RTG thermopile are made by sputtering tungsten over the ends of the piles with subsequent contact definition by photolithography techniques. The surface condition of the thermopile is an important factor in assuring good adherence, low contact resistance and adequate lifetime of the tungsten contacts. This report describes the procedures developed for the presputter surface preparation of the thermopiles. These procedures have usually resulted in satisfactory contacts and are presently recommended for production.

BACKGROUND

The thermopiles are constructed by pressing alternate layers of p and n doped silicon-germanium wafers, with glass as the insulator and adhesive between the wafers. After pressing, the stack is sliced into individual channels, each 1" x 0.14" x 0.351", with 44 wafers each. Two of the channels are then bonded together with 0.003" glass to complete the thermopile. Tungsten for the contacts is deposited on the ends of the thermopile where the surface consists of two channels, each containing alternate layers of p and n wafers, 0.14" x 0.007", separated by 0.001" glass (see Figure 1).

FIGURE 1. Thermopile with Thin Film Tungsten Contacts

The ends must be lapped and polished to provide acceptable surfaces to allow adequate photolithographic definition of the individual contacts. Prior to deposition, contaminants from the polishing and lapping need to be removed and excess surface oxide reduced to permit good electrical contact. Initial procedures to do this were defined by Hampy⁽¹⁾ as representative of technology used in the semiconductor industry. These procedures were reviewed and modified in the subsequent development studies described here.

PROCEDURES

The detailed procedures and materials are given in the Appendix. This section summarizes the processes to provide general insight into the basis for recommendations.

Lapping and Polishing

The lapping and polishing of the thermopiles has been done by Becker, Asbury, Baber, and Kraft in 7145. The original fixture (SK150, Thermopile Holding Fixture, Grinding and Polishing) did not provide satisfactory end surfaces square with the pile. The piles are now held in a V block to assure squareness and hand lapped using 1800 grit aluminum oxide to final dimensions of $1.000^{+0.000}_{-0.003}$ ". E. H. Baber suggests the holding fixture be redesigned to allow better alignment and to accept several thermopiles. After lapping, the piles are cleaned with water.

The thermopiles are then polished using subsequent applications of 6μ , 1μ , and $1/4\mu$ diamond paste; each on a separate piece of lapping paper. Precaution is required to prevent cross contamination of the polishing compounds. After polishing, the piles are cleaned in alcohol.

The extent of polishing by the various grit size compounds is determined by visual inspection. Surface roughness measurements have been made with a Clevite brush "Surfanalyzer" (see Figure 2) and indicate the roughness is less than 15 microinches. A roughness gage is not considered to be required for production control. Figure 2 does indicate preferential grinding of the glass binder layers and a slight rounding of the polished surface. Neither of these effects appear to be detrimental.

Cleaning

As received from polishing, the thermopile surfaces contain residual polishing oils and particulate matter (see Figure 3). Gross contamination is removed by scrubbing all surfaces with trichloroethylene and methyl alcohol applied by hand with a cotton bud. The three cleaning procedures studied are summarized in Table I.

FIGURE 2. ROUGHNESS OF RTG CONTACT SURFACE AFTER POLISHING

TABLE I

FINE CLEANING PROCEDURES

<u>Step</u>	<u>Original⁽¹⁾</u>	<u>Minimum with HF Etch</u>	<u>Minimum</u>
1	Ultrasonic, TCE ^(a)	Ultrasonic, TCE	Ultrasonic, TCE
		Blow Dry ^(c)	Blow Dry
2	Ultrasonic, Acetone	Ultrasonic, Det ^(b)	Ultrasonic, Det ^(b)
3	Ultrasonic, IPA ^(a)	Ultrasonic, DI	Ultrasonic, DI
		Blow Off Excess Liquid	Blow Off Excess Liquid
4	Ultrasonic, Det ^(a)	HF Etch	Ultrasonic, IPA
5	Ultrasonic, DI ^(a)	Ultrasonic DI	Blow Dry
		Blow Off Excess Liquid	
6	Transistor Wash, DI	Ultrasonic, IPA	
7	HF ^(a) Etch	Blow Dry	
8	Ultrasonic, DI		
9	Transistor Wash, DI		
10	Dry, MeOH Vapor		

(a) TCE = trichloroethylene, Reagent Grade

DI = deionized water, 18 megohm

IPA = isopropyl alcohol, Reagent Grade

HF = 1 part HF, 8 parts DI, 20 sec.

Det = 2 ml Igepal CO-710, 1 ml DI

(b) Det = detergent of 20% deionized water 80% isopropyl alcohol, 0.05% Span 80, 0.2% Remex 690.

(c) Blow Dry: Dry nitrogen through Tygon tubing and a brass air valve.

A , 100X

B , 1000X

FIGURE 3. SiGe as Received from Lapping and Polishing

The original procedures used by Hampy⁽¹⁾ were reviewed with Davis of Division 5525. The following changes were considered for subsequent studies:

1. The sequence of cleaning in trichloroethylene, acetone, and isopropyl alcohol could be replaced with just the trichloroethylene since that should remove the residual polishing oils. The acetone and alcohol did not appear to provide any advantage.
2. The original detergent used, Igepal CO-170, had given⁽²⁾ some indication of polymerization during ultrasonic agitation. Consequently, this was replaced with a solution of water, isopropyl alcohol, Span 80 and Remex 690 which has had extensive application in Sandia systems.
3. The HF etch was used to remove the SiGe surface oxides. However, the oxides reform in air, and were obviously replenished by the boiling water in the transistor wash step. Consequently, it was decided to eliminate the

transistor wash and to consider elimination of the HF etch. Elimination of the HF would be desirable to minimize processing and eliminate hazardous HF.

4. The final drying step using MeOH vapor did not appear to be effective with the procedures being used. This was replaced with drying by blowing with bottle nitrogen gas.

Present cleaning operations are straight forward and could be readily facilitated in production. One minor problem is the carryover of the detergent into the rinse steps. The detergent forms a scum on the rinse tanks and the scum is picked up when the piles are removed from the ultrasonic rinse. A flowing water rinse may be of benefit. A second recommendation is to design a special thermopile holding fixture for the ultrasonic cleaning. The present Teflon fixture (see Figure 4) is too massive (presents excess load to the cleaner), has too much surface area to allow convenient blowing dry of the thermopiles, and does not hold the thermopile adequately during handling. A new fixture using stainless steel wire could be designed.

STUDIES

Several procedures are available^(3,4) for the verification of cleanliness. The most meaningful tests for the thermopile were considered to be optical appearance and measurements of contact resistance, and aging characteristics of the SiGe tungsten electrical contacts after processing.

Studies were made on SiGe wafers, on complete thermopiles, and on thermopile sections (nubbins). The "original" cleaning procedures were done by Division 1436 in Building 880. Apparatus was set up near the tungsten sputtering apparatus for the other cleaning studies. Cleaning procedures used are detailed in the Appendix.

FIGURE 4. Thermopile Holding Fixture for Cleaning Operations

Procedures for tungsten sputtering operation, contact resistance measurements, and aging studies will be reviewed in other documents. The optical studies were made by Floyd Ganyard, using a Zeiss metallograph and a scanning electron microscope.

A standard etchant for silicon and germanium is a solution of nitric and hydrofluoric acid.^(8,9) The fluoride attacks the oxides of silicon and germanium; the nitric acid then reoxidizes the semiconductor materials. Wilcox⁽¹⁰⁾ has studied this reaction with the RTG semiconductor materials for making is wire intra-connections. In our case, it is sufficient to remove the excess oxide prior to tungsten deposition by etching an HF. The effect of etchant concentration and exposure time was evaluated. Ratios of HF/H₂O of 1/10, 1/20 and 1/50 were used to etch n type SiGe for 20 seconds, 1 minute, and 3 minutes. No significant change in surface topography could be attributed to differences in the etching (Figures 5 and 6). This is expected if the HF selectively attacks the surface oxide and suggests that, if an HF etch is used, it does not need to be tightly controlled.

RESULTS AND DISCUSSION

Experimental results that led to the recommended cleaning procedure are described in the following section. With exception of the etching step, the product characteristics did not appear sensitive to changes in cleaning procedures. Consequently, the cleaning study was not extensive.

Lapping and Polishing

Formation of voids at the SiGe contact interface during aging⁽⁵⁾ suggested that changes in the surface morphology of the semiconductor materials could change aging characteristics by providing more nucleation sites for void formation.

A. No Etch

B. 20 seconds, 1 HF/50 H₂O

C. 3 minutes, 1 HF/10 H₂O

FIGURE 5. Effect of Etch on SiGe Surface (1000X, SEM)

NOTE: Trace across the photo gives an indication of surface roughness.

A No Etch

B. 20 seconds, 1 HF/50 H₂O

C. 3 minutes, 1 HF/10 H₂O

FIGURE 6. Effect of Etch on SiGe Surface (1000X, Optical)

Yost⁽⁶⁾ prepared semiconductor surfaces with 6 μ , 1 μ , and 1/4 μ polishes. Tungsten was sputtered onto these surfaces and the samples aged at 600°C. The surface roughness had no significant effect on either the initial contact resistance or the time to contact failure (Figure 7). Experiments on the effect of surface scratch density have not been performed.

Uniform surfaces are important for contact definition in later photolithography work. Consequently, the lapping-polishing procedures, as defined here, are recommended for production. However, the degree of surface preparation apparently does not have to be tightly controlled.

Cleaning

The original cleaning process described in Table I was used by Hampy⁽¹⁾ in development of the 2-D thermopiles used for initial RTG studies. To determine the effect of proposed changes in that procedure, thermopiles were processed with the original procedures, were given the minimum cleaning, and were minimum cleaned plus HF etched. The average contact resistances for the product are given in Table II. These samples were all sputtered at the same time.

TABLE II
EFFECT OF CLEANING PROCEDURE ON CONTACT RESISTANCE

<u>Cleaning Procedure</u>	<u>No. of Thermopiles</u>	<u>No. of Nubbins</u>	<u>No. of Total Contacts</u>	<u>Avg. Resistance (Ohms)</u>
Original	2	--	172	0.40
Minimum	2	2	260	0.24
Minimum + HF Etch	1	2	168	0.16

The experiment showed that, not only was the reduced cleaning procedure desirable for reducing process complexity, the contact resistance was also significantly decreased. The HF etch also appeared to be important.

Cleaning studies were continued on samples and piles being prepared during the normal prototype production for RTG development. In all cases, the final cleaning was performed just prior to inserting the thermopiles into the sputtering apparatus, with a maximum exposure of approximately 10 minutes to ambient conditions. The results to date are shown in Table III.

TABLE III
CLEANING STUDY RESULTS

<u>Procedure</u>	<u>No. of Contacts Measured</u>	<u>Resistance (Ohms)</u>	
		<u>Preanneal</u>	<u>*Postanneal</u>
Original	980	0.44	0.24
Minimum	1140	0.21	0.16
Minimum + HF Etch	4100	0.19	0.15

*After 15 hours in vacuum at 500°C.

The data clearly show the advantage of the reduced cleaning schedule. The annealing process, which apparently promoted reaction between the tungsten and semiconductor material, had been initiated to bring the contact resistance into acceptable limits. These data suggest the annealing step can be eliminated using either of the minimum cleaning procedures. The values are approaching the minimum of about 0.1 ohm estimated⁽⁷⁾ for a W-SiGe contact. In this data, the HF etch appears to decrease the contact resistance slightly, but not significantly.

Other studies presently being pursued are needed to define the effect of the oxide layer thickness on contact resistance and aging characteristics. Preliminary aging data generated at 600°C indicated the etched piles had somewhat shorter lifetimes than unetched. More recent aging studies by Sweet⁽¹¹⁾ do not indicate degradation in lifetime due to etching and extrapolated contact lifetimes of the

contacts on etched SiGe exceed the required lifetime and those predicted for the 2-D contacts.⁽⁷⁾ However, controlled experiments are required to better define the effect of surface conditions, including etch, on contact lifetimes.

Experiments were performed in which etching was done one day prior to sputtering. The sample was compared to others processed at the same time using other cleaning procedures. Results listed in Table I show no significant effect of the one day delay.

TABLE IV
EFFECT OF ETCH AND AIR EXPOSURE AFTER ETCH

<u>Cleaning</u>	<u>No. of Contacts</u>	<u>Resistance (Ohms)</u>
Minimum clean, no etch	172	0.11
Minimum clean with etch	172	0.13
Minimum clean, with etch one day prior to deposition plus minimum clean just prior to deposition.	86	0.12

The surfaces of SiGe wafers were studied by Houston and Bland⁽¹²⁾ using the soft x-ray appearance spectrometer. Alternate analyses and backspitting indicated the oxide thickness on rough polished (600 microcut) and cleaned, but unetched material was extensive (1000's of Å). The etched surface had a thin oxide layer (10's of Å). In as much as excess oxide thickness would provide unacceptably high contact resistance and a consistent surface is desirable for production operations, an HF etch is recommended for production.

CONCLUSIONS

Lapping, polishing and cleaning procedures have been defined for the RTG thermopile surfaces prior to tungsten metallization. Studies of the procedures indicated that the characteristics of the final metallized contact are not sensitive to changes in the cleaning procedures. Observed variations in contact resistance in some of the tests may be caused by pile to pile variations in SiGe properties (dopant density, other impurity concentrations, grain size, etc.).

The use of a hydrofluoric acid etch to remove surface oxide does not significantly improve the tungsten-semiconductor contact resistance. However, the HF etch in production may be desirable to provide a consistent surface prior to tungsten deposition. Further studies on the effect of surface oxide thickness and etching on contact properties are warranted.

REFERENCES

1. R. E. Hampy, "MC2730 RTG Prototype Thermopile Contact Metallization Procedures and Processes," SC-DR-72 0640, September 1972.
2. D. M. Davis, Private Communication, May 1972.
3. D. E. Fjelseth, D. M. Davis, L. K. Jones, and C. F. Schroeder, "Clean Assembly Practices Guide," SC-DC-66 1118, October 1965.
4. Spectroscopy Division, "A Survey of Contamination (Its Nature, Detection and Control)," SC-M-70 303, March 1971.
5. C. E. Albright, "RTG Tungsten Thin Film Contact Compatability Program," SC-DR-71 0695, October 1971.
6. F. G. Yost, Unpublished Data.
7. J. N. Sweet, "MC2730 RTG Interconnection Resistance--Design Study and Experimental Measurements," SC-DR-71 0836, November 1971.
8. W. A. Plesken and H. S. Lehman, J. Electrochem. Soc. 112, 1013 (1965).
9. S. Margalit, A. Bar-Lev, A. B. Kuper, H. Aharoni and A. Neugroschel, J. of Crystal Growth 17, 288 (1972).
10. P. Wilcox, Unpublished Data.
11. J. N. Sweet, Unpublished Data.

REFERENCES (cont)

12. Memo, J. E. Houston and R. D. Bland, to R. K. Traeger, dtd March 16, 1973,
subject, Surface Analysis of the Sputter Removal of the Oxide Film on SiGe.

APPENDICIES

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A. THERMOPILE POLISHING

Equipment:

"V" block or shopmade holding fixture

Flat steel plate

Surface plate, Granite

Materials:

Lapping Compound, "Lapmaster"

1800 grit aluminum oxide

Product of: Crane Packing Company
6400 Oakton Street
Morton Grove, Illinois 60053

Lapping Vehicle #10, "Lapmaster"

Product of: Crane Packing Company
6400 Oakton Street
Morton Grove, Illinois 60053

Diamond Polishing Compound

Diamond Paste AB METADI - 6 micron, 1 micron & $\frac{1}{2}$ micron

Products of: Buehler Ltd.
2120 Greenwood Street
Evanston, Illinois 60204

Lapping Paper

Special Blue Polishing Paper

Product of: Spitfire Tool & Machine Company
4020 North Tripp Avenue
Chicago, Illinois 60611

Procedure:

Thermopiles are received from 1435. Finished thermopiles must conform to drawing #AY296741, entitled, "Thermopile, Polished, ID W Interconnect."

Lap:

1. Mix a quantity of lapping compound according to the following proportions:

- 1 cup Lapmaster 1800 grit aluminum oxide compound
- 1 cup Lapmaster #10 vehicle
- 2 cups water.

2. Lap ends of thermopiles to the finished size called out on drawing:

1.000" + .000" - .003"

- (1) Thermopiles are held by hand in the "V" block, or the shopmade fixture, drawing #SK-150, to insure squareness of the thermopile.

The shopmade fixture has so far proven unsatisfactory.

- (2) The thermopiles are lapped on the flat, steel plate with a quantity of lapping compound spread on it, using a Figure 8 motion.

- (3) Continue lapping until the final dimensions are achieved.

3. Clean the thermopile with water to remove the lapping compound.

Polish:

1. Cover the granite surface plate with lapping paper fixed securely with tape.

2. Spread a quantity of 6 μ , 1 μ , and $\frac{1}{4}$ μ diamond paste on separated places on the lapping paper.

3. Polish the thermopile in, first, the 6 μ paste, then the 1 μ paste, and finally the $\frac{1}{4}$ μ paste.

- (1) The 6 μ , 1 μ , and $\frac{1}{4}$ μ finishes are inspected visually only, to determine when sufficient work has been done.

- (2) Thermopiles are held either by hand or in the shopmade fixture.

- (3) Cleaning between polishing steps: Clean very thoroughly with alcohol.
4. Initial travelers and send to next station.

B. PRESPUTTER CLEANING PROCEDURES

The following procedure is used to clean the thermopiles prior to the tungsten sputtering. The cleaning (Part B) is to be done less than 10 minutes prior to loading the piles into the sputtering apparatus.

A. Prescrub (for removal of gross contaminants)

1. Materials

- a. Shallow dish
 - b. Teflon coated tweezers - Bel-Arts Products, Applied Coating Division, Pequannock, New Jersey, Cat. #F-37935.
 - c. Cotton buds - Johnson & Johnson, New Brunswick, New Jersey.
 - d. Trichloroethylene - A.R. stock #684728.
 - e. Methyl Alcohol - A.R. (ACS) stock #682190.
2. Scrub all surfaces of thermopiles in trichloroethylene using tweezers and a cotton bud.
 3. Scrub all surfaces of thermopiles in methyl alcohol using tweezers and a cotton bud.

B. Cleaning

1. Equipment Used

- a. Ultrasonic Cleaner
 - 1) Westinghouse Model #WEH-10
 - 2) Power density: 7.6 watts per square inch.

b. Fixturing

1) Holding fixtures

A-1401 Basket

A-01 Handle

Products of: Fluoroware, Inc.
Chaska, Minnesota

NOTE: Every second partition has been removed from the basket.

2) Beakers 1500 ml glass stock #675038

3) Beaker 1000 ml Teflon stock #677045

c. Safety Equipment

1) Fume hood

2) Apron

3) Polyethylene gloves

4) Face shield

d. Timer

e. Chemicals

1) Trichloroethylene - A.R. stock #684728

2) D.I. water - 18 megohm

3) Isopropyl Alcohol - A.R. (ACS) stock #682182

4) Dry Nitrogen Gas, liquid pumped, stock #681422

5) HF Solution

a) 8 parts D.I. water

b) 1 part hydrofluoric acid H.R. (ACS) stock #687255

6) Detergent Solution

a) 20% (by volume) D.I. water

79.3% (by volume) Isopropyl alcohol - A.R. (ACS) stock #682182

.5% (by volume) Span 80 - Product of: Atlas Powder Co.

Wilmington, Delaware

Sandia Spec. 4702401

.2% (by volume) Remex 690 - Product of: Atlas Powder Co.

Wilmington, Delaware

Sandia Spec. 4702403

2. Procedure

All of the following operations are to be performed under the fume hood. Use the timer for timed operations. Wear face shield, polyethylene gloves, and apron at all times while handling an open container of hydrofluoric acid.

- a. Place the thermopiles in holding fixture.
- b. Ultrasonically clean the thermopiles in trichloroethylene for two minutes and then blow dry with dry nitrogen.
- c. Ultrasonically clean the thermopiles in the detergent solution for two minutes. Shake off the excess liquid.
- d. Ultrasonically clean the thermopiles in D.I. water for two minutes. Blow off excess liquid with dry nitrogen.
- *e. Etch the thermopiles in the HF solution for 20 seconds at room temperature.
- *f. Ultrasonically clean the thermopiles in D.I. water for two minutes. Blow off the excess liquid with dry nitrogen.
- g. Ultrasonically clean the thermopiles in isopropyl alcohol for two minutes. Blow dry with nitrogen.
- h. Immediately load the thermopiles into the sputtering equipment and pump down the vacuum system.

*Optional

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