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DEVELOPMENT OF MC2730 RTG
THERMOPILE SIDE CONTACT ATTACHMENT PROCESS

September 1973

Sandia Laboratories
Albuquerque, New Mexico

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DEVELOPMENT OF MC2730 RTG THERMOPILE
SIDE CONTACT ATTACHMENT PROCESS

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ABSTRACT

Gold plated Kovar pads were eutectic bonded to p and n-type SiGe specimens using a 98 weight percent AuSi preform alloy. This joining technique was shown to yield strong reliable bonds. A method based on this technique is described for producing bonding pads to the outermost elements of the MC2730 RTG thermopile.

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INTRODUCTION

The MC2730 RTG uses a SiGe thermopile for conversion of thermal to electrical energy. The high temperature (350-400°C) end of the RTG thermopile has 22 interelement contacts per channel as shown in Figure 1a. The low temperature end (10°C above ambient) has 21 interelement contacts per channel, as shown in Figure 1b, arranged such that all 44 elements are connected in series. If placed in the above temperature gradient each channel would generate 25 milliwatts of power which is made available by connecting the two outermost elements of the low temperature end to output terminals. This report is concerned with the problem of producing strong and reliable connections to these outermost p and n-type elements.

Three techniques have been used to provide side contact pads to which .005 cm by .038 cm Au ribbons could be bonded. In the first,¹ each thermopile side was polished and sputtered with 0.4 μm W to provide a "glue" layer for a later sputter deposition of 2.0 μm Au. Contact pads were then photolithographically defined and etched. The second technique² eliminated side contact polishing and photolithography, although the sputtering operation was retained. Platinum was sputtered through a mask and Au ribbons were bonded directly.

Among the disadvantages of these techniques was the lengthy sputtering operation which doubled the process time per thermopile. Since high substrate temperatures (350-400°C) were required for an adherent W layer catastrophic Au-SiGe eutectic formation frequently occurred and yielded low strength bonds. The platinum bond also had characteristically low strength, possibly due to the formation of PtSi_x at the interface.

Eutectic bonding is a technique commonly used in the electronics industry to fasten Si chips to substrates coated with Au. This bonding scheme

a

b

Figure 1. (a) The hot end of the thermopile showing 22 contacts per channel.
(b) The cold end of the thermopile showing 21 contacts per channel.

utilizes a Au-Si alloy preform which melts at 370°C. The molten preform initiates partial melting of both Si chip and Au substrate after which solidification is commenced. It was thought possible to reverse the procedure and bond small Au pads to large semiconductor substrates. If successful, this process would completely eliminate the side contact sputtering and photolithography operations.

This report describes the bonding equipment, materials and procedures necessary for preparing strong reliable eutectic bonds to large SiGe substrates. The bonds are evaluated by tensile testing and metallographic analysis. Finally, a procedure for eutectic bonding side contacts to thermopiles is discussed, and a process description is provided in the appendix.

EXPERIMENTAL

The Bonder

All bonds were made using the Kulicke and Soffa Model 642 Universal Bench Die Mounter shown in Figures 2a and 2b. The tool (A) can be heated to approximately 290°C and the stage can reach temperatures well over the eutectic temperature of Au-Si. The stage (B) is adjusted to a temperature well below the melting temperature of the preform selected. When the tool temperature is approximately 290°C, the Scrubmaster head (C) is approximately 465°C; therefore, when the tool makes thermal contact heat flows from the head into the substrate and local heating occurs. When the tool is lowered, a microswitch is tripped thus initiating a scrubbing action or relative vibration between tool and substrate with a frequency of 60 Hz and an amplitude of approximately .010 cm. This scrubbing action is intended to break down surface films, most often oxides, thus providing clean metal to semiconductor contact. The Scrubmaster head may be loaded with various weights; however, none were used in the course of these experiments. A 150 gram capacity Halda gram gauge was used to measure the force exerted by the tool when in the bonding position. Ten readings yielded an average of 64 grams.

a

b

Figure 2. (a) The Kulicke and Soffa Model 642 Universal Bench Die Mounter.

(b) Thermopile bonding configuration showing the heated tool (A), the thermopile heating fixture (B), and Scrubmaster head (C).

Materials

Test samples of hot pressed SiGe (80 at. % Si, 20 at. % Ge) containing approximately 2.0×10^{19} dopant atoms per cubic centimeter and measuring approximately .721 cm by .891 cm by .064 cm were sliced on a DuAll bandsaw with a diamond blade. These specimens were etched in 10% hydrofluoric acid in water and stored in methanol for a period not exceeding 1 hour. The bonding pad chosen was Au plated Kovar* and measured .254 cm on a side and .015 cm thick. These pads are available in many sizes from Alloys Unlimited, Inc. The eutectic alloy preform contained 98% Au and 2% Si by weight and measured .127 cm on a side and .005 cm thick. The preform chosen was smaller than the pad but large enough to yield complete wetting of the Kovar pad and SiGe specimen. Preforms are available in many sizes and shapes from Alpha Metals, Inc.

Bonding Procedure

The tool temperature was adjusted to approximately 290°C while the stage was adjusted to approximately 260°C. Several Kovar pads were placed on the auxiliary stage in the "pad up" orientation (see Appendix). A SiGe specimen was placed on the stage and allowed to thermally equilibrate while the tool is used to pick up a Kovar pad. This operation requires approximately 10 seconds. The Au-Si preform was placed on the SiGe specimen where the bond was to be made and both were positioned under the tool. This process requires approximately 20 seconds. The tool was then lowered onto the specimen where the scrubbing action commenced. A scrubbing time of 20 seconds was measured after preform melting was observed. The tool was then raised and the bonded specimen was placed aside to cool.

*Kovar is a registered trademark of Westinghouse Electric Corporation.

RESULTS

A means of evaluating the strength of these bonds was developed and is discussed in detail in a separate report.³ Ultimate tensile failure loads were measured in a Mini-Instron machine and fracture areas were measured with a planimeter. These tensile results are shown in Table 1.

TABLE 1
FAILURE LOAD AND FRACTURE AREA FOR TENSILE
TESTED SiGe SPECIMENS

<u>Dopant Type</u>	<u>Failure Load (kg)</u>	<u>Fracture Area (10^{-2}cm^2)</u>
p	17.0	7.24
p	14.5	7.73
p	17.9	5.89
p	14.4	8.45
p	15.2	2.34
p	17.2	6.10
p	7.8	2.41
p	13.6	6.24
p	17.1	6.39
p	10.2	2.27
n	15.2	7.24
n	10.8	6.03
n	14.2	11.71
n	17.5	8.30
n	15.4	12.27
n	17.0	7.16
n	14.3	9.65
n	7.5	5.32
n	16.4	9.37
n	16.1	8.30

Analysis of variance has shown that dopant type has no significant influence (95% confidence limits) on failure load.⁴ The failure load of the average p-type specimen was 14.5 kg while that of the n-type was 14.4 kg. The standard deviations were 3.1 and 2.9 kg, respectively. Fracture of the eutectic bonds took place deep within SiGe without measurable plastic deformation. These bonds have more than sufficient strength and consistency for thermopile application.

To examine the nature of the bond several Au plated Kovar pads from the tensile tested specimens were etched in a solution containing:

50 parts H_2O

50 parts HNO_3

5 parts HF .

This etch preferentially attacks SiGe leaving the Au structure undisturbed. Figure 3 illustrates three microstructural regions of interest. Area A is the SiGe material pulled from the specimen. Area B is a transition layer which, prior to etching, had been covered with SiGe. Area C is preform alloy which had not broken through the SiGe oxide skin, i.e., unreacted interface. Figure 4a shows the transition from region A to region B. Note that several particles of SiGe, the dark phase, appear to have become isolated from the bulk. It is evident that commingling of phases has occurred. Figure 4b shows a foam like network of Au. The void size of this structure is approximately .0007 cm. The average grain or particle size of SiGe material is reported to be .001 cm.⁵ It is apparent, therefore, that SiGe preferentially dissolves at grain boundaries while the bond is being made.

THERMOPILE CONTACTS

It seemed entirely feasible to adapt the techniques developed for SiGe slabs to the eutectic bonding of gold plated Kovar pads to thermopiles. Gold ribbons could then be parallel gap welded to the Kovar pads. A fixture (Figure 2b) was designed to heat the thermopile, as uniformly as possible, to approximately 260°C. With the exception of pad and preform sizes, bonding proceeded in the manner described. The pads used were .178 cm by .229 cm by .015 cm, while the preforms were .076 cm on a side and .005 cm thick. Good bonds* were obtained in the very first attempt. Nondestructive infrared and laser holographic techniques were not sensitive enough to signal

*Difficult to remove by flicking with a tweezer.

Figure 3. Underside of specimen after tensile failure and etching. Region A is etched SiGe. Region B is a transition layer which prior to etching had been covered with SiGe. Region C is a portion of unreacted interface.

a

b

Figure 4. (a) The transition from Region A to B.
Magnification 300X.

(b) The foam or lacy structure of Region B.
Magnification 3000X.

even the poorest bonds made without prior etching in 10% HF. Thermopiles have been bonded and given a crude "flick" test ever since. Less than 8 percent⁶ of the bonds made to date have failed in subsequent thermopile processing and none have failed in test. The failures occurred when Au ribbons were parallel gap welded to the Au plated Kovar pads prior to the development of the present welding schedule. These bonds were repaired by simply rebonding. The appendix contains a complete process description.

The process of parallel gap welding .005 cm by .038 cm gold ribbon to the gold plated Kovar pads has been developed by D. Johnson of Division 2432 who reports⁷ the following welding parameters:

.43 volts

500 milliseconds.

Weld strengths measured on eutectic bonded SiGe slabs, using a 90° peel test, were typically 150 grams; failure occurred by peeling in the ribbon/pad interface. The final product is shown in Figure 5.

DISCUSSION

The reader will recall that the tool and stage temperatures were 290°C and 260°C, respectively. Neither of these temperatures are above the eutectic temperature of Au-Si. Melting occurs when heat from the Scrubmaster head flows into the bond area after thermal contact has been made. The bonding temperatures are, therefore, very transient. However, experience has shown that the approximate bonding temperatures given do not lead to transient temperature excursions which yield poor bonding. This experience also shows that a minimum scrubbing time of approximately 15 seconds is required for good bonding. Shorter scrubbing times are apparently insufficient to break down surface films. Longer scrubbing times promote a more complete eutectic reaction which occurs through the simultaneous dissolution of SiGe and Au plate. A scrubbing time of 20 seconds has proven to be an acceptable compromise between bonding time and strength. Extensive dissolution of

Figure 5. The thermopile with sputtered W contacts, eutectic bonded Au plated Kovar pads and parallel gap welded Au ribbons.

SiGe allows deep grain boundary penetration by the liquid preform alloy. The 98% Au alloy dissolves more Si and Ge than do alloys containing smaller percentages of Au. It, therefore, enhances grain boundary penetration.

The force applied by the tool was measured to be approximately 64 grams and is the smallest load attainable on the Kulicke and Soffa Model 642 bonder. There should exist a critical force, less than 64 grams, below which relative vibration between tool and Kovar pad will take place. There should also exist a critical load, greater than 64 grams, above which relative vibration between pad and thermopile is prevented by excessive friction. In a detailed study of bond microstructure³ it was shown that relative vibration between pad and specimen is an essential feature of good bond formation.

CONCLUSIONS

1. The average ultimate tensile load for eutectic bonded n and p-type SiGe slabs was approximately 14.4 kg.
2. Good repeatability was indicated by standard deviations which were 3.0 kg.
3. Fracture occurred deep into the SiGe material as opposed to the bond interface.
4. Thermopiles have been successfully bonded.

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APPENDIX

PROCESS DESCRIPTION FOR SIDE CONTACT BONDING

This description is concerned with the process of producing strong and reliable connections to the outermost p and n type elements of each thermopile channel. These connections transfer the power generated by each channel through Au wires and a printed interconnection board to output terminals located in the RTG base. All dimensions are given in inches as this is the system of units used by Kulicke and Soffa and the alloy suppliers.

PROCEDURE

- A. Preparation of Kulicke and Soffa Model 642 Universal Bench Die Mounter. (Figure A1).
1. Install thermocouple heating fixture. (Figure A2).
 2. Install .055" x .055" tool. (Figure A2).
 3. Adjust thermopile fixture temperature to approximately 260°C using a thermocouple and potentiometer. This temperature will vary during the bonding operation due to transient heating and cooling when contact is made with the tool.
 4. Adjust tool temperature to approximately 290°C using a thermocouple and potentiometer (dial adjust turned full clockwise).
 5. Place several .070" x .090" Au plated Kovar pads, supplied by Alloys Unlimited Inc. P/N SS290851-160, onto auxiliary stage in "pad up" orientation. (Figures A2 and A3).

Figure A1. Kulicke and Soffa Model 642
Universal Bench Die Mounter

Figure A2. Bonding Setup

Figure A3. Au Plated Kovar Pad

6. Turn vacuum chuck on.
7. Adjust height of tool, containing no load weights, for bonding compatibility with thermopile fixture surface.
8. Adjust height of auxiliary stage for loading compatibility with tool.
9. Adjust lamp and microscope for comfortable operation.

B. Side Contact Bonding Operation

1. Swab "cold end" of thermopile with 10% HF in water
(See Figures A4, A5a and A5b).
2. Immediately transfer thermopile to alcohol bath for rinsing.
A period of time no longer than one hour should elapse between swabbing and bonding. During this time, thermopiles should be left totally submerged in alcohol bath.
3. Transfer thermopile to thermopile fixture with "cold end" facing operator.
4. Pick up Au plated Kovar pad with tool so that .090" axis is parallel with long axis of thermopile.
5. Place one .030" x .030" 98% Au - 2% Si eutectic alloy preform, supplied by Alpha Metals Inc., in the approximate position shown in Figures A6 and A7a.
6. Orient thermopile and preform under the tool (See Figure A8).
7. Lower tool onto preform.
8. The tool should vibrate causing relative motion between the Au plated Kovar pad and the thermopile. This is extremely important since poor quality bonds are obtained when tab and thermopile vibrate in phase. If need be, the operator should manually prevent in phase vibration.
9. When melting is observed, the operator should initiate a 20-second bonding period.

Figure A4. 10% HF Swab and Alcohol Rinse

a

b

Figure A5. (a) Cold End of Thermopile
(b) Hot End of Thermopile

Figure A6. Thermopile Bonding Configuration

(a)

(b)

Figure A7. (a) Placement of Preform Alloy
(b) Location of 4 Bonding Pads

Figure A8. Placement of Au Plated Kovar Pad

10. After this 20 seconds, raise tool.
11. Push thermopile fixture to one side to allow solidification of the preform. The operator should "flick" the bonded pad with a sharp instrument to insure proper bonding.
12. Proceed in a similar fashion to bond four contacts as shown in Figure A7b.
13. Should a bonded contact fail the flick test, it can be removed by remelting the preform alloy.