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DEVELOPMENT OF AN INTERCONNECTION METHOD
FOR THE RTG (RADIOISOTOPE THERMOELECTRIC
GENERATOR) OUTPUT CIRCUIT

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Sandia Laboratories

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DEVELOPMENT OF AN INTERCONNECTION METHOD FOR THE
RTG (RADIOISOTOPE THERMOELECTRIC GENERATOR) OUTPUT CIRCUIT

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ABSTRACT

The results of development studies leading to an interconnection method for the output circuit are described. Procedures recommended include the use of thick film platinum-gold metallization in conjunction with parallel gap welding of the ribbon-to-circuit and ribbon-to-side contact joints. Variables investigated include the type and thickness of thick film, and the weld parameters such as voltage, time, electrode force, and electrode gap. Techniques proven in development are summarized in the form of process descriptions. Satisfactory metallization and bond parameters were developed and the system appears suitable for production application.

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INTRODUCTION

Interconnections between the thermopile and connector for the RTG are made by parallel gap welding gold ribbon to the side contact on the thermopile as well as to the conductor pattern leading to the connector. A typical prototype configuration is shown in Figure 1. The principal variables involved the weld parameters and the type and thickness of metallization. This report describes the procedures developed for ribbon interconnection, as well as those procedures developed for metallization of the ceramic. In addition, the report includes a discussion of the choice of metallization material.

The metallization technique and the welding procedures have generally resulted in satisfactory interconnections, and thus have been documented in the form of process descriptions which are detailed in Appendix A, B, and C. These procedures are recommended for production.

BACKGROUND

The initial prototype work for the RTG interconnections used a 96.5 percent alumina board with a pure gold thick film metallization for the main conductor pattern in combination with a platinum-gold thick film in the connector area. The advantages of this thick film approach were: (1) quick turn around, (2) weldability of the thick film gold, and (3) solderability of the platinum-gold for connector attachment. Due to the available technology from the hybrid microcircuit development program (HMC),¹ the original plans called for replacement of the thick film by

FIGURE 1

Welding Thermopile Leads to PIB

an evaporated thin film chromium-gold metallization for the conductor with a solder stop in the connector area. Initial procedures and materials for prototype fabrication were defined by Adams and Villanueva.² Subsequent development studies are described herein.

MATERIALS AND EQUIPMENT

The detailed procedures for materials and processes are presented in the appendices. The following section discusses the basic guidelines utilized for recommendations.

Alumina Circuit Board

The circuit board was fabricated by Becker in 7141. The material chosen was 96.5 percent alumina. The board configuration was fabricated in the form of a "U"-shaped bar, with holes drilled, prior to firing. After firing, the individual circuit boards were produced by diamond sawing. This basic configuration is illustrated in Figure 2. Figures 3, 4, and 5 present a comparison of the surfaces of the as-fired bar, the saw-cut face, and a typical commercial ceramic substrate. Floyd Ganyard, 2431, conducted the comparative surface study utilizing the scanning electron microscope.

Problem areas encountered with board fabrication included, (a) control of thickness, (b) waviness, and (c) tolerance on hole location. These problems should be minimized by the use of tape cast ceramic and hard tooling as would be utilized in production.

Conductor Metallization Material

The metallization scheme for the initial ceramic boards utilized DuPont 8831, a pure yellow gold thick film ink, for the conductor paths, and DuPont 8653, a

FIGURE 2. Alumina Board Basic Configuration

FIGURE 3

SCANNING ELECTRON MICROSCOPE
AS-FIRED EDGE, 96.5% ALUMINA

1000X

3000X

FIGURE 4

SCANNING ELECTRON MICROSCOPE
SAW-CUT FACE, 96.5% ALUMINA

1000X

3000X

FIGURE 5
SCANNING ELECTRON MICROSCOPE
COMMERCIAL CERAMIC SUBSTRATE
(TAPE CAST 99.5% ALUMINA)

1000X

3000X

thick film platinum-gold ink, for the area around the connector pinholes. This early configuration is depicted in Figure 6. Figure 7 illustrates the final metallized pattern chosen by 2334 utilizing a complete platinum-gold system, Cermalloy 4100, with a thick film glass overcoat serving as a solder stop.

Equipment

The parallel gap welder used for this study was a Hughes MCW-550 power supply with a VTA-66 weld head.³ Principle variables included voltage and pulse duration on the power supply, and electrode type, size, gap, and force on the weld head. The electrodes used were molybdenum with a nominal tip size of 0.015 by 0.025 inch.

In addition, a laboratory thermocompression bonder was utilized for comparison purposes. The principal variables for this bonding technique include force, temperature, and time.

Interconnection Ribbon

The ribbon used for interconnection was pure gold (99.99%) having nominal dimensions of 0.002 inch thick by 0.015 inch wide.

RESULTS AND DISCUSSION

The experimental results which led to the recommendations are discussed in this section. The first attempts at ribbon interconnection were made on the DuPont 8831 yellow gold. Evaluation of these welds revealed 90° peel strengths in the range of 20 to 25 grams. The failure mode was peeling of the yellow gold from the ceramic board. In addition, sample welds made by 2334 using a Hughes VTA-90 weld head exhibited similar low strength. Optimization of weld parameters and equipment set-up yielded welds with strengths ranging from 30 to 100 grams. Thermocompression bonds made to this same yellow gold resulted in peel strengths in the 40 to 45 gram

FIGURE 6

Printed Interconnection Board
(Thick Film Yellow Gold in
Combination with Thick Film
Platinum-Gold)

FIGURE 7

Printed Interconnection Board
(Thick Film Platinum-Gold with
Thick Film Glass Overcoat)

range. Continued work with the TC bonder was dropped at this time. And although the parallel gap welding set-up was in all probability producing a thermocompression type bond rather than a true resistance weld, no attempt was made in this development program to determine the true nature of the gold-gold bond. These early results prompted the experimental work subsequently described.

Thin Film Versus Thick Film

For comparison to the initial results, parallel gap welds were made to vacuum deposited thin film CrAu metallization on 99.5 percent alumina. These welds were accomplished with the same parameters, and generally resulted in peel strength values in the 100 to 250 gram range. These values seemed to support the original intent of the development program which was to utilize the first generation hybrid microcircuit technology. Based on these results, effort was extended to develop the technique for vacuum deposition of the chromium-gold thin film in the Physical Electronics Shop, 7121. Evaluation of the first deposition run resulted in peel strengths which were in the range of 10 to 35 grams.

An experiment was designed to determine the difference in the thin film from the Hybrid Microelectronics Lab and the Physical Electronics Shop. A group of 96.5 percent alumina output circuit boards was divided with some going through cleaning in the HMC area and the remainder being cleaned in the Physical Electronics area. All the boards were then vacuum deposited in the PE area. Parallel gap welding to these yielded peel strengths in the range of 40 to 60 grams for boards cleaned by the PE process, and 65 to 180 grams for those boards cleaned by the standard HMC process.⁴ The cleaning process utilized by the PE shop is detailed in Table I,⁵ while that of the HMC area is presented in Table II.

TABLE I
PHYSICAL ELECTRONICS CLEANING PROCEDURE
CERAMIC CIRCUIT BOARDS

1. Degrease 5 minutes in trichloroethylene -- no ultrasonic.
2. Scrub with Alconox and tap water. Rinse in tap water.
3. Five minutes in 20 percent sodium hydroxide solution at 150 to 180°F. Rinse in hot tap water.
4. Ten minutes in 20 percent nitric acid at 150 to 180°F. Rinse in hot tap water, followed by rinse in deionized water.
5. Soak in cascade washer at 180°F for one hour.
6. Rinse two times in acetone.
7. Drip dry.
8. Air fire at 1000°C for one hour.

TABLE II
HMC CLEANING PROCEDURE
CERAMIC SUBSTRATES

1. Trichloroethylene ultrasonic wash for two minutes at room temperature.
2. Acetone ultrasonic wash for two minutes at room temperature.
3. Detergent ultrasonic wash (2 ml Igepal CO-710/1 ml DI water) for two minutes at room temperature.
4. Rinse in running DI water.
5. Deionized water ultrasonic wash for two minutes at room temperature.
6. Boiling deionized water rinse in the transistor washer for two minutes per chamber (five chambers). Resistivity of water in inlet chamber final rinse must be at least 12 megohm-cm.

7. Nitrogen blow-off.
8. Air fire at $900 \pm 45^{\circ}\text{C}$ for one hour.

Table III presents the average peel strength data from these welds as well as from additional samples of HMC thin film on 99.5 percent and 96.5 percent alumina, and DuPont 8831 yellow gold thick film. Approximately 50 welds were made for each material at each setting.

TABLE III
METALLIZATION PROCESS COMPARISON

<u>Metallization</u>	<u>Average Peel Strength, Grams</u>	
	<u>0.70 Volts</u>	<u>0.80 Volts</u>
Thin Film CrAu on 99.5% Alumina (Standard HMC Process)	206	169
Thick Film DuPont 8831 Yellow Gold	38	-
Thin Film CrAu on 96.5% Alumina (PE Shop Cleaned and Deposited)	54	45
Thin Film CrAu on 96.5% Alumina (HMC Cleaned/PE Shop Deposit)	132	96
Thin Film CrAu on 96.5% Alumina (Standard HMC Process)	110	100

These results indicate that the film adherence is dependent on both the substrate cleaning process and the surface of the alumina substrate.

In an attempt to further characterize the thick film, two further experiments were conducted. One involved the welding of ribbon to the thick film platinum-gold (DuPont 8653) in the connector pin area of the circuit. Values for these welds ranged from 85 to 193 grams peel strength. The second involved the soldering of gold plated Kovar tabs to the thick film platinum-gold followed by parallel gap

welding of the ribbon to the tab. Despite the complicated nature of this approach, the results from this limited experiment yielded an average peel strength of 198 grams.

Prior to continuation of development of the thin film process in the Physical Electronics Shop, it was learned that the utilization of the proposed solder stop in the connector area was proprietary. Thus, rather than work toward an alternate solder stop, the decision was made to pursue an optimized thick film circuit.

Optimization of Thick Film Metallization

An optimization program was requested⁶ in order to study thick film materials as well as printing and firing profiles which might improve metallization adherence and response to welding. This study was pursued with the technical guidance of R. E. Knutson, 2432, wherein several varieties of pure yellow gold as well as platinum-gold were printed and fired and subsequently tested for weldability.

From this program DuPont 8831 yellow gold, DuPont 8760R yellow gold, DuPont 8653 platinum-gold, Cermalloy 4100 platinum-gold, and Cermalloy 4120 platinum-gold were chosen for evaluation. These materials were printed and fired with and without gold tabs in the weld pad area. For this evaluation, the welding parameters were changed from the high voltage/short time pulse to a low voltage/long time pulse. Previous experience had shown inconsistent response to the high heat input of the high voltage/short time pulse which resulted in peeling metallization and/or melting of the ribbon between the electrodes. Following an initial evaluation, the two yellow gold materials were excluded from further consideration due to continued low peel strength. Also, it was determined that the tabs did not significantly increase the peel strength but did complicate the printing and firing procedure.

Additional samples of DuPont 8653, Cermalloy 4100, and Cermalloy 4120 were prepared and evaluated without tabs. The results of the evaluation, without tabs,

for the platinum-gold materials are presented in Table IV. The average peel strengths presented are based on 25 welds at each setting for each thick film material.

TABLE IV
THICK FILM OPTIMIZATION

Thick Film Material	Voltage/ Milliseconds	Average Peel Strength, Grams			
		<u>.50/ 750-2000</u>	<u>.53/ 500-1000</u>	<u>.54/ 750-1000</u>	<u>.55/ 500-750</u>
DuPont 8653		74	123	162	117
Cermalloy 4100		114	135	114	147
Cermalloy 4120		49	50	65	44

The electrode gap was varied from 5 to 10 mils, and the force was varied from 4 to 6 on the dial indicator which was the equivalent of 4 to 6 pounds.

Based on these results, a decision was made to process a new series of circuit boards utilizing the Cermalloy 4100 platinum-gold thick film metallization for the entire circuit (Ref. Figure 7). The choice of Cermalloy 4100 over the DuPont 8653 was somewhat arbitrary, but was mainly due to greater consistency of welding response. This move to one material greatly simplified the manufacturing process in addition to offering metallization which was suitable for both soldering of the connector and parallel gap welding of the ribbon interconnection. These circuit boards were to be used for prototype fabrication by 2334.

A sample of this metallization run was evaluated to determine welding response and revealed significantly lower peel strength values than had been experienced previously. Using weld parameters of force 4 pounds, gap 5 mils, voltage .53-.55, and time 500-750 milliseconds, the values ranged from 26 to 50 grams. In an attempt to check the welding conditions, metallization from the previous series was utilized

for comparison with the same weld parameters. Results from this material yielded an average peel strength of 166 grams.

An analysis of this situation revealed that the thickness on the new metallization batch was in the range of 0.3 to 0.4 mil, while the thickness of the previous metallization was in the range of 0.7 to 0.8 mil. The process specification required a range of 0.5 to 1.0 mil.

In an attempt to rectify the problem, and salvage the circuit boards already processed, the boards were reprinted and refired. Also, additional boards were processed with a double printing and a single firing. The parallel gap welding response of this material is summarized in Table V. Twelve welds were made at each setting for each material.

TABLE V
DOUBLE PRINTED MATERIAL

Welding Parameters	Average Peel Strength, Grams	
	2-Print 2-Fire	2-Print 1-Fire
0.55 Volts x 750 Milliseconds	184	206
0.54 x 750	186	199
0.53 x 750	166	183

It was determined that the thickness of the above metallization was in the range of 0.7 to 0.8 mil. Several welds were produced such that the failure was in the gold ribbon above the weld indicating an optimum condition for both the metallization and the welding parameters.

Technical Liaison with Design Group

At this stage in the development process, a change was made in the welding equipment setup in 2334. Early prototype assembly had been conducted using the

same power supply, but using a VTA-90 weld head which utilized small electrodes and a much lower force. This was replaced with a VTA-66 weld head similar to the one used for development of the weld schedules cited.

Assembly of prototype units with this setup yielded satisfactory interconnection welds but was plagued with cracking of the ceramic circuit boards. This was apparently due to the combination of ceramic waviness, improper support from the assembly fixturing, and stresses introduced through a tight fit or misalignment over the connector pins.

The recommended force for the weld schedule was 4 pounds as set on the spring gauge indicator. The force indicator for the 2334 equipment was calibrated by 7113⁷ in order to determine the actual load and range variation. The curve for indicator setting versus pounds of force at the electrodes is presented in Figure 8. Assuming a decrease in force would help alleviate the ceramic cracking problem, an experiment was conducted to determine the criticality of force as related to the peel strength of the parallel gap weld. This experiment was conducted on a new metallization lot of Cermalloy 4100 utilizing the basic schedule previously developed but varying electrode force. The metallization was double printed and double fired, and the thickness was well within the specification limits. The average peel strength data are presented in Table VI. Twelve welds were made at each setting.

TABLE VI

PEEL STRENGTH VERSUS ELECTRODE FORCE

<u>Weld Parameters</u> <u>Force Setting/Voltage/Time</u>	<u>Average Peel</u> <u>Strength, Grams</u>
4/0.53/750	184
4/0.54/750	200
4/0.55/750	193
2/0.53/750	168

TABLE VI (cont)

<u>Weld Parameters</u> <u>Force Setting/Voltage/Time</u>	<u>Average Peel</u> <u>Strength, Grams</u>
2/0.54/750	168
2/0.55/750	183
1/0.55/750	170
1/0.60/500	191

From these data it would appear that the force applied to the electrodes could be reduced while still maintaining satisfactory interconnection weld strength. The results were reported to 2334 to be utilized as needed. Changes in the fixturing and the holes for the connector were being made concurrently with this experiment.

Ribbon to Thermopile Tab Interconnection

Development of a parallel gap welding schedule for attachment of the ribbon to the side contact on the thermopile was not expected to present a significant problem. This was due to the fact that a gold-gold joint was involved. For this same reason, attention was also given to thermocompression bonding as an alternate method. However, the initial attempts to utilize the TC bonding technique resulted in cracked thermopiles, and thus further development efforts were focused on parallel gap welding.

With regard to the parallel gap welding, it was determined that the most sensitive problem was remelting of the eutectic utilized in the side contact attachment.⁸ High voltage pulses, that is in the 0.75 to 1.0 volt range, were found to generate too much heat at the interface and disrupt the eutectic bond. Thus, the peel strength of the interconnection was low due to pulling the tab off the thermopile. The results of some early development work are presented in Table VII. Fifteen welds were made at each setting. Side contact tabs for this specific work were slightly undersize, and were seemingly more sensitive to eutectic melting.

FIGURE 8
Calibration Curve for Electrode Force

TABLE VII
RIBBON TO SIDE CONTACT WELD

<u>Weld Parameters</u> <u>Force/Voltage/Time</u>	<u>Average Peel</u> <u>Strength, Grams</u>
4/0.40/750	75
4/0.40/1000	115
4/0.43/500	156
4/0.43/750	122*

*Tabs were pulled off during peel testing.

Subsequent optimization of weld schedules was conducted with full size side contacts which had been bonded to the thermopile according to the final specifications for that process.⁸ The data are presented in Table VIII, and are representative of a dozen welds at each setting.

TABLE VIII
OPTIMIZED RIBBON TO SIDE CONTACT WELD

<u>Weld Parameters</u> <u>Force/Voltage/Time</u>	<u>Average Peel</u> <u>Strength, Grams</u>
4/0.43/500	198
4/0.43/600	203
4/0.43/750	206

Although no side contact tabs were pulled off in this evaluation, the conservative approach was taken wherein the weld schedule recommended to 2334 for prototype assembly utilized the 500 millisecond duration pulse.

CONCLUSION

Metallization and ribbon interconnection procedures have been defined for the RTG output circuit. Studies of the procedures indicated the type and thickness of the thick film metallization are important variables. With regard to parallel gap welding, parameters were obtained and optimized.

In summary, the following recommendations were made in the form of process descriptions:

1. Use a one system thick film metallization (Cermalloy 4100 platinum-gold ink) for the circuit pattern.
2. Maintain the as-fired thickness of the thick film between 0.5 and 1.0 mil.
3. Utilize a Hughes Micro Welder with a Model MCW-550 power supply, and a VTA-66 weld head using molybdenum electrodes of nominal 0.015 by 0.025 inch size.
4. For the ribbon to circuit board weld use a weld schedule with the following parameters: electrode force, 4.5 pounds; electrode gap, 5 mils; welding voltage, 0.53 to 0.55 volts; weld pulse duration, 750 milliseconds.
5. For the ribbon to thermopile side contact weld use a weld schedule with the following parameters: electrode force, 4.5 pounds; electrode gap, 5 mils; welding voltage, 0.43 volts; weld pulse duration, 500 milliseconds.

These recommendations are presented as a proven approach to production interconnection for the RTG. Time constraints restricted continued development and optimization of processes. Thus, these recommendations are not meant to be totally

exclusive of other techniques or approaches which are available should additional requirements arise.

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APPENDIX A

PROCESS DESCRIPTION

PROCEDURE FOR THICK FILM METALLIZATION OF RTG PRINTED INTERCONNECTION BOARD

1. GENERAL

This process description details the procedure for thick film metallization of the conductor pattern for the RTG printed interconnection board.

2. DOCUMENTS, DRAWINGS AND EQUIPMENT

The following shall form a part of this process description to the extent stated herein.

2.1 Documents

SS289306

2.2 Drawings

AY291604

2.3 Equipment

- a. A semi-automatic, precision, off-contact printer (Presco Model 150 Printer or equivalent).
- b. Stainless steel screens, 200 mesh, with the pattern defined by emulsion of sufficient thickness to provide conductor thickness > 0.0005 inch and < 0.001 inch.
- c. Belt furnace with a minimum of four independently controlled heating zones (Watkins-Johnson Model 3CA-36 Belt Furnace having a 5-foot

muffle, 2-1/2 inches in diameter, or equivalent).

d. Air circulating oven with a temperature capability of 150°C.

3. REQUIREMENTS

3.1 Housekeeping

Equipment, fixtures, and work surfaces shall be maintained in a clean condition.

3.2 Materials

The conductor material shall be a high viscosity platinum-gold ink Cermalloy 4100, as manufactured by Cermet Division of Bala Electronics Corp., 14 Fayette St., Conshohocken, Pennsylvania.

3.3 Conductor Metallization Procedure

3.3.1 Substrate Cleaning. The ceramic substrates per AY291604 shall be cleaned per SS289306.

3.3.2 Conductor Printing. The conductor material shall be deposited on the substrate by an off-contact, single direction printing. The breakaway distance between the substrate and the screen shall be 0.030 inch. The squeegee speed shall be 1 inch/second.

3.3.3 Pre-Dry. The freshly screened ink shall be allowed to settle for approximately 5 minutes, after which it shall be pre-dried in an air circulating oven at 125°C for 20 minutes.

3.3.4 Conductor Firing. The conductor firing shall be accomplished in the belt furnace using a forced air atmosphere. The four independent heating zones shall be adjusted as follows:

Zone 1 -- 750°C

Zone 2 -- 850°C

Zone 3 -- 875°C

Zone 4 -- 800°C

The temperature settings shall be utilized with a belt speed of 1 inch per minute providing a temperature profile wherein the maximum temperature of 875°C will be maintained for approximately 5 minutes.

The total time in the furnace will be approximately 60 minutes.

3.4 Conductor Thickness

There shall be a minimum conductor thickness of 0.0005 inch after firing.

4. QUALITY ASSURANCE PROVISIONS

4.1 Records

All inspection data, including visual observations, along with processing data and identity for each firing batch, will be recorded and maintained.

4.2 Process Certification

The process shall be certified for the equipment used, after which the furnace profile shall be monitored periodically to assure constant response of the heating zones. Monitoring should occur at least once a week during daily processing, or prior to any production when no processing has been conducted for one week.

4.3 Inspection

4.3.1 Conductor Thickness. The conductor thickness shall be determined through the use of a surface analyzer type instrument (Clevite Surfanalyzer or Talysurf or equivalent). Thickness should be determined after firing each printing batch.

4.3.2 Inspection. Visual inspection shall be performed at 20X magnification to assure continuous conductor patterns, free from voids and inclusions.

APPENDIX B

PROCESS DESCRIPTION

RTG PARALLEL GAP WELDING PROCEDURE RIBBON TO PRINTED INTERCONNECTION BOARD

I. MATERIALS

A. Ribbon

1. The ribbon shall be pure gold (99.99%).
2. Nominal dimensions shall be 0.002 inch thick by 0.015 inch wide.

B. Printed Interconnection Board

1. The ceramic board shall be per Sandia drawing AY291604.
2. The metallization shall be per AY291604.

II. EQUIPMENT

A. Welder

1. The welder shall be a Hughes MCW-550.
2. The electrodes shall be molybdenum of nominal tip size -- 0.015 inch by 0.025 inch.
3. The weld head shall be a VTA-66.

B. Fixturing

1. The fixturing shall be adequate to support the PIB and associated parts (connector and thermopile) during the welding operation.

III. CLEANING

A. PIB/Connector Assembly

1. The PIB/Connector Assembly shall be in a clean condition. Storage and handling after assembly, prior to welding, and during the welding operation shall be conducted so as to maintain the clean condition.

B. Thermopile/Ribbon Assembly

1. The Thermopile/Ribbon Assembly shall be in a clean condition. Storage and handling after assembly, prior to welding, and during the welding operation shall be conducted so as to maintain the clean condition.

IV. WELDING

A. Set-up

1. The electrodes shall be properly faced.
2. A preliminary weld shall be made and evaluated to check welder operation and parameter settings.

B. Assembly Procedure

1. Set weld parameters.
 - a. Weld voltage at 0.55 volts - 0.53 volts.
 - b. Weld duration at 750 milliseconds.
 - c. Electrode force at 4.
 - d. Electrode separation at 0.005 inch.
2. Align fixturing.
3. Align ribbon #1.
4. Weld
5. Repeat alignment and welding for Ribbons #2, 3, and 4.

V. EVALUATION

A. Visual

1. All welds shall be visually inspected at 10-20X magnification prior to removal of the assembly from the fixturing.

a. There shall be no discontinuity in the weld zone; i.e., no blow holes and no evidence of ribbon melt between the electrodes.

B. Weld Strength

1. Prior to assembly of PIB/Ribbon Thermopile, at least three welds shall be made at the proper parameter settings and evaluated destructively by a 90° peel test. These welds shall be made on the proper gold ribbon and on PIB of similar metallization history to production items. Minimum peel strength shall be 100 grams.

APPENDIX C

PROCESS DESCRIPTION

RTG PARALLEL GAP WELDING PROCEDURE RIBBON TO THERMOPILE

I. MATERIALS

A. Ribbon

1. The ribbon shall be pure gold (99.99%).
2. Nominal dimensions shall be 0.002 inch thick by 0.015 inch wide.

B. Thermopile

1. The thermopile, with tabs, shall be per 294255.

II. EQUIPMENT

A. Welder

1. The welder shall be a Hughes MCW-550.
2. The electrodes shall be molybdenum of nominal tip size -- 0.015 inch by 0.025 inch.
3. The weld head shall be a VTA-66.

B. Fixturing

1. The fixturing shall be adequate to support the thermopile during the weld operation.

III. CLEANING AND HANDLING

- ###### A. Clean ribbon pieces and thermopile assembly by ultrasonic agitation in

alcohol. Blow dry with N_2 .

- B. Store all pieces and assemblies in a clean, covered dish, or in a clean bench area.
- C. All handling before, during, and after welding shall be done with the use of finger cots, or lint-free gloves, and tweezers.

IV. WELDING

A. Set-Up

- 1. The electrodes shall be properly faced.
- 2. A preliminary weld shall be made and evaluated to check welder operation and parameter settings.

B. Assembly Procedure

- 1. Set weld parameters.
 - a. Weld voltage at 0.43 volts.
 - b. Weld duration at 500 milliseconds.
 - c. Electrode force at 4.
 - d. Electrode separation at 0.005 inch.
- 2. Align fixturing.
- 3. Align ribbon #1 with tab.
- 4. Weld.
- 5. Repeat alignment and welding for ribbons #2, 3, and 4.

V. EVALUATION

A. Visual

- 1. All welds shall be visually inspected at 10-20X magnification prior to removal of the assembly from the fixturing.
 - a. There shall be no discontinuity in the weld zone; i.e., no blow holes, and no evidence of ribbon melt between the electrodes.

- b. There shall be no ejection of eutectic material from under the tab.

B. Weld Strength

- 1. Prior to assembly of ribbon to thermopile for production purposes, at least three welds shall be made at the proper parameter settings and evaluated destructively by a 90° peel test. These welds shall be made using the proper gold ribbon and either tabs on "Reject" thermopiles or tabs on "Slabs" of thermopile material. Minimum peel strength shall be 100 grams for a failure in the ribbon to tab weld, and 125 grams for a failure between the tab and thermopile.

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