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EVALUATION OF MICROBONDING TECHNIQUES USED IN HYBRID MICROELECTRONIC CIRCUITS

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16. Abstract

Research data obtained from the production of hybrid microcircuits by three intraconnecting processes are presented. Parallel-gap welding, ultrasonic bonding, and thermocompression bonding processes were used to intraconnect gold and aluminum wires to thin films of gold, aluminum, and nickel. In some events, an alloy film of nickel and chromium was used with a film of gold or aluminum. One thin film consisted of a NiCr base deposition, a central depositon of molybdenum, and an external film of gold. Trial connections were made by each joining technique with various wire-to-film combinations to establish an optimum weld schedule by each respective process. Other specimens were produced by the respective weld schedules to determine the actual pull strength and bonding characteristics. Specimens were also subjected to environmental conditioning. Pull strength and visual observations were the criteria for evaluating each junction.

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TECHNICAL MEMORANDUM X-53823

EVALUATION OF MICROBONDING TECHNIQUES USED IN HYBRID MICROELECTRONIC CIRCUITS

SUMMARY

Parallel-gap welding, ultrasonic bonding, and thermocompression bonding processes were used to intraconnect gold and aluminum wires to thin films of gold, aluminum, and nickel. In some events, an alloy film of nickel and chromium was used with a film of gold or aluminum. One thin film consisted of a NiCr base deposition, a central deposition of molybdenum, and an external film of gold. Trial connections were made by each joining technique with the various wire-to-film combinations to establish an optimum weld schedule by each respective process. Other specimens were produced by the respective weld schedules to determine the actual pull strength and bonding characteristics. Specimens were also subjected to environmental conditioning. Pull strength and visual observations were the criteria for evaluating each junction.

INTRODUCTION

Astrionics Laboratory has conducted extensive research on the development and fabrication of hybrid microcircuits. Particular emphasis has been placed upon the intraconnecting aspects of microcircuit production.

The technology of microcircuit production is relatively new, but it has grown in such proportion that it is considered a major field of electronics. This report is not intended to give the history and evolution of microelectronics, but to present data relevant to the intraconnecting techniques of microcircuits.

The reliability of complex microelectronic systems depends upon the quantity and quality of the metal-to-metal bonds that connect the components and conductors. Microcircuits contain fewer connections (welds, solder joints, etc.) than conventional electronics, contributing greatly to the higher reliability of microcircuits. A certain number of connections are inevitable, however, and must be made by one process or another. These joining processes are of prime consideration when planning and fabricating microelectronic circuits.

A number of joining methods are currently used for microelectronic connections. The most common methods include parallel-gap welding, ultrasonic bonding, thermocompression bonding, and soldering. Other techniques, which include laser welding, electron-beam welding, percussive-arc welding, and flip-chip bonding, are being used but they are still considered to be in the experimental stage.

The approach to microcircuit production depends upon such factors as cost, size requirements, and volume of production. A system composed entirely of monolithic integrated circuits, including medium- and large-scale integration, may be considered optimum, but limited availability, high development costs, and undesirable electrical parameter tolerances, inherent with semiconductor devices, have made the hybrid circuit approach practical. This is particularly true for small- and medium-quantity productions (hundreds of devices as compared with hundreds of thousands, or with millions of monolithic integrated circuits). Because of the high reliability and low cost factors, hybrid circuits are being used extensively.

This study is to show the following: (1) the joining compatibility of selected thin films with gold and aluminum wires; (2) a comparison of thin films deposited by vapor deposition (resistance heating) with those deposited by triode sputtering; (3) a comparison of the adhesion of thin films to a glass substrate with the adhesion of the same films to a glazed ceramic substrate; (4) the reliability of the aforementioned conditions, using pull strength and visual inspection as the judging criteria.

Literature concerning these aspects of microcircuitry is not readily available; therefore, this program was initiated to determine detailed weld schedules that conform to the equipment and techniques available within this laboratory.

DESCRIPTION

Hybrid Microcircuits

A hybrid microcircuit is fabricated on an insulating substrate by using some combination of monolithic chips, film elements, and discrete components.

Figure 1 is an example of a typical hybrid microcircuit. This particular circuit functions as a power supply and is a modular part of a microelectronic accelerometer sensing system.

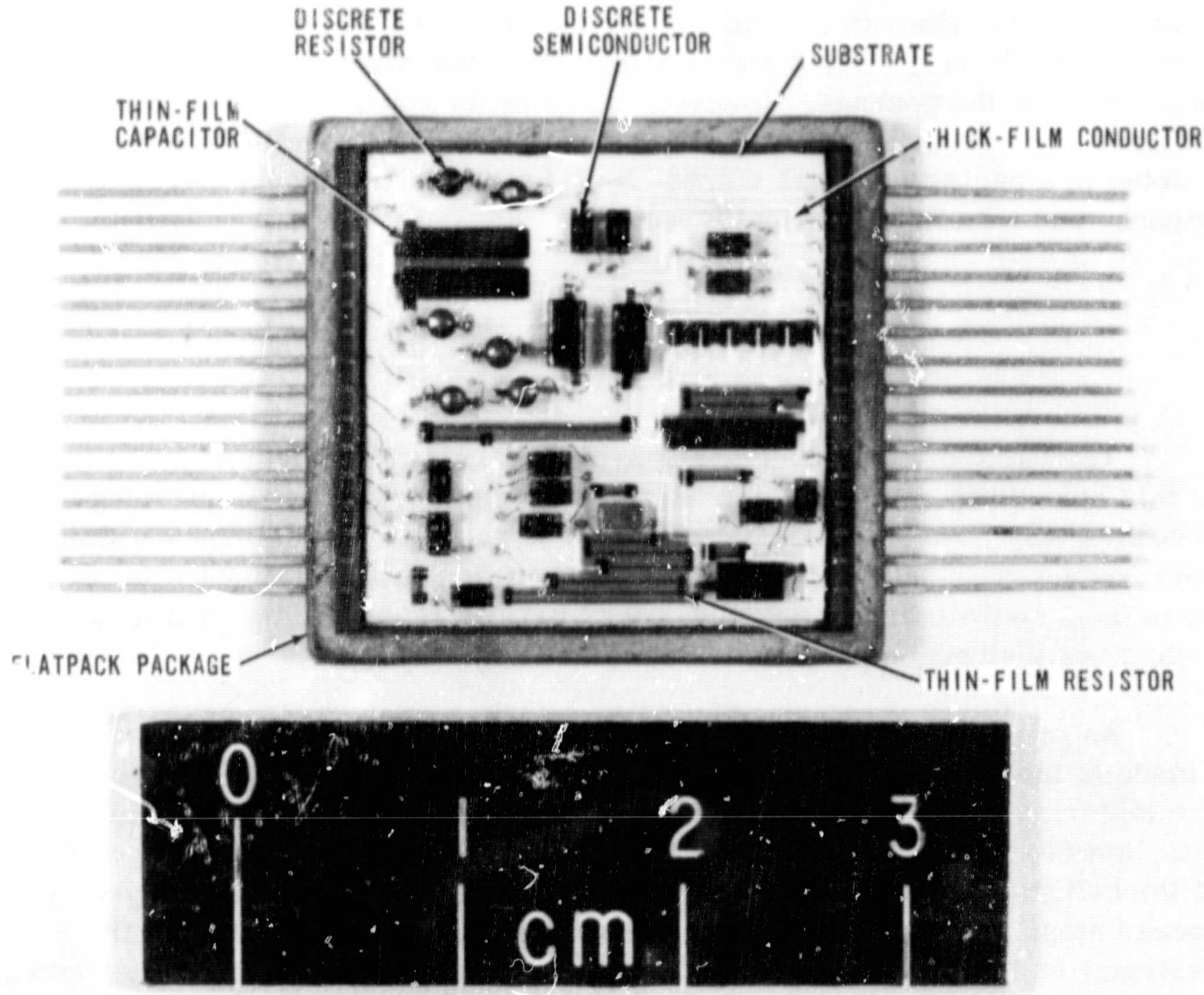

FIGURE 1. TYPICAL HYBRID MICROCIRCUIT

Hybrid Microcircuit Fabrication

The following is a brief description of a typical hybrid microcircuit fabrication process for this laboratory. A thick-film conductive paste is silk-screened onto a glazed alumina substrate, dried at 100°C, and fired at approximately 650°C [1]. The thick film serves as a conductive network and as weld pads for discrete components and wire leads. After firing, the substrate is placed in a vacuum system and thin-film resistors, capacitors, and conductors are vapor-deposited onto the substrate. The configuration of the thin-film elements is defined by metal masks placed in near contact with the substrate. The substrate, a standard 5.080- by 5.080- by 0.064-cm (2.000- by 2.000- by 0.025-in.) during processing, is scribed and broken to size for placement into the package. Discrete components are bonded to the substrate, and leads are then joined to the proper terminals. The completed circuit is mounted in a package such as a 2.54- by 2.54-cm (1.00- by 1.00-in.) metal flatpack and then is hermetically sealed.

Microbonding Criteria

The basic criteria concerning hybrid circuits, set forth as guidelines for this laboratory, restrict internal microcircuit connections to welding processes only. No soldering is allowed in areas that contain exposed thin films or active monolithic devices, or both. Currently, all connections on and to the substrate are effected by either parallel-gap welding, ultrasonic bonding, or thermocompression (ball and stitch) bonding.

As previously pointed out, thick-film pads are provided where a bond is made to the substrate. The thick film has a proven reliability and is a good base material for this purpose. There are cases during the layout of microcircuits, however, where a complete thin-film design is more advantageous than the thick-film-thin-film combination. An all thin-film design eliminates the process steps involved in thick-film screening, decreases handling of the substrate, and allows the film phase of the microcircuit to be completed during one pump-down cycle of the vacuum equipment. The unknown factor, prior to this study, was the reliability of welded connections to thin films.

EQUIPMENT

Parallel-Gap Welder

A Hughes, Model MCW 550, welding power supply with a VTA-90 welding head (Fig. 2) was used for parallel-gap welding of gold wire

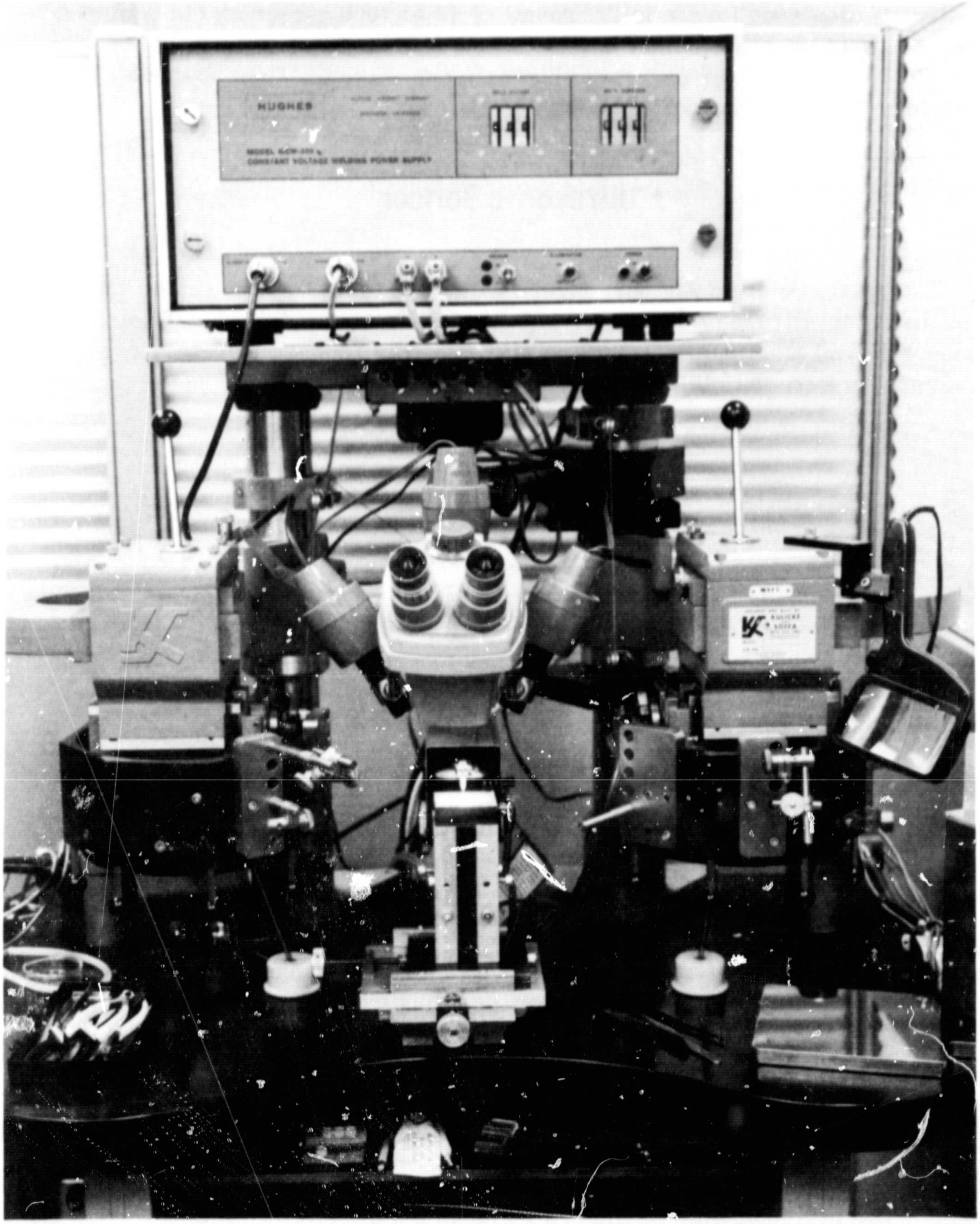

FIGURE 2. PARALLEL-GAP WELDER

to the thin-film materials. The head is designed to provide a repeatable control of electrode forces in the range of 10 to 1000 grams and is equipped with a pair of square-shanked electrodes with wrought-tungsten tips. The head can also be adjusted for different electrode gap widths. The substrates were maintained at room temperature during welding.

Ultrasonic Bonder

A Kulicke and Soffa wire bonder with a Sonoweld power supply (Fig. 3) was used for ultrasonic bonding. The equipment is capable of producing bonds using gold and aluminum wires of small diameter. Substrates, wires, and components were maintained at room temperature during the bonding processes.

Thermocompression Bonding

A Micro-Tech, Model 1100, bonder (Fig. 4) was used to produce the thermocompression bonds. A 2.54- by 2.54-cm (1.00- by 1.00-in.) flatpack heater column was used to hold the substrates, and the temperature was maintained at 100° C during processing. A tungsten carbide shank was maintained at 200° C to supply the additional heat needed for thermocompression bonding. Tungsten carbide tips were used for the wire capillary.

Pull Strength Tester

A pull strength tester with a constant-speed, motor-driven device that is capable of determining pull strength in the range of 1 to 1000 grams was used. Interchangeable indicator gauges provided the proper ranges for the wire being tested. The substrate holder can be adjusted to any position to pull the wires at any desired angle.

Environmental Chambers

The environmental chambers included a standard 25° to 250° C oven for temperature aging at 125° C and a heating-cooling chamber for temperature cycling from -55° to +125° C.

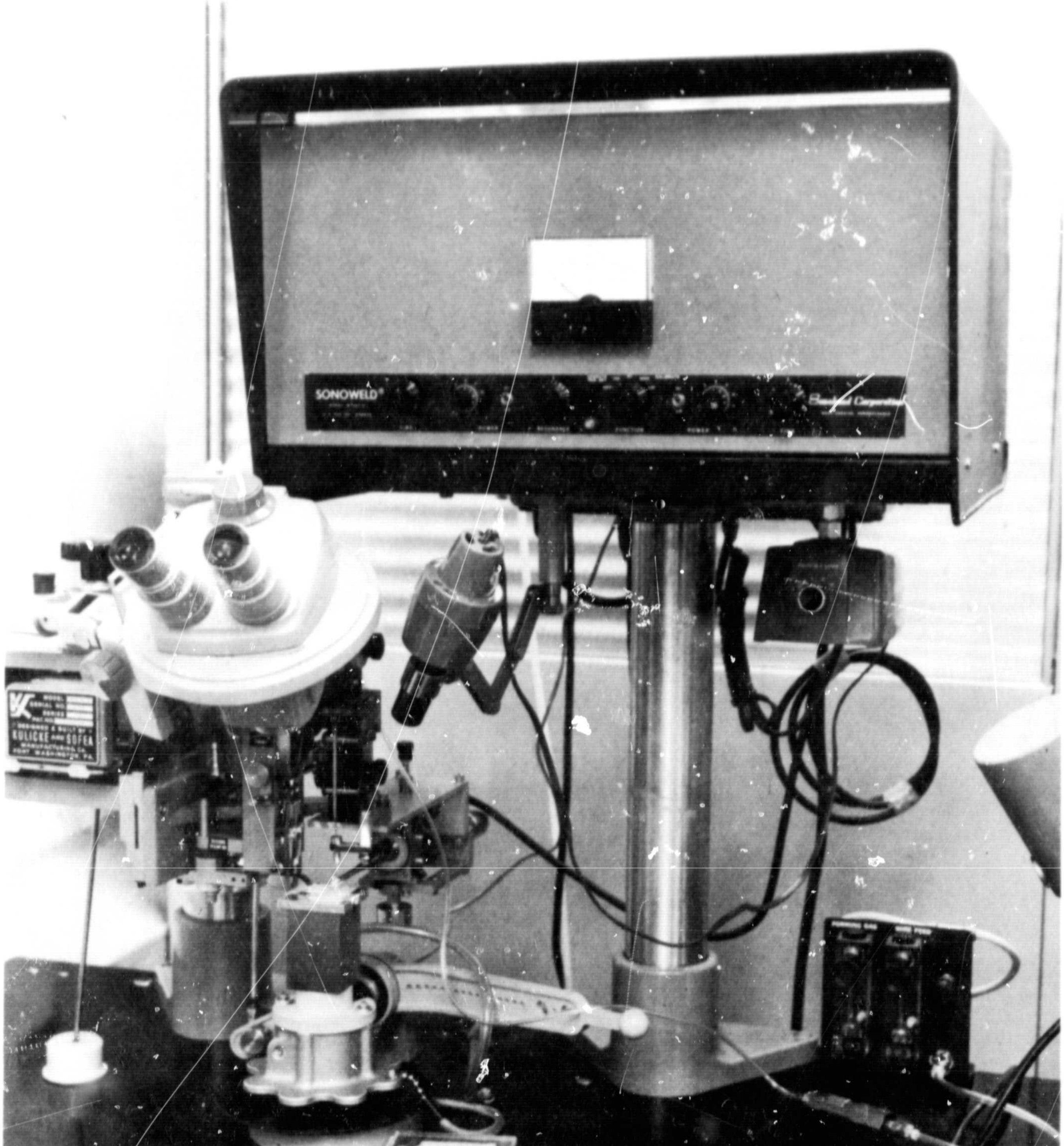

FIGURE 3. ULTRASONIC BONDER

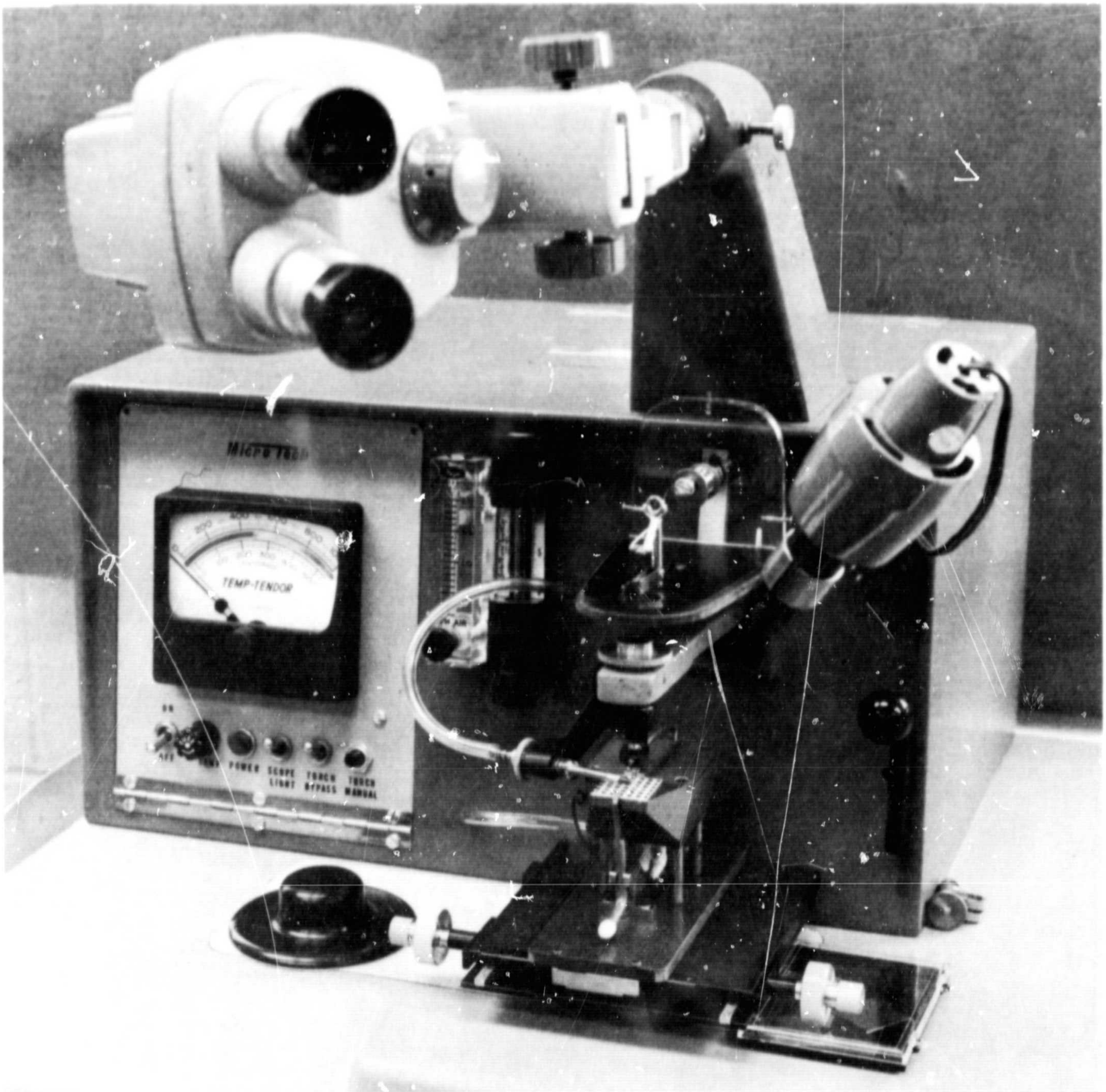

FIGURE 4. THERMOCOMPRESSION BONDER

MATERIALS

No new substrate, film, or wire materials were developed during this progr The practice was to choose available materials known to be compatible with each other and then to determine the most compatible joining process. For example, it was learned that aluminum thin film and aluminum wire are best joined by ultrasonic bonding.

As noted in the data, the gold-aluminum combination was excluded from this study. The "purple plague," or intermetallic formation caused by gold-aluminum contact, has been dealt with in considerable detail by researchers and by the semiconductor process industry. Opinions vary as to the severity of this problem and its probable effects on ultimate parts reliability. However, it remains a fact that an intermetallic formation will occur, the rate being temperature-dependent; therefore, whenever possible, use of a single metal system or other metal combinations would eliminate the plague problem. Table I shows the compatible materials and processes used in this program.

TABLE I. COMPATIBLE MATERIALS AND BONDING PROCESSES

MATERIALS		PROCESSES		
Wire	Thin Film	Parallel-Gap	Ultrasonic	Thermocompression
Au	Au	X	X	X
Al	Al		X	
Au	Ni	X	X	X
Al	Ni		X	
Au	NiCr-Au	X	X	X
Al	NiCr-Al		X	
Au	NiCr-Mo-Au	X	X	X

Thin-film materials were deposited by vacuum deposition or by triode sputtering, and the substrate materials were either glass or glazed ceramic. Wires of three diameters (0.0025-, 0.0050-, and 0.0075-cm) were used, but because of the large amount of data acquired, only the data from the 0.0050-cm wire were chosen for illustration purposes.

These materials and processes were chosen for determining weld schedules because they are most widely used in the production of hybrid microelectronic circuits.

PROCEDURES

Film Depositions

Thin films were vacuum-deposited in the conventional manner at 10^{-5} torr, or less, and with the substrate heated to 250° C. Resistance heating was used for most metal evaporation, with the exception of molybdenum, which had to be heated with an electron-beam source.

The sputtered thin films were produced in a CVC plasma-vac triode sputtering system. The substrates were heated to 250° C during the deposition process. Deposition rates were determined by calibration, using preset parameters such as pressure, target voltage, and anode current. These values were set at conditions that provided optimum adhesion of the film to the substrate.

Determining Weld Schedules

Four sets of 15 specimens (standard 5- by 5-cm, unbroken) were prepared for testing the various joining processes with each of the seven material combinations. The four sets of specimens were derived because there were two substrate types, two film deposition methods, and seven material combinations. The 15 specimens per set were derived from the number of joining processes used. Only one process was applied to any one specimen. Figure 5 illustrates the combinations and processes used to determine weld schedules.

Thick-film materials were not applied in these specimens, because it is generally known that junctions can be made successfully when the proper thick film is applied as a welding pad.

For clarification, consider the set that was subjected to the parallel-gap welding process. Trial welds were made to each specimen by varying the instrument settings to determine the best weld schedule parameters for the particular combination. The pull strength of all junctions was tested by pulling the wire from the substrate at an angle of 45 degrees.

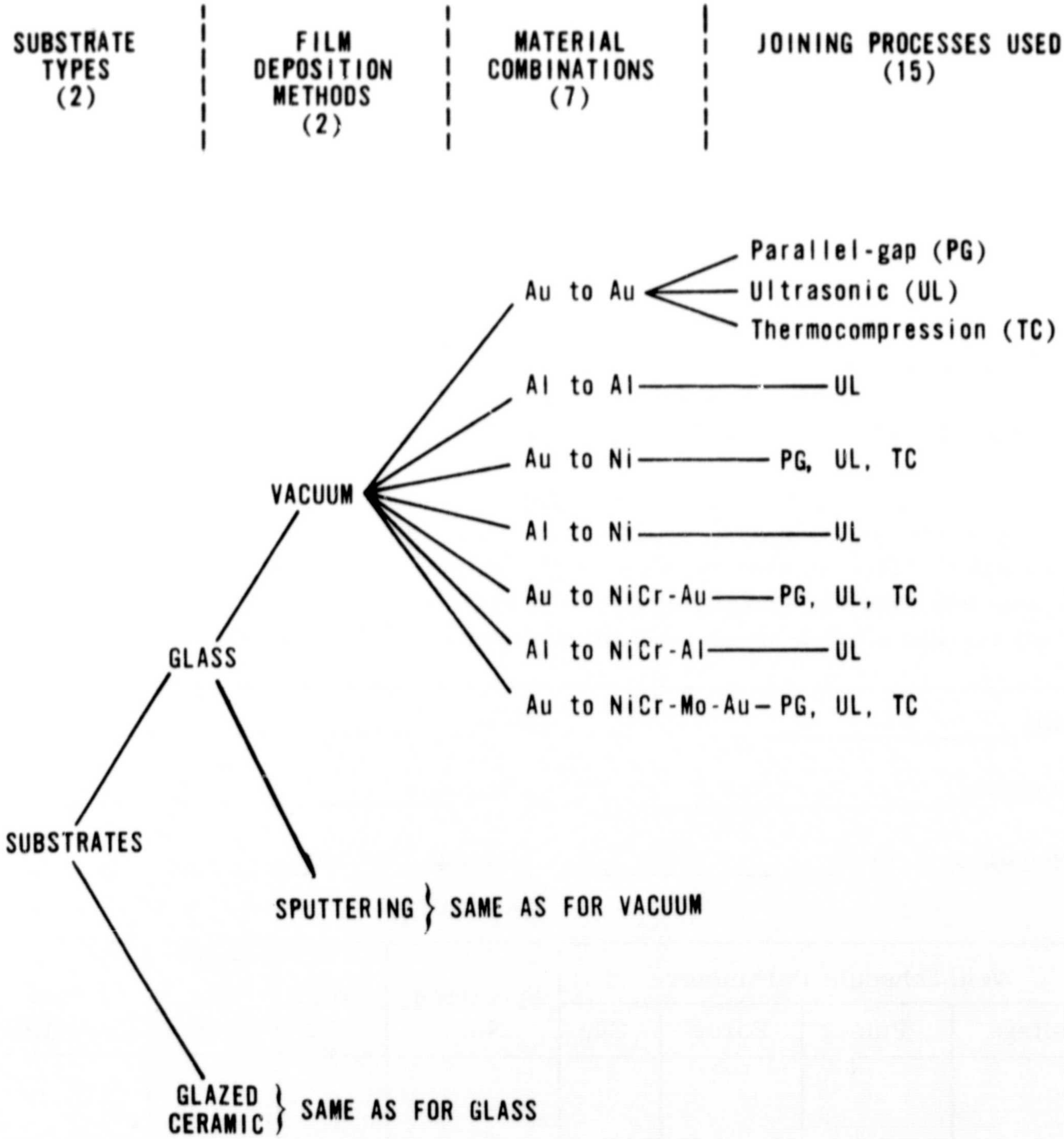

FIGURE 5. SPECIMEN COMBINATIONS AND PROCESSES USED FOR DETERMINING WELD SCHEDULES

Ten additional welds were produced at the weld schedule parameters that were determined from the trial settings. This group of ten welds was tested and used as a control group. Other groups of ten welds were produced at parameter settings above and below those derived by trial. The average pull strength of each group above or below was compared with the average pull strength of the control group. If the varied parameters increased the pull strength, the new parameters were accepted as the better schedule.

This method provided two important types of information: an optimum weld schedule, and maximum and minimum values for each particular combination. This procedure was also used for determining the optimum weld schedules for ultrasonic and thermocompression bonding.

Each 5- by 5-cm specimen provided ample space for making up to 45 test junctions. Considering this procedure, there were 60 specimens and 1380 welds. This number is based on three trial welds, one group above trial parameters, and one group below trial parameters. Each specimen was numbered and all data were carefully recorded in a prepared form (Fig. 6).

Date________________ Film____________________

Substrate________________ Wire____________________

Deposition Method________________ Welding Process________________

Weld Schedule Parameters				Specimen No.	Weld No.	Pull Str. (grams)	Visual Inspection
Voltage	Pulse	Force	Gap				

FIGURE 6. TYPICAL WELDING SCHEDULE TEST DATA FORM

Environmental Testing

New specimens were prepared at optimum weld schedules that were established for each respective combination. These specimens were then subjected to temperature aging and cycling environments. The pull strength and visual examination criteria used for determining weld schedules were also used for judging the effects of extreme temperature exposures.

The aging temperature was set at 125° C and the exposure periods were set at 0, 240, and 500 hours. Control specimens were maintained at room temperature and tested, along with the exposed specimens, at the end of each exposure period.

The temperature cycling range (Fig. 7) was from -55° to +125° C over a 4-hour period. Control specimens were again kept at room temperature and tested along with specimens that were exposed to 0, 10, and 50 cycles. From +125° to -55° and back to 125° C constituted one cycle. The relative humidity varied in proportion to the temperature cycle, as Figure 7 illustrates.

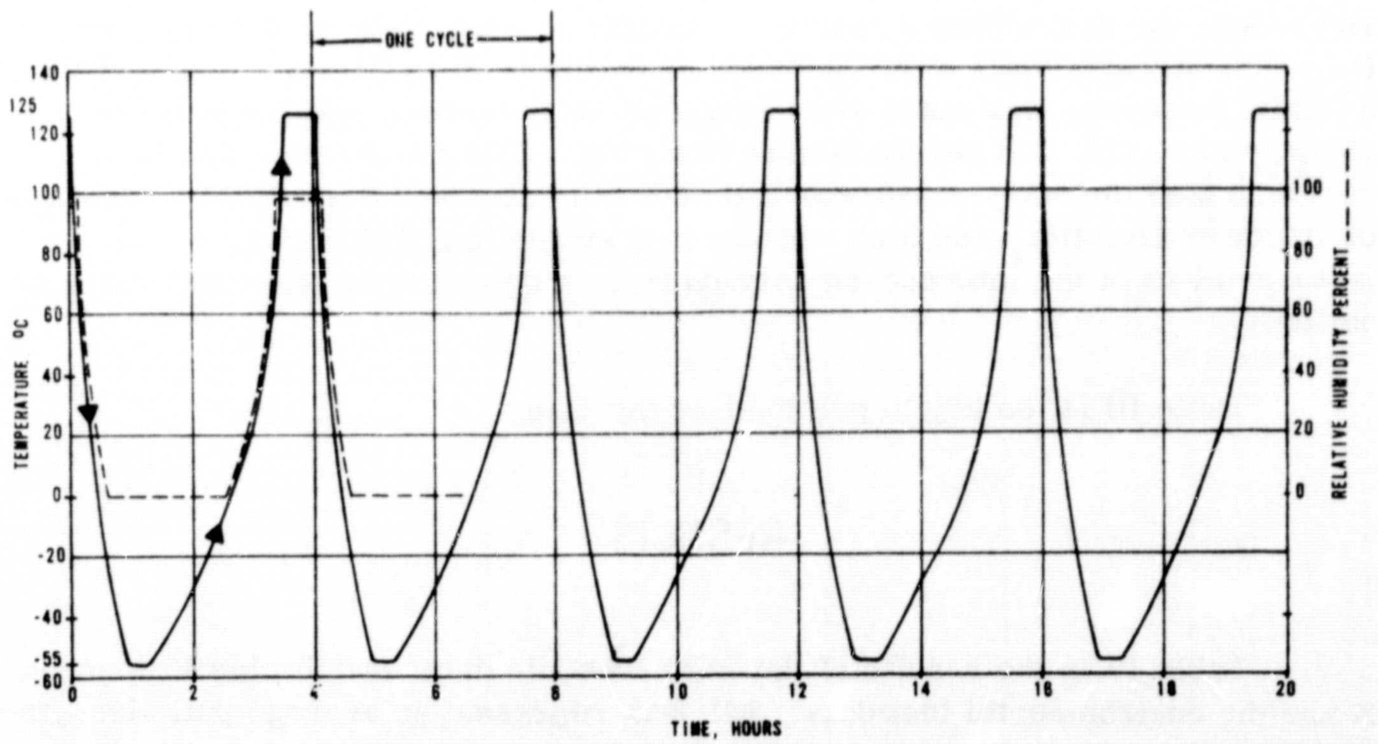

FIGURE 7. TEMPERATURE CYCLING CHART

Environmental testing required 90 specimens and 3950 junctions. These figures were based on the following:

1. Only ceramic-substrate specimens were used.

2. A control group was added for each joining process and environmental condition.

3. Only gold wires were used with the parallel-gap and thermocompression processes.

4. Forty-five wires were joined to each specimen. Fifteen wires were pulled at each condition.

DATA PROCESSING

The data acquired from weld schedule determinations and environmental tests became so voluminous that a computer program was developed to process and reduce the data within a reasonable length of time. The values obtained from pull strength tests were recorded on forms such as Figure 6. In addition, a visual inspection was made after each pull strength test, and the condition of the wire, weld, and substrate was recorded. This information was then computerized to show the average pull strength, standard deviation, percentage of standard deviation, and high and low pull strengths. Table II is a computer printout of the information derived from a typical weld schedule determination.

Table III is the key to printouts of the data.

RESULTS

Table IV is the results of the weld schedule data, and Tables V through X are the environmental test data. All data represent an average pull strength in grams.

TABLE II. TYPICAL COMPUTER PRINTOUT

08 SPT GL AU1 PG V35 TM025 F500 GP0020 102367

PS	WI	PI	SI	APS	SD	PSD	HPS	LPS
6.0	4.	1.	1.					
4.5	3.	3.	1.					
5.0	9.	1.	1.					
3.5	3.	3.	1.					
5.0	4.	1.	1.					
3.0	3.	3.	1.					
2.5	3.	3.	1.					
2.5	3.	3.	1.					
3.0	3.	3.	1.					
4.5	3.	2.	1.	3.95	1.15	29.11	6.0	2.5

08 SPT GL AU2 PG V40 TM025 F500 GP0020 102367

PS	WI	PI	SI	APS	SD	PSD	HPS	LPS
5.5	4.	1.	1.					
5.0	4.	1.	1.					
4.5	4.	1.	1.					
5.0	4.	1.	1.					
4.5	4.	1.	1.					
5.0	4.	1.	1.					
5.5	4.	1.	1.					
5.0	4.	1.	1.					
5.0	4.	1.	1.					
5.0	4.	1.	1.	5.00	0.32	6.32	5.5	4.5

08 SPT GL AU1 PG V45 TM025 F500 GP0020 102367

PS	WI	PI	SI	APS	SD	PSD	HPS	LPS
5.0	4.	1.	1.					
4.5	2.	2.	1.					
4.5	4.	1.	1.					
5.0	4.	1.	1.					
5.5	4.	1.	1.					
5.0	4.	1.	1.					
5.0	4.	1.	1.					
3.5	2.	2.	1.					
5.0	4.	1.	1.					
5.0	4.	1.	1.	4.80	0.51	10.62	5.5	3.5

TABLE III. KEY TO DATA PRINTOUT

PS	Pull strength	APS	Average pull strength
WI	Weld inspection, visual	PSD	Percent standard deviation
PI	Pad inspection	HPS	High pull strength value
SI	Substrate inspection	LPS	Low pull strength value

SD Standard deviation

DEPOSITION

SPT Sputtering
VAC Vacuum

WELD METHOD

PG Parallel-Gap
TC Thermocompression
UL Ultrasonic

SUBSTRATE

CR Ceramic
GL Glass

CODE FOR TYPE OF THIN FILM

Vacuum

1 - Au
2 - Al
3 - Ni
4 - Ni
5 - NiCr-Au
6 - NiCr-Al
7 - NiCr-Mo-Au

Sputtering

8 - Au
9 - Al
10 - Ni
11 - Ni
12 - NiCr-Au
13 - NiCr-Al
14 - NiCr-Mo-Au

VISUAL INSPECTION

WELD

1 - Wire broke at bond
2 - Weld pad pulled up
3 - Wire pulled up
4 - Wire broke at ball
5 - Too much setdown
6 - Wire broke
7 - Fell off
8 - No weld
9 - Ball pulled up
10 - Not affected

WELD PAD

1 - Not affected
2 - Pulled up
3 - Scarred
4 - Too much setdown
5 - Scorched
6 - No weld

SUBSTRATE

1 - Not affected
2 - Too much setdown
3 - Glass broken
4 - Glaze broken

TABLE IV. AVERAGE PULL STRENGTH (GRAMS) OF WELD SCHEDULE DATA

Wire	Film	Parallel-Gap				Ultrasonic				Thermocompression			
		Glass		Ceramic		Glass		Ceramic		Glass		Ceramic	
		Sput.	Vac.	Sput.	Vac.	Sput.	Vac.	Sput.	Vac.	Sput.	Vac.	Sput.	Vac.
Au	Au	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Al	Al	a				11.2	10.7	10.6	10.0				
Au	Ni	24.9	18.6	24.3	23.6	19.6	20.2	19.4	19.0				
Al	Ni					18.6	19.7	20.1	18.9				
Au	NiCr-Au	21.0	21.6	19.7	21.7	19.7	18.9	19.5	18.8	19.7	20.4	19.6	20.4
Al	NiCr-Al					19.7	14.9	11.1	10.7				
Au	NiCr-Mo-Au	27.1	20.5	27.3	20.2	26.8	19.8	25.0	19.7	21.2	21.6	29.5	20.2

a. Blanks indicate no junction.

TABLE V. AVERAGE PULL STRENGTH (GRAMS) OF PARALLEL-GAP WELDS (After Aging at 125° C)

Wire	Film	Sputtered Film[a]						Vacuum-Deposited Film					
		0 Hr		240 Hr		500 Hr		0 Hr		240 Hr		500 Hr	
		Cont.[b]	Test	Cont.	Test	Cont.	Test	Cont.	Test	Cont.	Test	Cont.	Test
Au	Au	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Al	Al	c											
Au	Ni	27.2	27.7	27.2	25.7	27.6	24.8	26.6	26.5	27.7	24.0	27.2	24.9
Al	Ni												
Au	NiCr-Au	26.3	26.2	27.4	6.0	27.6	4.1	26.7	26.9	27.4	25.3	28.0	22.7
Al	NiCr-Al												
Au	NiCr-Mo-Au	27.3	27.3	27.9	25.8	28.0	26.1	26.5	26.5	27.9	24.1	28.1	27.2

a. All films were deposited on glazed ceramic substrates.

b. All control specimens were kept at room temperature. Test specimens were cooled to room temperature before being pulled.

c. Blanks indicate no junction.

TABLE VI. AVERAGE PULL STRENGTH (GRAMS) OF ULTRASONIC BONDS (After Aging at 125° C)

Wire	Film	Sputtered Film[a]						Vacuum-Deposited Film					
		0 Hr		240 Hr		500 Hr		0 Hr		240 Hr		500 Hr	
		Cont.[b]	Test	Cont.	Test	Cont.	Test	Cont.	Test	Cont.	Test	Cont.	Test
Au	Au	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Al	Al	10.2	10.6	11.6	8.0	12.2	8.8	11.9	10.3	10.6	7.5	9.7	7.9
Au	Ni	[c]											
Al	Ni	14.1	15.1	14.7	8.6	14.4	9.1	19.2	20.2	21.9	20.8	20.8	19.4
Au	NiCr-Au	24.5	24.6	21.1	23.1	20.1	21.5	24.8	24.9	25.4	22.3	25.0	20.1
Al	NiCr-Al	10.6	13.6	12.8	8.3	13.3	8.0	16.3	16.0	16.8	15.2	17.0	13.8
Au	NiCr-Mo-Au	25.0	25.0	5.4	21.8	25.0	22.7	24.9	25.3	24.2	16.7	25.0	15.0

a. All films were deposited on glazed ceramic substrates.

b. All control specimens were kept at room temperature. Test specimens were cooled to room temperature before being pulled.

c. Blanks indicate no junction.

TABLE VII. AVERAGE PULL STRENGTH (GRAMS) OF THERMOCOMPRESSION BONDS (After Aging at 125° C)

		Sputtered Film[a]						Vacuum-Deposited Film					
		0 Hr		240 Hr		500 Hr		0 Hr		240 Hr		500 Hr	
Wire	Film	Cont.[b]	Test	Cont.	Test	Cont.	Test	Cont.	Test	Cont.	Test	Cont.	Test
Au	Au	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Al	Al	[c]											
Au	Ni												
Al	Ni												
Au	NiCr-Au	20.9	20.6	21.3	21.8	22.7	22.4	20.1	18.9	18.8	21.5	22.2	21.5
Al	NiCr-Al												
Au	NiCr-Mo-Au	20.9	21.6	21.4	22.0	23.0	22.3	20.9	20.9	19.9	22.3	19.2	20.9

a. All films were deposited on glazed ceramic substrates.

b. All control specimens were kept at room temperature. Test specimens were cooled to room temperature before being pulled.

c. Blanks indicate no junction.

TABLE VIII. AVERAGE PULL STRENGTH (GRAMS) OF PARALLEL-GAP WELDS (After Cycling, -55° to +125°)

Wire	Film	Sputtered Film[a]						Vacuum-Deposited Film					
		0 Cycles		10 Cycles		50 Cycles		0 Cycles		10 Cycles		50 Cycles	
		Cont.[b]	Test	Cont.	Test	Cont.	Test	Cont.	Test	Cont.	Test	Cont.	Test
Au	Au	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Al	Al	c											
Au	Ni	27.2	26.8	27.2	27.1	27.2	27.7	26.6	26.8	26.6	25.2	27.7	24.5
Al	Ni												
Au	NiCr-Au	26.3	26.0	26.3	26.5	27.4	8.5	26.7	27.9	26.7	26.9	27.4	26.8
Al	NiCr-Al												
Au	NiCr-Mo-Au	27.3	27.3	27.3	27.4	27.9	27.8	26.5	26.6	26.5	26.5	27.9	26.8

a. All films were deposited on glazed ceramic substrates.

b. All control specimens were kept at room temperature. Test specimens were cooled to room temperature before being pulled.

c. Blanks indicate no junction.

TABLE IX. AVERAGE PULL STRENGTH (GRAMS) OF ULTRASONIC BONDS (After Cycling, -55° to +125°)

Wire	Film	Sputtered Film[a]						Vacuum-Deposited Film					
		0 Cycles		10 Cycles		50 Cycles		0 Cycles		10 Cycles		50 Cycles	
		Cont.[b]	Test	Cont.	Test	Cont.	Test	Cont.	Test	Cont.	Test	Cont.	Test
Au	Au	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Al	Al	11.2	11.2	11.2	11.4	11.5	12.4	11.9	9.9	11.9	9.1	10.6	9.3
Au	Ni	[c]											
Al	Ni	14.1	19.7	14.1	20.4	14.7	20.7	19.9	19.7	19.9	20.9	21.9	20.7
Au	NiCr-Au	24.5	25.0	24.5	24.4	21.1	24.2	24.8	25.3	24.8	25.0	25.4	25.4
Al	NiCr-Al	10.6	13.4	10.6	12.4	12.8	11.8	16.3	16.1	16.8	15.5	17.1	15.4
Au	NiCr-Mo-Au	25.0	25.0	25.0	25.5	25.4	24.7	24.9	25.1	24.2	25.0	25.0	25.1

a. All films were deposited on glazed ceramic substrates.

b. All control specimens were kept at room temperature. Test specimens were cooled to room temperature before being pulled.

c. Blanks indicate no junction.

TABLE X. AVERAGE PULL STRENGTH (GRAMS) OF THERMOCOMPRESSION BONDS (After Cycling, -55° to +125°)

Wire	Film	Sputtered Film[a]						Vacuum-Deposited Film					
		0 Cycles		10 Cycles		50 Cycles		0 Cycles		10 Cycles		50 Cycles	
		Cont.[b]	Test	Cont.	Test	Cont.	Test	Cont.	Test	Cont.	Test	Cont.	Test
Au	Au	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Al	Al	[c]											
Au	Ni												
Al	Ni												
Au	NiCr-Au	20.9	20.2	21.9	21.2	21.3	20.4	20.1	20.1	20.1	20.6	18.8	21.6
Al	NiCr-Al												
Au	NiCr-Mo-Au	20.9	21.5	20.9	22.4	21.4	21.8	20.9	20.2	20.9	19.1	19.9	13.0

a. All films were deposited on glazed ceramic substrates.

b. All control specimens were kept at room temperature. Test specimens were cooled to room temperature before being pulled.

c. Blanks indicate no junction.

DISCUSSION

Weld Schedule Data (Table IV)

With the exception of gold wire to gold film and thermocompression bonding of gold wire to nickel film, a successful weld schedule was determined for each of the thin-film materials and wires that were compatible. The lack of good adhesion between gold and glass accounts for the failures among the gold-to-gold specimens. A bond between the gold wire and film was obtained in all cases, but the wire pulled a portion of film from the substrate when subjected to pull; thus, deposition of a base metal beneath the gold is accounted for. NiCr-gold proved to be an excellent film combination. A layer of molybdenum between the NiCr and gold films prevents the gold from diffusing into the NiCr during high temperature exposure or long-term storage.

Ultrasonic bonding is considered most versatile because both gold and aluminum wires can be joined to any of the seven films by this process. The attempt at thermocompression-bonding gold wire to nickel film failed because an oxide formed on the nickel, preventing fusion between the nickel and gold when the substrate was subjected to 100°C. Since the tip on the thermocompression bonder was limited to 200°C, investigations are currently being made into the use of a pulse-heated tip, which would allow the substrate to remain at room temperature.

No significant differences were found between glass and glazed ceramic substrates; therefore, only the glazed ceramic substrates were used for environmental testing.

Visual Inspection

An important phase of the data evaluation was visual inspection of the junction, film, and substrate after each junction was subjected to the pull strength test. This evaluation is available but it is not presented in detail because of the large number of tests involved. A junction was considered successful when the wire broke above the junction without damaging the weld surrounding the film or substrate. These specimens also reflected the best weld schedules.

During parallel-gap welding, care was taken to insure that the substrate did not crack beneath the joint because of thermal shock. The proper combination of pressure, current, and time was necessary to avoid cracking the substrate. The predominate failure that occurred during and after environmental testing was the separation of films from the substrates, particularly when the parallel-gap or thermocompression process was used. When ultrasonic bonds weakened or failed, the wire separated from the film. A strong adhesion between the film and substrate is an important factor in the reliability of a hybrid circuit.

Environmental Test Data

The data obtained from environmental testing were shown in Tables V through X. All values represented pull strength in grams. A brief summary of the data follows:

1. Gold Wire to Gold Film. Less than 1 gram tensile strength was obtained by each process, because the film pulled from the substrate. The data correspond to that obtained from determining weld schedules; thus, the influence of environmental conditioning could not be determined.

2. Aluminum Wire to Aluminum Film. Only the ultrasonic process was successful, and the sputtering method proved to be stronger than the vacuum-deposition method. Aging caused a significant decrease in strength and thermal cycling caused a slight increase for sputtered film and a slight decrease for vacuum-deposited film. Weakness of the bond occurred between the wire and the film rather than between the film and substrate.

3. Gold Wire to Nickel Film. No bonds were obtained by the ultrasonic and thermocompression processes, and the sputtered film was generally stronger than the vacuum-deposited film when welded by the parallel-gap process. Aging caused a slight decrease in pull strength. Cycling increased the strength of sputtered film and decreased the strength of vacuum-deposited film.

4. Aluminum Wire to Nickel Film. These junctions were made by ultrasonic bonding only. Vacuum-deposited film gave a stronger bond with a slight decrease in strength after aging. Aging caused a large decrease in pull strength among the bonds made on sputtered film. Cycling caused the bonds to become stronger on both vacuum-deposited and sputtered films.

5. Gold Wire to NiCr-Au Film. Good junctions were made by all joining processes. Sputtered films were generally stronger than vacuum-deposited films. Aging caused a large decrease in strength among parallel-gap and ultrasonically-processed specimens, but it increased the strength of thermocompression-processed specimens. Cycling gave results similar to those of aging.

6. Aluminum Wire to NiCr-Al Film. Junctions were made only by ultrasonic bonding, and vacuum-deposited films were generally stronger. Both aging and cycling caused a large decrease in pull strength.

7. Gold Wire to NiCr-Mo-Au Film. Junctions were made by all processes, and sputtered films gave a stronger junction. Aging decreased the strength of parallel-gap and ultrasonic junctions, but it increased the strength of thermocompression bonds. Cycling increased the strength of all junctions on sputtered films and decreased the strength of junctions made on vacuum-deposited films.

CONCLUSIONS

The program has proven valuable to this laboratory for determining reliable systems of metallurgical bonds that can be used in certain hybrid circuit applications. An indexing system has been established that shows correct weld schedules for the joining processes currently in use. The most important information derived from the program is the degree of reliability that can be expected from each metallic combination tested.

Based on the information collected during this program, several joining processes and materials may be used to fabricate hybrid circuits with highly reliable intraconnections. Thermocompression bonding is the least versatile, but the bonds withstood environmental conditioning without significant degradation. The use of a pulse-heated tip may make the thermocompression process superior to parallel-gap welding or ultrasonic bonding for certain applications, specifically in cases where bonds must be made directly to semiconductor die. The substrate could be maintained at room temperature, thus eliminating the danger of reflowing eutectic bonded parts.

Ultrasonic bonding was found to be most versatile, because both gold and aluminum wires can be bonded to any of the tested film materials. Gold wire ultrasonically-bonded to aluminum or gold film showed no significant degradation when exposed to temperature aging and cycling. Aluminum wires did indicate some degree of bond decay when exposed to the 125°C aging. Thermal cycling showed the same effect, but to less degree.

Parallel-gap welding is limited to gold-wire junctions, but it has satisfied the requirements of assembly work at this laboratory to date.

By selecting the proper combination of wire, materials, and joining process, all films except a monolayer of gold can be used as the microcircuit pattern.

The extent of testing and time expended on any one test was limited in this program, and the data indicate that additional study should be conducted. For example, microbonds for a particular application might require more strenuous environmental testing than was conducted in this initial study. Other conditions, such as shock, vibration, acceleration, and metallurgical examinations, are being conducted on selected circuits.

This laboratory is continuing its efforts to upgrade equipment, materials, and processes and to develop new concepts in the fabricating and packaging of hybrid microcircuits.

REFERENCE

1. Caruso, S. V., and Filip, G. L.: Fabrication of Hybrid Microelectronic Circuits. NASA TM X-53491, July 25, 1966.

APPROVAL

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EVALUATION OF MICROBONDING TECHNIQUES USED IN HYBRID MICROELECTRONIC CIRCUITS

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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