27
11/8/77
25 @ NTIS

BDX-613-1740

FEASIBILITY OF ELECTROPLATED GOLD FOR HYBRID MICROCIRCUITS

PDO 6989265, Final Report

P. L. Blessner, Project Leader

Published November 1977

MASTER

Prepared for the United States Energy Research and Development Administration Under Contract Number EY-76-C-04-0613 USERDA

Bendix **Kansas City Division**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Printed in the United States of America

Available From the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

Price: Microfiche $3.00
Paper Copy $5.25

BDX-613-1740
Distribution Category UC-38

FEASIBILITY OF ELECTROPLATED GOLD FOR HYBRID MICROCIRCUITS

Published November 1977

Project Leader:
P. L. Blessner
Department 842

PDO 6989265
Final Report

Communications Services **Bendix** **Kansas City Division**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

FEASIBILITY OF ELECTROPLATED GOLD FOR HYBRID MICROCIRCUITS

BDX-613-1740, UNCLASSIFIED Final Report, Published November 1977

Prepared by P. L. Blessner, D/842, under PDO 6989265

Electroplated gold was investigated as a feasible alternative to vacuum evaporated gold for use as a conductive metallization layer on HMC substrates. Conductor definition and resolution, RF electrical characteristics, via resistance, solder wettability, thermocompression bondability, and environmental stability of 6, 10, and 25 μm electroplated gold films were examined and compared to 6 μm evaporated gold films. No incompatibilities were found between electroplated gold and HMC requirements or fabrication processes.

WPC-sp

The Bendix Corporation
Kansas City Division
P.O. Box 1159
Kansas City, Missouri 64141

A prime contractor with the United States Energy Research and Development Administration under Contract Number EY-76-C-04-0613 USERDA

CONTENTS

Section Page

SUMMARY 7

DISCUSSION. 8

SCOPE AND PURPOSE 8

ACTIVITY. 8

<u>Film Physical Properties</u>. 8

<u>RF Characteristics</u>. 10

<u>Via Resistance</u>. 15

<u>Conductor Definition and Resolution</u> 16

<u>Solder Wettability</u>. 20

<u>Lead Frame Bondability</u>. 23

ACCOMPLISHMENTS 34

FUTURE WORK 34

APPENDIX: SUPPORT DATA 36

DISTRIBUTION. 57

ILLUSTRATIONS

Figure		Page
1	SEM Views of Structure of 8 μm Evaporated (Left) and 7 μm Electroplated (Right) Gold Film (5000X) (Polaroids)	11
2	SEM Views of Structure of 10 (Left) and 25 μm (Right) Electroplated Gold Film (5000X) (Polaroids)	11
3	Auger Spectrograph of 6 μm Evaporated Gold Film After Stabilization.	12
4	Auger Spectrograph of 6 μm Electroplated Gold Film After Stabilization	12
5	Auger Spectrograph of 6 μm Evaporated Gold Film After Stabilization; Top Layer of Gold Has Been Sputtered Off	13
6	Auger Spectrograph of 6 μm Electroplated Gold Film After Stabilization; Top Layer of Gold Has Been Sputtered Off.	14
7	Test Pattern Used to Determine RF Characteristics	15
8	Plot of RF Stripline Attenuation Data for 6 μm Evaporated and Electroplated Gold. . .	16
9	Plot of RF Stripline Attenuation Data for 6, 10, and 25 μm Electroplated Gold	17
10	Plot of RF Stripline Reflection Coefficient Data for 6 μm Evaporated and Electroplated Gold.	18
11	Green Punched Via Pattern	19
12	Ultrasonic Drilled Via Pattern.	19
13	Plot of Via Resistance Data for Electroplated Versus Evaporated Gold.	20
14	Conductor Edge Definition of 6 μm Evaporated (Top) and Electroplated (Bottom) Gold (740X) (Polaroids).	22

15	Lead Frames 127 μm Thick Thermocompression Bonded to 25 μm Electroplated (Left) and 6 μm Evaporated (Right) Gold Substratc Metallization (74X) (Polaroids)	29
16	Effect of Stabilization and CAN Etch on Lead Frame Bonds.	32
17	Effect of Temperature Cycling on Lead Frame Bonds	33
18	Effect of Thermal Aging (150°C) on Lead Frame Bonds	35
A-1	Lead Frame Bondability of 6 μm Evaporated Gold.	41
A-2	Lead Frame Bondability of 6 μm Electroplated Gold.	42
A-3	Lead Frame Bondability of 10 μm Electroplated Gold.	43
A-4	Lead Frame Bondability of 25 μm Electroplated Gold.	44
A-5	Lead Frame Bondability: 6 μm Evaporated Gold Stabilized and CAN Etched.	45
A-6	Lead Frame Bondability: 6 μm Electroplated Gold Stabilized and CAN Etched.	46
A-7	Lead Frame Bondability: 10 μm Electroplated Gold Stabilized and CAN Etched.	47
A-8	Lead Frame Bondability: 25 μm Electroplated Gold Stabilized and CAN Etched.	48

TABLES

Number Page

1 Metallization Process Parameters 9

2 Conductor Line Widths. 21

3 Solder Spread Factor 24

4 Lead Frame Bonding Evaluation of Evaporated and Electroplated Substrates 26

5 Lead Frame Bonding Evaluation of Pre-Sputtered and Pre-Evaporated Substrates. 27

6 Lead Frame Bonding Evaluation of Stabilized and CAN Etched Evaporated and Electroplated Substrates Without Photolithography. 30

7 Lead Frame Bonding Evaluation of Stabilized and CAN Etched Pre-Sputtered and Pre-Evaporated Substrates Without Photolithography 31

A-1 Gold RF Stripline Attenuation Data 37

A-2 Gold RF Stripline Reflection Coefficient Data 38

A-3 Via Resistance Data. 39

A-4 Temperature Cycling Effect on Lead Frame Bonds. 49

A-5 Lead Frame Bond Failure Modes: Temperature Cycled Substrates. 52

A-6 Thermal Aging Effect on Lead Frame Bonds 53

A-7 Lead Frame Bond Failure Modes: Thermally Aged Substrates. 56

SUMMARY

Vacuum evaporated gold is presently used for 3 μm and 6 μm metallization layers on hybrid microcircuit (HMC) substrates. Some future RF HMCs will require gold thicknesses greater than 6 μm. Since vacuum evaporation is neither technically nor economically feasible for producing gold films much greater than 6 μm, electroplating was investigated as an alternative method of providing the thick gold films required. Because electroplated gold has never been used for HMC substrate metallization at Bendix Kansas City, this feasibility study was also designed to determine the characteristics of electroplated gold and its compatibility with present HMC fabrication processes.

Ceramic substrates 95 by 114 mm (3.75 by 4.5 in.) were electroplated with 6, 10, and 25 μm of gold after 20 nm of chromium and 500 nm of gold had been either sputtered or vacuum evaporated onto the substrate surfaces. Substrates vacuum evaporated with 6 μm of gold were used as a control group. The substrates were evaluated for via resistance, RF electrical characteristics, conductor definition and resolution, solder wettability, thermocompression bondability, and environmental stability.

For 6 μm thick films, the electrical resistance of electroplated vias was almost an order of magnitude lower than that of evaporated vias. Green punched holes had essentially the same via resistance as ultrasonically drilled holes (of the same diameter) when metallized with electroplated gold. The thickness uniformity of the electroplated films was not as good as that of evaporated films; however, this can be improved by modifying the plating fixture. The RF electrical characteristics, conductor definition and resolution, solderability, thermocompression bondability, and environmental stability of the electroplated gold were all comparable to those qualities of the evaporated gold.

Based on this study, electroplated gold appears to be a feasible alternative to vacuum evaporated gold for use on HMC substrates. Future development work to be done in electroplating should include modification of fixturing to improve thickness uniformity, improving plating parameters versus electroplated film structure, and improving photolithography and bonding processes to suit electroplated gold films.

DISCUSSION

SCOPE AND PURPOSE

The purpose of this project was to evaluate the suitability of electroplated gold for use on HMC substrates. Vacuum evaporation is presently used to provide gold metallization 3 and 6 μm thick. It is expected that some future RF HMCs will require gold films greater than 10 μm thick. Since the vacuum evaporation process is neither technically nor economically feasible for producing films of this thickness, electroplating was investigated as one approach to providing the thick gold films required.

This project evaluated the properties of electroplated gold films related to HMC requirements, while the electroplating process itself was investigated separately.* The investigation included 6, 10, and 25 μm thick gold film which had been electroplated over a sputtered or vacuum evaporated layer of chromium and gold. These films were then tested for via resistance, solderability, thermocompression bondability, RF electrical characteristics, conductor definition and resolution, and environmental stability. The same properties were measured on a control group of substrates having 6 μm of vacuum evaporated gold. This work was done during April through December 1975.

ACTIVITY

A total of forty-eight 95 by 114 mm (3.75 by 4.5 in.) substrates were used in this study. All were taken from a single lot of MRC brand substrates. They were subjected to the typical sequence of HMC processes: stamp and bake serial number on back side, clean, bake at 900°C, and sputter tantalum nitride on front side. The substrates were then metallized with either vacuum evaporated or sputtered chromium and gold (Table 1). A range of values is given in Table 1 when more than one metallization lot was run. The substrates with 0.5 μm of gold were then electroplated with 6, 10, or 25 μm of gold using a SEL-REX Pyr-Au-Bond 140 solution with the following parameters: 60°C bath temperature, 6.5 pH, and 2 to 3 A/ft^2 current density.

Film Physical Properties

Electroplated and evaporated gold films were examined and compared on the basis of three properties: film thickness and sheet resistivity, surface topography, and composition.

---

*PDO 6989266, *Plating Hybrid Microcircuits*, is covered in Bendix Kansas City Report BDX-613-1575.

Table 1. Metallization Process Parameters

Deposition Method and Quantity of Substrates	Nominal Thickness (nm)	Deposition Rate (nm/min)	Maximum Substrate Temperature (°C)
Chromium			
Evaporation (13)	30	37-45	225
Evaporation (20)	30	40-61	225
Sputtering (15)	60	30	*
Gold			
Evaporation (13)	6	129-283	290-335
Evaporation (20)	0.5	166-309	250-270
Sputtering (15)	0.6	110	*

*Not measured

Beta backscatter techniques were used to measure film thickness in five locations on both the front and back sides of substrates. Measurements were performed only on 6 μm evaporated and electroplated gold since thickness standards were not available for 10 and 25 μm thick films.

Out of 4 electroplated substrates, the gold thickness from substrate to substrate ranged from 6.0 to 8.1 μm, with an average thickness of 7.0 μm. The maximum variation on one side of a substrate was 1.2 μm, or 18 percent of the average thickness on that side. Out of 14 evaporated substrates, the thickness ranged from 5.9 to 8.5 μm, with an average of 7.4 μm. The maximum variation on a given side was 0.6 μm, or 8 percent of the average thickness on that side.

Similar variations were found for the sheet resistivity. On an electroplated substrate having an average gold thickness of 7.2 μm, the average sheet resistivity was 3.5 mΩ/square, compared to 3.8 mΩ/square for an evaporated substrate with a 7.0 μm average thickness.

The data indicates that electroplating produced a larger variation in film thickness across a given substrate surface in comparison to the evaporation system geometry used in this study; however, it is more repeatable from substrate to substrate than vacuum evaporation. Thickness variations as low as 2 percent have been achieved with electroplating, and modifications to the plating fixture should produce HMCs approaching this value.

The surface topography of the films was examined using a scanning electron microscope (SEM). SEM photographs of electroplated and evaporated films 7 and 8 μm thick are shown in Figure 1. The electroplated film appears to be much less porous than the evaporated film because of the greater intergranular growth. Photographs of the structure of 10 and 25 μm thick electroplated films indicate that the grain size at the surface of the film increases as the film thickness increases (Figure 2).

Auger Electron Spectroscopy (AES) was used to examine the composition of the gold films. Spectrographs of 6 μm evaporated and electroplated films, taken after the films had been stabilized for 2 hours at 300°C, are shown in Figures 3 and 4. The graphs of the two substrates are almost identical, showing that chromium had diffused to the surface of both films. The other elements detected are the result of handling and storage in plastic bags. After sputtering off the surface of the films, chromium was not detected on either type of film (Figures 5 and 6).

This project did not attempt to modify the plating conditions to improve the properties of the gold films. If the diffusion of the chromium occurs along the grain boundaries of the gold, it might be possible to produce an electroplated gold structure which will reduce or prevent chromium migration to the surface of the gold.*

RF Characteristics

A total of 24 substrates were used to evaluate the RF electrical characteristics of electroplated gold films and compare them to those of evaporated gold films. Two substrates 51 by 51 mm (2 by 2 in.) were scribed from each of 12 larger substrates. An RF test pattern (Figure 7) was photo-processed on each substrate. The test pattern consisted of a meandering stripline with a total length of 395 mm (15.566 in.).

---

*See D. L. Rehrig, "Effect of Deposition Method on Porosity in Gold Thin Films," *Plating*, 61, 43 (1974), and J. M. Leeds and M. Clarke, "The Effects of Plating Conditions on Porosity in Gold Electrodeposits," *Transactions of the Institute of Metal Finishing*, 43, 50 (1965).

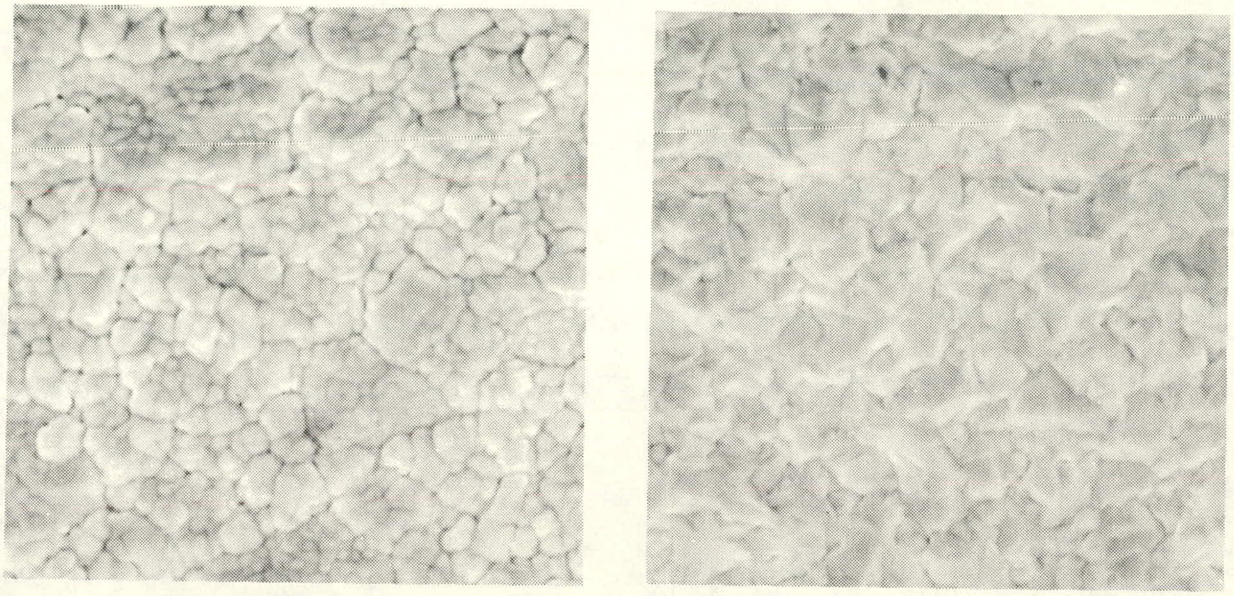

Figure 1. SEM Views of Structure of 8 μm Evaporated (Left) and 7 μm Electroplated (Right) Gold Film (5000X)

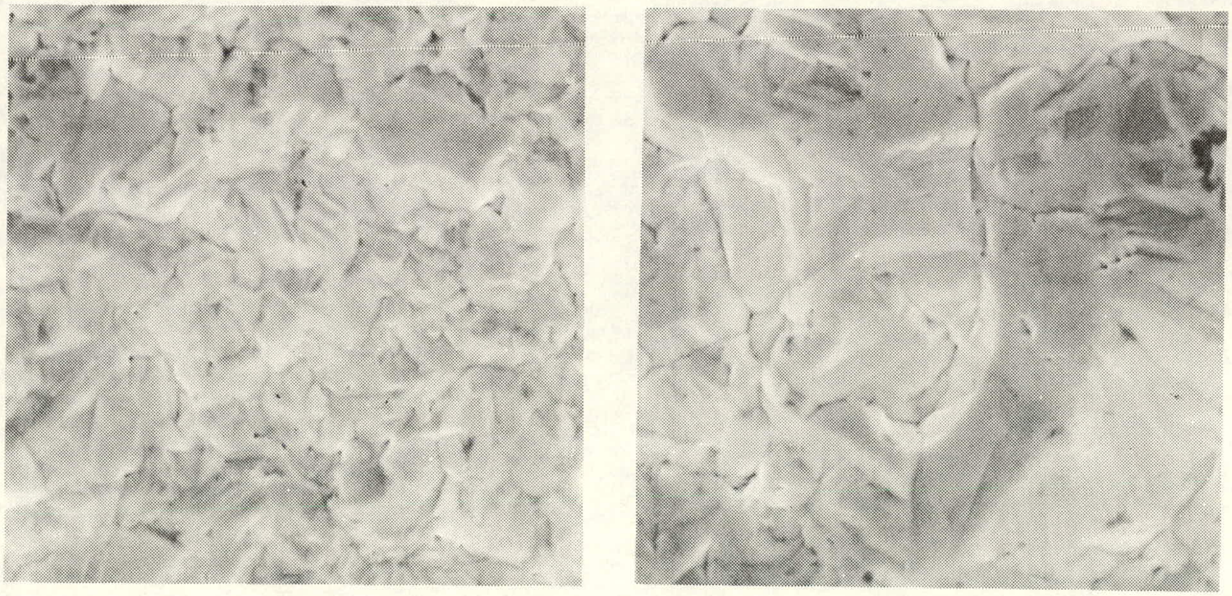

Figure 2. SEM Views of Structure of 10 (Left) and 25 μm (Right) Electroplated Gold Film (5000X)

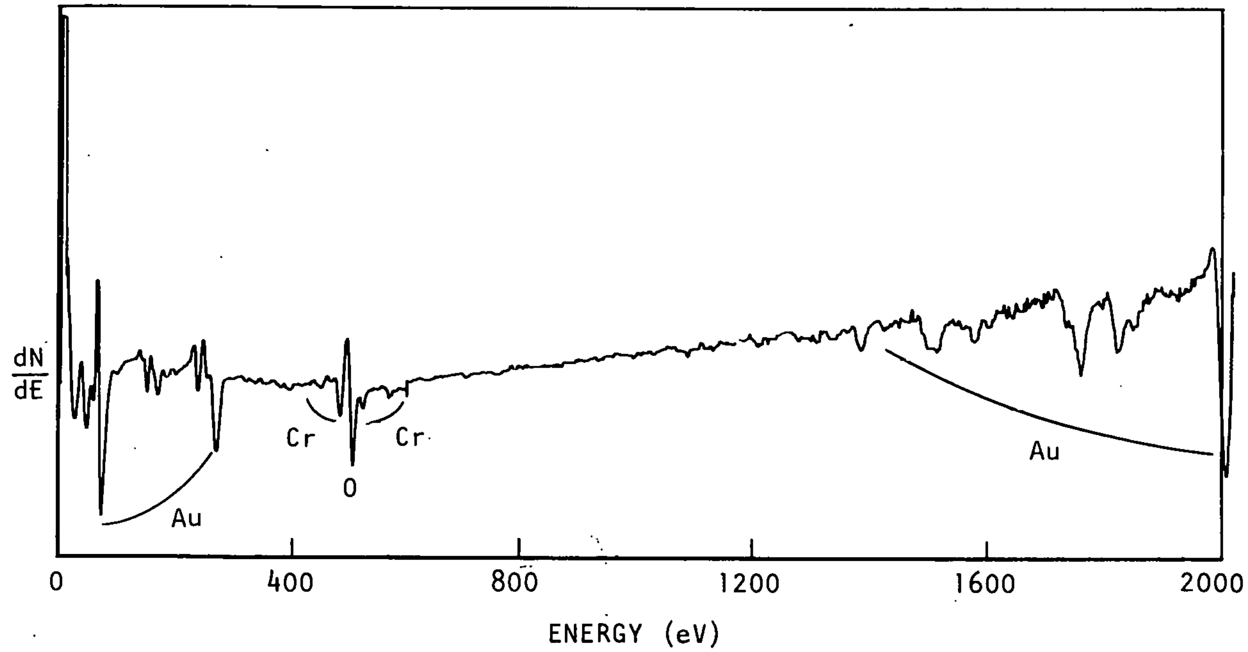

Figure 3. Auger Spectrograph of 6 μm Evaporated Gold Film After Stabilization

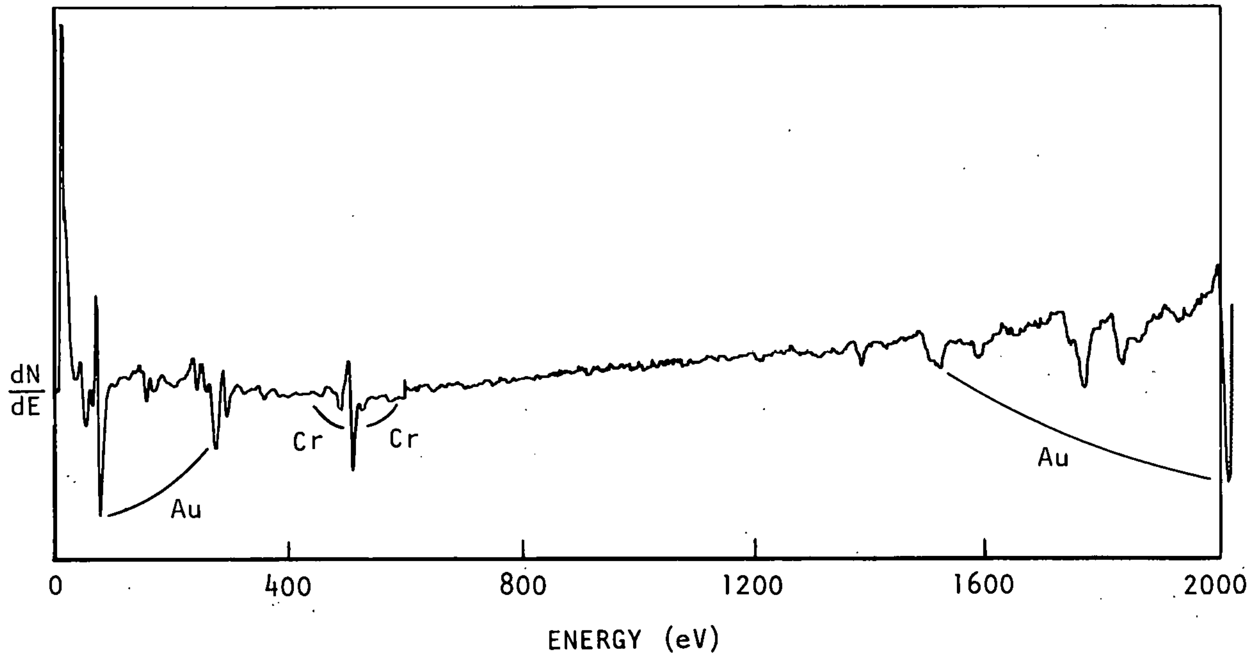

Figure 4. Auger Spectrograph of 6 μm Electroplated Gold Film After Stabilization

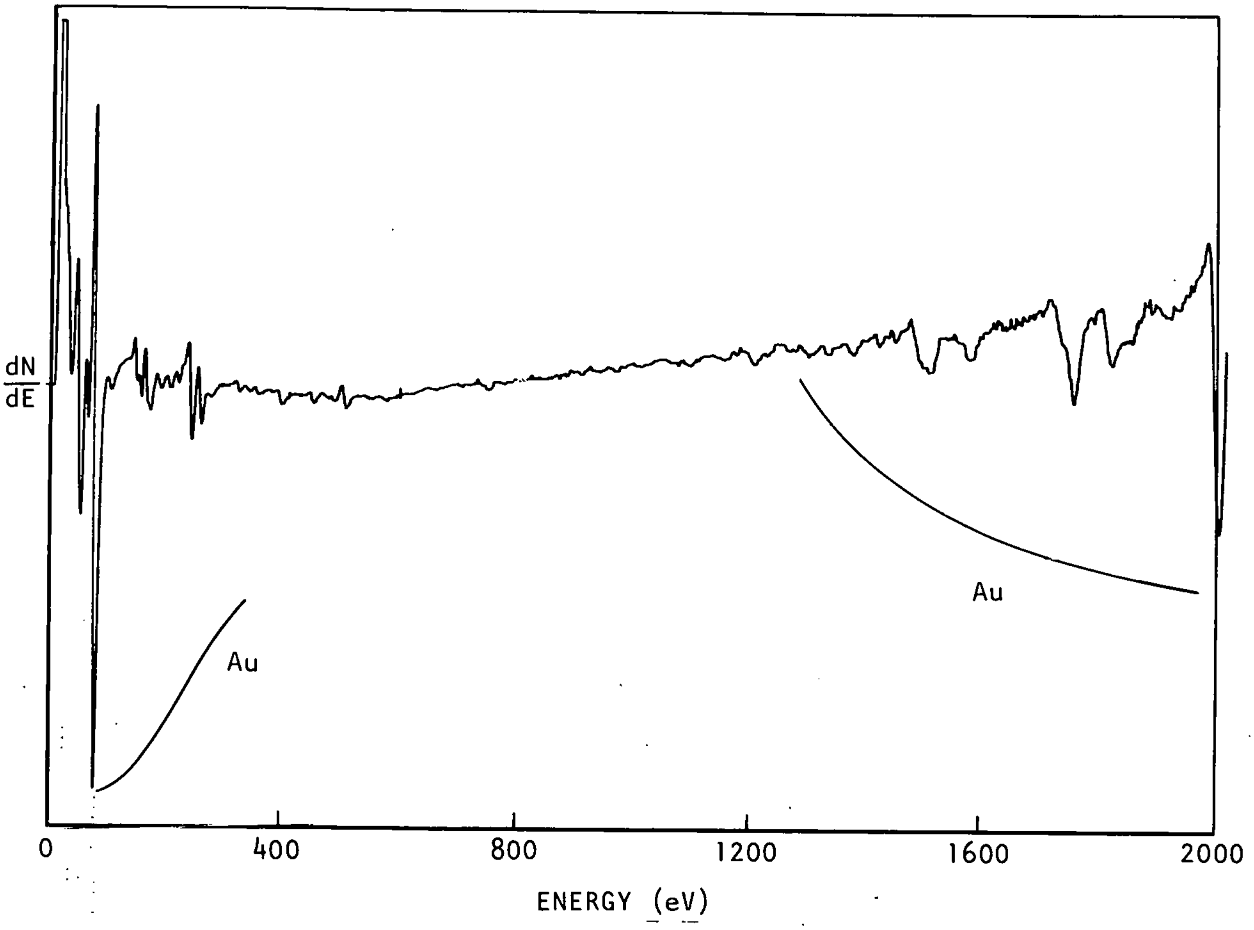

Figure 5. Auger Spectrograph of 6 μm Evaporated Gold Film After Stabilization; Top Layer of Gold Has Been Sputtered Off

An aluminum test fixture was made for mounting the substrates during electrical testing. The air gap between the bottom surface of the substrate and the inner surface of the aluminum cover was 4.8 mm (0.190 in.) which is typical for RF HMCs. Measurements were made on an automatic network analyzer system. To eliminate any variations in data resulting from calibration, all 24 substrates were tested consecutively without recalibrating the system. Measurements were taken at 100 MHz intervals between 100 and 2000 MHz.

Attenuation data is given in Table A-1 (See Appendix). The measured values in decibels were converted to linear values for determining the average attenuation at a given frequency for each metallization type and thickness. The typical loss through a pair of connectors, 0.13 db, was subtracted from these average

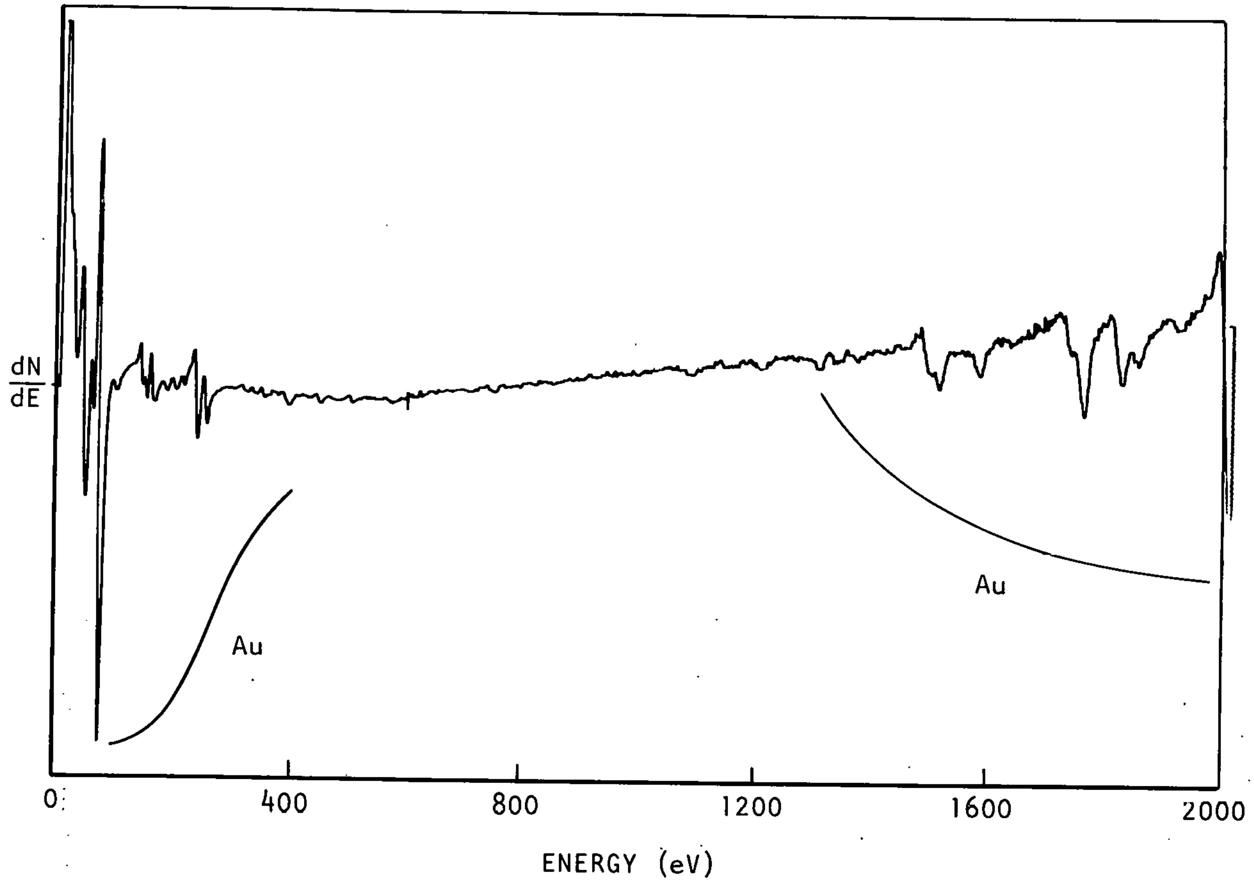

Figure 6. Auger Spectrograph of 6 μm Electroplated Gold Film After Stabilization; Top Layer of Gold Has Been Sputtered Off

values. The values were then divided by the physical length of a line to determine the loss per unit length of line. A plot of this data (Figure 8) shows that there is no significant difference between electroplated and evaporated 6 μm thick gold. In Figure 9 it is seen that lower attenuation occurs in thicker gold, which is expected.

Data on reflection coefficient is given in Table A-2. As seen in Figure 10, there appears to be no difference in reflection coefficient between 6 μm evaporated and electroplated gold films. There does appear to be a resonance between 1200 and 1500 MHz, since the reflection coefficient is approximately an order of magnitude higher at these frequencies. This occurred for all metallization conditions and is therefore characteristic of the stripline design rather than of the metallization itself.

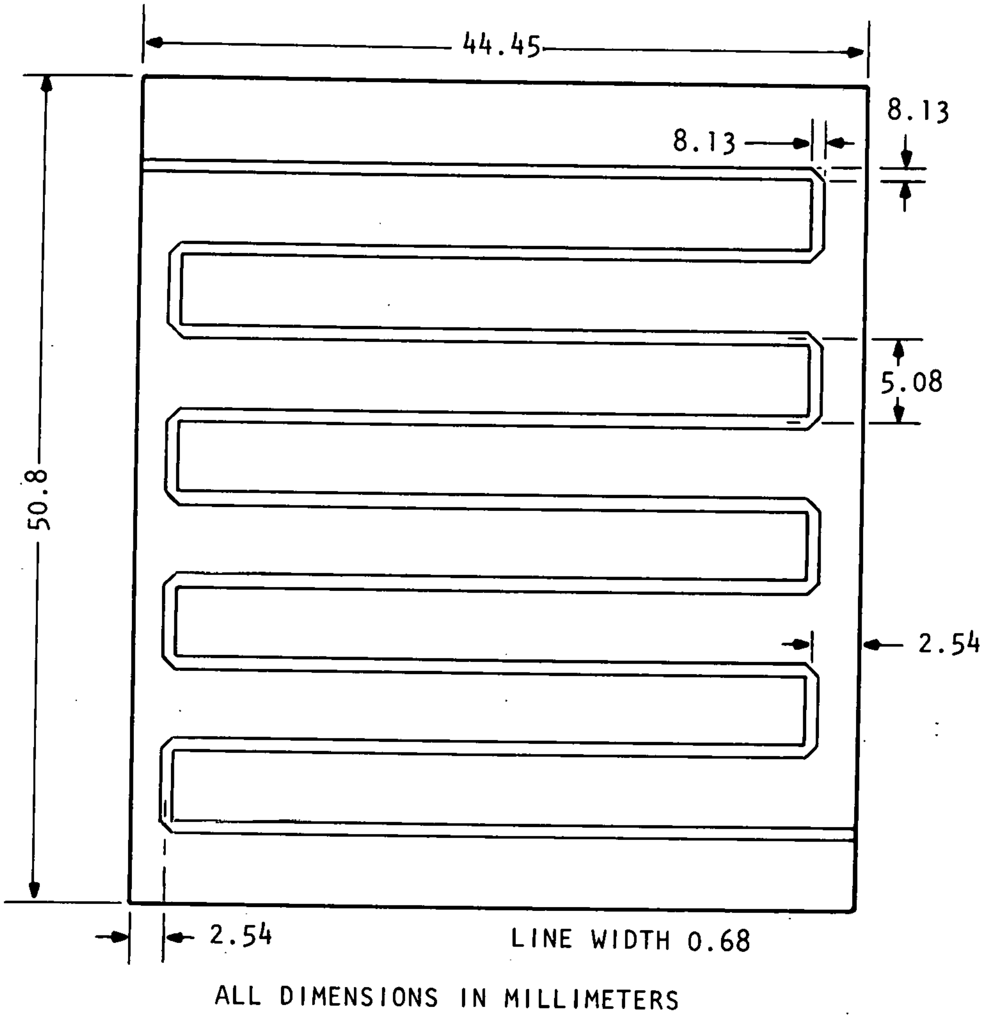

Figure 7. Test Pattern Used to Determine RF Characteristics

Via Resistance

A total of sixteen 95 by 114 mm (3.75 by 4.5 in.) substrates were used to evaluate the electrical resistance of vias metallized with electroplated gold and compare it to that of evaporated gold. Eight substrates had ultrasonically drilled holes and eight had green punched (punched in uncured ceramic) holes. The hole sizes and patterns on these substrates are shown in Figures 11 and 12.

After the substrates were metallized, the vias were electrically isolated from one another (on the top side of the substrate) using a dry-film photolithography process. Via resistance was then measured using a four-point probe setup.

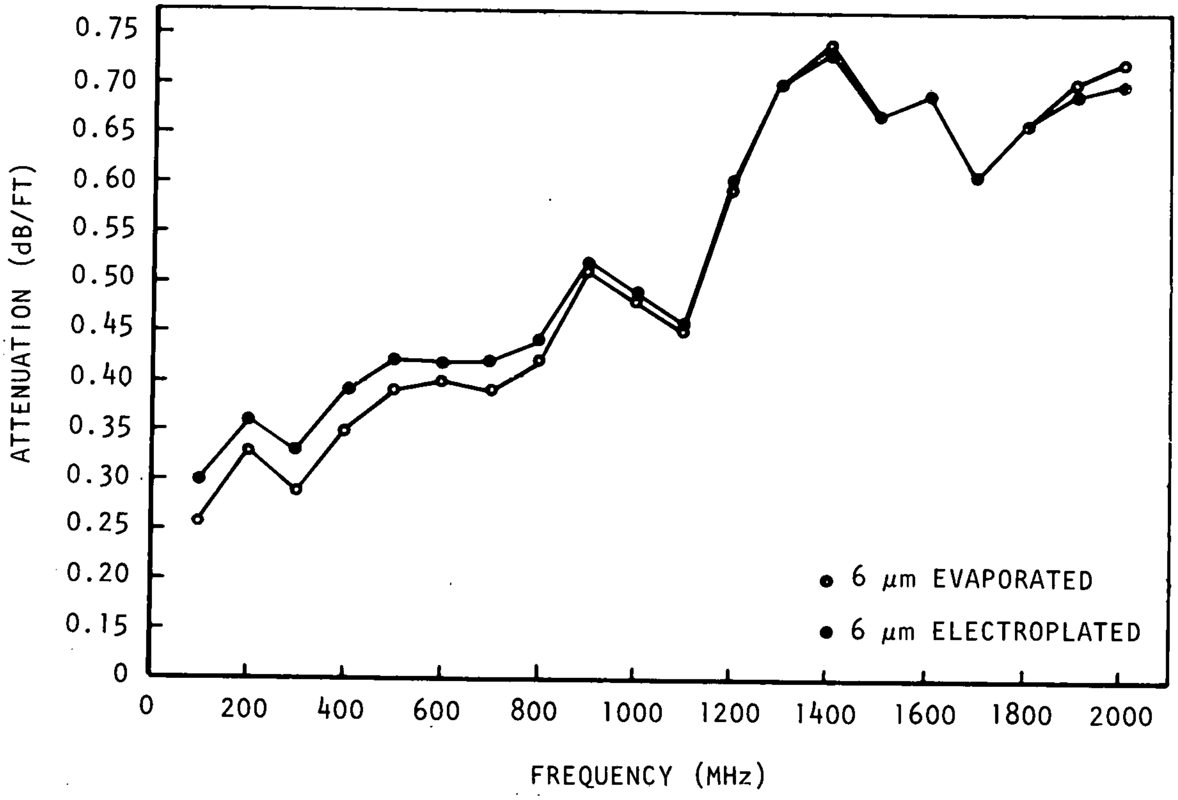

Figure 8. Plot of RF Stripline Attenuation Data for 6 μm Evaporated and Electroplated Gold

Resistance data is given in Table A-3 and Figure 13. All via resistances were below the maximum allowable value of 10 mΩ. For green punched holes, the average via resistance of 6 μm evaporated gold was approximately 7 to 10 times higher than that of 6 μm electroplated gold. With 6 μm evaporated gold, ultrasonically drilled vias had an average resistance at least 50 percent greater than green punched vias. Green punched and ultrasonic drilled holes had approximately the same via resistance, for a given diameter hole, for all thicknesses of plated gold. The average via resistance values given for 10 and 25 μm plated gold and hole diameters greater than 762 μm (30 mils) level off at about 0.12 mΩ, which is essentially the lower limit of resolution of the measuring equipment used.

Conductor Definition and Resolution

To determine if conductor lines could be suitably defined by standard photolithographic procedures, a total of 12 substrates were processed: 5 with 6 μm evaporated gold, 3 electroplated to

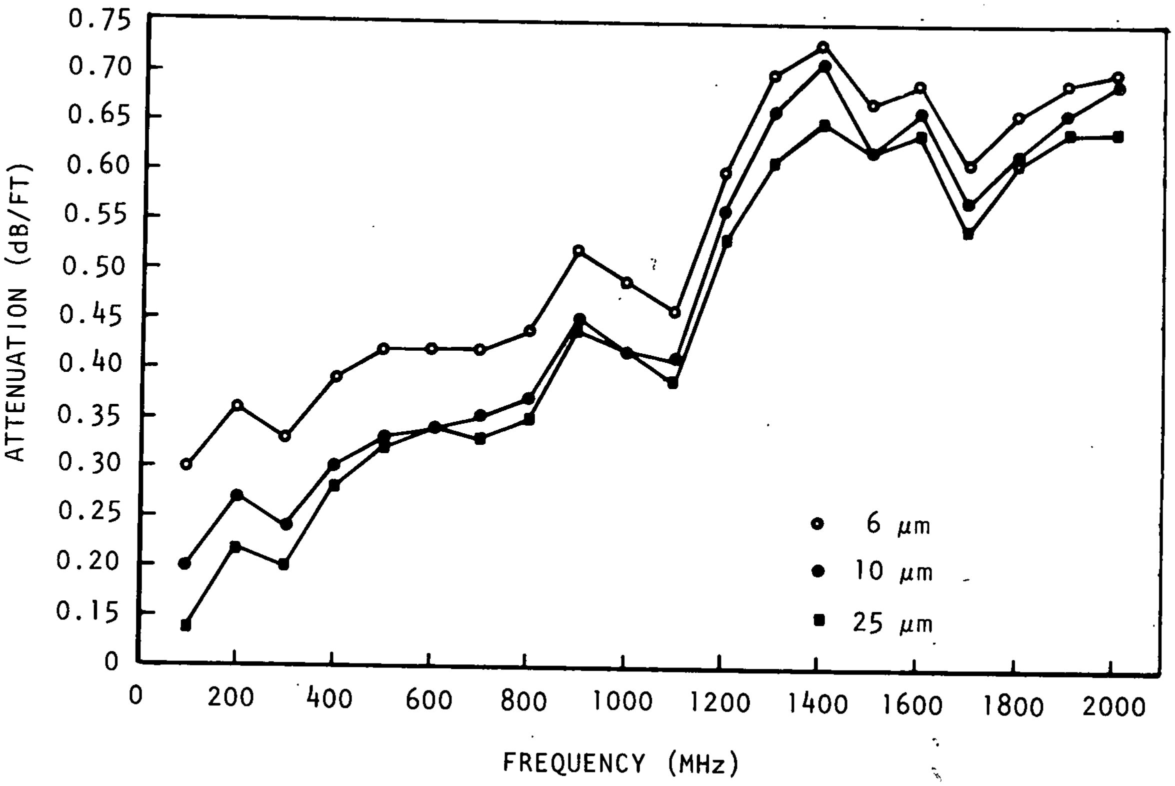

Figure 9. Plot of RF Stripline Attenuation Data for 6, 10, and 25 μm Electroplated Gold

6 μm, 2 electroplated to 10 μm, and 2 electroplated to 25 μm. The substrates used were 38 by 38 mm (1.5 by 1.5 in.), each of which was scribed out of the lower right hand corner of a 95 by 114 mm (3.75 by 4.5 in.) substrate.

All five evaporated substrates had been metallized in a common vacuum deposition process. The as-metallized substrates were laminated with dry-film photoresist (25 μm thick) and were then exposed with a pattern of varying line widths and spaces, ranging from 127 μm (5 mil) lines with 508 μm (20 mil) spacing to 51 μm (2 mil) lines with 51 μm spacing. The substrates were then individually immersion etched, using visual observation to determine when etching was complete. It was noted when etching 25 μm thick films that the large amount of gold entering the solution caused the etching rate to decrease fairly rapidly.

After stripping away the remaining photoresist, line width measurements were made on all substrates. Five measurements were

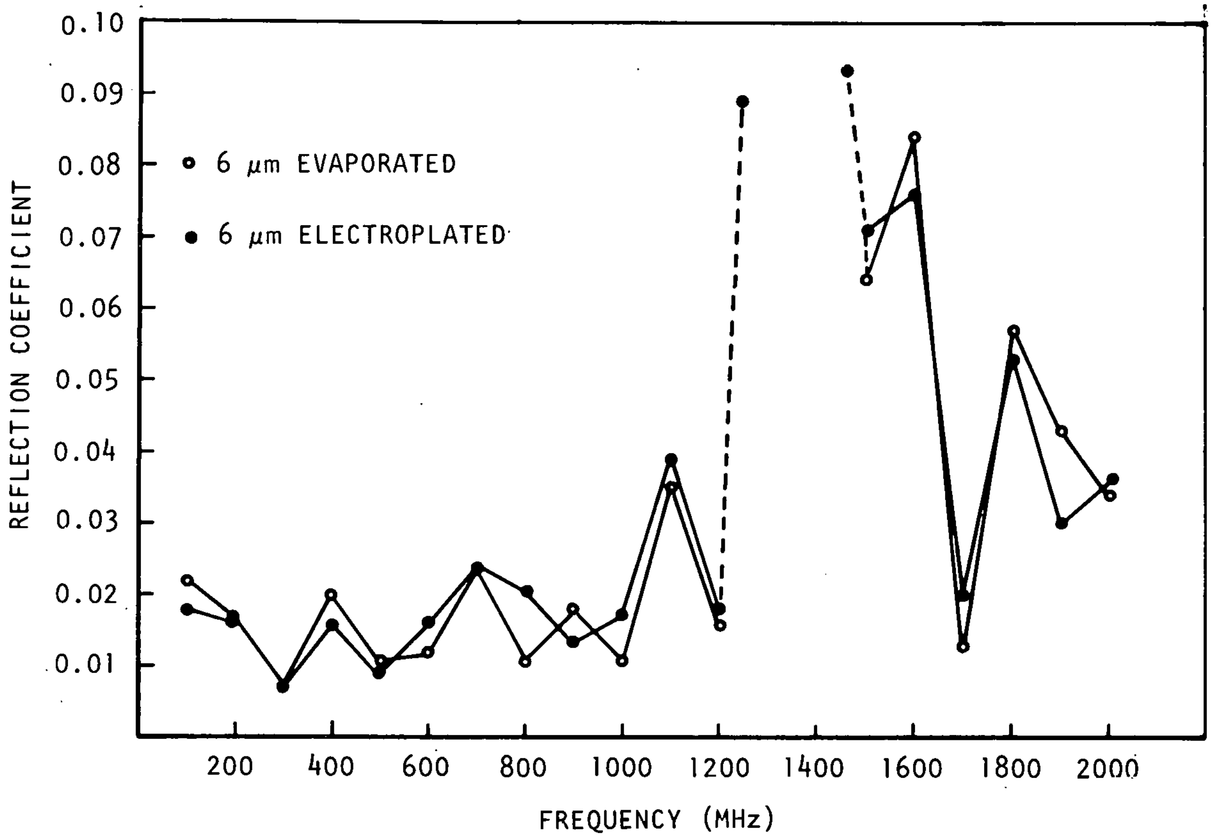

Figure 10. Plot of RF Stripline Reflection Coefficient Data for 6 μm Evaporated and Electroplated Gold

made in the X direction, one on each of the five patterns, and three in the Y direction. Measurements were not made on 51 μm lines since they were not adequately defined. The line width data is given in Table 2.

For all metallization and line width conditions, the average line widths were less than the nominal values. For a given nominal line width, the range of measured values for 6 μm evaporated, 6 μm electroplated, and 10 μm electroplated films were approximately equal. For 25 μm gold, the range of values had a much larger spread for all line width and spacing conditions. This could have been caused by variations in both the gold thickness and the etching rate across a substrate. When gold of this thickness is etched, a large amount of undercutting can occur; therefore, the amount and manner of agitation will have a critical effect on the accuracy and uniformity of the etching. It is believed that spray photolithographic processing will significantly improve conductor line definition and resolution of gold films greater than 6 μm, and will in fact be a necessity for films much greater than 10 μm thick.

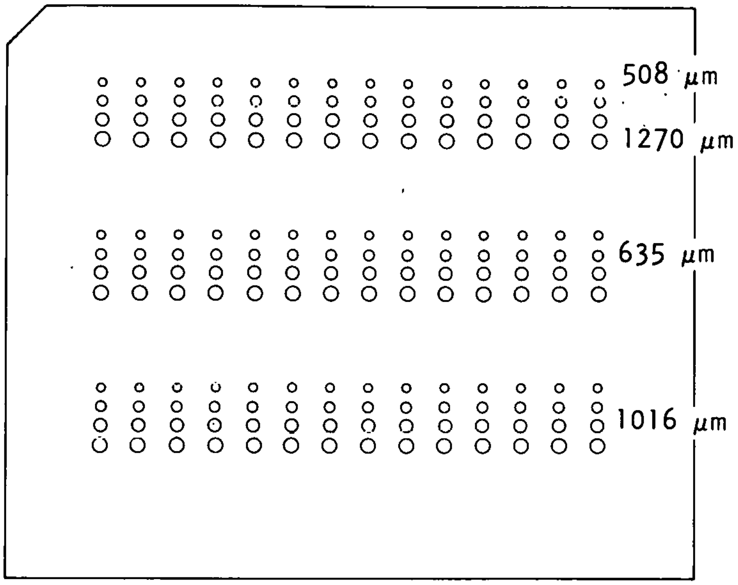

Figure 11. Green Punched Via Pattern

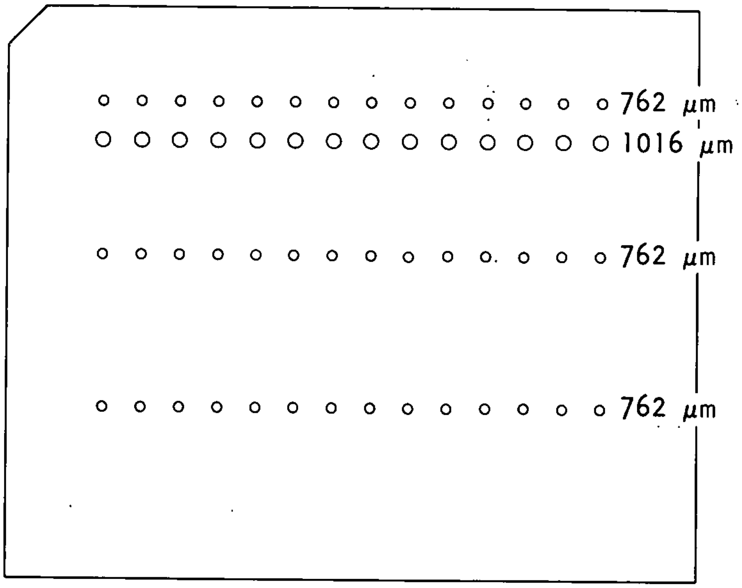

Figure 12. Ultrasonic Drilled Via Pattern

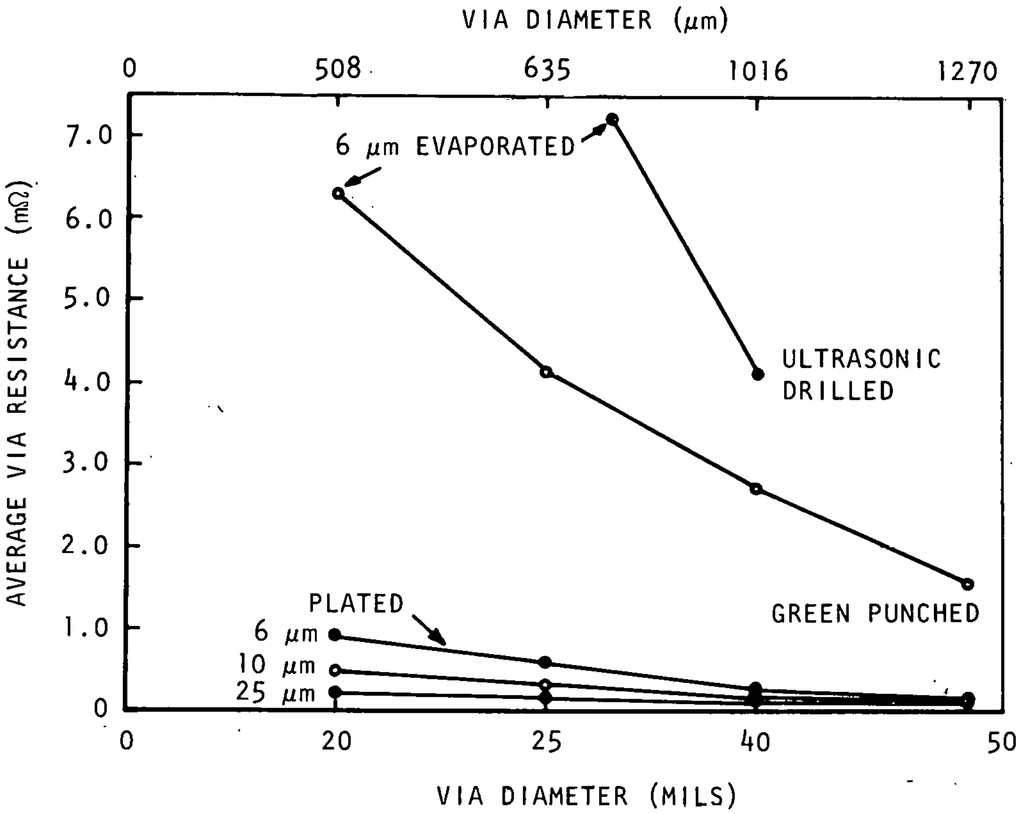

Figure 13. Plot of Via Resistance Data for Electroplated Versus Evaporated Gold

To qualitatively determine the line definitions obtainable on electroplated gold, the etched conductors in the centers of the patterns on 6 μm thick films were microscopically examined and a well-defined line was selected. This was similarly done on a 6 μm evaporated substrate. Photomicrographs of these are shown in Figure 14. Although this was by no means a quantitative or objective measure of line definition, it does indicate that conductor edge definition comparable to that obtainable on evaporated gold can be produced on electroplated gold films.

Solder Wettability

Twenty substrates were used in the evaluation of the solderability of electroplated gold: 5 evaporated to 6 μm, 6 electroplated to 6 μm, 4 electroplated to 10 μm, and 5 electroplated to 25 μm. The 25 by 25 mm (1 by 1 in.) substrates, which were laser scribed out of larger substrates, were initially stabilized

Table 2. Conductor Line Widths

		Electroplated		
Parameter	6 μm Evaporated	6 μm	10 μm	25 μm
127 μm (5 mil) Line With > 127 μm Space				
$\bar{x}$	121.4 (4.78)	117.6 (4.63)	117.1 (4.61)	117.6 (4.63)
σ	4.3 (0.17)	5.3 (0.21)	5.6 (0.22)	7.9 (0.31)
Maximum	132.1 (5.20)	131.8 (5.19)	128.8 (5.07)	130.3 (5.13)
Minimum	105.7 (4.16)	102.6 (4.04)	108.0 (4.25)	97.5 (3.84)
127 μm Line With 127 μm Space				
$\bar{x}$	121.4 (4.78)	118.4 (4.66)	115.8 (4.56)	117.6 (4.63)
σ	3.6 (0.14)	4.8 (0.19)	4.8 (0.19)	7.6 (0.30)
Maximum	128.3 (5.05)	129.3 (5.09)	125.7 (4.95)	132.1 (5.20)
Minimum	110.0 (4.33)	110.5 (4.35)	107.2 (4.22)	99.6 (3.92)
101 μm (4 mil) Line With 101 μm Space				
$\bar{x}$	96.3 (3.79)	93.2 (3.67)	92.2 (3.63)	95.3 (3.75)
σ	3.8 (0.15)	4.6 (0.18)	4.8 (0.19)	8.4 (0.33)
Maximum	102.9 (4.05)	104.7 (4.12)	101.4 (3.99)	108.7 (4.28)
Minimum	85.6 (3.37)	84.3 (3.32)	84.8 (3.34)	77.0 (3.03)
76 μm (3 mil) Line With 76 μm Space				
$\bar{x}$	71.6 (2.82)	68.8 (2.71)	67.6 (2.66)	72.6 (2.86)
σ	3.3 (0.13)	4.6 (0.18)	5.3 (0.21)	8.6 (0.34)
Maximum	77.2 (3.04)	79.0 (3.11)	78.7 (3.10)	89.7 (3.53)
Minimum	65.3 (2.57)	60.7 (2.39)	57.7 (2.27)	56.4 (2.22)

All units are in μm (mils).

(2 hours at 300°C), CAN etched, and TC cleaned. To assure their cleanliness, the substrates were rinsed in trichloroethylene before the solder spread test was performed. A 12.7 mm (0.5 in.) length of 0.76 mm (0.030 in.) diameter 50:50 PbIn solder was placed on each substrate along with mildly activated Alpha 197 flux. Using a rotary reflow solder system, the substrates were heated to 264°C for 5 seconds. This temperature was used because

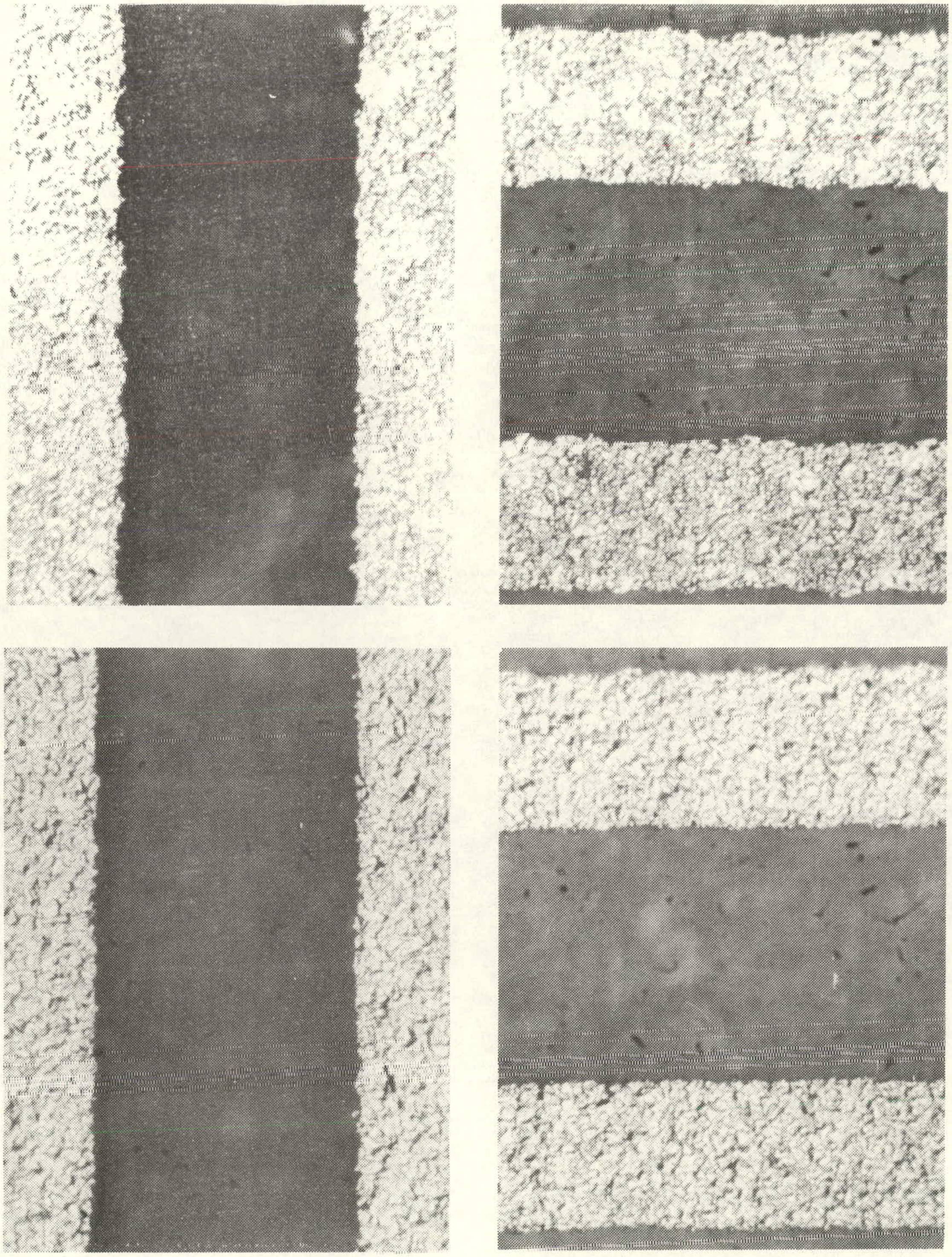

Figure 14. Conductor Edge Definition of 6 μm Evaporated (Top) and Electroplated (Bottom) Gold (740X)

the liquidus temperature of 50:50 PbIn solder is 209°C and this solder spread test typically uses a temperature 55°C higher than the liquidus temperature. After heating, the substrates were rapidly cooled and handled carefully to prevent jarring the molten solder.

The height of the solder with respect to the substrate surface was measured after the flux was cleaned off. An LVDT probe setup, which measures the highest point of the solder with the frame of the fixture resting on the substrate surface, was used. The solder spread factor, a measure of the solder wettability of the gold metallization, is calculated from

$$S.F. = \frac{D-H}{D} \times 100,$$

where

D = the diameter of a sphere having a volume equal to the original volume of solder used, and

H = the height with respect to the substrate surface of the solder after melting.

The calculated spread factor values are given in Table 3. There is apparently no difference between the solder wettability of evaporated and electroplated gold or between pre-sputtered and pre-evaporated electroplated gold. Any variance in the values given is considered to be within the experimental error of measurements made.

Lead Frame Bondability

To evaluate the thermocompression bondability of the electroplated gold films 127 μm (0.005 in.) thick gold-plated copper lead frames were bonded to the substrates and then pull tested to determine the quality of the bond. This evaluation was made on eighty 25 by 25 mm (1 by 1 in.) substrates which had been laser scribed out of twenty 95 by 114 mm (3.75 by 4.50 in.) substrates. The sample included 20 substrates with 6 μm thick vacuum evaporated gold, 24 electroplated to 6 μm, 16 plated to 10 μm, and 20 plated to 25 μm. Bonding was performed on the substrates both before and after resistor stabilization (2 hours at 300°C); however, none of the substrates had been processed through photolithography. All substrates and lead frames were subjected to the standard "cleaning for bonding" process before thermocompression bonding.

The bonding was done on a laboratory bonder with a straight rail bonding tool, using typical operating parameters for 6 μm evaporated gold films: tool temperature of 680°C; bond force of 1.67 kN (375 lb); and bond time of 30 seconds. No attempts were made to modify the operating parameters to improve the bonding process for the different thicknesses of electroplated gold.

Table 3. Solder Spread Factor

Substrate	Spread Factor
6 μm Evaporated Gold ($\bar{x}$ = 91.17)	
E304104	90.19
E304204	92.93
E304304	93.50
E304404	90.76
E304504	88.48
6 μm Electroplated Gold ($\bar{x}$ = 90.99)	
A100104	93.16
A100204	89.62
A222104	90.65
A222204	88.37
A131104	90.54
A230104	93.61
10 μm Electroplated Gold ($\bar{x}$ = 91.22)	
B100304	89.97
B230204	90.54
B131204	92.82
B222304	91.56
25 μm Electroplated Gold ($\bar{x}$ = 91.04)	
D230404	91.11
D222304	88.71
D131404	90.88
D131504	90.88
C100404	93.61
Average spread factor for all plated substrates = 91.07	

The 90 degree peel test was used to evaluate the quality of the thermocompression bonds. This test involves bending the lead upward to form a 90 degree angle with the substrate, and then pulling the lead until it either breaks or delaminates from the substrate. The maximum force attained during pulling was measured and recorded. To avoid stressing the leads near the bond zone and thus influencing the pull strength and mode of failure, the leads were supported between the bonded area and the edge of the substrate during the bending operation.

As-Metallized Substrates

Two lead frames were bonded to each of 20 substrates which had been subjected to no post-metallization processing other than a pre-bond cleaning operation. The substrates used had been taken from the same relative location on each of the 20 larger substrates. Alternate leads were pull tested, providing a total of 20 leads on each substrate. A summary of the pull test data is given in Tables 4 and 5 and histograms are given in Figures A-1 through A-4.

The lowest average pull strength occurred on 6 μm electroplated films--on which one lead failed at less than the minimum requirement of 3.36 N (0.75 lb). After pulling this lead, ceramic was visible over more than 30 percent of the bond zone, with evidence that some ceramic had been pulled out of the substrate by the substrate metallization. Of the non-heel failures on 6 μm electroplated gold, 96 percent had ceramic visible within the bond zone, and the majority of these showed evidence of ceramic pull-out. This has since been found to be a common occurrence on the brand of substrates used in this evaluation. A possible explanation for the higher percentage of this type of failure on 6 μm plated films than on 6 μm evaporated films can be given by considering the stress transmitted to the substrate during bonding. The front side thickness of the nominal 6 μm evaporated gold films ranged from 7.8 to 8.5 μm, with an average thickness of 8.1 μm, while that of the 6 μm electroplated films ranged from 6.0 to 7.8, with an average of 6.8. The thinner gold on the plated substrates, along with the slightly harder gold deposit, would cause the bonding force to impose a higher stress on the substrate in the bond zone. This apparently caused some ceramic microcracking. In any case, these types of failures do not indicate poor thermocompression bondability of electroplated gold films; rather, they indicate that the bonding parameters need to be modified for bonding to 6 μm electroplated gold on MRC brand substrates.

All substrates with 10 and 25 μm electroplated gold met the minimum specification of 60 percent heel failures and 3.36 N (0.75 lb) minimum pull strength. The 25 μm plated substrates had the highest average, maximum, and minimum pull strengths of the

Table 4. Lead Frame Bonding Evaluation of Evaporated and Electroplated Substrates

Parameters	6 μm Evaporated	Electroplated 6 μm	Electroplated 10 μm	Electroplated 25 μm
Pull Strength [N (lb)]				
$\bar{x}$	11.2 (2.51)	8.54 (1.92)	10.94 (2.46)	12.94 (2.91)
σ	1.47 (0.33)	2.71 (0.61)	2.05 (0.46)	2.31 (0.52)
Maximum	14.72 (3.31)	14.46 (3.25)	14.72 (3.31)	16.68 (3.75)
Minimum	6.41 (1.44)	2.49 (0.56)	5.29 (1.19)	7.78 (1.75)
Failure Modes* (Percentages)				
A	0	0	0	1
B	100	75	99	97
C	0	1	0	0
E	0	24	1	2

*A - Lead breaks at least 2.54 mm away from bond zone
B - Lead breaks in or near bond zone
C - Lead peels away from substrate and less than 20 percent of the gold is peeled off
E - Ceramic is visible over more than 30 percent of bond zone

four metallization types tested. One lead frame broke greater than 2.5 mm (0.100 in.) away from the bond zone with a pull strength of 16.68 N (3.75 lb), indicating that the strength of the thermocompression bond was greater than the tensile strength of the lead frame.

Measurements were made of the lead frame deformation which occurred during bonding to determine if the higher pull strengths on the 25 μm plated gold films were a result of lower deformation. Deformation greater than the minimum required for a good thermocompression bond will merely weaken the lead frame near the bond

Table 5. Lead Frame Bonding Evaluation of Pre-Sputtered and Pre-Evaporated Surfaces

	Pull Strength (N) (lb)				Failure Modes*			
Metallization Type	$\bar{x}$	σ	Maximum	Minimum	A	B	C	E
Pre-Sputtered Electroplated 6 μm	8.23 (1.85)	2.36 (0.53)	13.34 (3.00)	2.49 (0.56)	0	78	2	20
Pre-Evaporated Electroplated 6 μm	8.85 (1.99)	2.98 (0.67)	14.46 (3.25)	4.48 (1.00)	0	72	0	28
Pre-Sputtered Electroplated 10 μm	11.17 (2.51)	2.09 (0.47)	14.72 (3.31)	5.29 (1.19)	0	100	0	0
Pre-Evaporated Electroplated 10 μm	10.68 (2.40)	1.96 (0.44)	14.46 (3.25)	6.41 (1.44)	0	95	0	5
Pre-Sputtered Electroplated 25 μm	13.97 (3.14)	1.82 (0.41)	16.41 (3.69)	7.78 (1.75)	0	100	0	0
Pre-Evaporated Electroplated 25 μm	12.28 (2.76)	2.40 (0.54)	16.68 (3.75)	7.78 (1.75)	2	95	0	3

*Percentages

zone, thereby causing a lower strength heel failure to occur. The deformation measurements were made using a light section microscope which measures the distance from the top of the substrate metallization to the top surface of the bonded portion of the lead frame. Percent deformation was then calculated using the nominal lead frame thickness value of 137 μm (0.0054 in.).

The average deformation values were 57.4, 54,9, 56.6, and 58.2 percent for 6 μm evaporated, and 6, 10, and 25 μm electroplated films, respectively. The higher deformation value for the 25 μm films is not consistent with the pull test data. However, in Figure 15, it is evident that the substrate metallization has been squashed out around the lead frame bonded to the 25 μm thick plated gold, but not on the bond made to the thinner evaporated gold. This indicates that bonding to the thicker gold films causes the lead frame to sink into the substrate metallization, thereby causing less deformation of the lead itself. This would explain the higher pull strengths seen on the thicker plated gold films.

Stabilized and CAN Etched Substrates

Two lead frames were bonded to each of 20 substrates which had been subjected to stabilization (2 hours at 300°C), followed by a CAN etch and pre-bond cleaning process. These substrates did not receive any photolithographic processing. It was noted that the stabilization and CAN etching caused the back side metallization to completely delaminate from all five of the 6 μm evaporated substrates. A summary of the pull test data is given in Table 6, and histograms are given in Figures A-5 through A-8.

All substrates met the minimum bondability requirements. On 6 μm films, electroplated gold had slightly lower lead frame pull strengths than did evaporated gold, while 25 μm plated films had the highest values of average, maximum, and minimum pull strengths. Once again, a significant number of "E" failures (ceramic visible within bond zone), with evidence of ceramic pull out, occurred on 6 μm plated films.

A comparison of pull strength data for pre-sputtered and pre-evaporated electroplated films is given in Table 7. For all thicknesses of plated films, the average, maximum, and minimum pull strengths for pre-sputtered films were equal to or greater than those for pre-evaporated films.

A comparison of data for as-metallized versus stabilized and CAN etched substrates is given in Figure 16. With the exception of 6 μm plated substrates, the stabilized and CAN etched substrates had pull strengths slightly lower than those for as-metallized substrates. Since these were two different groups of substrates and were processed separately after metallization, the differences

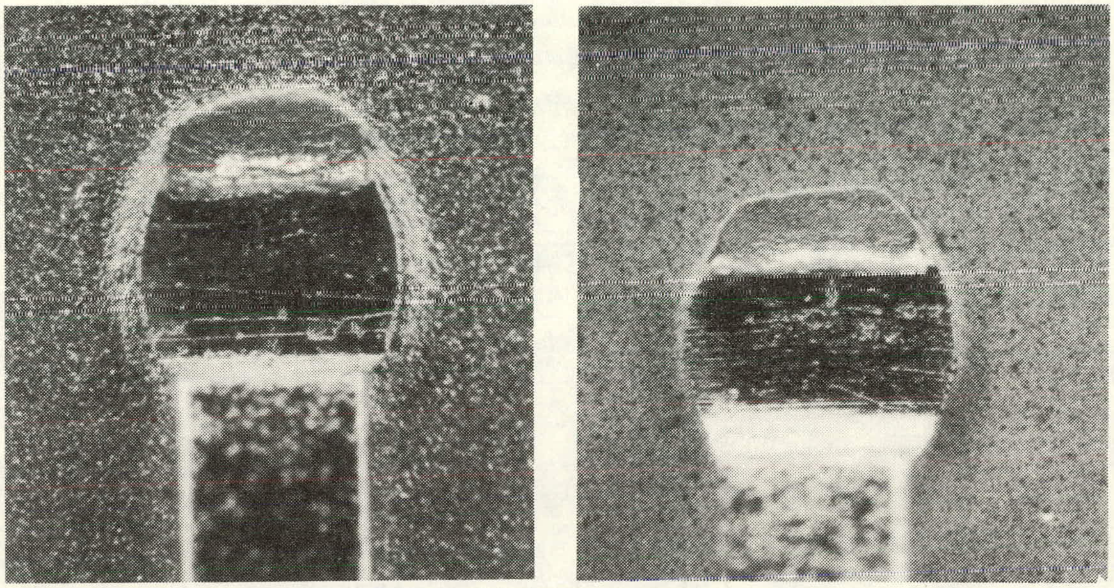

Figure 15. Lead Frames 127 μm Thick Thermocompression Bonded to 25 μm Electroplated (Left) and 6 μm Evaporated (Right) Gold Substrate Metallization (74X)

in pull strengths could have been caused by variations in the cleaning or bonding operations. Substrates pre-sputtered and electroplated to 25 μm had the best pull strength results, with 100 percent heel failures both before and after the stabilization and CAN etch processes.

Temperature Cycling Effect on Bonds

Two lead frames were bonded to each of 20 substrates which had been stabilized and CAN etched but not photoprocessed. The substrates were then subjected to 30 temperature cycles from -55°C to +125°C, with a temperature change rate of 20°C per minute and a 15-minute dwell time at each temperature extreme. Approximately one-fourth of the lead frames on each substrate were pull tested before temperature cycling, and after 10, 20, and 30 cycles. Bond pad thickness measurements showed that the thickness varied approximately 13 μm (0.0005 in.) across a given lead frame. This probably was caused either by misalignment of the bonder or by a variation in the thickness of the Kapton spacer used between the substrate and the bonder work table. Lead frames pulled at each of the four intervals were selected to compensate for the variations in bond deformation, with the same pattern of leads being pulled on all substrates.

Table 6. Lead Frame Bonding Evaluation of Stabilized and CAN Etched Evaporated and Electroplated Substrates Without Photolithography

Parameters	6 μm Evaporated	Electroplated 6 μm	Electroplated 10 μm	Electroplated 25 μm
Pull Strength (N) (lb)				
$\bar{x}$	10.81 (2.43)	10.05 (2.26)	10.50 (2.36)	11.61 (2.61)
σ	1.73 (0.39)	2.49 (0.56)	2.00 (0.45)	2.54 (0.57)
Maximum	14.72 (3.31)	15.03 (3.38)	14.46 (3.25)	16.68 (3.75)
Minimum	4.72 (1.06)	3.34 (0.75)	5.03 (1.13)	7.52 (1.69)
Failure Modes* (Percentages)				
B	89	77	93	99
C	11	8	5	0
E	0	15	3	1

*B - Lead breaks in or near bond zone
C - Lead peels away from substrate and less than 20 percent of the gold is peeled off
E - Ceramic is visible over more than 30 percent of bond zone

The pull test data is given in Tables A-4 and A-5 and Figure 17. All substrates met the minimum bondability requirements. Temperature cycling appeared to cause no significant degradation of the thermcompression bonds. Substrates plated to 25 μm produced the best results with regard to both pull strength and failure modes, with pre-sputtered films having slightly higher strengths than pre-evaporated films.

Thermal Aging Effect on Bonds

Two lead frames were bonded to each of 20 substrates which had been stabilized and CAN etched but not photoprocessed. The substrates were then subjected to 150°C for a total of 1000 hours.

Table 7. Lead Frame Bonding Evaluation of Stabilized and CAN Etched Pre-Sputtered and Pre-Evaporated Substrates Without Photolithography

	Pull Strength (N) (lb)			Failure Modes*		
Metallization Type	$\bar{x}$	Maximum	Minimum	B	C	E
Pre-Sputtered Electroplated to 6 µm	10.68 (2.40)	15.03 (3.38)	6.41 (1.44)	90	5	5
Pre-Evaporated Electroplated to 6 µm	8.99 (2.02)	13.92 (3.13)	3.34 (0.75)	65	10	25
Pre-Sputtered Electroplated to 10 µm	10.63 (2.39)	14.46 (3.25)	5.29 (1.19)	95	5	0
Pre-Evaporated Electroplated to 10 µm	10.28 (2.31)	14.19 (3.19)	5.03 (1.13)	90	5	5
Pre-Sputtered Electroplated to 25 µm	12.90 (2.90)	16.68 (3.75)	8.05 (1.81)	100	0	0
Pre-Evaporated Electroplated to 25 µm	11.65 (2.62)	16.68 (3.75)	7.52 (1.69)	98	0	2

*Percentages

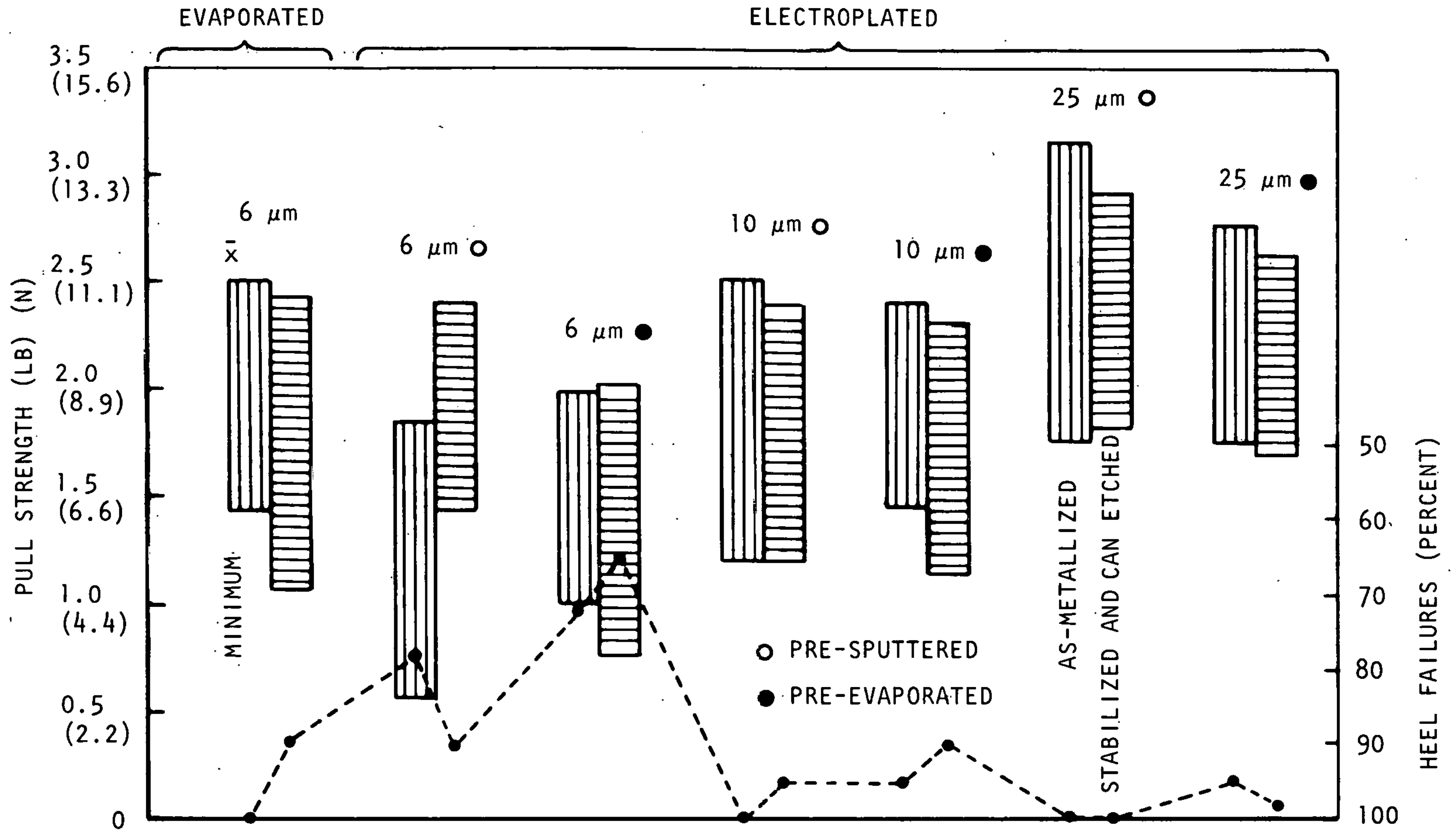

Figure 16. Effect of Stabilization and CAN Etch on Lead Frame Bonds

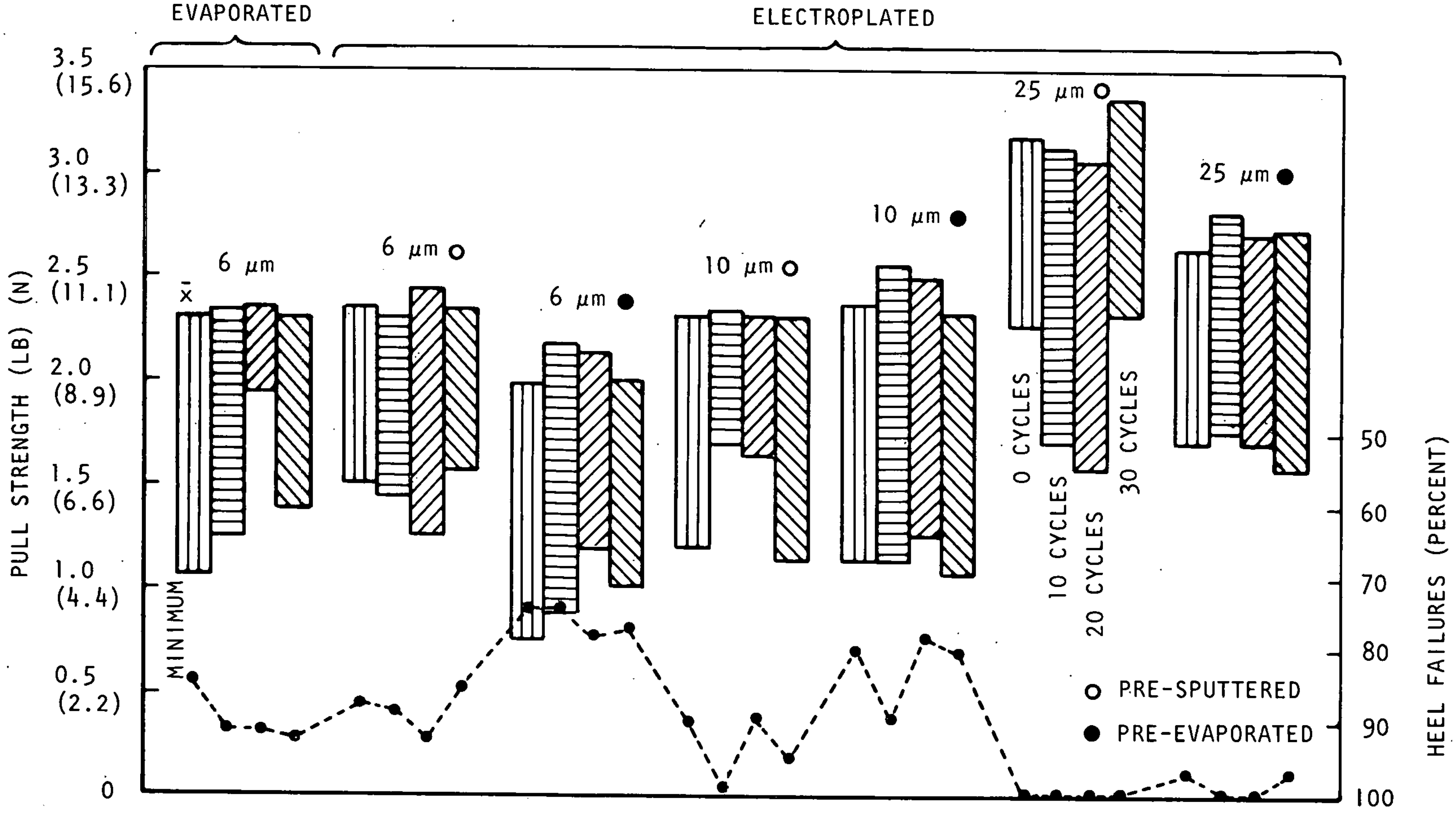

Figure 17. Effect of Temperature Cycling on Lead Frame Bonds

Approximately one-fourth of the lead frames on each substrate were pull tested before thermal aging, and after 250, 500, and 1000 hours. The lead frames were pulled in the same pattern as was used for the temperature cycling evaluation. Summarized pull test data is given in Tables A-6 and A-7 and Figure 18. All substrates met the minimum bondability requirements. Thermal aging did not cause any significant degradation of the thermocompression bonds.

ACCOMPLISHMENTS

Electroplated gold 6, 10, and 25 μm thick was investigated and was found to be feasible for use on hybrid microcircuit substrates. The via resistance obtained on electroplated substrates was superior to that obtained on evaporated substrates. The solder wettability, thermocompression bondability, RF electrical characteristics, conductor definition, and environmental stability of electroplated gold were found to be compatible with HMC requirements and fabrication processes and comparable to those properties of evaporated gold films. The variation in thickness across one side of a large substrate was not as good as that obtained with evaporated gold; however, it is believed that this can be significantly improved by modifying the plating fixture.

FUTURE WORK

Future development work in HMC electroplating should include the following projects:

- Determine the type of plating box and fixture needed to improve the thickness uniformity across a substrate;
- Determine the plating parameters which will minimize the porosity of electroplated gold films and possibly eliminate the need for pre-bond etching;
- Determine the photolithography process parameters required to optimize conductor definition and resolution;
- Develop bond schedules for thermocompression bonding lead frames, ribbons, fine wires, and beam lead devices to electroplated gold; and
- Determine the plating bath operating limits within which metallization acceptable for HMC usage is produced.

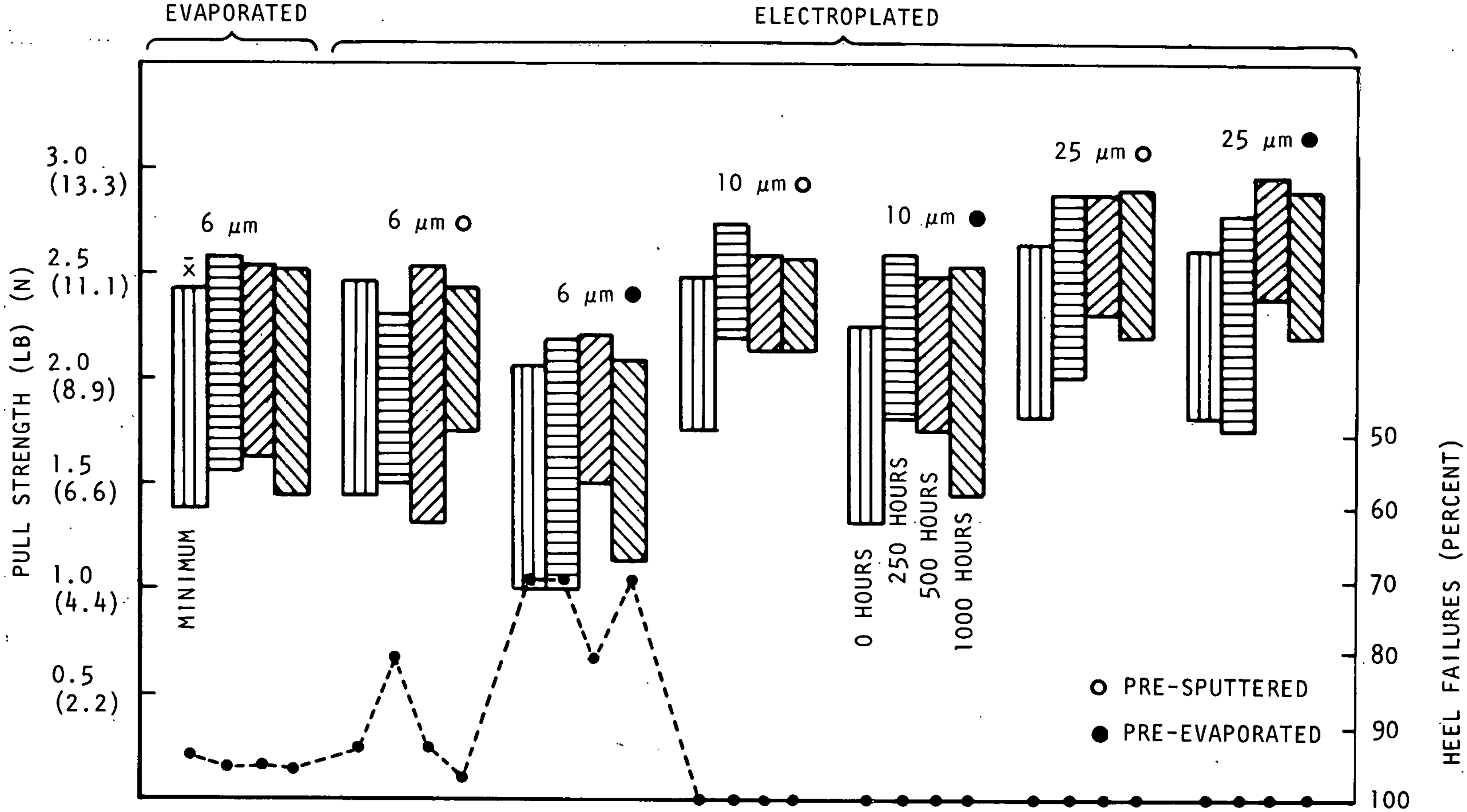

Figure 18. Effect of Thermal Aging (150°C) on Lead Frame Bonds

Appendix

SUPPORT DATA

Table A-1. Gold RF Stripline Attenuation Data

	6 μm Evaporated		6 μm Electroplated		10 μm Electroplated		25 μm Electroplated	
Frequency (MHz)	$\bar{x}$ (db)	Loss* (db/ft)	$\bar{x}$ (db)	Loss* (db/ft)	$\bar{x}$ (db)	Loss* (db/ft)	$\bar{x}$ (db)	Loss* (db/ft)
100	0.053	0.26	0.058	0.30	0.044	0.20	0.035	0.14
200	0.062	0.33	0.067	0.36	0.054	0.27	0.047	0.22
300	0.056	0.29	0.062	0.33	0.049	0.24	0.044	0.20
400	0.065	0.35	0.070	0.39	0.058	0.30	0.055	0.28
500	0.071	0.39	0.075	0.42	0.062	0.33	0.060	0.32
600	0.072	0.40	0.075	0.42	0.064	0.34	0.063	0.34
700	0.071	0.39	0.074	0.42	0.065	0.35	0.062	0.33
800	0.074	0.42	0.077	0.44	0.068	0.37	0.066	0.35
900	0.087	0.51	0.088	0.52	0.080	0.45	0.077	0.44
1000	0.083	0.48	0.084	0.49	0.075	0.42	0.074	0.42
1100	0.079	0.45	0.081	0.46	0.073	0.41	0.070	0.39
1200	0.098	0.59	0.099	0.60	0.093	0.56	0.090	0.53
1300	0.113	0.70	0.113	0.70	0.108	0.66	0.101	0.61
1400	0.118	0.74	0.117	0.73	0.114	0.71	0.106	0.65
1500	0.109	0.67	0.109	0.67	0.103	0.62	0.103	0.62
1600	0.112	0.69	0.111	0.69	0.107	0.66	0.105	0.64
1700	0.101	0.61	0.100	0.61	0.095	0.57	0.091	0.54
1800	0.107	0.66	0.107	0.66	0.102	0.62	0.101	0.61
1900	0.113	0.70	0.112	0.69	0.108	0.66	0.105	0.64
2000	0.115	0.72	0.113	0.70	0.111	0.69	0.105	0.64

*Correction made for 0.13 db loss per connector pair

Table A-2. Gold RF Stripline Reflection Coefficient Data

Frequency (MHz)	6 μm Evaporated		6 μm Electroplated		10 μm Electroplated		25 μm Electroplated	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
100	0.022	0.006	0.018	0.007	0.018	0.009	0.022	0.008
200	0.017	0.007	0.016	0.006	0.016	0.005	0.016	0.009
300	0.008	0.004	0.007	0.004	0.014	0.001	0.011	0.006
400	0.020	0.006	0.016	0.010	0.019	0.005	0.023	0.010
500	0.011	0.003	0.009	0.006	0.010	0.004	0.017	0.007
600	0.012	0.005	0.016	0.007	0.017	0.011	0.024	0.012
700	0.023	0.011	0.024	0.010	0.031	0.015	0.026	0.016
800	0.011	0.007	0.020	0.008	0.018	0.005	0.035	0.021
900	0.018	0.006	0.013	0.006	0.021	0.006	0.021	0.008
1000	0.011	0.005	0.017	0.014	0.012	0.012	0.028	0.017
1100	0.035	0.005	0.039	0.008	0.036	0.013	0.035	0.018
1200	0.016	0.011	0.018	0.005	0.012	0.005	0.017	0.013
1300	0.168	0.016	0.174	0.010	0.168	0.046	0.148	0.067
1400	0.229	0.022	0.232	0.012	0.229	0.040	0.213	0.065
1500	0.064	0.009	0.071	0.022	0.066	0.014	0.087	0.019
1600	0.084	0.010	0.076	0.011	0.084	0.006	0.065	0.019
1700	0.013	0.008	0.020	0.012	0.014	0.004	0.021	0.013
1800	0.057	0.006	0.053	0.003	0.059	0.003	0.058	0.009
1900	0.043	0.009	0.030	0.018	0.037	0.010	0.032	0.020
2000	0.034	0.009	0.036	0.015	0.037	0.011	0.041	0.012

Table A-3. Via Resistance Data

	Via Diameter (mils) (μm)				
Parameter	20 (508)	25 (635)	30 (762)	40 (1016)	50 (1270)
6 μm Evaporated Gold					
Green Punched					
$\bar{x}$	6.27	4.14		2.71	1.56
σ	0.45	0.30		0.26	0.33
Maximum	7.41	4.90		3.80	2.06
Minimum	5.32	3.31		1.98	0.52
Ultrasonic Milled					
$\bar{x}$			7.21	4.10	
σ			0.84	0.58	
Maximum			9.78	5.26	
Minimum			4.90	2.00	
6 μm Electroplated Gold					
Green Punched					
$\bar{x}$	0.90	0.57		0.26	0.17
σ	0.13	0.12		0.03	0.02
Maximum	1.18	0.83		0.38	0.24
Minimum	0.61	0.12		0.17	0.14
Ultrasonic Milled					
$\bar{x}$			0.40	0.25	
σ			0.06	0.02	
Maximum			0.59	0.29	
Minimum			0.22	0.21	
10 μm Electroplated Gold					
Green Punched					
$\bar{x}$	0.49	0.32		0.17	0.13
σ	0.04	0.05		0.01	0.01
Maximum	0.58	0.37		0.20	0.17
Minimum	0.39	0.11		0.13	0.12
Ultrasonic Milled					
$\bar{x}$			0.29	0.15	
σ			0.04	0.02	
Maximum			0.40	0.20	
Minimum			0.18	0.13	

Table A-3 Continued. Via Resistance Data

	Via Diameter (mils) (μm)				
Parameter	20 (508)	25 (635)	30 (762)	40 (1016)	50 (1270)
25 μm Electroplated Gold					
Green Punched					
$\bar{x}$	0.22	0.18		0.13	0.12
σ	0.03	0.03		0.01	0.01
Maximum	0.29	0.27		0.17	0.15
Minimum	0.14	0.13		0.11	0.11
Ultrasonic Milled					
$\bar{x}$			0.14	0.12	
σ			0.02	0.01	
Maximum			0.20	0.15	
Minimum			0.11	0.11	

All resistance measurements are in milliohms.

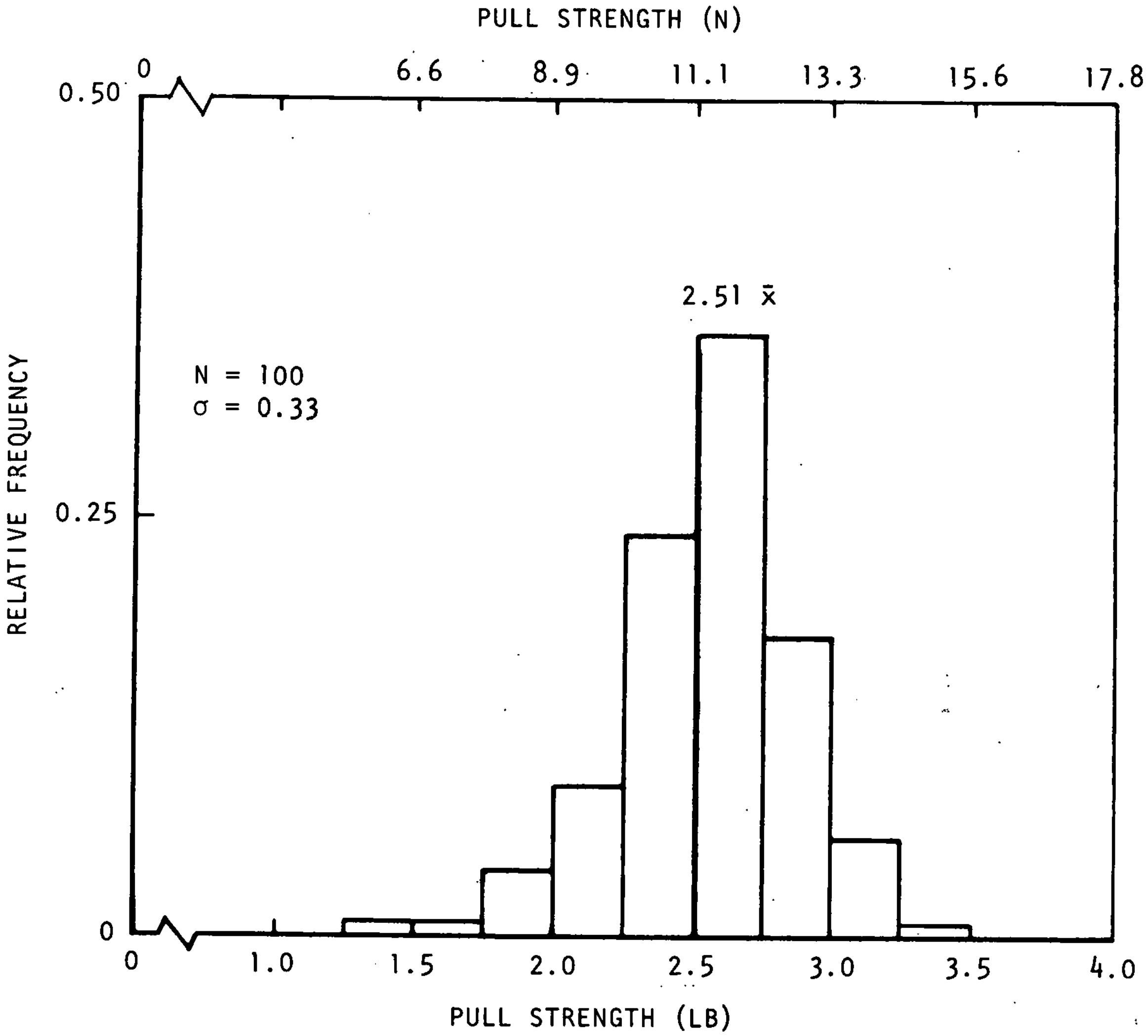

Figure A-1. Lead Frame Bondability of 6 μm Evaporated Gold

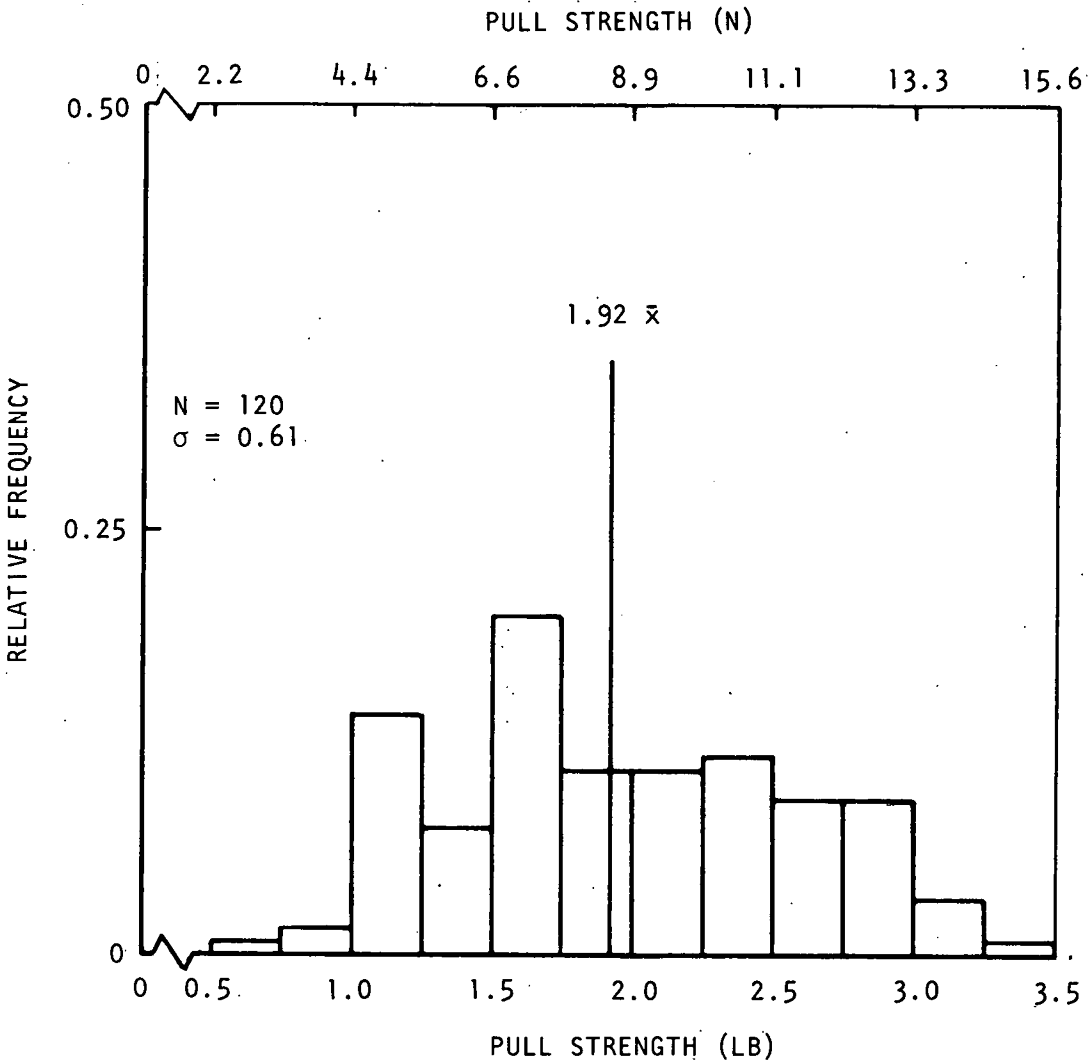

Figure A-2. Lead Frame Bondability of 6 μm Electroplated Gold

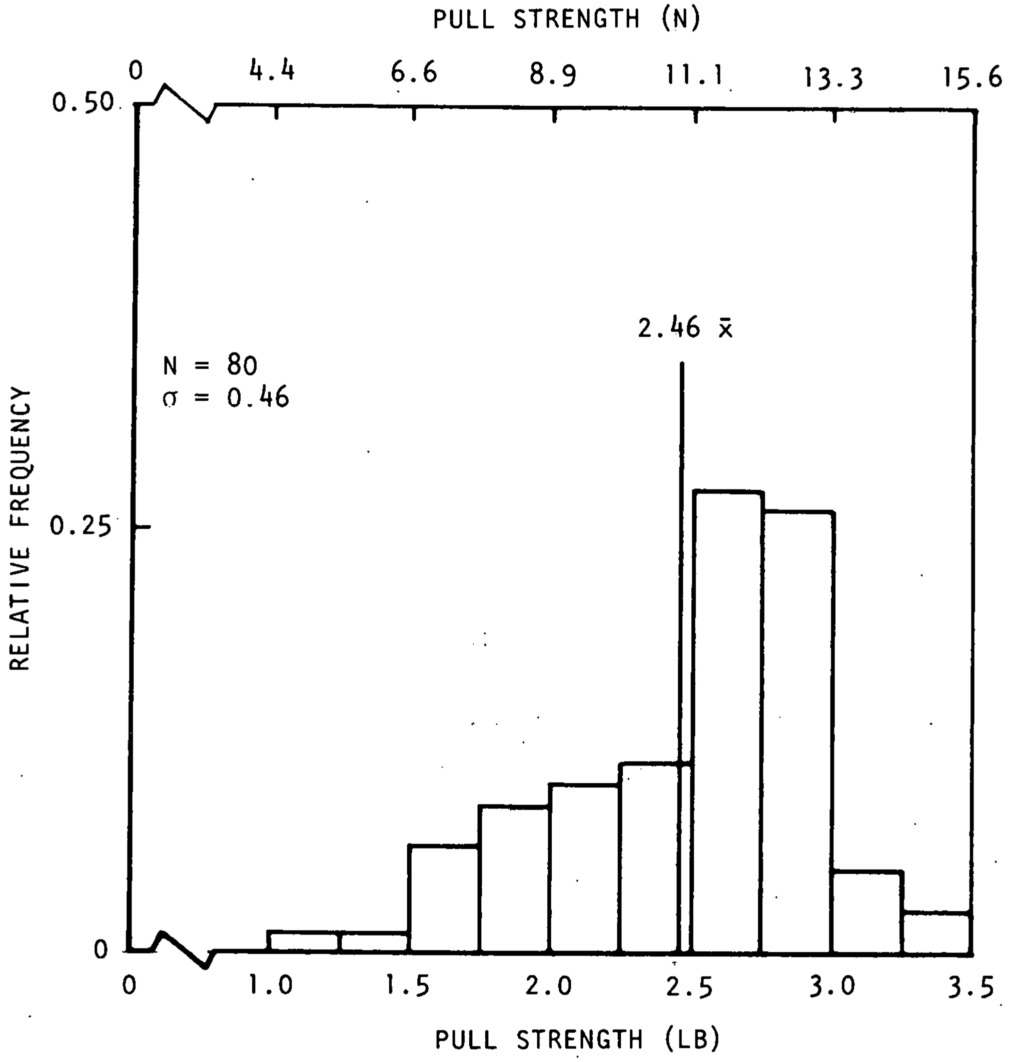

Figure A-3. Lead Frame Bondability of 10 μm Electroplated Gold

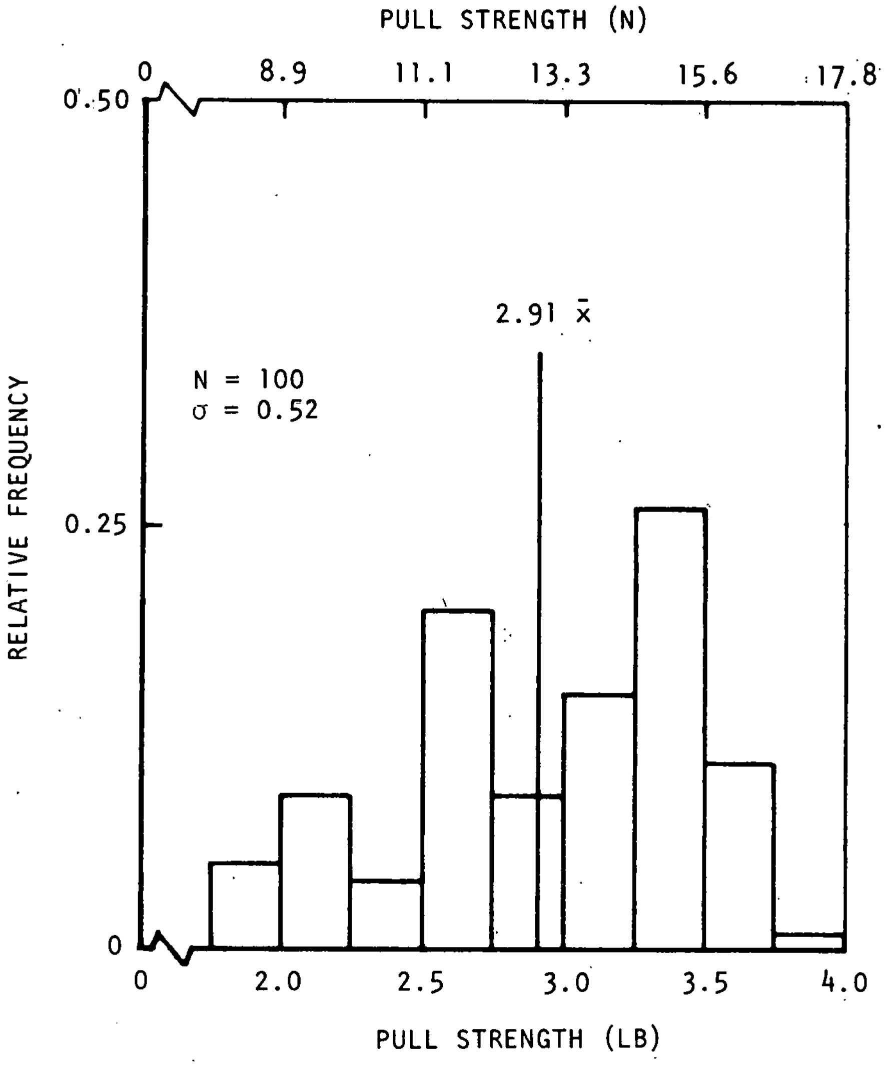

Figure A-4. Lead Frame Bondability of 25 μm Electroplated Gold

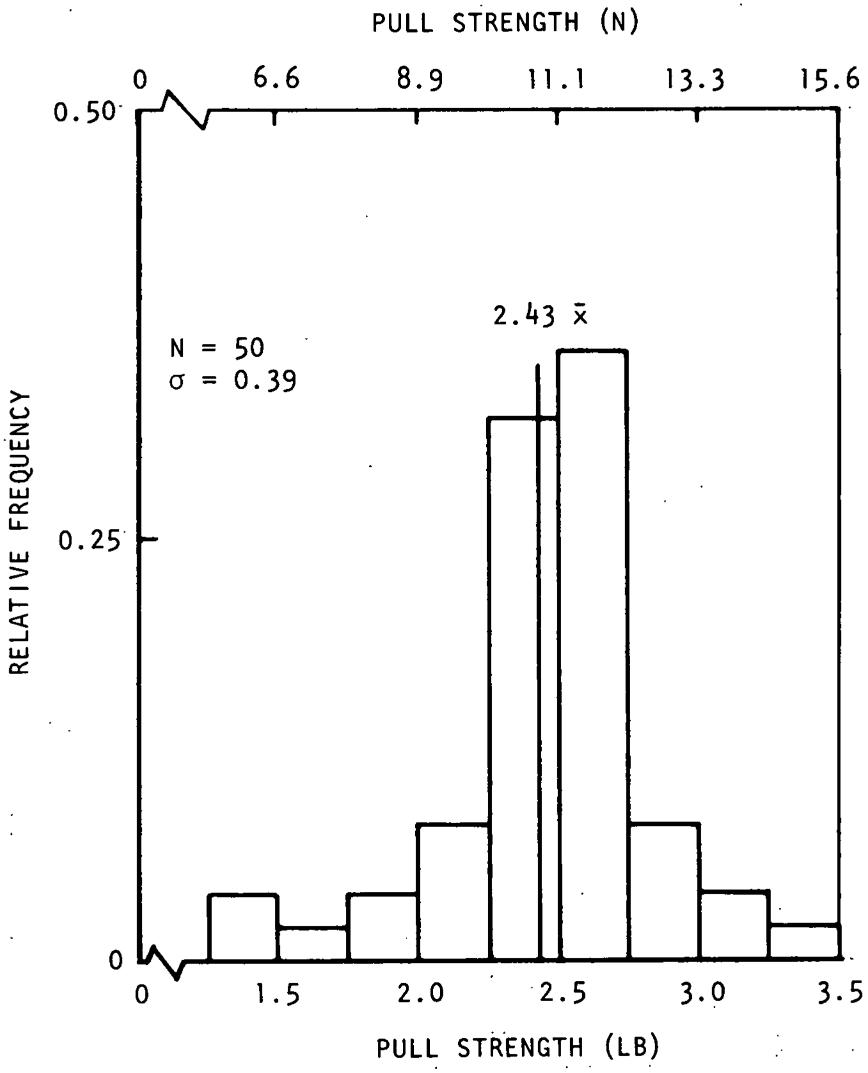

Figure A-5. Lead Frame Bondability: 6 μm Evaporated Gold Stabilized and CAN Etched

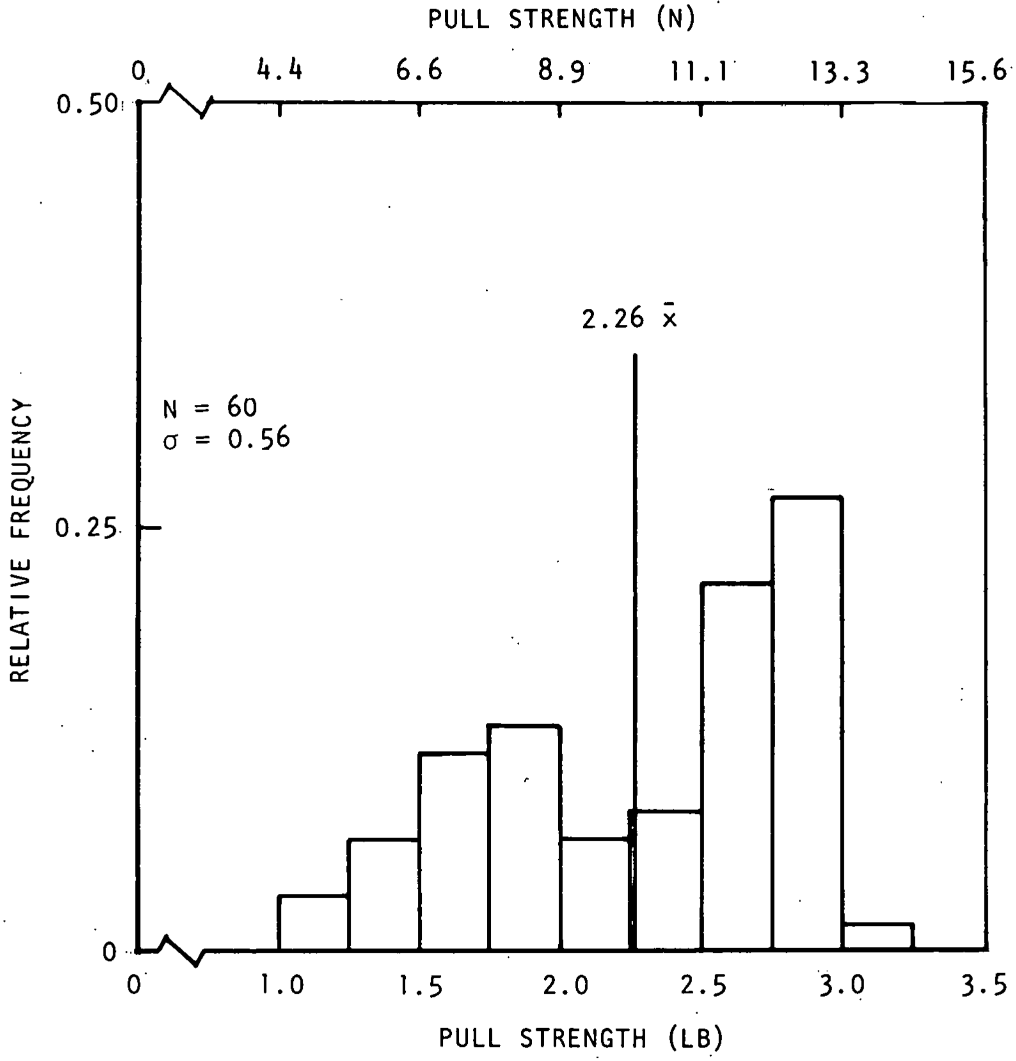

Figure A-6. Lead Frame Bondability: 6 μm Electroplated Gold Stabilized and CAN Etched

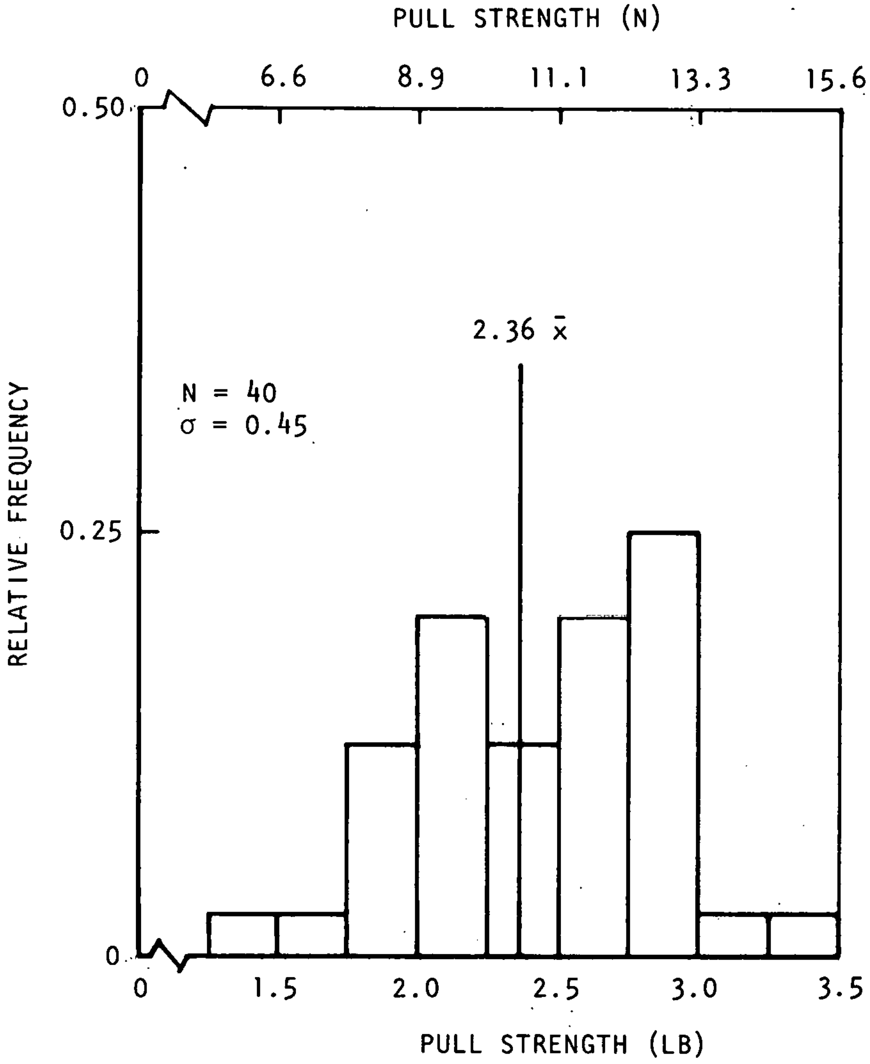

Figure A-7. Lead Frame Bondability: 10 μm Electroplated Gold Stabilized and CAN Etched

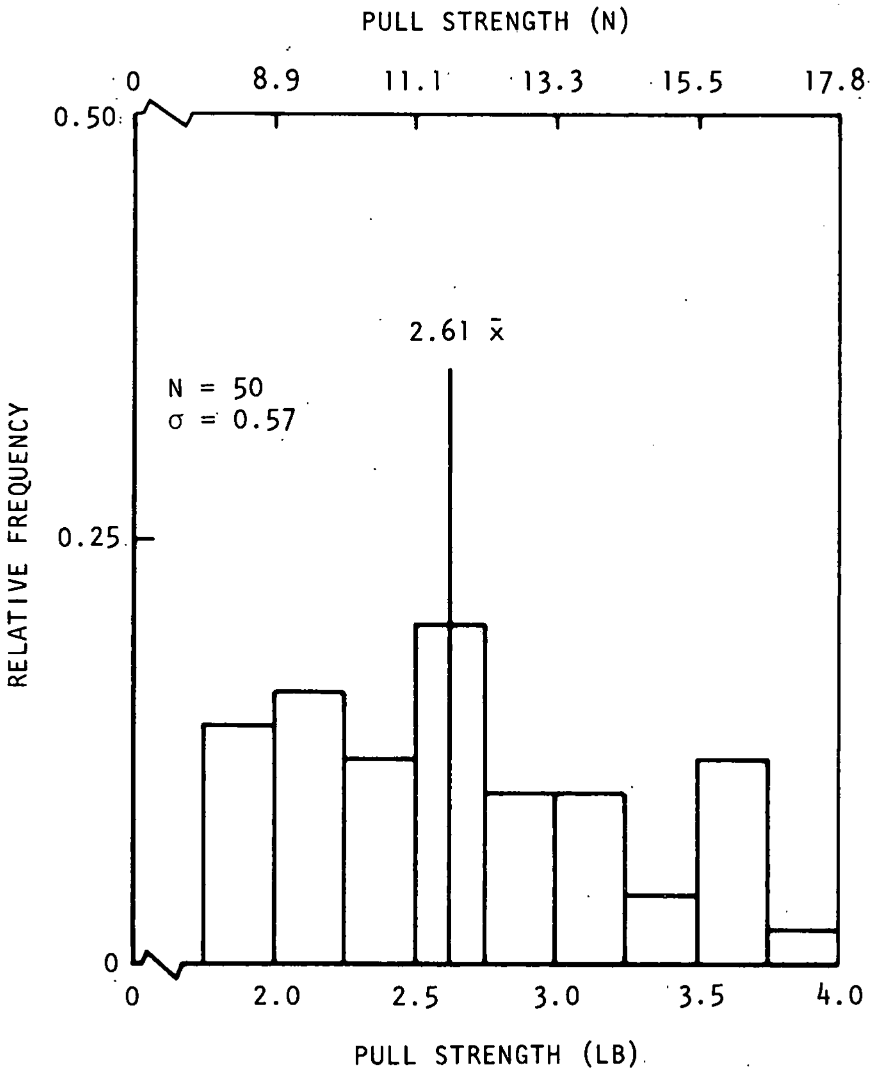

Figure A-8. Lead Frame Bondability: 25 μm Electroplated Gold Stabilized and CAN Etched

Table A-4. Temperature Cycling Effect on Lead Frame Bonds

Metallization Type	Pull Strength (N) (lb) $\bar{x}$	Maximum	Minimum	Heel Failure Modes (Percent)
0 Cycles				
6 μm Evaporated	10.28 (2.31)	13.92 (3.13)	4.72 (1.06)	84
Sputtered and Plated to				
6 μm	10.45 (2.35)	15.03 (3.38)	6.67 (1.50)	87
10 μm	10.28 (2.31)	13.34 (3.00)	5.29 (1.19)	90
25 μm	14.10 (3.17)	16.68 (3.75)	10.01 (2.25)	100
Evaporated and Plated to				
6 μm	8.81 (1.98)	13.61 (3.06)	3.34 (0.75)	74
10 μm	10.50 (2.36)	14.19 (3.19)	5.03 (1.13)	80
25 μm	11.70 (2.63)	16.68 (3.75)	7.52 (1.69)	97
10 Cycles				
6 μm Evaporated	10.36 (2.33)	13.92 (3.13)	5.56 (1.25)	91
Sputtered and Plated to				
6 μm	10.23 (2.30)	13.61 (3.06)	6.41 (1.44)	88
10 μm	10.36 (2.33)	13.08 (2.94)	7.52 (1.69)	94
25 μm	13.88 (3.12)	17.62 (3.88)	7.52 (1.69)	100

Table A-4 Continued. Temperature Cycling Effect on Lead Frame Bonds

Metallization Type	Pull Strength (N) (lb) x̄	Maximum	Minimum	Heel Failure Modes (Percent)
10 Cycles (Continued)				
Evaporated and Plated to				
6 μm	9.65 (2.17)	13.92 (3.13)	3.91 (0.88)	74
10 μm	11.34 (2.55)	14.46 (3.25)	5.03 (1.13)	89
25 μm	12.46 (2.80)	17.62 (3.88)	7.78 (1.75)	100
20 Cycles				
6 μm Evaporated	10.45 (2.35)	13.92 (3.13)	5.56 (1.94)	91
Sputtered and Plated to				
6 μm	10.81 (2.43)	15.03 (3.38)	5.56 (1.25)	92
10 μm	10.28 (2.31)	13.34 (3.00)	7.25 (1.63)	89
25 μm	13.57 (3.05)	16.95 (3.81)	6.94 (1.56)	100
Evaporated and Plated to				
6 μm	9.47 (2.13)	14.46 (3.25)	5.29 (1.19)	78
10 μm	11.08 (2.49)	14.46 (3.25)	5.56 (1.25)	78
25 μm	12.01 (2.70)	16.41 (3.69)	7.52 (1.69)	100

Table A-4 Continued. Temperature Cycling Effect on Lead Frame Bonds

Metallization Type	Pull Strength (N) (lb) $\bar{x}$	Maximum	Minimum	Heel Failure Modes (Percent)
30 Cycles				
6 μm Evaporated	10.23 (2.30)	13.08 (2.94)	6.14 (1.38)	92
Sputtered and Plated to				
6 μm	10.41 (2.34)	15.57 (3.50)	6.94 (1.56)	85
10 μm	10.23 (2.30)	13.08 (2.94)	5.03 (1.13)	95
25 μm	14.90 (3.35)	17.62 (3.88)	10.28 (2.31)	100
Evaporated and Plated to				
6 μm	8.90 (2.00)	12.50 (2.81)	4.45 (1.00)	77
10 μm	10.32 (2.32)	13.92 (3.06)	4.72 (1.06)	80
25 μm	12.10 (2.72)	16.41 (3.69)	6.94 (1.56)	97

Table A-5. Lead Frame Bond Failure Modes: Temperature Cycled Substrates

	Failure Modes											
	0 Cycles			10 Cycles			20 Cycles			30 Cycles		
Metallization Type	B	C	E	B	C	E	B	C	E	B	C	E
6 μm Evaporated	84	16	0	91	9	0	91	9	0	92	8	0
Pre-evaporated, Plated to 6 μm	67	3	30	74	4	22	78	0	22	77	0	23
Pre-sputtered, Plated to 6 μm	87	7	7	88	8	4	92	8	0	85	11	4
Pre-evaporated, Plated to 10 μm	80	10	10	89	6	6	78	17	6	80	15	5
Pre-sputtered, Plated to 10 μm	90	10	0	94	6	0	89	11	0	95	5	0
Pre-evaporated, Plated to 25 μm	97	0	3	100	0	0	100	0	0	97	0	3
Pre-sputtered, Plated to 25 μm	100	0	0	100	0	0	100	0	0	100	0	0

All figures are percentages
Failure Mode Codes:
B - Lead breaks in or near bond zone
C - Lead peels away from substrate and less than 20 percent of the gold is peeled off
E - Ceramic is visible over more than 30 percent of the bond zone

Table A-6. Thermal Aging Effect on Lead Frame Bonds

Metallization Type	Pull Strength (N) (lb) $\bar{x}$	Maximum	Minimum	Heel Failure Modes (Percent)
0 Hours				
6 μm Evaporated	10.81 (2.43)	14.72 (3.31)	6.14 (1.38)	94
Sputtered and Plated to				
6 μm	10.94 (2.46)	12.81 (2.88)	6.41 (1.44)	93
10 μm	11.03 (2.48)	14.46 (3.25)	7.78 (1.75)	100
25 μm	11.70 (2.63)	15.57 (3.50)	8.05 (1.81)	100
Evaporated and Plated to				
6 μm	9.16 (2.06)	13.92 (3.13)	4.45 (1.00)	70
10 μm	10.01 (2.25)	12.50 (2.81)	5.83 (1.31)	100
25 μm	11.61 (2.61)	16.68 (3.75)	8.05 (1.81)	100
250 Hours at 150°C				
6 μm Evaporated	11.48 (2.58)	15.30 (3.44)	6.94 (1.56)	96
Sputtered and Plated to				
6 μm	10.28 (2.31)	14.46 (3.25)	6.67 (1.50)	81
10 μm	12.14 (2.73)	15.03 (3.38)	9.74 (2.19)	100
25 μm	12.77 (2.87)	15.82 (3.56)	8.90 (2.00)	100

Table A-6 Continued. Thermal Aging Effect on Lead Frame Bonds

Metallization Type	Pull Strength (N) (lb) $\bar{x}$	Maximum	Minimum	Heel Failure Modes (Percent)
250 Hours at 150°C (Continued)				
Evaporated and Plated to				
6 μm	9.74 (2.19)	14.46 (3.25)	4.45 (1.00)	70
10 μm	11.52 (2.59)	14.72 (3.31)	8.05 (1.81)	100
25 μm	12.32 (2.77)	16.95 (3.81)	7.78 (1.75)	100
500 Hours at 150°C				
6 μm Evaporated	11.30 (2.54)	14.72 (3.31)	7.25 (1.63)	96
Sputtered and Plated to				
6 μm	11.25 (2.53)	13.61 (3.06)	5.83 (1.31)	93
10 μm	11.52 (2.59)	14.46 (3.25)	9.47 (2.13)	100
25 μm	12.77 (2.87)	15.82 (3.56)	10.28 (2.31)	100
Evaporated and Plated to				
6 μm	9.83 (2.21)	13.61 (3.06)	6.67 (1.50)	81
10 μm	11.03 (2.48)	13.92 (3.13)	7.78 (1.75)	100
25 μm	13.17 (2.96)	17.62 (3.88)	10.59 (2.38)	100

Table A-6 Continued. Thermal Aging Effect on Lead Frame Bonds

Metallization Type	Pull Strength (N) (lb) $\bar{x}$	Maximum	Minimum	Heel Failure Modes (Percent)
1000 Hours at 150°C				
6 μm Evaporated	11.21 (2.52)	14.46 (3.25)	6.41 (1.44)	96
Sputtered and Plated to				
6 μm	10.81 (2.43)	14.46 (3.25)	7.78 (1.75)	97
10 μm	11.43 (2.57)	13.34 (3.00)	9.47 (2.13)	100
25 μm	12.86 (2.89)	16.15 (3.63)	9.74 (2.19)	100
Evaporated and Plated to				
6 μm	9.30 (2.09)	13.92 (3.13)	5.03 (1.13)	70
10 μm	11.25 (2.53)	14.72 (3.31)	6.41 (1.44)	100
25 μm	12.86 (2.89)	16.95 (3.81)	9.74 (2.19)	100

Table A-7. Lead Frame Bond Failure Modes: Thermally Aged Substrates

	Failure Modes											
	0 Hours			250 Hours			500 Hours			1000 Hours		
Metallization Type	B	C	E	B	C	E	B	C	E	B	C	E
6 μm Evaporated	94	6	0	96	4	0	96	4	0	96	4	0
Pre-evaporated, Plated to 6 μm	63	17	20	70	4	26	81	4	15	70	3	27
Pre-sputtered, Plated to 6 μm	93	3	3	81	7	11	93	3	3	97	0	3
Pre-evaporated, Plated to 10 μm	100	0	0	100	0	0	100	0	0	100	0	0
Pre-sputtered, Plated to 10 μm	100	0	0	100	0	0	100	0	0	100	0	0
Pre-evaporated, Plated to 25 μm	100	0	0	100	0	0	100	0	0	100	0	0
Pre-sputtered, Plated to 25 μm	100	0	0	100	0	0	100	0	0	100	0	0

All figures are percentages
Failure Mode Codes:
B - Lead breaks in or near bond zone
C - Lead peels away from substrate and less than 20 percent of the gold is peeled off
E - Ceramic is visible over more than 30 percent of the bond zone

DISTRIBUTION

	Copy
R. Bulcock, ERDA-KCAO	1
V. C. Vespe, ERDA-ALO	2
J. A. Freed, LASL	3
S. J. Buginas, LLL	4
H. M. Brinkmeier, Monsanto	5
A. R. Engquist, SLA	6
J. T. Grissom, SLA	7
J. W. Dini, SLL	8
J. D. Corey, D/554, BD50	9-10
L. Stratton, D/554, 2C44	11-13
R. F. Cell, D/755, 1A42	14
R. P. Frohmberg, D/800, 2A39	15
F. A. Clay, D/814, 2C43	16
A. O. Bendure, D/842, MD40	17
P. L. Blessner, D/842, MD40	18-27
J. S. Bosnak, D/842, MD40	28
J. A. Peters, D/842, MD40	29
D. D. Peterson, D/842, MD40	30
T. A. Wiley, D/842, MD40	31
R. E. Kessler, D/865, 2C40	32

BDX-613-1740 PDO 6989265

FEASIBILITY OF ELECTROPLATED GOLD FOR HYBRID
MICROCIRCUITS, P. L. Blessner, D/842, UNCLAS
Final, November 1977

Electroplated gold was investigated as a feasible alternative to vacuum evaporated gold for use as a conductive metallization layer on HMC substrates. Conductor definition and resolution, RF electrical characteristics, via resistance, solder wettability, thermocompression bondability, and environmental stability of 6, 10, and 25 μm electroplated gold films were examined and compared to 6 μm evaporated gold films. No incompatibilities were found between electroplated gold and HMC requirements or fabrication processes.

ELECTRICAL: Electroplating Gold on HMCs

FEASIBILITY OF ELECTROPLATED GOLD FOR HYBRID
MICROCIRCUITS, P. L. Blessner, D/842, UNCLAS
Final, PDO 6989265, BDX-613-1740, November 1977

Electroplated gold was investigated as a feasible alternative to vacuum evaporated gold for use as a conductive metallization layer on HMC substrates. Conductor definition and resolution, RF electrical characteristics, via resistance, solder wettability, thermocompression bondability, and environmental stability of 6, 10, and 25 μm electroplated gold films were examined and compared to 6 μm evaporated gold films. No incompatibilities were found between electroplated gold and HMC requirements or fabrication processes.

FEASIBILITY OF ELECTROPLATED GOLD FOR HYBRID
MICROCIRCUITS, P. L. Blessner, D/842, UNCLAS
Final, PDO 6989265, BDX-613-1740, November 1977

Electroplated gold was investigated as a feasible alternative to vacuum evaporated gold for use as a conductive metallization layer on HMC substrates. Conductor definition and resolution, RF electrical characteristics, via resistance, solder wettability, thermocompression bondability, and environmental stability of 6, 10, and 25 μm electroplated gold films were examined and compared to 6 μm evaporated gold films. No incompatibilities were found between electroplated gold and HMC requirements or fabrication processes.