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AUTOMATIC LEAD FRAME PLATING

PDO 6984859, Final Report

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November 1975

MASTER

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**Kansas City
Division**

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Technical Communications

**Kansas City
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AUTOMATIC LEAD FRAME PLATING

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November 1975

Prepared by D. M. Jarboe, D/814, under PDO 6984859

An automated plating system has been developed which will enable microelectronic lead frames to be gold plated with improved quality and at significantly lower cost. Based on the concept of continuous plating, this system eliminates the need for manual fixturing of short lengths by providing a method of processing lead frame material in a continuous strip form. The feasibility of continuously monitoring the gold thickness on a copper lead frame was established using a specially developed scintillation type beta backscatter probe. This measurement system as it currently exists, is capable of a precision of 5 percent.

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SUMMARY

Gold plated lead frames are used as electrical connections between hybrid microcircuits (HMCs) and printed wiring boards (PWBs). One end of each lead is thermocompression (TC) bonded to metallized gold pads on the HMC ceramic substrate surface. The other end of the lead is soldered onto the PWB (Figure 1). Therefore, lead frames are required to be solderable and capable of being diffusion bonded. Factors such as gold deposit purity, plating thickness, hardness, and plating adhesion are of significant importance for these two requirements.

The present method of plating lead frames consists of hand racking short lengths and manually processing the racks through the various cleaning and plating operations. Using this technique, it has not been possible to continually produce acceptable lead frames. Problems experienced include plating thickness variation, discolored gold deposits, and poor plating adhesion. In addition, producing lead frames by this batch method is costly because of the time involved in manual processing and the amount of unacceptable material produced.

A new method was developed that would enable microelectronic lead frames to be gold plated with improved quality and at significantly lower cost. To further reduce lead frame costs, the feasibility of adapting beta backscatter techniques to the continuous process for plating thickness monitoring was studied. This reduces inspection time by eliminating much of the metallography used for plating thickness measurements. In addition, continuous gold thickness measurement during the actual plating process can reduce scrap losses by rapidly signalling the operator if the thickness is outside acceptable limits.

Figure 1. HMC Leads Soldered Into a Printed Wiring Board

DISCUSSION

SCOPE AND PURPOSE

This project, PDO 6984859, was initiated with the objective of improving reproducibility and reducing production costs of HMC lead frames. The approach taken was to develop an automated plating system which would continuously plate a moving strip of lead frame material and to determine if the continuously plated lead frames met current production requirements.

PRIOR WORK

Continuous electroplating is not a recent technological development. As early as 1936, a pilot plant was in operation which continuously plated tin onto steel strip.¹

Since that time many other industries have recognized the advantages of high production rates and good reproducibility that can be realized by continuous plating. More recent applications of continuous plating include copper plated steel rod for high speed welding, zinc plated steel wire for spiral notebook binding, and silver plated wire for electronics industries.²

The recent widespread use of semiconductor devices and HMCs has resulted in the need to produce large quantities of reliable lead frames for electrical interconnections. Consequently, several major producers of microcircuits are presently involved in applying continuous electroplating technology to lead frame production.³

ACTIVITY

Lead Frame Definition and Present Production Techniques

Microelectronic lead frames fabricated by Bendix Kansas City are made from continuous lengths, approximately 500 feet (152 meters), of cold-rolled copper alloy 194, nominal composition Cu-2.35 Fe-0.12 Zn-0.03P (weight percent). After the lead configuration is stamped, the strip is sheared into 10 inch lengths (254 mm) and annealed in vacuum for one hour at 700°C to lower the hardness to 100 KHN (100 gram load).

The short lengths are then hand wired into plating fixtures and processed through the following steps:

Cathodic alkaline clean, 1-2 minutes.

Water rinse.

Ammonium persulfate dip, 5-10 seconds.

Water rinse.

Sulfuric acid dip (10 percent), 10-20 seconds.

Water rinse.

Acid copper strike.

Water rinse.

Sulfamate nickel plate 30 to 100 microinches thick (0.76 to 2.54 μm).

Water rinse.

Acid gold strike.

Water rinse.

Alkaline bright gold plate 100 to 200 microinches thick (2.54 to 5.08 μm).

Save rinse.

Water rinse.

Blow dry.

The plated, 10-inch (254 mm) lengths were then cut into individual lead frames having lengths of 0.950 inches (2.41 cm) (Figure 2).

Automatic Lead Frame Plating System

The automatic plating system has 15 tanks to provide the various cleaning, rinsing, and plating operations required to produce HMC lead frames. After the final rinse tank, an air knife produces a flat, wide angled air current to dry the plated lead frame (Figure 3).

Movement of the lead frame strip through the plating system is accomplished by means of chain driven rollers mounted above the solution tanks. Roller speed is controlled by a variable speed motor.

A second set of rollers directs the moving strip in and out of the tank solutions. These rollers are not powered, but merely idle on Teflon bearings. By mounting the idling rollers on vertical sliding beams, the depth in any tank can be adjusted.

Figure 2. HMC Lead Frame, Part Number 293379

This feature allows selection of the desired plating current density, within limits, by varying the length of strip submerged in the solutions. In addition, the idling rollers can be raised completely out of the solutions to facilitate rethreading of the lead frame strip at the beginning of each plating run.

The plating tanks were designed with one large and one small compartment. The wall separating the two compartments extends from the bottom of the tank to approximately 2 inches (3.08 cm) below the top of the tank. A filter in the small reservoir returns the filtered solution to the large compartment. This, in turn, causes an equal volume of the plating solution to flow over the wall from the large compartment into the filtration compartment.

In this way, the wall separating the two compartments in each plating tank acts as an overflow weir. This assures a constant

Figure 3. Automatic Lead Frame Plating System

solution level in the large compartment, where the actual plating process is occurring, to compensate for evaporation losses of water from the solutions. The overflow feature in these tanks also provides a skimming action on the surface of the solution to carry airborne contaminants, such as dust, into the filtration compartment.

Each electrolytic cleaning or plating process tank is fitted with anodes hung on copper bus bars. In order to make the lead frame strip cathodic, the drive rollers which the strip passes over just prior to entering the electrolytic solutions are made from 304L stainless steel. These rollers are electrically connected to the individual power supply cathode terminals (Figure 4).

The lead frame strip is supplied to the plating system from a 35 millimeter movie film reel which rests on a spindle that is connected to a slip clutch. The slip clutch provides an adjustable tension in the strip and prevents free-wheeling or slack in the strip. After completing all of the process steps, the strip coils onto a second 35 millimeter movie film reel which is on a spindle that is connected, via a slip clutch, to a rotating shaft. In this case, the slip clutch allows the speed of the take-up film reel to decrease and thus compensate for the increase in coil diameter as the strip is plated.

Selection of Gold Plating Solution

The plating system was designed to operate at strip speeds up to 30 inches/minute (1.27 cm/s). The copper strike, nickel plating, and gold strike solutions were capable of operating at current densities high enough to allow this; conventional gold plating baths, however, were not. These operate well only at current densities less than 5 amperes/square foot (1 ampere/square foot [ASF] is about 1 milliamperes/square centimeter). Preliminary calculations indicated that the gold solution should be able to function properly at about 45 ASF in order to achieve a speed of 24 inches/minute (1.01 cm/s). PYR-AU-BOND 140GV (The Sel-Rex Company, Division of Oxy Metal Finishing Corporation) was chosen as the gold plating solution. This proprietary plating bath was developed to operate at current densities up to 80 ASF. The specifications for this solution are given in Table 1.

Prove-In and Operation of the Plater

After the automatic plating system was installed, prove-in runs were made to evaluate the mechanical operation of the equipment. The relationship between strip speed through the plater and the variable speed drive motor rheostat setting was experimentally determined with Mylar strip that was marked in 1 inch (2.54 cm) intervals. This strip was run through the plater with various

Figure 4. Plating Tank Configuration

Table 1. Pyr-Au-Bond 140GV Physical Properties and Operating Conditions

Physical Properties	Value
Deposit Purity	99.99 Percent
Hardness	50 to 80 Knoop
pH	6.8 to 7.5 (7 nominal)
Specific Gravity	>15° Baume (>1.115 g/cm ³)
Gold Concentration	3.8 to 4.5 troy ounces/gallon*
Plating Temperature	150 to 175°F**
Cathode Current Density	Up to 80 ASF

*1 ounce/gallon equals 31.1 g/0.003m³

**°C = (°F-32)/1.8

rheostat settings, and the number of inch marks to pass a reference point in 1 minute were noted. It was determined, using this technique, that the plating system was capable of maximum strip speeds of 32 inches/minute (1.35 cm/s).

The relationship between the depth of the idling rollers in the tanks and the length of strip submerged in the solutions, which is necessary for current density calculation, was also determined using the marked Mylar strip. By making reference marks on the sliding beams which support the idling rollers, any desired strip length in the solutions was easily set.

The major mechanical problem encountered with the equipment was a tendency of the lead frame strip to drift over the edges of the drive rollers. This was corrected by adding tapered flanges to the sides of each drive roller (Figure 5).

Before actual plating experiments were made, a quick, simple method was needed for selecting strip speed, length of strip in solution, and plating current values to control plating thickness.

OLD ROLLER DESIGN NEW ROLLER DESIGN

Figure 5. Comparison of Original and Revised Drive Roller Design

To do this, a nomogram was developed (Figure 6). Besides the three parameters listed, the nomogram also provided the current density at which the solution was operating. This is an important feature since there are upper current density limits above which solutions will not operate successfully.

Several plating runs were then made using 50 foot lengths (15 meters) of lead frame material. During these experiments, the currents for both the nickel and gold plating were varied in order to provide plating thickness data. The results of metallographic thickness measurements correlated very well with those predicted by the nomogram, as shown in Table 2.

Additional runs were made to determine the optimum plating parameters that produced the correct gold thickness at the highest possible strip speed. The temperature of the gold plating solution was initially set at 150°F (56°C). When current densities above 30 ASF were used, the deposit discolored (burned). This indicated that the current density was too high for the solution under the existing conditions. Since 30 ASF was considerably below the maximum quoted by the manufacturer, possible causes were considered. Initially, the solution temperature was increased to 175°F (80°C). This was found to greatly improve the resulting deposit, but it did not eliminate the burned gold completely at current densities above 40 ASF. Next, additional solution agitation was provided by two external stirrers. Subsequent plating runs indicated that plating thicknesses of 200 microinches (5 mm) were obtained with no sign of discoloration. This corresponded to a current density of 52 ASF with 35 inches of strip (89 cm) submerged in the solution. In order to assure that plating at 52 ASF was not close to the limit for a good deposit, additional runs were made at current densities of 56, 58, 69, and 72 ASF. None of these deposits showed any signs of discoloration.

Figure 6. Nomogram Developed for Automatic Lead Frame Plating

Table 2. Predicted and Actual Plating Thicknesses
(Microinches) (μm)

Nickel Underplate		Gold	
Predicted	Actual	Predicted	Actual
30 (0.76)	28 (0.71)	150 (3.81)	149 (3.78)
45 (1.14)	40 (1.02)	175 (4.45)	186 (4.72)
60 (1.52)	59 (1.50)	200 (5.08)	198 (5.03)
65 (1.65)	63 (1.60)	225 (5.72)	217 (5.51)
70 (1.78)	70 (1.78)	250 (6.35)	267 (6.78)

Based on the results, the decision was made to operate the plater at a speed of 30 inches/minute (1.27 cm/s) with 35 inches (889 mm) of strip in the gold solution using a gold plating current of 17.5 amperes (corresponding to a nomogram's current density of 52 ASF). Since the selection of plating current for the copper and the gold strike operations was not critical for thickness purposes, values were experimentally chosen based on visual detection of the base metal being plated.

After the trial plating run began, a joint decision was made by Bendix Kansas City and Sandia Albuquerque, based on extensive test data gathered at both facilities, to eliminate the normal nickel underplate from the lead frames and increase the range of gold thickness from 100-200 to 175-300 microinches (2.54-5.08 to 4.45-7.62 μm). Consequently, the nickel plating solution was removed and replaced by the copper strike solution. The tank which had previously held the copper strike solution was filled with a 10 percent sulfuric acid solution to maintain the tarnish-free surface of the strip until it reached the copper strike operation.

Evaluation of Continuously Plated Lead Frames

In order to assure that the continuously plated lead frames would be of sufficient quality for use on HMCs, a program was initiated to study the following characteristics:

Gold plating thickness variation as a function of distance plated,
Purity and hardness of the gold deposit versus current density, and

Bondability and electrical resistance of continuously plated lead frames.

Thickness Variation

To evaluate the thickness uniformity of the gold plating as a function of the length of strip plated, a 100 foot length (30 m) of lead frame material was plated using the parameters previously defined in this report.

The target gold thickness was 200 microinches ($5.08 \mu\text{m}$). After plating, sections were taken from the strip at 1 foot intervals, copper plated for edge retention, and prepared for metallographic examination. Gold thickness measurements were made in the TC bonding region of the leads at a magnification of 1000X with a calibrated filar eyepiece. The graph presented in Figure 7 illustrates the gold thickness versus distance plated for both sides of the lead frame. Each data point represents an average of six thickness measurements. The abnormal thicknesses at the beginning and end of the graph, which correlate to the first and last 35 inches (889 mm) of strip, are caused by current density fluxuations which occur while the ends of the strip are entering and leaving the gold plating tank. Disregarding this, the gold thickness is seen to remain within the required thickness limits of 175 to 300 microinches (4.45 to $7.62 \mu\text{m}$).

Purity and Hardness of the Gold Deposit

As reported earlier, the Pyr-Au-Bond 140GV is formulated to produce a deposit of gold 99.99 percent pure having a Knoop hardness number (KHN) of 50 to 80. It is known, however, that dissolution of base metals in plating solutions can drastically alter both purity and hardness. In order to determine if the bath was being affected, chemical analyses (by gas fusion and emission spectrometer techniques) and hardness measurements were made after 1000 feet (470 meters) of strip had been plated. Samples for the chemical analyses were plated onto tantalum coupons so that the gold could be easily removed. (Electroplated gold does not adhere to tantalum. Also, tantalum is not a trace impurity in gold solutions and would not be treated as such if detected.) The hardness specimens consisted of gold plated nickel panels. Three nomogram current densities were used to produce the gold deposits: 50 ASF, 70 ASF, and 90 ASF. The results of these tests are presented in Table 3.

Some increase in impurity levels is seen as the plating current density is increased. It was noted, however, that all of the deposits are more pure than those currently used in production (99.0 percent).

Figure 7. Plating Thickness Versus Distance Plated for Automatic Lead Frame Plating System

Figure 7. Continued. Plating Thickness Versus Distance Plated for Automatic Lead Frame Plating System

Table 3. Chemical Analysis in Parts per Million and Hardness of Gold Deposit (Pyr-Au-Bond 140GV)

Element	Plating Current Density (A/ft ²)*		
	50**	70	90
Nitrogen	24.0	76.0	210.0
Oxygen	638.0	903.0	6351.0
Hydrogen	47.0	80.0	829.0
Carbon	38.0	74.0	207.0
Silver	5.7	40.0	7.3
Copper		14.0	1.0
Calcium		17.0	88.0
Magnesium	1.0	13.0	7.2
Silicon	1.0	9.0	1.0
Gold	99.92	99.87	99.23
(by Difference)	(Percent)	(Percent)	(Percent)

*1 A/ft² $\approx$ 1 mA/cm²

**Knoop Hardness 65.0

Determination of the hardness of the deposits plated at 70 and 90 ASF was not possible due to poor plating quality. These deposits were found to be very porous, as a result of inadequate agitation on the surface of the solid panels. The hardness value obtained for the panel plated at 50 ASF, however, is within the, quoted range and is acceptable.

Bondability and Electrical Resistance of Continuously Plated Lead Frames

A lead frame bonding test was performed to serve as a comparison of the relative bond strengths and contact resistance of the continuously plated lead frames with the two types currently produced at Bendix Kansas City.

Three sets of lead frames were used:

30 to 100 microinches (0.76 to 2.54 μm) nickel underplate with 100 to 200 microinches (2.54 to 5.08 μm) BDT 200 gold plating,

175 to 300 microinches (4.45 to 7.62 μm) Temperex HD gold plating, and

175 to 300 microinches Pyr-Au-Bond 140GV gold plating.

The lead frames were bonded with a production type bonding tool. Standard HMC substrates having 3 μm of vacuum metallized gold in the CAN etched condition were used. One lead frame of each type gold was bonded to each mirror. The bonding schedule was not varied with each gold type, but kept constant as follows: bonding tool temperature; 650°C, prebond pressure; 10 psi (68.9 kPa) (4 seconds), bonding pressure; 50 psi (349.6 kPa) (10 seconds). (These pressures are not those at the lead frame/substrate bond interface, but are the air pressures on the piston which applies the load to the bonding tool.) The samples were then split into two groups. The first group was tested immediately after bonding. The second group was tested after aging at 200°C for 1000 hours in air.

Bond strengths were determined by the use of a 90 degree peel test. In this test, the leads were bent perpendicular to the substrate surface and pulled off. The strength is then listed as the maximum load sustained by the lead and bond prior to failure. In addition to the failure load, the fracture location is generally noted, since it is desirable for the failure to occur in the lead or the heel of the joint. The present product requirements for these joints specify a minimum pull strength of 0.75 pounds (10.9 N) with no more than 40 percent bond delamination failures. Table 4 lists the results of the peel tests made immediately after bonding. The difference in the average peel strengths is not considered significant. The high percentage of plated gold to metallized gold bond delaminations for the Temperex HD gold (22.5 percent) and the Pyr-Au-Bond 140GV (74.8 percent), however, is excessive.

Table 5 gives the peel test data after the 1000 hour aging at 200°C. The elevated temperature storage did not effect the peel strengths. Bond delamination rate for the Pyr-Au-Bond 140GV gold was still the highest at 14 percent.

Electrical resistance measurements of the bond zones were made before and after aging. The equipment used to obtain resistance data consisted of a digital ohmmeter with ± 10 microohms sensitivity and a special fixture which would contact all the leads at

Table 4. Peel Test Results Before Aging

Plating	Sample Size and Failure Mode	Minimum (Pounds)*	Maximum (Pounds)	Average (Pounds)	Sigma (Pounds)
30-100 μ in. Ni	145 Heel	1.13	2.88	2.35	0.26
100-200 μ in. Au	4 Bond	1.00	1.75	1.39	0.27
75-300 μ in. Au	126 Heel	1.25	2.81	2.09	0.36
	36 Bond	.81	2.31	1.52	0.32
175-300 μ in. Au	38 Heel	1.13	2.81	2.17	0.36
	113 Bond	0.13	2.50	1.59	0.41

*1 pound equals 4.48N

Table 5. Peel Test Results After Aging at 200°C for 1000 Hours

Plating	Sample Size and Failure Mode	Minimum (Pounds)*	Maximum (Pounds)	Average (Pounds)	Sigma (Pounds)
30-100 μ in. Ni	50 Heel	1.63	2.81	2.35	0.26
100-200 μ in. Au					
175-300 μ in. Au	50 Heel	1.50	2.50	2.04	0.25
175-300 μ in. Au	43 Heel	1.31	2.19	1.72	0.22
	7 Bond	1.31	2.00	1.61	0.24

*1 pound equals 4.48N

once. A set of switches allowed each lead to be tested individually. The resistance was measured between the leads and a probe placed in the center of the substrate. Table 6 gives the resistance data for the three lead frame types before and after aging. No significant changes occurred.

In general, the continuously plated lead frames were the same, in terms of strength and electrical resistance, as those types presently in production. A high rate of bond delamination failures, however, was cause for concern. Scanning electron microscopy of the delamination failure surfaces indicated the majority of the fractures to be along the plated gold/metallized gold interface. Isolated regions were found where either the gold plating was pulled from the lead or the substrate failed, leaving Al_2O_3 on the lead, as shown in Figure 8. Since Auger electron analysis of the failure surfaces revealed no significant contamination, the major cause for the bond delamination determined to be the lack of an effective bonding schedule for the continuously plated lead frames.

Concurrent with planned bonding studies to improve the schedule, a significant increase in bond delaminations occurred in production. Separate studies were initiated to locate the cause of this problem, and it was decided not to proceed with further bonding tests until the production problems had been resolved.

Cost Reduction

Table 7 presents the material cost and standard hours required to produce one lead frame for the three lead frame types discussed in the previous section. Although the material cost is the same, the use of the automated process reduces the labor by a factor of four. In reality, the total cost savings will be even larger than this due to less material rejection as a result of nonconforming plating thickness.

Plating Thickness Monitor Development

Although a significant cost savings was predicted for the plating system, it was felt that a method of nondestructively monitoring plating thickness was needed. This would eliminate much of the labor involved in metallographic measurement techniques as well as provide an in-process check.

It was recognized that beta backscatter techniques could be used to measure gold on copper thicknesses to the precision dictated by the product specification. Traditionally, however, beta backscatter has been used only for spot type measurements as a result of dead time limitations of Geiger-Müller type detectors used in commercial systems. The accuracy of a particular beta

Table 6. Resistance Data in Milliohms After Bonding and Aging

Plating	Resistance After Bonding				Resistance After Aging			
	Minimum	Maximum	Average	Sigma	Minimum	Maximum	Average	Sigma
30-100* μ in. Ni								
100-200 μ in. Au	60.8	72.8	66.7	2.6	60.9	75.8	67.7	3.1
175-300 μ in. Au	59.8	80.2	66.2	3.5	60.7	88.1	66.8	3.8
175-300 μ in. Au	60.1	77.0	67.6	3.9	61.1	78.3	67.9	3.8
*1 microinch equals 0.025 μ m

Figure 8. Scanning Electron Fractograph of Pull-Tested Lead Frame TC Bond Delamination Failure

backscatter measurement is proportional to the square root of the total number of beta particles counted. Commercial systems produce fluxes of 3000 counts/second maximum. To obtain the type of precision required for this application, for instance, to assure a 5 percent precision measurement, 30,000 counts would be required. A commercial system would, therefore, require a minimum count time of 10 seconds.

Since the lead frame material travels at 30 inches (76.2 cm) per minute, the maximum time allowed for a given measurement is on the order of 0.1 second, which would require a flux of 300,000 counts/second. Geiger tubes, however, cannot handle fluxes in excess of 10,000 counts/second. Consequently, a new type of detector system would have to be developed for the continuous plating application. If such a detector system could be developed, there remained the problems of fabricating adequate thickness standards, and building fixturing so that measurements could be made on the moving lead frame material.

Development of a Continuous Beta Backscatter Detector System

Bendix Kansas City has carried on a program to advance the state of the art in nondestructive thickness measurements of various coatings on a variety of substrates using beta backscatter. As

Table 7. Material Cost and Labor Comparison

Lead Frame Type	Material Cost (Dollars)	Labor (Standard Hours)
293379-101 (30-100 μ in.* Ni 100-200 μ in. Au)	0.55	0.036
293379-102 (175-300 μ in. Au)	0.54	0.038
Continuously Plated (175-300 μ in. Au)	0.54	0.009
*1 microinch equals 0.025 μ m		

indicated by this work, a scintillation detector was selected for the continuous lead frame plater application.

Scintillation detectors, unlike Geiger-Müller detectors, have much shorter dead times and hence can handle fluxes of 4×10^5 counts/second very easily. A schematic of the basic scintillation probe is shown in Figure 9. The photomultiplier tube used in the first prototype was a 1P21-RCA sidewindowed tube. An NE103 plastic scintillator was selected as the crystal, and a Thallium-204 isotope was used.

The two sources (Figure 10) were specially fabricated by Nuclear Environment Engineering of Houston, Texas. The strength of each individual source was between 1 and 3 millicuries so, when combined, a flux of 2 to 4 millicuries nominal was available. This corresponds to a theoretical incident and backscattered flux of 1.2×10^7 and 1.4×10^6 counts/second, respectively. These theoretical values are used since it is virtually impossible to obtain absolute flux measurements of point type beta sources. At present, neither the National Bureau of Standards nor any other facility can accommodate beta sources in this flux range.

The sources were fabricated by a plating process and then mounted in a steel outer jacket. A 0.005 inch thick Mylar (0.127 mm) seal was applied to prevent leakage of the thallium.

The only area of the lead frame strip that could be used for continuous thickness measurements was the wide margin between the edge and indexing holes. This provided a 0.020-inch-wide path (0.508 mm) along the strip. The detector was, therefore, designed with an aperture 0.015 inch wide (0.381 mm) and 0.250 inch long (6.35 mm).

Figure 9. Scintillation Probe Schematic

Figure 10. Beta Particle Source Configuration

The schematic of the detector system is shown in Figure 11. The anode of the phototube was connected to a Keithly Model 414 S Picoammeter and the voltage output of this device was used to drive a strip chart recorder.

With this prototype system, the following optimum system parameters were determined:

Tube Voltage	700 volts,
Picoammeter Range	1×10^{-9} ampere, and
Chart Recorder	0.5 volts/division.

With these settings, a full scale deflection could be obtained between the 151 microinch ($3.83 \mu\text{m}$) standard and the 325 microinch ($8.25 \mu\text{m}$) standard. The system, however, did not display good stability. The statistical spread of the line on the chart recorder was on the order of 50 microinches ($1.27 \mu\text{m}$).

In an attempt to reduce this noise, several changes were made. First, the geometry of the scintillation crystal was modified from a flat front surface to a spherical surface. This change was indicated from work conducted by D. G. Gardner and W. W. Meinke.⁴

Figure 11. Detector System Schematic

The improvement in current output is shown in Figure 12. An EMI 9662B photomultiplier tube was substituted for the 1P21 tube originally used. This tube is essentially the same as the 1P21 except it has a quartz window and produces a lower dark field current (the current measured with no input to the tube). Little, if any, improvement was obtained using this tube as compared to the 1P21. In actual testing, the 1P21 actually exhibited a lower dark field current (Figure 13). Although the stability of the EMI 9662B tube was slightly better, this advantage was outweighed by the extremely delicate quartz window which was easily cracked or became unbonded.

At this point, the source selection was reconsidered. Thallium 204 has initially been selected since it constituted a minimal safety hazard and was readily available. Further testing indicated that the 300 microinch maximum thickness requirement was extremely close to the maximum range for Thallium 204 in gold. Consequently, Radium D (Lead-210), which has much higher energy, offered greater sensitivity in the range of interest (namely, 175 to 300 microinch). Two Radium D sources were obtained from Nuclear Environment Engineering and installed in the probe housing. With this isotope, the signal-to-noise ratio was improved and the statistical band of the output signal was reduced from 50 to 20 microinches.

Figure 12. Effect of Scintillation Crystal Geometry on Output Current for Several Photomultiplier Tube Voltages

Figure 13. Dark Field Current Versus Photomultiplier Voltage

It was now possible to resolve thickness changes on the order of 30 microinches and the system possessed adequate stability to be used as a process control device, although the statistical width of the output was still undesirably wide.

A test strip of lead frame material of various known gold plating thicknesses covering the range from 150 to 300 microinches was assembled. This strip was run through the beta backscatter thickness probe at a rate of 30 inches (762 mm) per minute. The thicknesses obtained were checked against the standards (discussed in the next section). The results of this test verified that the system was capable of monitoring the thickness of the lead frame material to within a tolerance of ± 25 microinches. It was therefore concluded that the feasibility of making continuous thickness measurements using beta backscatter was established.

Fabrication of Thickness Standards

Standards for calibration purposes were fabricated by using pieces of solid copper strip the same thicknesses as the lead frame material. The absolute thickness of the plating was then determined using a weight gain technique. To facilitate the use of these standards, they were mounted in an aluminum holder which had a standoff of 0.090 inches (Figure 14). This standoff was determined experimentally to be that value which gave the maximum signal output for this particular source configuration. This standoff behavior was an interesting phenomenon observed with this particular source configuration. It made the fixturing problem simpler since variations of 0.005 inches (1.27 mm) in standoff distance did not affect the output of the detector. Since the standards were made by the same process and with the same gold solution as the lead frame material, variations in density, etc. were minimal. The standardizing procedure consisted of merely slipping the aluminum holder over the probe head and noting the deflection of the chart recorder pen.

The fixturing to hold the lead frame as it passed by the detector constituted a major problem. This problem was somewhat alleviated because the standoff could vary by as much as 0.005 inches without effecting the output flux. After considerable development, the fixture shown in Figure 15 was designed. To allow for shifting of the lead frame as it passed over the rollers, two linear slides were used so that the detector could move with the strip. The lead frame was held in place by using a Teflon coated slide (similar to the way in which film is held in place in a movie projector) as shown in Figure 15. The actual measurement was made on the inside of the wide strip of the lead frame material, as shown in Figure 16.

Figure 14. Gold Plating Thickness Standard for the Developed Beta Backscatter System

ACCOMPLISHMENTS

An automatic lead frame plating system has been developed which will allow continuous lengths of lead frame strip to be gold plated. The use of this system will eliminate the need for much of the manual labor presently involved with this part. In addition, scrap losses will be reduced due to improved plating thickness uniformity. Evaluation of the lead frame quality by thermocompression bonding tests has shown that, aside from failure modes, the continuously plated lead frames met requirements and were equivalent to the lead frame types now in production.

The feasibility of making continuous thickness measurements using beta backscatter techniques on lead frame material during a continuous plating operation was established. The system in its present stage of development is capable of 5 percent precision.

Figure 15. Beta Backscatter System in Process of Measuring Gold Plating Thickness on Lead Frame

Figure 16. Location of Thickness Measurements on Lead Frames Using Beta Backscatter System

FUTURE WORK

The implementation of the automatic lead frame plating process is, at present, being delayed due to current production bonding problems and the lack of a lead frame definition. Once these problems have been resolved, efforts will be directed towards prove-in of the process for the HMCs. Additional work should be done at that time to interface the developed beta backscatter techniques directly to the plating process not only to monitor plating thickness, but also to control the gold plating operation by a closed loop minicomputer system.

Plans are underway to study the possibility of selective electroplating of gold onto only those areas of the lead critical for thermocompression bonding. This would result in a substantial reduction of gold usage, thus further reducing production costs.

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