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PLATING HYBRID MICROCIRCUITS

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PLATING HYBRID MICROCIRCUITS

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Prepared by F. A. Clay, D/814, under PDO 6989266

A non-proprietary and a proprietary gold plating bath were investigated to determine if they were capable of producing thick ($76\text{ }\mu\text{m}$) films for RF hybrid microcircuits. Both solutions were found to produce high purity, soft gold deposits over a wide range of plating conditions. Test circuits plated with 6, 10, and $25\text{ }\mu\text{m}$ gold deposits passed the HMC production requirements of bondability, through-hole resistance, and other electrical characteristics.

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SUMMARY

Both a proprietary and non-proprietary gold electroplating solution were investigated to determine if they could be controlled to produce hybrid microcircuits (HMCs). The solution characteristics, including the metal concentration, pH, specific gravity, cathode efficiency, and Hull cell were determined and compared to the measured deposits hardness and purity. The ease of solution control was evaluated. Sample HMC circuits were electroplated with 6, 10, and 25 micrometer thick deposits to show process consistency. These electroplated HMC samples met the microelectronic production requirements of bondability, through-hole (VIA) resistance, and electrical characteristics. Details of the HMC testing evaluation are reported in Process Development Project 06989265, *Evaluation of Electroplated Gold for HMCs*.

The results of these tests show that the electroplating process can be controlled to produce HMCs. The plating process controls are simple and both solutions are tolerant to small process variations. The electroplated HMCs had a lower VIA resistance than vacuum metallized HMCs. They also passed bondability, aging, and temperature cycling tests.

DISCUSSION

SCOPE AND PURPOSE

RF hybrids require gold films that are 6 μm or greater in thickness. Some of these circuits also have plated-through-holes (VIA). The present production method of vacuum evaporation is not a cost effective method of producing films of this thickness. Electroplating is one alternative being considered.

The purpose of this project was to evaluate electroplating as a method for producing HMCs that require thick (greater than 6 micrometers) gold films. This project evaluated only the electroplating process. Process Development Project 6989265 evaluated the compatibility of electroplated mirrors with normal HMC processes.

Two gold solutions were selected for investigation. One was a proprietary solution, Sel-Rex Corporation, Pyr-Au-Bond 140, and the other was a non-proprietary solution. These two solutions were selected because they were capable of producing the high purity, soft gold deposits needed for hybrid circuits. The proprietary solution is currently being used by some commercial manufacturers of HMCs. The non-proprietary solution has been used by various agencies within the Energy Research and Development Administration complex for several years during which time it has been shown to be a reliable plating bath for general use.

The methods of controlling the solution to produce a deposit having consistent properties were of primary importance. Several tests were run on these solutions during this project to determine if the deposit changed due to age or solution variation. Sample HMCs were electroplated with 6, 10, or 25 μm thick gold films to show process consistency. They were evaluated for VIA resistance, bondability, and compatibility with HMC processes.

PRIOR WORK

Several gold electroplating development projects and production processes have been worked on previously at Bendix but no projects had been directed toward the production of hybrid microcircuits. Other companies (Western Electric, Motorola, and Texas Instruments), however, do routinely electroplate HMCs.

ACTIVITY

Solution Characteristics

Five gallon quantities (0.0189 m^3) of each of the gold solutions were prepared for evaluation. Both the plating solution and deposit properties were monitored periodically.

The plating efficiency, gold concentration, pH, and specific gravity of the solutions were checked daily. The plating efficiency was measured by comparing the actual amount of gold deposited by a given current for a fixed time to the amount that should be deposited as predicted by Faraday's Law (0.1226 grams per ampere minute). The actual amount deposited was measured by weight difference using an analytical balance. The current and time were monitored using an ampere-minute integrator that had been calibrated to plus or minus 1 percent accuracy. The efficiency was calculated according to the following formula:

$$\text{Plating Efficiency} = \frac{\text{Actual Weight Deposited} \times 100}{\text{Ampere Minutes} \times 0.1226}$$

The average plating efficiency of both solutions was about 90 percent.

The gold concentration of the plating solution was monitored by running a daily assay using standard chemical gravimetric procedures. Between assays, the gold concentration was estimated by measuring the weight gain of plated parts or calculating gold consumption using ampere-minute data. During circuit plating, the gold content was maintained within preset limits by making additions of potassium gold cyanide as required. Test panels were used to determine the effect of gold content on efficiency and appearance of the deposits. Plated deposits from solutions containing 5 grams/liter up to 15 grams/liter showed no differences.

The pH of the solution was monitored continuously. The pH of both solutions was very stable and no adjustments were necessary. This agrees with past experience which has shown that most plating solutions are highly buffered which prevents sudden changes in pH. Since pH was so easy to control, the effects of pH changes on deposit properties were not investigated.

The specific gravity of the solution was measured using a hydrometer. A sample of the solution was cooled to 16°C and placed in a graduated cylinder containing the hydrometer. The specific gravity was read directly from graduations on the hydrometer.

As expected, the specific gravity increased slowly with solution usage due to an accumulation of potassium cyanide from the gold replenishing additions. These gold solutions are very tolerant to specific gravity changes and no problems would be expected to be encountered within 2 to 3 years. At that time, the solution would routinely be replaced or the excess salts precipitated out and removed. The specific gravity of the Sel-Rex solution started at 1.117 and increased to 1.128 during this plating project. The non-proprietary solution had a specific gravity of 1.104 that did not change during the short time it was used.

A Hull cell test was run on these solutions weekly. This plating test shows the effect of current density variations on the appearance of the deposit. It is a good method of detecting organic and inorganic contamination in the plating solution. No contamination problems were encountered during this project because care was taken to prevent them by thorough rinsing of all parts prior to plating and covering the tank when it was not in use; and because the project time was short. Eventually all gold plating solutions, these included, will build up organic contamination from accumulation of airborne soil, leaching of tank linings, filters, and contact with photo-resist coated parts. This contamination can be detected using the Hull cell test. Treatment of the solution with activated carbon will remove organic contamination.

Properties of Deposit

The deposit hardness and purity were monitored weekly. A Knoop hardness test was performed on a metallurgical section of 50 μm thick gold deposit using a 25 gram load. This was done to verify that the deposit had the consistent physical properties needed for thermocompression bonding. Typical hardness values are 65 to 70 for Pry-Au-Bond 140 and 60 to 75 for the non-proprietary solution. Both of these baths produce soft gold deposits, as compared to typical hard gold hardness values ranging from 130 to 250 Knoop.

These hardness values are consistent with those reported in the literature (Safranek, W. H., *The Properties of Electrodeposited Metals and Alloys*. New York: American Elsevier Publishing Company, Incorporated, 1974.) for these solutions. No significant variations in the hardness of the deposit were found during this project. Current density variations of 30 A/m^2 and temperature variations of 10°C did not cause the hardness to vary outside the value reported. Large variations could be expected if the solution became contaminated; therefore, the hardness test and the Hull cell test should be used to provide a control of the contamination level.

The deposit purity was measured using part of the same foil that was produced for the hardness check. The original plan was to check a small part of the foil on an emission spectrograph to determine the type of impurities and then measure an exact amount of each impurity using atomic absorption (AA) analysis. In all cases, however, no detectable impurities were found using the emission spectrograph, so an AA analysis was not run. This indicates that the gold deposit is 99.99+ percent pure.

Evaluation of HMC Samples

During the tests, large (95 by 114 mm) HMC substrates were gold electroplated and sent to the production area for evaluation of VIA resistance, bondability, and compatibility with standard HMC processing techniques. These substrates were plated with either 6, 10, or 25 μm of gold. These gold thicknesses were selected because they covered the anticipated range thought to be required for RF applications. All three thicknesses of gold were plated using the Sel-Rex solution. Only 10 μm thick deposits were produced using the non-proprietary solution. The 6 and 25 μm deposits were not produced in the non-proprietary solution to minimize the total number of samples needing evaluation, and to keep the gold usage within the dollar limit of the project. Any differences in the deposits of the two solutions would be apparent by comparing the results of the 10 μm deposits. Both solutions are capable of plating any desired thickness of deposit.

The HMC substrates were reactively sputtered with tantalum nitride and metallized with approximately 20 nm of chromium and 500 nm of gold by either sputtering or vacuum evaporation prior to electroplating. The tantalum nitride-chromium-gold metallized parts were cleaned and electroplated using the following procedure:

Dip in isopropyl alcohol for 60 seconds;

Cathodic clean in Oakite 191 (Oakite Products) for 60 to 90 seconds at 5 volts;

Warm water rinse for 60 seconds minimum;

Dip in 20 to 30 percent hydrochloric acid for 30 to 60 seconds at room temperature;

DI water rinse 30 to 60 seconds;

Gold electroplate to desired thickness;

Save rinse;

Water rinse; and

Dry using nitrogen.

Plating problems were encountered initially during cleaning and plating. Some of the tantalum nitride-chromium-gold metallized parts did not have adhesion on one side of the substrate, while others had spots where the tantalum nitride film was exposed. Since these parts were metallized during the time that the production department was experiencing similar problems and these defects appeared prior to the cleaning step, they were not caused by the electroplating operation. Some other parts, however, were ruined by the cleaning operation. It was found that anodic cleaning in the Oakite solution could cause poor adhesion of the metallized film by stripping off the chromium layer. Cathodic cleaning did not affect adhesion.

During plating, the parts were placed in a plastic box to improve the thickness uniformity across the substrate surface because of the shielding action of the sides of the box.

The gold plating results of these HMC substrates are shown in Tables 1, 2, and 3. As shown, the plating process is capable of producing parts having less than a 4 percent weight variation. Deposit thickness data on a 38 by 38 mm part (lower right corner) of a 25 μm thick large substrate is shown in Figure 1. The optically measured values listed show a trend toward thicker, 27 to 29 μm , gold at the bottom edge and thinner, 24 to 26 μm , gold at the top. The low values of 19 and 23 μm shown on the right edge are due to the masking action of the slot in which the substrate was held during plating. The small weight variation between substrates indicates that the process is in good control. The larger thickness variation indicates that the plating box is not doing a good job of leveling the deposit. This type of fixturing has been used previously to plate printed circuits (150 by 150 mm) with a maximum thickness variation of 3 percent across the surface. It appears, therefore, that a new fixture should be fabricated to improve thickness uniformity.

In a production setup, each substrate would be in its own box with individual current control. This would provide gold uniformity both part-to-part and across the surface of a single part.

The plated parts were sent to the HMC production area for further evaluation. Some of the consolidated data are presented to show that acceptable parts were produced.

Table 1. Results of Plating 6-Micrometer Substrates
for 21 Ampere-Minutes

Substrate Number	Weight			Efficiency (Percent)
	Plated (Grams)	Tare (Grams)	Gold (Grams)	
A101101	31.2097	28.8869	2.3228	90.7
A100101	31.8726	29.5494	2.3232	90.7
A100201	31.3549	29.0282	2.3267	90.8
A203601	32.0520	29.6790	2.3730	92.2
A106500	31.5334	29.1672	2.3662	92.0
A113600	31.7430	29.3652	2.3778	92.5
A208100	31.3582	29.0118	2.3464	91.2
A222101	32.1355	29.7367	2.3988	93.2
A222201	32.1326	29.7614	2.3712	92.2
A208500	31.7888	29.4155	2.3733	92.3
A230101	31.3350	29.0312	2.3038	89.5
A106100	32.6499	30.2714	2.3785	92.4
A131101	32.1032	29.7864	2.3168	90.0
			2.3522A*	91.5A
*Average				

Figure 2 shows the results of VIA resistance measurements for electroplated and vacuum metallized films. As shown, the electroplated films have almost an order of magnitude lower through-hole resistance. This is because the electroplated films have about a 1 to 1 thickness ratio of plating in the hole-to-plating on the surface. Electroplating is also unaffected by through-hole roughness that can cause shadowing during metallizing. The electroplated films also passed thermocompression bonding, temperature aging, and temperature cycling tests.

ACCOMPLISHMENTS

Two high purity gold plating baths were investigated to determine if they could be controlled to produce hybrid microcircuits. Both baths were found to be easy to control. Variations in metal concentration did not affect the deposit. The pH and specific gravity were stable. Hardness and purity analyses showed the deposits to be soft and 99.99+ percent pure.

Table 2. Results of Plating 10-Micrometer Substrates

Substrate Number*	Plating Time (Ampere- Minutes)	Weight		Gold (Grams)	Efficiency (Percent)
		Plated (Grams)	Tare (Grams)		
B101301*	38.0	33.7632	29.6206	4.1426	89.4
B100301	38.0	33.2509	29.1524	4.0985	88.4
B203801	38.0	33.1802	28.8838	4.2864	92.1
B208200	38.0	33.7964	29.5349	4.2615	91.6
B222301	38.0	33.9612	29.6848	4.2764	91.9
B113700	38.0	34.1464	29.9174	4.2290	90.9
B230201	38.0	33.3218	29.1370	4.1848	89.8
B131201	38.0	34.0242	29.8346	4.1896	89.9
B106200	38.0	33.6850	29.5096	4.1754	89.6
				4.2049A	90.4A
C230301**	37.0	33.0955	28.9601	4.1354***	91.6
C1-40	38.2	33.8360	29.4390	4.3970	94.4
C106300	38.2	33.6317	29.3710	4.2607	91.4
C-1-40	38.2	33.6678	29.3207	4.3471	92.8
C131301	38.2	33.4150	29.1066	4.3084	92.0
C208300	38.2	34.9460	30.6400	4.3060	91.9
C101401	38.2	34.1973	29.8684	4.3289	92.4
C113800	38.2	31.8645	27.6264	4.2381	90.5
				4.3123A†	92.1A

*Pyr-Au-Bond 140 bath

**Non-proprietary bath

***Not included in average

†Average

Sample HMCs plated in these solutions met the production requirements of bondability, VIA resistance, and electrical characteristics. The plating thickness of sample HMCs varied more than was expected from side-to-center, but thickness variation was still comparable to the amount encountered with vacuum coated parts. Also, it is thought that the plating thickness variation could be reduced by improving the plating fixturing.

FUTURE WORK

This initial electroplating effort for metallized HMC substrates is very encouraging and suggests that a more detailed activity should be initiated to evaluate electroplating as a method for

Table 3. Results of Plating 25-Micrometer Substrates
for 95 Ampere-Minutes

Substrate Number	Weight			Efficiency (Percent)
	Plated (Grams)	Tare (Grams)	Gold (Grams)	
D101501*	39.5796	29.9009	9.6787	91.2
D100504	38.9950	28.6275	10.3675	89.5
D203001	39.5545	28.8882	10.6663	91.7
D208400	39.5869	28.9505	10.6364	91.4
D113900	40.3554	30.0490	10.3064	88.5
D113000	39.4978	29.0418	10.4560	89.8
D230401	40.4471	30.0087	10.4384	89.6
D230501	39.7275	29.3696	10.3579	88.9
D106400	39.4090	29.1005	10.3085	88.5
D131501	39.6900	29.1099	10.5801	90.8
D131401	39.7828	29.2038	10.5790	90.8
			10.470A**	90.1A

*Plating time of 87 ampere-minutes not included in
average.

**Average

producing hybrid microcircuits. A new plating fixture will have to be designed to improve the thickness uniformity of the plated deposit. Facility environments must be controlled to minimize contamination. Automatic control of plating solution should be evaluated. Plating of the substrates without cleaning between metallizing and electrodeposition should be tried. This additional work would result in a high volume production process that would produce parts having a consistently high quality and be compatible with existing HMC production processes. Parts should be produced at the maximum and minimum limits of the process control parameters to show that these limits are compatible with HMC production. A porosity test, such as CAN etch, should be made on electroplated films to show that they are as pore free as evaporated ones.

Figure 1. Gold Thickness Values in Micrometers at Various Points on a 38 mm² Substrate

Figure 2. Comparison of Through-Hole Resistance and Diameter

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