CHARACTERIZATION OF CHROMIUM-GOLD
FILMS FOR HYBRID MICROCIRCUITS

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SUMMARY

This project was initiated to develop the capability to routinely vacuum deposit 6000 nm (60,000 Å) of gold as required for certain HMCs. Activity included the development of a crucible design for gold deposition in the electron beam evaporation system and the evaluation of the metallurgical properties and resistivity of vacuum evaporated 6000 nm (60,000 Å) thick gold. This work was done between October 1974 and March 1975.

To increase both evaporation rate and crucible life, an electrically conductive thermal barrier was needed between the molybdenum liner and the water cooled copper source. A carbon liner was found to be well suited for this application. This new crucible design saves approximately \$25 per evaporation run in the electron beam gold evaporation system because of longer crucible life and shorter process time. Three deposition runs of 8, 10, and 12 nm/s (80, 100, and 120 Å/s) gold rate were conducted with this crucible. The lead frame bondability and solderability of the resulting gold films were excellent and resistivity met all requirements.

DISCUSSION

SCOPE AND PURPOSE

The purpose of this project was to develop the capability to routinely vacuum deposit 6000 nm of gold as required for certain HMCs. The project included evaluating the electron beam vacuum evaporation system for deposition of 6000 nm thick gold, modifying the system as required, and evaluating the metallurgical properties and resistivity of vacuum evaporated 6000 nm gold film.

PRIOR WORK

Certain new HMCs require 6000 nm thick gold compared to the 3000 nm (30,000 Å) thick gold required for earlier products. This new thickness required that the evaporation crucible be modified and that the metallurgical properties and resistivity of vacuum evaporated 6000 nm gold be evaluated.

When the Bendix electron beam gun evaporation system was purchased, the plan was to evaporate the gold directly out of the copper water-cooled crucible source. This proved impossible because the 8 kW power supply was not large enough to overcome the heat loss to the cooling water.

Several crucible liners were then evaluated and it was found that a molybdenum liner was best for depositing gold because the gold would wet the molybdenum liner and result in a source with little gold spitting, few comets, and a nodule-free gold film. This new source was suitable for the gold films, but it was limited to an evaporation rate of 3000 nm/s and it was very expensive because the molybdenum crucible liner would develop cracks after one or two depositions and the gold would seep through to the copper jacket. When this happened, the 8 kW power supply could not maintain the evaporation rate.

The crucible liner had to be improved to handle 6000 nm, gold films to increase the evaporation rate, and to reduce costs. The increased evaporation rate is important because at the 3000 nm/s rate it would take 30 minutes to deposit 6000 nm of gold--which results in a less pure gold film because of impurities picked up during the long process time. The longer process time also increases the chance of a system malfunction which results in a lower yield.

ACTIVITY

Crucible Design

The new crucible design is the result of over 18 month's experience with the electron beam gun.¹ An electrically conductive thermal barrier was needed between the molybdenum liner and the water cooled copper source to increase the evaporation rate and increase crucible life. A carbon liner met the two requirements. Carbon crucibles had been evaluated during the initial characterization but could not be used to deposit gold because of excessive spitting, which caused nodules in the gold film. It was decided to combine the molybdenum and carbon liners to make a new crucible liner: the molybdenum liner was machined to fit inside the carbon liner (Figure 1).

Deposition Process

Since the chromium deposition rate, substrate temperature, and planetary rotation speed had already been optimized by an earlier study, these factors were not varied for this study. Three deposition runs of 8, 10, and 12 nm per second gold rate were evaluated with a chromium rate of 0.1 nm per second and a 200°C substrate temperature. The bell jar was loaded with five 95 by 114 mm (3.75 by 4.5 in.) tantalum nitride coated 99.6 percent alumina substrates and pumped to 53.3 μ Pa (4×10^{-7} torr) prior to the deposition process.

Film Conditions

Three thin film conditions were evaluated: as-deposited, as-stabilized, and prebond-etched. The as-deposited condition refers to films immediately after removal from the vacuum deposition system. The as-stabilized condition refers to films which are given a 300°C two-hour bake in air after being removed from the deposition system. This heat treatment stabilizes the exposed tantalum-nitride resistor network. The prebond-etched condition refers to films which have been stabilized and then subjected to CAN etch (164 g ceric ammonium nitrate, 130 cm³ concentrated nitric acid, and water to 1 liter) for 10 minutes to improve bondability. All samples were solvent cleaned immediately before bonding.

Previous work has shown that chromium will diffuse rapidly through gold films,^{2,3} and that the diffusion of chromium to the surface of the gold film during the stabilizing bake causes degradation in the thermocompression bondability of the film.^{2,4} CAN etching of the stabilized substrate has proven to be an effective method of removing surface chromium oxide and improving bondability.

Figure 1. The Carbon-Molybdenum Crucible

Adhesion and Thickness

Beta backscatter was used to measure the thickness of the chromium-gold films. These measurements confirmed the gold thickness to be 7200 nm (72 kÅ) ± 5 percent on the three depositions.

Adhesion was checked with a standard tape test and with lead frame bonding. There were no adhesion failures with the tape test. The lead frame bonding results will be discussed in a later section.

Bondability

Bondability was evaluated using 0.025 mm (0.001 in.) diameter gold wires and 0.127 by 0.381 mm (0.005 by 0.015 in.) gold plated copper lead frames. Ten 0.025 mm (0.001 in.) gold wires were bonded onto substrates from each of the three evaporation runs and film conditions and pulled to destruction (Figure 2). The failure mode was observed but the strength of the bonds was not. There were 100 percent wire breaks for all conditions.

Two types of lead frames were evaluated: 101 and 102. The 101 lead frames are plated with a nickel flash between the base copper and the gold plating and have been used in the MCCS since early production. The 102 type lead frames are plated without the nickel flash and were being phased into production.

Figure 2. Wire Bond Failure

Figure 3. Lead Frame Bond Failure

Lead frame bonds were pulled to destruction in a 90 degree pull test (Figure 3). For a film to be defined as lead frame bondable, the average pull strength must be equal to or greater than 6.7 N (1.5 lb), individual strengths must exceed 3.3 N (0.75 lb), (3.3 N) and 60 percent or more of the total failures must be heel, or B-type, failures. Heel (B-) and C-type failures were the only failures present in this study. A B-type failure is one in which the lead breaks with no lifting of the bond deformation area. A C-type failure is a bond delamination or a bond failure at the gold-to-gold interface. Bondability results are shown in Figures 4, 5 and 6.

Figure 4 shows the results for as-deposited films for all three gold deposition rates studied. The failures were all B-type with the average peel strengths near 13.3 N (3 lb).

Figure 5 shows the results for as-stabilized films. The bonding has degraded and 70 percent of the failures are C-type. The average peel strength meets the bondability criteria, but the percent B-type failure and the individual peel strength do not. A trend is noticed with a higher percent of B-type failures at the higher gold deposition rates.

Figure 6 shows the results for the pre-bond etched films. The pre-bond etch has restored the bondability with the average peel strength being the same as that of as-deposited films. There were eight C-type failures at the 12 nm/s (120 A/s) gold rate, but the average and minimum peel strengths exceeded requirements.

Type 102 (no nickel) lead frames were bonded onto the same substrates as the 101 type. The 102 lead frames had 80 percent C-type failures and an average peel strength of 5.3 N (1.2 lb) with several individual strengths of less than 3.3 N (0.75 lb). The data for 102 lead frames is from the as-deposited and the pre-bond etched film conditions only since the as-stabilized films exhibited 70 percent C-type failures regardless of lead frame type.

Solderability

Solderability tests were performed for the three different gold deposition rates and the three film conditions using a Browne Rotary Reflow Soldering System, 50Pb-50In solder, and Kester 197 flux. Soldering times of 8 and 64 seconds were used with a substrate temperature of 260°C.

The resulting spread factors, which are a measure of solderability,⁵ are listed in Table 1. A comparison of the figures reveals a slight decrease in solderability for the as-stabilized mirrors. The decrease in solderability for as-stabilized films is a result

Figure 4. As-Deposited Lead Frame Bondability

of the chromium oxide on the surface of the gold. In addition, there seems to be an indication that the above effect is most prominent on mirrors with 12 nm/s (120 $\text{\AA}/\text{s}$) deposition rate.

Resistivity

Sheet resistance was measured with a standard four-point probe system. Ten 25.4 by 25.4 mm (1 by 1 in.) substrates from each of the evaporation runs were measured in the as-deposited condition and after the 2 hour 300°C stabilization. The resistivity was then calculated using the average of sheet resistance and film thickness. Data for each of these conditions is shown in Figure 7; the values are within the required limits. These gold films increased in resistivity approximately 4 percent

Figure 5. As-Stabilized Lead Frame Bondability

during the stabilization process. Previous work has shown that 3000 nm (30 kA) gold films increase 8 to 15 percent during the stabilization process.

Gold Film Surface Analysis

Auger electron spectroscopy (AES) was used to analyze the surface of the gold films. This work was performed for two primary reasons. The new crucible design uses a carbon and a molybdenum liner and the films were analyzed to ensure that the carbon or molybdenum was not contaminating the gold films. The results showed no increase in the carbon present and molybdenum was not detected on any of the gold films. The AES was also used to determine the effect of gold evaporation rate on the chromium diffusion during the two hour stabilization. Results

Figure 6. Prebond-Etched Lead Frame Bondability

indicated the presence of chromium on all the stabilized films and it was concluded that an increase in gold evaporation rates does not restrict chromium diffusion.

ACCOMPLISHMENTS

As a result of the characterization of the deposition system for the modified hybrid microcircuits, a new crucible design was found that resulted in a \$25 per evaporation run reduction in crucible cost because of longer crucible life and shorter process times. Gold films deposited using this crucible were found to have excellent bondability and solderability and the gold film resistivity met all requirements.

Table 1. Solderability Data

Condition	Time (Seconds)	Percent Spread Factor		
		8 nm/s	10 nm/s	12 nm/s
As Deposited	8	93.13	92.86	92.72
	16	94.19	93.28	94.52
As Stabilized	8	93.82	93.82	83.05
	16	88.49	88.49	87.10
Prebond Etched	8	91.29	90.88	91.48
	16	92.95	94.66	92.86

Figure 7. Gold Resistivity

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