# *Electroplated Palladium Coating As a Nickel Migration (Thermal) Barrier*

By J.K. Lim, J.S. Russo and E. Antonier

**Recent industry studies indicate that palladium plating provides a barrier to nickel migration at elevated temperatures. Coupled with a known thermal barrier such as nickel cobalt, the resulting plating surface should have good hermetic sealing characteristics. Twenty-seven Ni-Co plated chip carriers were coated with an acid palladium strike and electrolytic palladium deposits.* Three different plating combinations were used: Ni-Co/Au (Pd strike), Ni-Co/Pd, and Ni-Co/Pd/Au. Ni-Co/Au plated carriers were used as the standard. The test samples achieved equivalent or better nickel migration and solderability results than the standard (less than 10 atomic percent nickel migration** and nearly 100 percent solder flow)**.

Palladium appears to exhibit several attributes that can be applied to micro-electronics packages. Straschil *et al*., and Kudrak *et al.*[1,2] claim that palladium plating provides good nucleation sites, resulting in reduction of porosity, while simultaneously enhancing adhesion. In a separate study conducted by General Electric,[3] it was reported that several metals, including palladium, were found to be an effective thermal barrier at elevated temperatures. Palladium plating, therefore, should promote good bonding and sealing characteristics for typical solder sealing or solder attachment applications. Moreover, palladium, coupled with a known effective thermal barrier such as nickel-cobalt (Ni-Co),[4] should theoretically reduce the amount of nickel diffusion to the surface and produce a void-free solder interface; that is, promoting increased solderability and reliability.

A project was undertaken to investigate these claims. This research focused on the development and potential applications of using an acid-palladium strike bath and a thicker palladium electrodeposit as a migration barrier and plating composite for the chip carrier used. The intent of this study was to determine whether a specific palladium plating chemistry could provide a nickel migration barrier and improve chip carrier solderability.

## Experimental Procedure

The tests conducted during this evaluation are based on one central theme; namely, which plating applications or coating systems would yield the most hermetic and void-free solder joints. In all cases, the least amount of nickel diffusion and solder dewetting are the most desirable conditions. These standards have been developed and refined during the last five years and more recently used to evaluate the quality of plated hardware.[5] A description of the three plating groups selected for this study is given below:

- Ni-Co as a thermal layer, Pd strike and with an electrolytic gold plated finish.
- Ni-Co and palladium as a potential final finish and thermal barrier.
- Both Ni-Co and palladium as a dual thermal barrier with a final deposition of gold.

Ni-Co plating replaced the traditional nickel plating (sulfamate or Watts), based on recent internal studies. In these findings, Hughes Aircraft Co. had demonstrated that Ni-Co is an excellent thermal barrier and improves the quality in sealing characteristics, based upon its ability to retard nickel diffusion.[6] The Ni-Co plating thickness ranged from 100 to 150 µin. Energy dispersive analytical X-Ray (EDAX) analysis measured approximately 12 to 17 percent cobalt in the Ni-Co deposit.

* Plating chemistry inquiries should be directed to AT&T Metals, 286 Richmond Valley Rd., Staten Island, NY 10307.

** Throughout this report, references to nickel migration will be indicated as atomic percent.

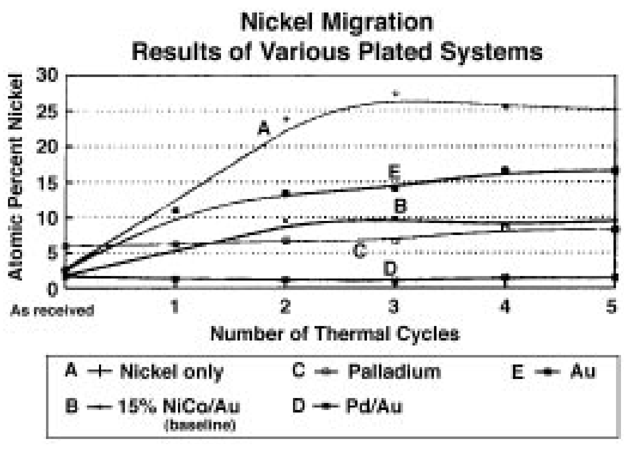


*Fig. 1—Nickel migration test results for various electroplated coatings.*

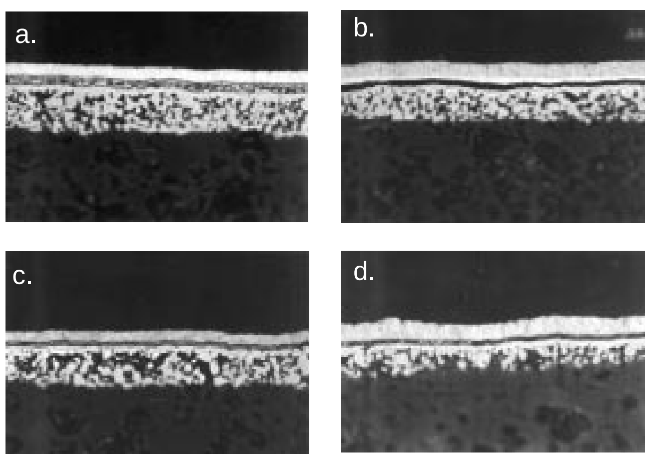


*Fig. 2—Palladium study: Plating thickness; (a) Ni, 140 µin.; Pd, 180 µin.; (b) AT&T process Pd and Au plating. Ni, 150 µin.; Pd, 140 µin.; Au, 179 µin.; (c) AT&T process Pd and Au plating. Ni, 140 µin.; Au, 152 µin.; (d) standard carrier; Ni, 140 µin.; Au, 250 µin. All 1000X.*
*Note: Ni is actually Ni-Co in all packages.*

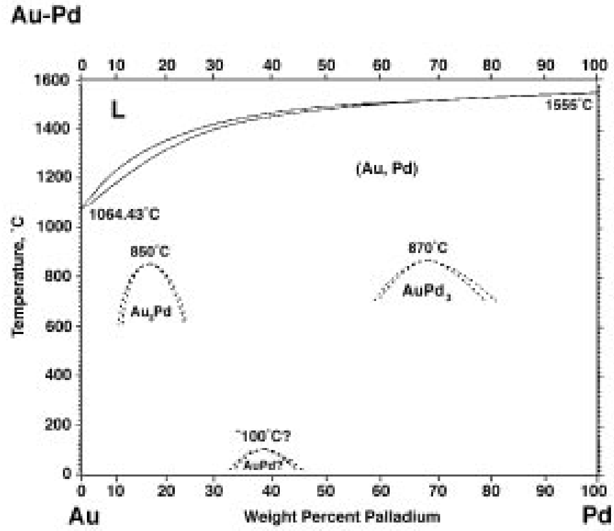


*Fig. 3—Phase diagram of Au and Pd. Note occurrence of random alloying of Au and Pd at 50 at.% Pd and normal package processing temperatures.*

## Evaluation and Testing Criteria

The atomic percent of nickel reported in this study is based upon the percentage for a complete analysis for oxygen and other non-metallic elements. The surface to be measured was initially sputtered about 15 Å; a typical range of carbon found on the surface varied from about 15 to 20 percent.

### *Migration Studies*

The effectiveness of suppressing nickel migration was evaluated by analyzing the surface of the gold plating for nickel after heating for approximately 30 min in a belt furnace in air, with a peak temperature of 450 °C. One pass through the belt furnace with this thermal profile is defined as one thermal cycle.

Three carriers from each plating group were initially measured as received, using an Auger microprobe and subsequently submitted to temperature exposure for a total of five cycles. Auger measurements were then taken after each thermal run. Migration tests were conducted by taking and averaging nickel concentration (Auger measurements) at different locations on the gold plated surfaces. These results were compared to nickel and to the standard (baseline) nickel-cobalt gold-plated carriers.

### *Solderability Studies*

One of the key objectives of this project was to manufacture hermetic packages, using palladium plating. The ability to wet (75-100 percent solder flow) an 80/20 (gold-tin) preform on the seal ring typically indicates that the package can be hermetically sealed. Nine carriers were used for this solderability evaluation. A .001-in.-thick solder preform was cleaned and placed on the seal ring surface. The chip carrier was then placed in a convection oven. The solder reflowed and was allowed to wet the gold or palladium electroplated surface. The results from each package were reviewed for the amount of solder flow on the gold or palladium plated surface and graded as "Passing" (90 to 100 percent coverage), "Marginally Pass" (75 to 89 percent coverage), or "Fail" (less than 75 percent coverage).

## Results and Discussion

### *Migration Studies*

Hughes Aircraft Co. has studied nickel migration during the last five years and has empirically determined that the ability to produce hermetic packages with void-free cover seals requires a low atomic percent of nickel concentration on the chip carrier sealing surface.[6] During these studies, Ni-Co plating provided an effective barrier to Ni diffusion, because it consistently maintained approximately 10 percent Ni concentration on the sealing surface, even after repeated temperature cycling. The 10 percent value derived from Ni-Co plating is used as a baseline. The nickel migration results from the Pd-plated carriers were compared to the standard Ni-Co/gold-plated carriers, as shown in Fig. 1.

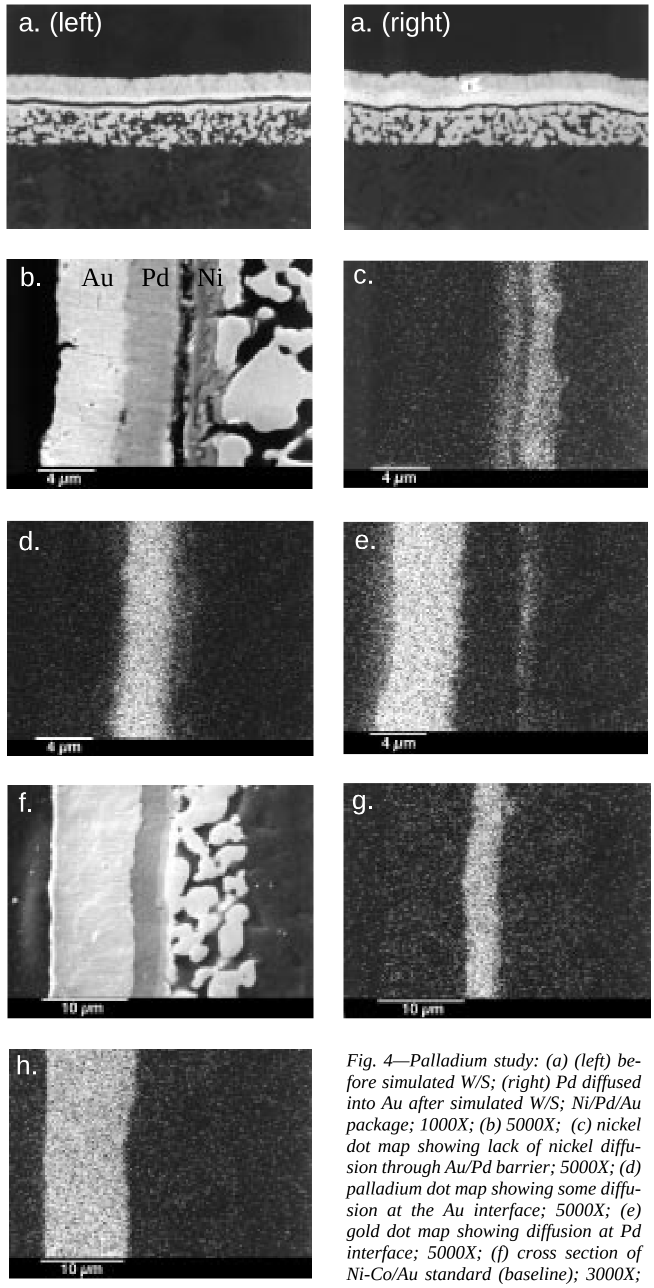


*Fig. 4—Palladium study: (a) (left) before simulated W/S; (right) Pd diffused into Au after simulated W/S; Ni/Pd/Au package; 1000X; (b) 5000X; (c) nickel dot map showing lack of nickel diffusion through Au/Pd barrier; 5000X; (d) palladium dot map showing some diffusion at the Au interface; 5000X; (e) gold dot map showing diffusion at Pd interface; 5000X; (f) cross section of Ni-Co/Au standard (baseline); 3000X; (g) Ni-Co dot map; 3000X (h) Gold dot map; 3000X.*

### Gold-plated Carriers

The gold-plated carriers had significant amounts of nickel diffusion to the surface. The amount of atomic nickel found was surprisingly high, averaging above 12 percent after undergoing only two thermal ramps. Clearly, with this amount of nickel on the surface, achieving both a hermetic and void-free cover seal solder bond could be extremely difficult.

For these samples, it was assumed that the amount of nickel migrating to the surface of the gold would be comparable to that found on the standard nickel-cobalt/gold-plated carriers. Because of the large amount of atomic nickel found on the surface, and taking into account that the only variable between these parts is the palladium strike, it was suspected that the thickness of the final deposit of gold could be lower than that of the standard parts.

Representative samples from the three different plating configurations and a typical standard package were cross-sectioned (Figs. 2a-d). Apart from the palladium strike, the gold plating was found to be thinner (*i.e.*, 150 µin. as compared to the standard average of 250 µin.) Therefore, it appears that the thinner gold does not suppress the migration of nickel as well as the baseline Ni-Co/Au plating combination.

### Palladium-plated Carriers

The palladium-plated parts had an upper limit of approximately 8 and 10 atomic percent nickel after the second and fifth thermal cycles, respectively. Overall, the amount of nickel migration indicates that palladium is as good or slightly better as a thermal barrier (compared with gold) when plated directly on the nickel-cobalt alloy.

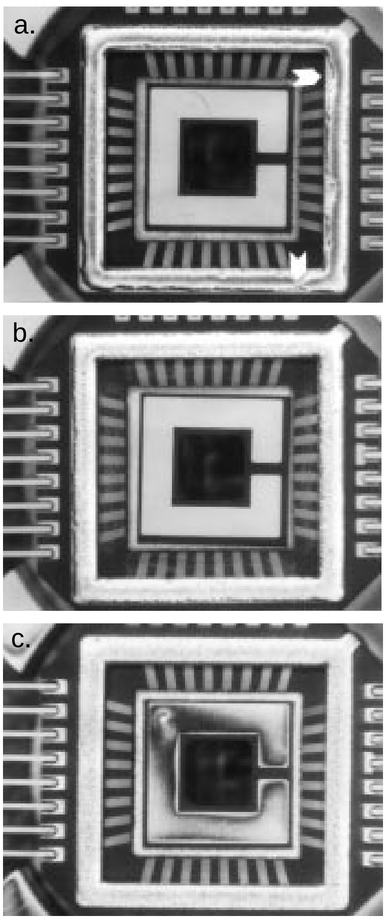

*Fig. 5—AT&T Au-plated parts: (a) Ni-Co/Au, arrows indicate where typical part failed wettability; (b) Ni-Co/Pd/Au, typical part passed wettability; (c) Ni-Co/Pd, typical part passed wettability. All 7X.*

### Palladium/Gold-plated Carriers

The results of the palladium/gold-plated parts with respect to nickel migration were extremely impressive and were found to be superior when compared to the standard nickel-cobalt chip carriers. After five thermal cycles, less than two percent of atomic nickel was measured on the surface. With this level of nickel on the bonding surfaces, less voiding in the solder joint and a more robust hermetic seal could be expected.

Although the plating thickness of the Pd/Au vs. the Au-coated carriers could play a role in minimizing nickel diffusion, the lack of nickel migration on the Pd/Au plated parts could be better explained by the presence of an adherent and intimate barrier, consisting of palladium and gold. Gold and palladium form a complete solid solution below the liquids as shown in the Pd-Au phase diagram (Fig. 3).[7] Figure 4a-h microprobe elemental maps on a sectioned part support this interpretation and are compared to the Ni-Co/Au plating combination.

### Solderability Results

A representative copy of the photographs from the solderability tests are included in Fig. 5 and summarized in the table.

**Table**
**Solderability Tests Using Gold-Tin Preforms**

| Plating/sample | Sample 1 | Sample 2 | Sample 3 | Remarks |
|---|---|---|---|---|
| Gold | Fail | Fail | Pass | Atypical flow. Poor solder wetting |
| Palladium | Pass | Pass | Pass | 3/3 Approx. 100% wetting |
| Palladium/gold | Pass | Pass | Pass | 3/3 Approx. 100% wetting |

### Gold-plated Carriers

The gold-plated carriers displayed poor wetting characteristics, which was anticipated as a result of the high surface nickel found during the migration studies. Only one of the three carriers had nearly 100 percent coverage on the seal ring surface. The other two carriers failed the solder test criteria. One package sealing surface had a narrow pinch point that caused it to fail, and a second package had nearly one side of the seal surface that wetted less than 40 percent of the available area.

The solderability results of the gold plated hardware are uncharacteristic of our standard production hardware. These carriers typically have solder coverage of at least 95 percent on the entire sealing surface. There exists a strong possibility that a thinner gold plating thickness may have influenced these results.

### Palladium and Palladium/Gold-plated Carriers

The palladium and palladium/gold solder samples displayed excellent results. The flowed solder covered nearly 100 percent of the plated surfaces on each of the test packages.

## Findings

Based upon the above test results, the palladium-plated hardware (Ni-Co/Pd/Au and Ni-Co/Pd) have met or exceeded the standard plating in both of the criteria selected. The migration of nickel on the gold plated surfaces of the Ni-Co/Pd/Au test carriers was held to approximately two percent. The nickel migration on the Ni-Co/Pd test samples was held to less than 10 percent.

The excellent solderability characteristics, nearly 100 percent of the test carriers' plated test surface, make the Ni-Co/Pd/Au and Ni-Co/Pd plating system a step toward achieving a good solderable coated surface, even after repeated temperature excursions. These combinations of palladium and gold over nickel-cobalt should be given serious consideration for future investigative study.

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## Acknowledgment

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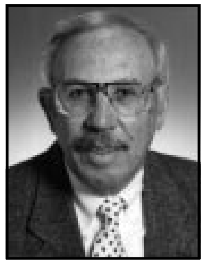

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