# Substrate-Catalyzed Electroless Gold Plating

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## ABSTRACT

Hydrazine is used as a reducing agent in a novel electroless gold plating formulation. Anodic polarization curves have shown that excess free cyanide, used to stabilize the gold cyanide complex, poisons hydrazine oxidation on gold but not on transition metals such as nickel and cobalt. This allows a new type of plating, "substrate-catalyzed," which is neither immersion nor autocatalytic plating. This bath plates pure gold films at high initial rates up to 10  $\mu$ m/h with exceptional bath stability and life.

A significant number of electroless gold plating compositions have been reported in the literature dating as early as 1942 (1). Two excellent review articles by Ali and Christie (2) and Ganu and Mahapatra (3) have summarized the art. The conclusion of each review was that no formulation has been developed that provides a reliable, stable, fast-build process for widespread application. Ali and Christie outline two different approaches to electroless gold deposition. The first is a displacement/immersion process where the electrons to reduce the gold ions are supplied by anodic dissolution of the substrate. The main virtue of this approach is bath stability; however, several key disadvantages include dissolution of the substrate to be coated, poorly adhered deposits, limited plating thickness, high porosity, and restricted number of suitable substrate materials. The second approach is autocatalytic plating where the electrons are supplied by the oxidations of a reducing agent on a catalytic surface. The use of a reducing agent can eliminate the need for dissolution of the substrate, and if the metal being deposited is catalytic there is no limit to plating thickness.

The greatest emphasis recently in electroless gold formulations has been on autocatalytic plating based on the work of Okinaka (4-7) using KAu(CN)<sub>2</sub>, KCN, KOH, and either borohydrides or (di-tri)methyl-aminoboranes (DMAB) as reducing agents. Although a truly autocatalytic bath, this formulation had several limitations, including stability, plating rate, sensitivity to contaminants such as Fe and Ni, and inability to plate on several desirable substrates. While several investigators (8-11) have improved upon Okinaka's formulation, these limitations still exist.

In this paper we will present a new bath formulation (12) to coat electroless nickel substrates which overcomes these drawbacks. This is achieved by plating in a composition which is neither an immersion nor autocatalytic process. The most descriptive term is substrate-catalyzed plating. It is similar to an autocatalytic process in that a reducing agent, e.g., hydrazine, is used as the source of the electrons rather than a sacrifical metal. It is not, however, truly autocatalytic because the reducing agent is not active on the metal being deposited, i.e., gold. This discrepancy between the catalytic activity of the substrate and the metal being deposited for hydrazine oxidation kinetics is the key to the nature of this process. As will be shown, among the reducing agents examined, hydrazine was unique in being able to protect substrate dissolution during gold plating.

#### Experimental

To examine the feasibility of using hydrazine as a reducing agent for electroless gold plating, the kinetics of hydrazine oxidation on nickel and gold foils was examined following the procedure outlined in a companion paper (13). Polarizations were measured in alkaline solutions, with and without cyanide present. Gold plating experiments were carried out using the formulation shown in Table I on Ni foils as well as electroless and chemical vapor deposited (CVD) nickel. The latter two were deposited on tungstenmetallized ceramic packages. **Results and Discussion** 

Anodic polarizations.—A common technique for determining the kinetics of electrochemical reactions is to measure potential vs. current polarization curves on the materials of choice (14, 15). Shown in Fig. 1 is a schematic representation of these curves for gold, nickel, and hydrazine. Several salient features can be seen in this plot. First, the driving force for the overall reaction,  $E_{\rm D}$ , is the difference in potential between metal ion reduction,  $E_{\rm Au}$ , and reducing agent oxidation,  $E_{\rm N_2H_4}$ 

$$E_{\rm D} = E_{\rm Au} - E_{\rm N_2H_4} \,(\rm Volts)$$
<sup>[1]</sup>

For gold vs. hydrazine,  $E_{\rm D}$  is several hundred millivolts depending on pH and [CN<sup>-</sup>]. At some mixed potential,  $E_{\rm mp}$ , the oxidation and reduction current densities are equal. This approximates the plating rate,  $i_{\rm PL}$ . Comparing  $E_{\rm Au}$  and  $E_{\rm Ni}$  shows ~100 mV driving force for plating gold and dissolving nickel by a displacement reaction described earlier. Thus, in electroless gold plating directly on nickel, the potential for substrate dissolution is always present. Ideally, the reducing agent as well as providing electrons for gold deposition will cathodically protect the nickel substrate from dissolving.

As mentioned above, the kinetics of the hydrazine oxidation is critical to the rate of plating and is a function of the catalytic activity of the substrate. A measure of the catalytic activity of the substrate is represented by the exchange current density  $i_0$ . As the catalytic activity decreases, the hydrazine polarization curve shifts to lower current and generally to a less negative potential. This causes the hydrazine oxidation curve to cross the gold reduction curve at a lower plating current and more positive  $E_{mp}$ . Figure 2 shows polarization curves for hydrazine oxidation [2] on nickel foil from a solution of 0.5M hydrazine at 85°C as a function of hydroxide concentration

$$N_2H_4 + 4 OH^- \xrightarrow{Ni} N_2 + 4H_2O + 4e^-$$
 [2]

The equilibrium potential (16) for reaction [2] vs. a standard hydrogen reference is in alkaline solution

$$E_{N_2H_4} = -1.16 + \left(\frac{RT}{nF}\right) \ln \frac{1}{[OH^-]^4[N_2H_4]}$$
 (Volts) [3]

For a 0.5M N<sub>2</sub>H<sub>4</sub> solution at 85°C Eq. [3] reduces to

$$E_{\rm N_2H_4} = -0.289 - 0.0619 \, \rm pH \, (Volts)$$
 [4]

Increasing the hydroxide concentration has two effects on hydrazine oxidation. The first, as demonstrated by Eq. [4], is to decrease the equilibrium potential (potential with no net current flow) from -1.03 to -1.13 V. The second effect is to increase the rate of oxidation at any given potential.

Table	1.	Electroless	gold	composition	1,
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$N_2H_4 \cdot H_2O$ KAU(CN)	0.50M 0.017M
KCN	0.035M
$\begin{array}{c} { m KOH} { m K_2CO_3} \end{array}$	0.87M 0.75M

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Fig. 1. Schematic representation of mixed potential electroless plating.

The potential effect of this increase in hydrazine kinetics on gold plating can be seen by superimposing the gold reduction curve (13).  $E_{\rm mp}$  would decrease from -0.78 to -0.86 V with a corresponding increase in  $i_{\rm PL}$  from  $\sim 3.0$  to  $\sim 18$  mA/cm<sup>2</sup>.

In contrast to hydroxide, cyanide is a known poison for hydrazine oxidation (17). The role of cyanide as a poison in the bath is pivotal to the manner in which the process operates. Figure 3 demonstrates how cyanide poisons hydrazine oxidation kinetics on nickel. At 0.01M KCN, the hydrazine polarization curve on nickel shifts ~100 mV more positive, resulting in a factor of 2 decrease in plating rate from ~18 to ~9 mA/cm<sup>2</sup>. Little change was observed with increasing cyanide concentration to 0.05M. The effect of cyanide on hydrazine oxidation using a gold foil substrate was dramatic. The already poor catalytic activity of gold for hydrazine oxidation (13) decreased significantly with only trace amounts of cyanide. With 0.007M cyanide, no catalytic activity was observed.

Since hydrazine is not oxidized on gold in the presence of cyanide, this bath is not autocatalytic, *e.g.*, it will not plate gold on gold. It will, however, plate gold on nickel. Shown in Fig. 4 is a schematic representation of how the bath operates. Hydrazine is oxidized on the nickel surface. Gold ions are reduced to gold on the nickel surface initially in nucleation sites. With time, hydrazine continues to react on the nickel which is not covered with gold, while the initial gold nucleation sites grow and coalesce. As the nickel surface is covered with gold,  $E_{\rm mp}$  moves closer to  $E_{\rm Au}$  and the amount of nickel available for hydrazine oxidation decreases; both slow the plating rate. When the nickel is completely covered with gold, no further plating occurs. Shown in Fig. 5 is a typical plot of gold thickness



Fig. 3. Effect of cyanide on hydrazine kinetics with nickel substrates.

and  $E_{\rm mp}$ . vs. time. Although Fig. 5 plots gold thickness vs. time, the process actually controls thickness with composition not time, e.g., the bath composition is adjusted to obtain a given thickness and substrates are left in the bath until they no longer plate. Composition vs. thickness control will be discussed in more detail in subsequent sections. It is obvious from Fig. 5 that thickness can be controlled by time if the bath composition were adjusted to obtain thickness greater than desired. In general, this procedure is not desirable because the gold deposit will have too much residual porosity to pass severe environmental testing. It can be done, however, if the functional requirements of the gold are minimal.

As shown in Fig. 1, gold deposition on nickel can occur simply by an immersion process. To verify that this composition is not simply an immersion bath containing a reducing agent, nickel substrates were immersed in various compositions for 30 min at 85°C. The solution was then analyzed by inductively coupled plasma to determine the amount of nickel which had dissolved. Table II lists the results of these tests. Columns 2-5 show the composition, concentration of nickel dissolved, equivalent loss of nickel (calculated assuming uniform dissolution of the electrode), equivalent amount of gold that could have been deposited by an immersion process, and the amount of gold

 $N_2H_4$ 



Fig. 2. Effect of hydroxide activity on hydrazine kinetics with nickel substrates.

Fig. 4. Schematic representation of "substrate-catalyzed" electroless deposition.



Fig. 5. Profile of gold thickness and  $E_{mp}$  vs. time during gold plating on a nickel substrate.

that was plated. Solution 1 shows that Ni will dissolve in an alkaline cyanide solution even in the absence of gold ions. Presence of Ni, therefore, in a gold plating bath is not sufficient to prove immersion plating. Solution 2 shows that hydrazine is effective at cathodically protecting Ni against dissolution. In contrast, sodium hypophosite and DMAB (solutions 3 and 4), slowed the rate of dissolution but did not prevent it. Comparing solutions 6-8 shows the ability of these three reducing agents to prevent nickel dissolution during gold plating. As shown, only hydrazine was effective. With NaH<sub>2</sub>PO<sub>2</sub> and DMAB, there was sufficient nickel in solution after plating for all of the gold to have been deposited by an immersion process. Solutions 6 and 9-12 demonstrate the effect of cyanide activity. As the cyanide increased the nickel dissolution also increased but not enough to provide the amount of gold plated. For example, at 0.065M KCN (sample 11), which is much higher than typically used, the quantity of Ni dissolved could only account for  $\sim 15\%$  of the gold deposited. Increasing the hydrazine concentration was effective at preventing Ni dissolution even at 0.065M KCN.

*Plating results.*—The cyanide ion activity (free, uncomplexed species) has a large influence on plating results. It is used to control gold thickness and to maintain reproducible thicknesses in subsequent platings. Two reactions occur which influence the activity of cyanide in the bath. Cyanide increases by being released from the gold-cyanide complex during gold deposition, Eq. [5], and decreases by a hydrolysis reaction, Eq. [6]

$$Au(CN)_2^- + e^- \rightarrow Au^o + 2CN^-$$
[5]

$$CN^- + 2H_2O \rightarrow HCOO^- + NH_3 \uparrow$$
 [6]

To illustrate the effect of increasing the cyanide activity by Eq. [5], a bath was formulated using the composition given in Table I but with an initial cyanide activity of 7.0 mM. Three electroless nickel-based substrates were sequentially plated for identical times. The gold thicknesses that resulted were about 1.6, 1.9, and 2.2  $\mu$ m, respectively. The



Fig. 6. Effect of increasing cyanide activity on gold plating thickness. Arrows indicate addition of nickel acetate to reduce cyanide activity.

gold concentration in the bath decreased from 17.4 to 14.8 mM as a result (15% depletion), and the cyanide activity correspondingly increased from 7 to about 12 mM. This is shown graphically as the first three data points in Fig. 6. Subsequently, as indicated by the arrows in Fig. 6, the cyanide activity was reduced to the original value of 7.0 mM by adding nickel ion (as nickel acetate) in accordance with Eq. [7]

$$Ni^{++} + 4CN^{-} \rightarrow Ni(CN)_{4}^{=}$$
[7]

Subsequently plated substrates showed a reproducible trend in resultant gold thickness. A saw-tooth shaped curve resulted for three such cycles over the range of 0-45% gold depletion. The data demonstrates the reproducibility and sensitivity of gold thickness to cyanide activity and also shows the insensitivity of thickness to gold concentration within these limits.

As shown, nickel ion can be used in this formulation to lower the free cyanide activity in solution. No deleterious effects on bath performance were observed for up to equal molar concentrations of nickel and gold. This is unlike autocatalytic gold baths which are poisoned by nickel ions (3).

The level of cyanide also decreases in the bath by the hydrolysis reaction, given in Eq. [6]. Figure 7, as an example, shows the decrease in cyanide activity as the bath is maintained at operating temperature without any gold deposition. The rate of loss was on the order of 1 mM per hour at  $85^{\circ}$ C.

Plating profiles.—A unique feature of this bath, as was discussed earlier, is that gold deposition is catalyzed solely by the substrate being plated. This means that during the course of gold deposition, as the substrate surface becomes covered with gold, the driving force for gold deposition is reduced. Thus, as the area of catalyst exposed to the plating bath chemistry approaches zero, so does the gold deposition rate.

Figure 8 shows typical gold thickness plating profiles on nickel foil as a function of time for various cyanide activities. During the early stages of plating, the deposition rate is high. Here the rate is controlled by the hydrazine oxidation kinetics. Later during the profile, as the substrate becomes covered with gold attaining limited access to the solution, the rate subsequently falls and approaches zero. At

Table II. Nickel dissolution in	n 0.87M KOH at 85°C.
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Solution	KCN	Additive (M) reductant	Gold	Ni (ppm)	Ni (µm)	Equivalent Au (µm)	Au deposit (µm)
1	0.025			4.5	0.058	0.181	
$\overline{2}$	0.025	0.5 N₂H₄		0	0	0	
3	0.025	0.5 NaH <sub>2</sub> PO <sub>2</sub>	-	3.1	0.048	0.134	
4	0.025	0.5 DMAB		3.9	0.051	0.157	chickey and a second
5	0.025		0.017	26.8	0.348	1.078	0.96
6	0.025	0.5 N₂H₄	0.017	2.0	0.026	0.080	1.17
7	0.025	0.5 NaH <sub>2</sub> PO <sub>2</sub>	0.017	22.5	0.292	0.905	0.79
8	0.025	0.5 DMAB	0.017	15.4	0.200	0.618	0.61
9	0.020	$0.5 N_2 H_4$	0.017	0	0	0	0.90
10	0.045	$0.5 N_2 H_4$	0.017	8.5	0.110	0.342	2.78
11	0.065	$0.5 N_2 H_4$	0.017	18.1	0.235	0.728	4.77
12	0.065	$1.0 N_{2}H_{4}$	0.017	0	0	0	4.00



Fig. 7. Change in cyanide concentration with time from a bath maintained at  $85^\circ\!C.$ 

this point (at about 20 min for the profiles of Fig. 8), substantially no more gold will deposit on the substrate. The maximum obtainable thickness has been reached.

Figure 8 also demonstrates that the limit or maximum gold thickness obtainable can be changed by altering the concentration of free cyanide prior to deposition. In these examples an activity of 10 mM cyanide gave about 0.4  $\mu$ m of gold as the upper limit and an activity of 30 mM gave about 1.4  $\mu$ m.

Figure 9 shows the maximum thickness of gold obtained on nickel foil at various cyanide levels. It is noted that the resultant deposits at the various levels are substantially pore-free if the substrate is allowed to attain the gold thickness limit. As will be discussed later, the substrate condition also affects the gold thickness for a given bath condition. In practice, a curve such as Fig. 9 can be generated to determine the activity of cyanide required to give the desired gold thickness for a given substrate condition and/or process.

Mechanism of deposition.—The actual mechanism by which cyanide controls the gold thickness is not known. It is believed that cyanide ions absorb onto the substrate (catalyst) and the depositing gold film so as to affect (*i*) the number of gold nucleation sites at the onset of plating, and (*ii*) the growth in the x,y directions vs. the z-direction (throwing power). For example, Fig. 10 schematically depicts the nucleation and growth scenarios when gold was deposited from two baths (20 mM KCN, 45 mM KCN) using a two-step plating of 4 min followed by 45 min. After the electroless Ni substrates were plated for 4 min in either the low-cyanide or the high-cyanide baths, equivalent masses of gold were deposited (an apparent gold thickness of ~0.4 µm if uniformly distributed about the surface). It is



Fig. 9. Effect of cyanide activity on final gold plating thickness.

hypothesized that the low cyanide bath results in a greater nucleation density, Fig. 10a. Subsequently, when the samples were replated to their maximum thickness (the low cyanide sample replated in the low cyanide bath; the high cyanide sample in the high bath) 0.6 and 2.4  $\mu$ m of gold was obtained, respectively. Here, both nucleation and growth were affected. To differentiate this cyanide effect, a low-cyanide-1st gold sample was replated in the highcyanide bath, and conversely, a high-cyanide-1st gold sample was replated in low-cyanide bath, to the maximum gold thickness. The low-high combination resulted in  $1.9 \,\mu m$  of gold—a significant increase in the amount of gold required to completely cover the substrate (catalyst) when compared to the low-low cyanide sample  $(0.6 \,\mu\text{m})$ . This supports that higher cyanide favors z direction growth, since both samples had equivalent nucleation densities initially. When the high-cyanide-1st gold sample was replated in the low-cyanide bath, only 0.9 µm of gold was obtained-a significant decrease in the amount of gold required to completely cover the substrate when compared to the high-high cyanide case (2.4 µm). This reduction in gold thickness results from improved throwing power and the possibility of renucleation. Thus, the cyanide concentration in the gold bath greatly influences the nucleation and growth of the deposit. High cyanide favors a lower nucleation density and greater z-direction growth yielding thicker gold deposits.

Plating rate as a function of temperature.—The effect of bath temperature on gold plating was determined by plating nickel-based substrates at three different temperatures in a bath at 10 mM cyanide. Figure 11 shows the corresponding plating profiles, *i.e.*, gold thickness as a function of time. The maximum deposition rates were taken from



Fig. 8. Gold plating thickness vs. time for various cyanide activities.



Fig. 10. Schematic representation of the effect of cyanide activity on gold nucleation and growth.



Fig. 11. Effect of temperature on gold plating profiles.

the linear portion of the plating profiles. Shown in Fig. 12 is a plot of those rates *vs.* reciprocal temperature. This plots shows an Arrhenius dependence on temperature with an activation energy of 18 kcal/mol. This compares well with published data for electroless gold deposition reactions of about 19 kcal/mol using KBH<sub>4</sub> as a reducing agent (4) and with the oxidation kinetics of hydrazine reported earlier. It should be noted, however, that although similar activation energies are reported using other reducing agents, operating temperatures of those baths are limited to about 80°C due to decomposition of the bath. No decomposition of this formulation occurs up to the boiling point of the bath (102°C), as long as the cyanide activity does not drop below ~0.004M.

Plating reproducibility.—The working concentration of KAu(CN)<sub>2</sub> is typically 17.4  $\pm$  0.5 mM. When the concentration of gold and cyanide are maintained, reproducible rates, thicknesses, and morphologies result. Figure 13 shows a plot of gold thickness vs. bath recycle with the gold and cyanide activity controlled to 0.5 mM. The thicknesses obtained out to 2.5 gold replenishments are constant. Figure 14 compares the morphology obtained initially (left) and after 2.5 recycles (right). As shown, no degradation in morphology is observed if the bath composition is maintained.

## Substrate Effects

The surface condition of the substrate plays a very important role in the integrity of the gold coating obtained



Fig. 12. Effect of temperature on gold deposition rate. Rates determined from linear portion of plating profiles presented in Fig. 11.



Fig. 13. Reproducibility of gold plating thickness vs. percent gold replenished. Cyanide activity controlled by nickel acetate additions.

from this formulation, not unlike all other plating systems. The condition of the surface can affect gold nucleation and growth (thickness), hydrazine oxidation kinetics, adhesion, porosity, and the overall appearance of the deposit. Processes to control and/or modify the substrate surface prior to plating will be discussed.

It has been observed that one of the most important substrate factors affecting the gold deposit from this bath is the amount of surface metal oxide. Figure 15 shows the gold thickness obtained as a function of nickel oxide thickness on the substrate surface. The substrates of this experiment were nickel foils (99.95% Ni) pretreated as noted below and subsequently gold-plated for 15 min at  $85^{\circ}$ C at 0.030M KCN. The oxide thicknesses reported were obtained by x-ray photoelectron spectroscopy (XPS) surface analysis.

The gold thickness obtained at point A in the curve results from plating foils with their native oxides present. About 15-25 Å of nickel oxide (NiO, Ni(OH)<sub>2</sub>) results from environmental exposure. Thickness at point B results from treating the foil in aqueous hydrochloric acid, prior to plating, to minimize the oxide content. Points C and D result from plating foils which were heated in air for 10 min at 300°C and 1 min at 475°C, respectively, to further oxidize the nickel surface prior to gold plating.

Samples plated in the region of point A, while appearing dense, smooth, and brightly colored, are poorly adhered to the substrate and sometimes blistered. Gold deposited onto substrates with a surface condition near point C are poorly adhered and have a very open structure (at  $40 \times$  magnification the deposit appears as discreet islands). Samples plated near point D are so oxidized as to show no gold deposition. Surfaces in the region of point B show the best integrity. This coating is dense, smooth, brightly colored, and strongly adhered to the substrate. The decrease in gold thickness at low oxide levels corresponds to an increase in the number of active sites, *i.e.*, metal content, for



Fig. 14. Reproducibility of gold plating morphology from a fresh bath (left) and a bath that had 2.5 complete recycles of the initial gold content (right). Cyanide activity controlled by nickel acetate additions.



Fig. 15. Effect of nickel oxide thickness on gold thickness.



Fig. 16. Effect of various nickel substrates on gold thickness obtained with increasing cyanide activity.

gold nucleation and hydrazine oxidation, thereby yielding a thinner deposit. The oxide sites otherwise act as inclusions which generate porosity in the deposit causing the deposit to be thicker (point A, Fig. 15) until so many inclusions are present that no deposition takes place (point D, Fig. 15) because there are no active sites for hydrazine oxidation. It is, therefore, desirable to minimize the amount of surface oxide, e.g., by cleaning in HCL prior to gold plating.

Nickel and nickel alloy substrates.—As outlined earlier, the role of the substrate as a catalyst for gold deposition is pivotal in substrate-catalyzed deposition. It is, therefore, expected that changes in the substrate such as morphology and composition would affect the gold deposit. A few examples will give a feel for the sensitivity of the bath to variations in the substrate. Four different types of nickel deposits have been examined. The first three were CVD Ni (18), electroless nickel boron (Allied Kellite 752®), and pure electroless Ni (19). Each deposit was  $\sim 2 \,\mu m$  thick on screen-printed tungsten metallization which had a surface roughness of  $\sim 0.5 \,\mu\text{m}$ . The approach to plating all of these substrates was to normalize the substrates with respect to morphology and composition. For CVD Ni, this involved only a standard HCl activation, since its morphology is essentially a sintered smooth morphology due to the elevated temperature of deposition, typically 850°C. The remaining substrates were sintered in 10% H<sub>2</sub> 90% Ar at 750°C for typically 20 min to smooth and densify the substrate. Allied Kellite 752<sup>®</sup> Ni/B was a special case, since B, which is in the deposit at  $\sim$ 1%, is not a good catalyst for hydrazine oxidation. It was found that adding moisture (25-45°C humidification) to the  $H_2/Ar$  would form  $B_2O_3$ which volatilized away. In contrast, heating in dry H<sub>2</sub>/Ar enhanced the surface boron content to ~10% B and heating in dry  $H_2/N_2$  caused the formation of islands of BN. Shown in Fig. 16 are the resultant gold thicknesses as a function of cyanide level for each of these deposits. As shown in this figure, the different nickel types after treating are undiscernible. All nickel types resulted in approximately the same gold thickness. The only distinct difference was observed with pure electroless nickel, which exhibited a much slower deposition rate in the early stages of deposition but plated to the same final thickness. Also shown in this plot are results obtained with a CVD Ni/Co alloy. As seen, this alloy mimics the results obtained with the other deposits. It should be pointed out, however, that considerable care was given to produce a CVD alloy with a morphology which closely resembled that of CVD Ni. CVD Co in general has a tendency to produce a rough granular surface which behaves quite differently in this bath.

## Conclusion

A unique plating formulation was developed principally for depositing gold onto nickel. The specific nature of cyanide as a selective poison for hydrazine oxidation on gold vs. nickel gives rise to a novel type of plating "substrate-catalyzed" which is neither autocatalytic nor immersion plating. Gold thickness is controlled by bath composition rather than time with cyanide activity as the key control component. This bath is comprised of five components [KAu(CN)2, KOH, KCN, K2CO3, and N2H4] all of which can be easily monitored and replenished. When maintained within the recommended operating range, the bath will plate pure, lemon yellow, gold films with excellent stability, reproducibility, and life. Production baths (~400 liters) have been successfully operated for over a year without seeding or deterioration in deposit characteristics.

Functionality of the gold deposit is obviously dependent upon the particular application involved and as such was not covered in this paper. In the specific application of metallized ceramics for electronic packages, millions of parts have been processed using this formulation. These parts have passed standard Mil Spec 883C requirements for wiring bonding, die attach, lid sealing, solderability, and salt spray.

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