	High Concentration	*Low Concentration*
Copper fluoborate	60 oz/gal (450 g/L)	30 oz/gal (225 g/L)
Fluoboric acid	5.4 oz/gal (40.5 g/L)	2 oz/gal (15 g/L)
pH (colorimetric)	0.2–0.6	1.0–1.7
Temperature	65–150°F	65–150°F
Baume	37.5–39.5°	21–22°
Current density	125–350 ASF	75–125 ASF

The anodes should be OFHC copper. Anode bags should be made of Dynel or polypropylene. Normally, the bath is made up with copper fluoborate concentrate (1.54 gm/cc or 50.84° Be) which contains 92.0 oz/gal cupric fluoborate (26.9% by weight copper metal), 1.4 oz/gal fluoboric acid and 2 oz/gal boric acid (to prevent the formation of free fluoride due to fluoborate hydrolysis). The fluoboric acid (1.37 gm/cc on 39.16° Be) typically contains 90 oz/gal of fluoboric acid and 0.9 oz/gal of boric acid.

Contaminants:

Organic contaminants can affect the deposit appearance/uniformity and mechanical properties, especially ductility. These can be removed by carbon treatment. Cellulose filter aids, free of silica can be used. These baths are often carbon filtered continuously. Lead is the only common metallic contaminant which causes problems and it can be precipitated with sulfuric acid.

Additives:

Normally no organic additives are used. Molasses can harden deposits and minimize edge effects. Some of the same additives (e.g. acetyl cyanamide) used for copper sulfate baths can also be used with the fluoborate formulations.

GOLD PLATING

by Alfred M. Weisberg

Technic, Inc., Providence, RI

All types of gold and gold alloy electroplates are applied for many different applications by many different industries. However, there are eight general classes that may be listed that will include much of present day gold plating.

Class A— Decorative 24K gold flash (2 to 4 millionths), rack and barrel.

Class B— Decorative gold alloy flash (2 to 4 millionths), rack and barrel.

Class C— Decorative gold alloy heavy (20 to over 400 millionths), rack. These deposits may be either C-1 karat color or C-2 karat assay.

Class D— Industrial/electronic high purity soft gold (20 to 200 millionths), rack, barrel and selective.

Class E— Industrial/electronic hard bright heavy 99.5% gold (20 to 200 millionths), rack, barrel, and selective.

Class F— Industrial/electronic gold alloy heavy (20 to over 400 millionths), rack and selective.

Class G— Refinishing, repair and general, pure and bright alloy (5 to 40 millionths), rack and selective brush.

Class H— Miscellaneous, including electroforming of gold and gold alloys, statuary and architectural, etc.

To further simplify an enormous and diverse subject, gold and gold alloy plating solutions may be considered to belong to five general groups:

1. Alkaline gold cyanide, for gold and gold alloy plating. Class A, B, C, D, occasionally F and G, and H.
2. Neutral gold cyanide, for high purity gold plating. Class D and G.
3. Acid gold cyanide, for bright hard gold and gold alloy plating. Occasionally Class B, C, E, F and G.
4. Non-cyanide, generally sulfite, for gold and gold alloy plating. Occasionally Class A, B, C, D, F, G and H.
5. Miscellaneous.

There are literally hundreds of formulations within these five classes of gold plating solutions.

Physical, engineering or aesthetic considerations will determine which of these groups should be considered for a particular job, but economics will usually be the determining factor in selecting a specific formulation and plating method. The price of gold per troy ounce is only one aspect of the economics that must be considered in deciding between rack, barrel, brush, continuous or selective plating. For any individual applications, it is necessary to balance and optimize:

1. The cost of the bath. The volume necessary for a particular method and the gold concentration.
2. The speed of plating. This determines the size of the equipment and the bath and the cost for a given desired production.
3. The cost of drag-out loss. This will depend on the gold concentration used, the shape of the part, if it is rack, barrel, continuous or selective plating, and must include the probable recovery of dragged-out gold by electrolytic or ion exchange recovery.
4. The cost of control and maintenance. Some high speed and high efficiency baths require almost constant attendance and analysis.
5. The cost of the longevity of the bath. High speed and especially high purity

baths with good drag-out recovery must be changed periodically to maintain purity. This results in a certain loss on changeover.

6. Cost of money (interest) to keep the bath.
7. The initial cost of the equipment.
8. The overhead cost of the equipment (whether it is operating or not operating), that is, the interest cost per hour or per day.

Sometimes a simple manual rack or barrel method will be cost effective and at other times, a high speed fully automated plant is justified.

Gold is, today, a freely traded commodity with a different price everyday. In order to plate successfully, it is necessary to watch and control costs.

DECORATIVE GOLD PLATING
Class A, B, C and sometimes G

Much, but not all, decorative plating is applied to jewelry, watch attachments, and other items of personal use and adornment. The thicknesses of gold or gold alloy are usually 0.000002-5″ and the time of plating is 5 to 30 seconds. The recommended trade practice rules for the jewelry industry require that this deposit be called gold flash or gold wash. (In order to be called gold electroplate, it is necessary to have a minimum of 0.000007″.) These deposits are usually applied over a bright nickel underplate and are bright as plated. They do not require any brightening agents or grain refining agents. There are hundreds of different colors and hues but the Class A and B baths shown in Table I will give a representative sample of colors.

All of the "coloring" baths in Table I should use 316 stainless steel anodes. The ratio of anode to cathode area is best at 1:1 or 3:1. Very high ratios, when the tank is used as an anode, tend to give an uneven color, and thickness of deposit and the end pieces will frequently burn. No agitation should be used to ensure a uniform color. Sliding or tapping on the cathode bar will increase the deposition of gold and make each color richer but will quickly deplete gold and unbalance the bath. Gold and alloying metals should be added periodically, based on ampere-hour meter readings. The baths, with the exception of the white, green and rose solutions, should operate at approximately 6% cathode current efficiency. Every 11 ampere-hours of operation, five grams of gold should be added, together with the proper amount of alloy.

All operating conditions should be controlled as closely as possible. Any variation of the conditions will affect the cathode current efficiency of either the gold or the alloy, or both. Changes in the amount of the metals deposited will change the color of the deposit. Other factors that will alter the color of the deposit are:

1. The surface finish of the basis metal will change the apparent color of the deposit. This is particularly noticeable when a single item has both bright and textured areas. Plated in the same bath, they will appear to be two different colors.
2. The color of the basis metal alters the color of the gold deposit by adding its color to the gold until the deposit is sufficiently thick to obscure the base. Most gold alloy deposits, if properly applied, will obscure the base after 2½ millionths of an inch have been applied. Proprietary additives will allow the gold to obscure the base with as little as 1½ millionths to allow richer colors with the use of less gold.
3. Current density. Too low a current density tends to favor the deposition of gold and causes the alloy to become richer. Too high a current density at first favors the alloy and pales out the color. Further raising the current density causes the development of pink or orange or red tones.
4. Free cyanide. Solutions containing copper are very sensitive to changes in the free-cyanide content. Low cyanide causes an increase in the pink or red shades and high cyanide significantly increases the yellow by holding back the copper.
5. Temperature. The effect is similar to current density. Low temperatures favor

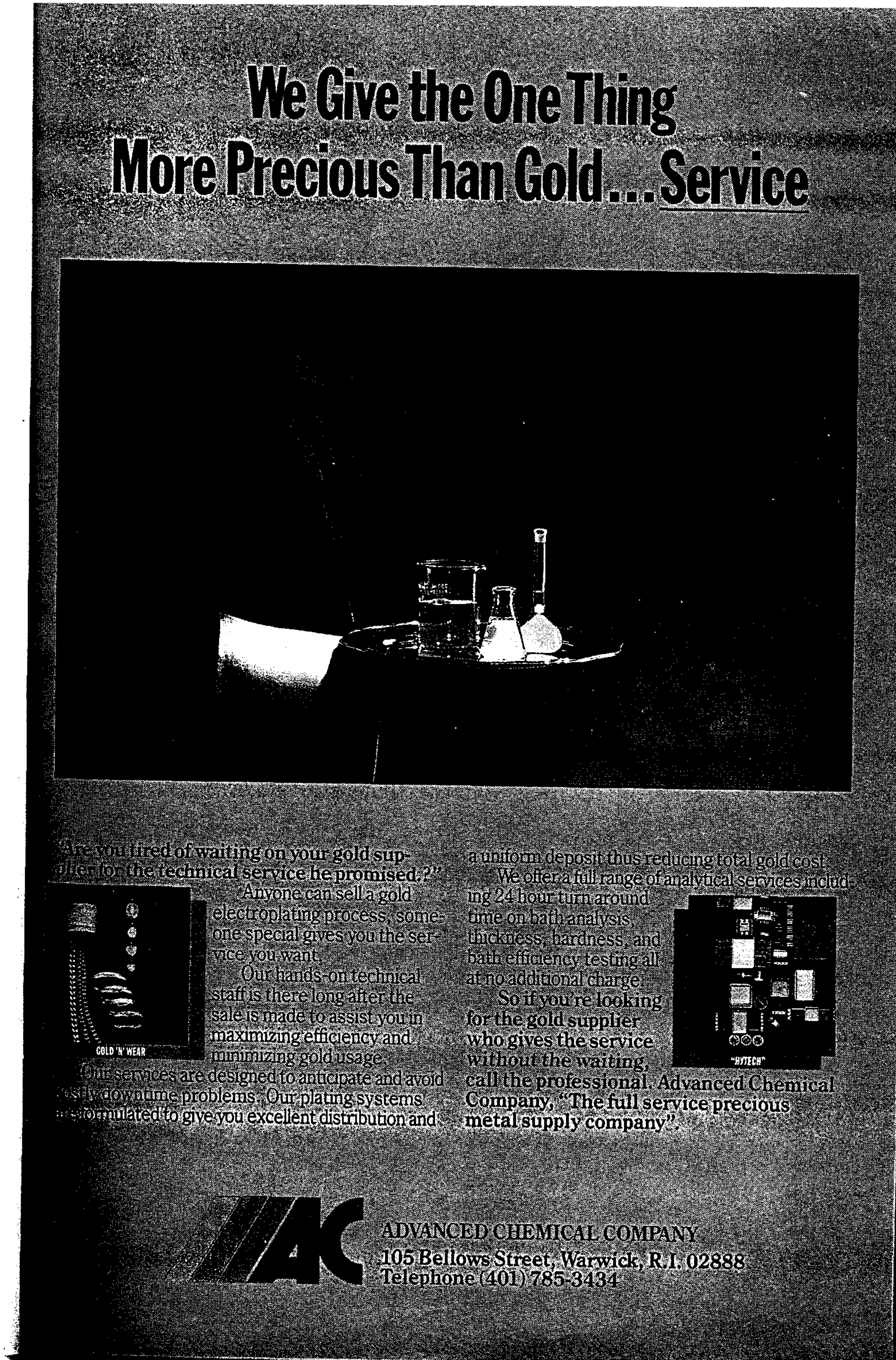
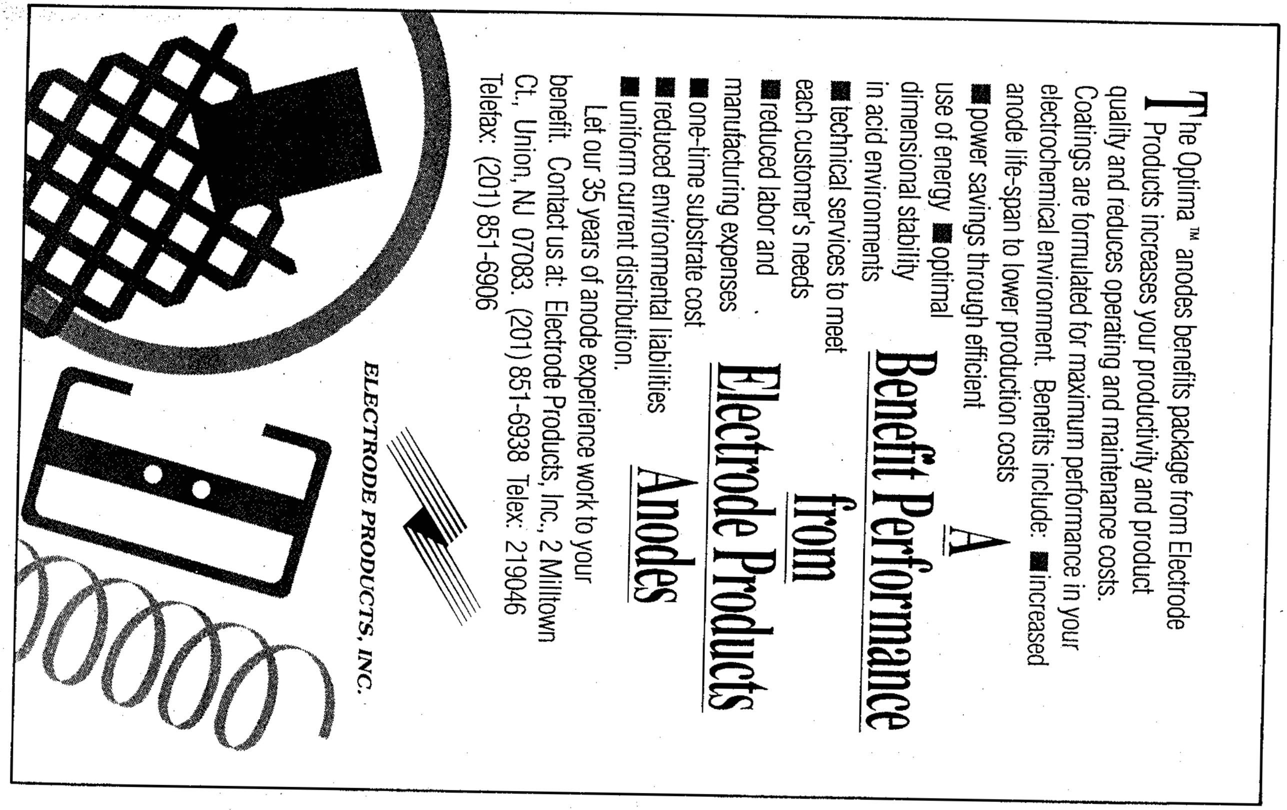


Table I. Gold and Gold Alloy Flash Baths (Type A & B)

	24K or English	*Low Cyanide English*	*HAMILTONS Yellow*	*HAMILTONS Pink*	*HAMILTONS Green*	*White #1*	*White #2*	*Green*	*Pink*	*Rose*
Gold as potassium gold cyanide, g/L	1.25–2	1.25–2	1.25–2	1.25–2	1.25–2	0.4	0.325	2	0.82	6
Free potassium cyanide, g/L	7.5	7.5	7.5	2.0	2.0	15	15	7.5	4	4
Dipotassium phosphate, oz/gal	2	2	2	2	2	2	2	2	2	—
g/L	15	15	15	15	15	15	15	15	15	—
Sodium hydroxide, g/L	—	—	—	—	—	—	—	—	—	15
Sodium carbonate, g/L	—	—	—	—	—	—	—	—	—	30
Nickel as potassium nickel cyanide, g/L		0.025-1.4	0.025	0.025	0.025	1.1	—	—	0.2	—
Copper as potassium copper cyanide, g/L	—	—	0.13	1.1	—	—	—	—	2.7	—
Silver as potassium silver cyanide, g/L	—	—	—	—	0.05	—	—	0.25	—	—
Tin, g/L	—	—	—	—	—	—	2.1	—	—	—
Temperature, °F	140–160	140–160	150–160	140–160	140–160	150–160	150–160	130–160	150–160	150–180
Current density, ASF	10–40	10–40	10–35	20–50	10–40	30–60	30–50	10–30	30–40	20–50



the gold yellows and higher temperatures favor the alloy colors. Temperatures over 160°F should be avoided, except in the case of rose golds, because of the rapid breakdown of cyanide and the darkening of the color.

6. pH. It is rarely necessary to adjust the pH of a gold or gold alloy bath. They are usually buffered between 10 and 11. Only pink or rose or red golds are favored by higher readings.

BARREL PLATING
Class A and B

Gold as $KAu(CN)_2$	0.4 g/L
Free cyanide NaCN	30 "
Disodium phosphate	23 "
Temperature	100-120°F
Anodes	Stainless steel 1:1 or better

In typical jewelry barrel plating, about 6 V is necessary. A decorative finish of 0.000002" is deposited in three to four minutes. If the parts are small and densely packed in the barrel, it may be necessary to plate up to eight minutes to get an even coverage.

The above formulation may be altered to achieve various colors. Champagne or light Hamilton colors may be achieved by adding 1.5 to 3 g/L of nickel. Lowering the temperature will also produce a lighter and more uniform color.

ANTIQUE GOLDS
Class A and B

The art of the 19th century platers was to produce a finish that looked as if it had been mercury gilt over silver or copper (Vermeil) and buried or weathered by the elements for a century or so. Each master plater developed an antique finish that was his trademark. The modern basic method to achieve this effect is to:

1. "Burn on" a dark smutty finish.
2. Relieve the highlights on a deeply recessed piece or the flat surface on a filigreed piece by either hand-rubbing with pumice and sodium bicarbonate, wheel-relieving with a cotton buff, tampico brush or a brass or nickel-silver wheel. Other methods are possible.
3. Flash gold or a gold alloy deposit on the imperfectly cleaned highlights.

The more the solutions in Table II are abused, and the more the operator violates good plating practice and good cleanliness, the better and more distinctive the finish will be.

Table II. Antique Baths

	Bright Yellow Highlights Orange Brown Smut	*Green Highlights Green Black Smut*
Gold as $KAu(CN)_2$, g/L	6	2
Silver as potassium silver cyanide, g/L	—	0.3
Sodium hydroxide, g/L	15	—
Sodium carbonate, g/L	30	—
Ammonium carbonate, g/L	—	38
Sodium cyanide, g/L	4	15
Temperature, °F	160–180	70–90
Agitation	none	none
Current density, ASF	30–40	10

An expensive finish, requiring double-racking, but a beautiful finish, is Russian Antique. This may be produced by relieving the green gold antique in Table II and then flashing over with the 24K or English gold.

Table III. A Selection of Typical Acid Gold Color Baths for Thick Deposits

	22 K Yellow	*24 K Yellow*	*Hamilton 1N*	*Hamilton 2N*	*Hamilton 3N*
Gold, g/L	4-8	4-8	4-8	4-8	4-8
Conducting salts, g/L	120	120	120	120	120
Nickel as nickel metal, g/L	0.2	—	7-10	4-6	1-3
Cobalt as cobalt metal, g/L	1	0.5	—	—	—
pH	4.0-4.5	4.4-4.8	4.0-4.2	4.0-4.2	4.0-4.2
Temperature, °F	90-100	80-90	120-140	100-120	90-100
Current density, ASF	10-20	10-20	10-20	10-20	10-20
Agitation	Required	Required	Required	Required	Required

The old bath antiques of the 1940's and 1950's that did not require double-racking or stringing are no longer practical because of the high price of gold.

HEAVY DECORATIVE GOLD
Class C-1 and C-2

It is necessary to distinguish between the actual karat assay of a gold alloy electroplate and the apparent karat color of the plate. In general, a decorative karat deposit will appear to be a much lower karat than it actually will assay. A 14K color deposit may actually assay 20 to 21 K. The formulas in Table III will deposit karat colors but will actually assay a higher karat. (In computing costs, it is best to assume the deposit is pure gold.)

INDUSTRIAL/ELECTRONIC GOLD PLATING

Gold is electroplated for many different electrical and electronic purposes, however, today the majority of gold plating is applied to three specific classes of components:

Semiconductors
Printed/etched circuits
Contacts/connectors

The requirements for the deposit of each of these components, and the methods of plating that are used, are:

	Purity	*Hardness*	*Surface*	*Rack*	*Barrel*	*Continuous*
Semi-conductors	99.95%	60-80 Knoop	mat	yes	yes	yes
Printed/etched circuits	99.5 - 99.7%	120-180 Knoop	bright	yes	no	yes
Contact/connectors	99.5 - 99.7%	120-180 Knoop	bright	yes	yes	yes

The gold plating solutions that are actually used by the electronic plater may be conveniently classified by pH range.

Alkaline cyanide	pH over 10
Neutral cyanide	pH 6 to 9
Acid cyanide	pH 3½ to.5

(Below a pH of 3½, the gold cyanide is generally unstable and precipitates.)

Non-cyanide (usually sulfite)	pH 9 to 10

The baths that are primarily used by the industry are as follows:

	Alkaline cyanide	*Neutral cyanide*	*Acid cyanide*	*Non-cyanide*
Semiconductors	Class D	Class D	—	—
Printed circuits	—	—	Class E	—
Connectors	Class E	—	Class E	—

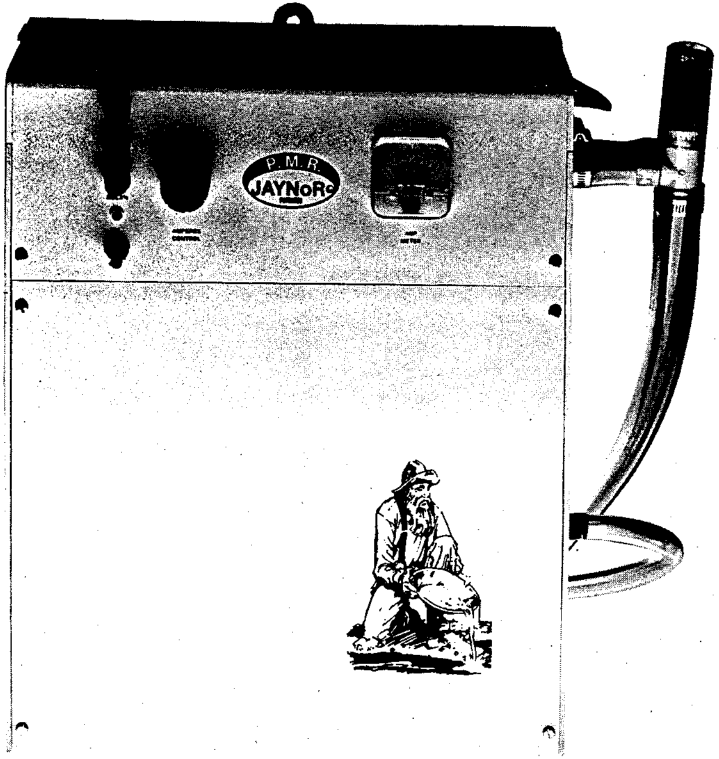
Low karat gold alloys, Group 2 or 3 (Class F), have not found much application in the US. The alloying metal generally affects the electrical properties of the gold adversely. As little as 1% of iron will increase the electrical resistance of gold over 1000%, and similar amounts of other metals have less, but still unacceptable, effects on the conductivity of the gold deposit. Even amounts of alloy, much less than 1%, will inhibit or totally prevent good welding or die bonding of semi-conductor chips to a gold surface. Duplex coatings of a low karat gold base overplated with a high karat gold surface, while acceptable in some applications from an electrical point of view, have tended to lose their economic advantages as good engineering and new design has required less total gold.

ALKALINE CYANIDE BATHS
Group 1 (Class D)

Typical baths that are still used are:

	Mat	*Bright*
Gold as potassium gold cyanide, g/L	8–20	8–20
Silver as potassium silver cyanide, g/L	—	0.3–0.6
Dipotassium phosphate, g/L	22–45	—
Potassium cyanide, g/L	15–30	60–100
pH	12	12
Temperature, °F	120–160	60–80
Anodes	stainless steel	stainless steel
Anode/cathode	1:1	1:1 to 5:1
Agitation	moderate-vigorous	none to moderate
Current density (Rack), ASF	3–5	3–8
Current density (Barrel), ASF	1–2	1–2
Current efficiency, %	90–95	90–100
Time to plate 0.0001″	8 min @ 5 ASF	7 min @ 6 ASF
Replenishment	1 oz gold/ 4½ amp-hours	1 oz gold/ 4½ amp-hours

Note: For the mat deposit, the higher the temperature, the better the deposit and the higher the speed of plating; however, temperatures over 150°F result in rapid breakdown of the free cyanide and a build up of cyanide breakdown impurities.



The alkaline cyanide baths are particularly sensitive to organic impurities—both those introduced by drag-in and by the absence of general cleanliness, as well as those caused by cyanide breakdown. In order to maintain a good appearing and structurally sound deposit, it is necessary to carbon treat and filter the solution periodically. The grade of carbon used must be pure enough not to introduce more impurities than it removes. Constant filtration through a filter packed with carbon is accepted practice, but is not as efficient in removing impurities as a batch treatment. If the solution is quite contaminated before treatment, it is important to save the used carbon and the used filter cartridge for refining to recover any gold lost in the treatment.

The best method to carbon treat a solution is to:

1. Heat the solution to 150–160°F.
2. Transfer the hot solution to an auxiliary tank.
3. Add 1/8 to 1/4 oz of carbon per gallon of solution.
4. Mix for no longer than 20 to 30 minutes.
5. Filter the solution by decantation back into the original tank.

No general rule can be given for the frequency of carbon treatment. This will depend upon general cleanliness and housekeeping, as well as the work being processed; however, it will vary from once every two weeks to once every two months. The room temperature bright bath will require much less carbon treatment than the hot cyanide bath.

NEUTRAL CYANIDE SOLUTIONS

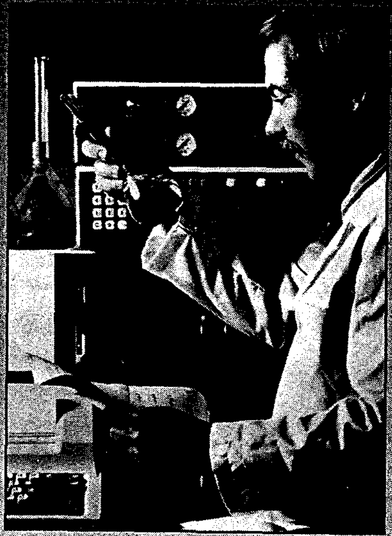
Group 2 (Class D)

The neutral cyanide baths are primarily used by the semi-conductor industry. Considerable care must be exercised to prevent contamination of the solution as even a few parts per million of undesirable inorganics can cause the deposit to fail in compression or die bonding.

Typical non-proprietary solutions are:

	Rack or Barrel	*High Speed Continuous*
Gold as potassium gold cyanide, g/L	8–20	15–30
Monopotassium phosphate, g/L	80	—
or		
Potassium citrate, g/L	70	90
pH	6.0–8.0	4.5–5.5
Temperature, °F	160	120–160
Agitation	desired	violent
Anodes	Platinum clad columbium	Platinum clad columbium
Current density, ASF	1–3	100–400
Current efficiency, %	90	95–98
Time to plate 0.0001″	12 minutes	10–20 seconds
Replenishment	1 oz gold/ 4½ amp-hrs	1 oz gold/ 4½ amp-hrs

Note: Pulse plating may be used to advantage with the high speed formulation. Most effective is a 10% duty cycle. Proprietary baths add grain refiners that decrease porosity, increase the maximum allowable current density, decrease grain size, and generally improve the appearance of the deposit.



ACID CYANIDE PLATING SOLUTIONS
Group 3 (Class E)

	Barrel *Mat Bath #1*	*Rack or Barrel* *Bright* Bath #2	*High Speed/ Continuous*
Gold as potassium gold cyanide, g/L	8	8	8-16
Citric acid, g/L	60	60	90
Cobalt as cobalt metal, g/L or Nickel as nickel metal, g/L	—	0.2-0.5	0.75
pH	3.8-5.0	3.8-4.5	3.8-4.3
Temperature, °F	120-140	70-90	70-120
Anodes	platinum clad	platinum clad or stainless steel	platinum clad
Agitation	desirable	desirable	violent
Current density, ASF	1-5	5-20	100-400
Current efficiency, %		30-40	30-40
Time to plate 0.0001″		10 min @ 10 ASF	15 sec @ 400 ASF
Replenishment		1 oz gold/ 12 amp-hrs	1 oz gold/ 12 amp-hrs

Note: Pulse plating can be applied with the high speed bath, but is not widely used.

INDIUM PLATING

by James A. Slattery

Indium Corporation of America, Utica, NY

Indium Cyanide Bath:

Indium is the only trivalent metal that can readily be electrodeposited from a cyanide solution. Solution make-up and operational parameters are summarized in Table I. Indium hydroxide is first prepared by the precipitation of $InCl_3$ using NH_4OH or NaOH. The purified and dried $In(OH)_3$ is then dissolved in an alkaline cyanide solution stabilized with a sugar such as D-glucose, dextrose or sorbitol. The cyanide bath is used in applications demanding extremely high throwing power and adhesion. Deposits are uniform and bright mat in appearance. Since this is a high pH bath it has the disadvantage of requiring the use of insoluble anodes, necessitating replenishment in the form of an indium cyanide concentrate. Its cathode efficiency is initially 90% but upon bath aging decreases from this value to 50 to 75%; thus, periodic determination of the plating rate is required.

Indium Sulfamate Bath:

The indium sulfamate bath was developed to overcome several disadvantages of the cyanide bath.

Table I. Indium Cyanide Plating Bath

Indium as metal	4 Troy oz/gal	(33 g/L)
Dextrose	4 ″	(33 ″)
Total cyanide (KCN)	12.77 Av. oz/gal	(96 ″)
Potassium hydroxide (KOH)	8.5 Av. oz/gal	(64 ″)
Temperature (static)	Room temperature	
Cathode efficiency	50-75%	
Anodes	Plain Steel	
Throwing power	Excellent	
Quality of plate	Excellent	
Ease of solution analysis	Difficult	
Critical temperature (working)	None, with or without agitation	
Color of solution	Clear, pale yellow to dark amber	
Wettability	Easy	
Tendency to pit	None	
Control of solution	Cyanide and metal by additions	
Use	General	
Current	15-20 ASF (162-216 A/m²)	
pH	High pH	

Replenishment: Since insoluble anodes are used, it is necessary to replace the indium metal content of this alkaline bath. A concentrate, Cy-An-In, can be added directly to the bath. Under normal conditions addition of cyanide will not be required, however, it is best to keep the cyanide concentration at about 100 g/L.

Efficiency: Plating efficiency of the bath will be maintained within a range suitable enough for normal plating until the indium content is reduced. Its plating rate should be checked at regular intervals because, as the bath is depleted, a decrease in rate of deposition is to be expected.