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CURRENT ELECTROPLATING AND ELECTROFORMING PRACTICES AT NRAO

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1. INTRODUCTION

The chemistry laboratory is equipped to perform the following operations at present: electroplating gold, copper, nickel, chromium, tin; immersion plating zinc; electropolishing aluminum, copper; electroforming copper, nickel; anodizing aluminum; and photofabrication of mini-circuits using photo-etching methods developed by the Eastman Kodak Company[1].

Plating is performed in the baths listed below:

Gold:

(1) American Chemical and Refining Company, C-27 acid gold plate process, and #56 strike gold plate process[2]

Copper:

(1) Sel-Rex Corporation, Cu Bath #1 acid copper plate process[3]
(2) Standard rochelle salt cyanide copper strike bath[4]

Nickel:

(1) Sel-Rex Corporation, Lectro-Nic 10-03, semi-bright nickel plating process[3]

Chromium:

(1) Standard chromic acid plating bath[4]

Tin:

(1) Stannate alkaline tinplate modified with bismuth addition[5]

Electropolishing is performed in a bath manufactured by Ashland Chemical Corporation, Electropolish #1[6].

2.1 GOLD PLATING

Gold is presently being applied to thicknesses ranging from 40 microinches (1.0 microns) to 80 microinches (2.0 microns) for general purposes. This thickness should provide adequate protection in normal environments. If a part will be subjected to wear, thicker coatings are applied, or another metal is chosen, since gold is rather soft, (Knoop hardness value of 100-200) about as hard as copper. Plating thickness is measured by monitoring the total current passed during plating, From this value, one obtains the weight of metal plated which is used to find the average thickness of the applied coating[7].

$$T = C \cdot \frac{W}{AxD}$$

where C = constant dependent only on units

W = weight

A = area

D = density

T = thickness

In mixed units, this becomes

$$T \text{ (inches)} = (.394 \text{ W (grams)})/(\text{A}(\text{cm}^2) \text{ x D } (\text{gms/cm}^3))$$

An approximate formula for gold which yields results in mils (1 mil = .001 inch) is

$$[\text{WT (grams)} \div \text{area (inches}^2)] \text{ x } 3.462 = \text{mils plated}$$

The weight of gold plated per unit current passed is measured by plating tests. If all the current were carried by gold ions, the weight of gold deposited would equal 120 milligrams per ampere minute, or 7.28 grams per ampere hour. In practice, only 1/4 of the charge is actually used in gold deposition, yielding a value of 30 milligrams per ampere minute. The remaining charge is wasted in hydrogen gas evolution and breakdown of bath constituents. The ratio between the charge carried by the primary metal ions (in this case, gold) to the total charge passed through the plating tank is commonly referred to as the cathode efficiency of the plating process. Most acid gold baths have cathode efficiencies of roughly 25%.

2.2 CLEANING

To obtain sound gold plate, several steps are necessary to prepare the surface for plating. First, the part is degreased to remove soldering fluxes, oils, and some fingerprints. Perchlorethylene is the best solvent for general applications, often used in conjunction with ultrasonic agitation. After drying, the part is soak-cleaned in an alkaline detergent cleaner to remove inorganic salts, dirt, remaining fingerprints, light grease, and light oxide films. The part is thoroughly inspected for cleanliness. It is then dipped in an acid bath, chosen for the particular base metal, to prepare the surface for plating. This dip removes all remaining oxide layers, and may also serve to activate the base metal, as in stainless steel preparation.

After cleaning, the article is transferred wet into the plating tank as quickly as possible to prevent re-oxidation and spotting due to drying. The plating cycle must be chosen for the specific metal or metal combination which is to receive the coating.

2.3 STRIKE DEPOSITS

Most metals are first coated with a thin layer of copper, known as a "strike" or "flash". This coating is on the order of 10 microinches (.4 micron) or less.

A copper strike improves adhesion of subsequently plated metal layers and produces a more uniform and attractive finish. Copper cyanide baths (from which most strikes are applied) possesses exceptional throwing power, assuring total coverage of the part. Copper also is one of the easier metals to apply, and, when plated from cyanide baths, will cover a wide variety of base metals. This is due in part to the inherent cleaning power of the alkaline cyanide radical.

Another function of strike baths is to act as contamination barriers. As an example, the gold strike bath presently in use not only serves to improve the adhesion of the subsequent heavier gold plate, but also serves as a final rinse, leaving only gold ions and bath electrolytes on the surface of the plated article, which do no harm to the more expensive main plating bath.

2.4 QUALITY CONTROL

Quality control depends on bath maintenance and cleanliness. Sources of contamination include airborne dust, drag-in, i.e. contamination introduced into solutions from the surface of parts, and dissolution of the base metal before applying current. These can be prevented by taking appropriate steps, such as thorough rinsing between plating steps, including a distilled water rinse, adequate ventilation of the plating tanks, having the current on as the part to be plated is immersed, and utilization of a strike bath or a dip composed of one of the plating bath salts as a contamination barrier. Plating baths should periodically be analyzed for contamination and control purposes. For example, the ACR C-27 gold bath requires a pH of 4.2 and a specific gravity of 12° Baume' for optimum results, which are controlled with a pH meter and a hydrometer, respectively. The pH may be lowered by additions of ortho-phosphoric acid and may be raised with reagent grade potassium hydroxide. The specific gravity is controlled by the addition of water. A chemical analysis of gold content is valuable for correlating the actual gold remaining with the ampere-hour reading of the bath. Another useful test is that using the Hull cell, manufactured by the R. O. Hull Company[8]. Specifics for these and other tests can be found in the literature[9].

2.5 BATH DECONTAMINATION

Several methods are useful for removing organic contaminants from plating baths. The most effective is treatment with activated carbon. One or two ounces per gallon will suffice, aided by heat if contamination is suspected to be high. Treatment is continued for 2-4 hours with agitation in a separate tank from that used for plating. The carbon is then filtered from the solution and any additives present in the bath are replenished, since these also will be removed by the carbon. Most bright plating baths require organic additives. Specifically, the Cu Bath #1 copper bath used at NRAO requires a combination addition agent for producing bright deposits. This additive is called Cu Bath "HY" addition agent and is proprietary to the Sel-Rex Corporation.

2.6 AGITATION

Several methods of agitation are presently in use. For gold plating, solution agitation with a magnetic stirrer has proven adequate, with occasional cathode agitation to dislodge bubbles of hydrogen from the article being plated. Ultrasonic agitation is useful, since it will continually degas the solution. Cathode rod agitation is useful for maintaining uniform agitation for electropolishing or plating, and consists of mechanically moving the article being plated (cathode) by means of a motor and rod attachment. Cathode rod agitation is often used in copper plating.

3.1 ELECTROFORMING

Electroforming has been in development over the past several months. Presently, copper is the metal being electroformed for its electrical characteristics; however, the capability also exists for nickel electroforming.

In this process, an aluminum mandrel is copper plated to a thickness ranging from 25 mils (.025 inch) to an inch or more. The aluminum is subsequently dissolved, producing parts with complex internal shapes and close tolerances. The limitations involved in electroforming require that the mandrel possess no deep recesses or sharp internal corners, which cannot be completely filled. If a recess exists in a mandrel which is deeper than it is wide, copper inserts must be machined to fit these depressions and grown into the electroform.

Electroforming is presently done in a proprietary copper plating bath, Cu Bath #1 acid copper plating process, manufactured by the Sel-Rex Corporation[10]. This bath is a low copper-high acid bath using a patented addition agent to produce bright, levelled copper plate. It possesses high throwing power and is easily maintained.

For aluminum mandrels, (usually alloy 6061) the following preparation is employed:

(1) Degrease in perchlorethylene using ultrasonic agitation.
(2) Dry
(3) Soak clean in mild, neutral (pH7) detergent bath
(4) Rinse in cold water
(5) Dip in 40% (by volume) HNO_3
(6) Rinse
(7) Dip in 10% (by weight) NaOH until the aluminum just begins to gas
(8) Rinse in cold water
(9) Dip in zincate immersion bath for 30 seconds, using ultrasonic agitation
(10) Rinse in cold water
(11) Dissolve zinc film in 40% (by volume) HNO_3
(12) Rinse in cold water
(13) Repeat step 9
(14) Rinse in cold water
(15) Copper strike in cyanide bath, 2 minutes at 24 asf (amperes per square foot)
(16) Rinse in cold water
(17) Dip in 10% (by volume) H_2SO_4
(18) Transfer into electroforming bath

Gold may be plated after the cyanide copper strike to provide an internal gold plate on the finished part.

3.2 DEPOSIT CONTROL

Electroforming is plagued with the same problems as electroplating, only to a greater extent. Internal stress in the electrodeposit is of primary concern, and must be controlled. Copper deposits from sulfate baths (such as Cu Bath #1) possess inherently low stress. Nickel, however, usually has much higher stress values when deposited from aqueous plating baths. Sulfamate type baths produce the lowest stress values and this bath is currently in use at NRAO.

Two forms of stress occur in electrodeposits. The first, tensile stress, causes deposits to contract and pull away from the base metal, while the second, compressive stress, produces buckling of the plate and blisters, due to expansion of the deposit. Both forms may exist in an electrodeposit; they are not mutually exclusive.

Anode placement is important to promote uniform growth during electroforming. Portions of the mandrel closest to the anode receive the most plate, while more remote sections receive less plate, due to a lower effective current density. Sharp external corners build up most rapidly and internal corners are difficult to plate due to low current density.

4. PLATING CYCLES FOR VARIOUS BASE METAL COMBINATIONS

4.1 GOLD ON COPPER, BRASS, AND SOLDERED COPPER OR BRASS

(1) Degrease in perchlorethylene using ultrasonic agitation.

(2) Dry

(3) Soak clean in alkaline detergent, 1 ounce per gallon NaOH, 2-4 oz/gal detergent at 150-180°F.

(4) Rinse in cold water

(5) Inspect for clean surface

(6) Dip in 10-20% (by volume) HBF_4

(7) Rinse in cold water

(8) Copper strike, cyanide copper bath at 10 asf until the part is covered, moving the part to dislodge hydrogen gas bubbles

(9) Rinse in cold water

(10) Dip in 10-20% acid

(11) Rinse in cold water

(12) Apply gold strike as per manufacturer's directions

(13) Gold plate, without rinsing after gold strike

The acid dip is chosen for its ability to clean solder joints, which may also require hand scrubbing with an abrasive detergent. Other acids, such as H_2SO_4 or HCl may be used if no solder is present.

The gold baths presently used are operated under the following conditions:

Gold strike #56, 30-60 seconds at 5 asf, 90°F until the part is uniformly covered.

Gold plate C-27, 10 asf, 80°F with agitation (solution and/or otherwise). This bath deposits gold at a rate of .03 grams per ampere minute, or roughly 0.1 mil (2.5 microns) in 15 minutes at 10 asf.

Insoluble platinum plated titanium anodes are required with an anode/cathode ratio of 2:1. After being plated to the desired thickness, the part is rinsed in hot water and air dried.

4.2 STAINLESS STEEL

(1) Degrease as for copper

(2) Dry

(3) Soak clean as above (stronger cleaner may be necessary)

(4) Rinse

(5) Dip in 10% (by volume) H_2SO_4

(6) Activate, making part cathodic in .05 oz/gal $CuSO_4$ in conc. HCl at 50 asf, 1-5 minutes using Ni anode

(7) Copper strike as above

(8) Plate with desired metal as above

Other activation methods may be found in the literature[11].

4.3 ALUMINUM

Aluminum is plated following the procedure for preparing electroforming mandrels. If a solderable surface is desired, the aluminum may be anodized in phosphoric acid and subsequently copper plated to resist soldering temperatures[12].

5.1 SPECIAL PLATING APPLICATIONS

Research at present involves plating the interior walls of WR10 (75-110 GHz) waveguide with gold to obtain a low-loss finish. The waveguide measures 0.1 inch x0.05 inch and is made of stainless steel. This represents an especially difficult job for plating. First, the stainless steel must be activated, and then plated as rapidly as possible to avoid formation of a passive oxide film. Interior anodes are required, either of stainless steel or platinum, and must be insulated from the walls of the waveguide. The set-up for producing these pieces was suggested by the American Chemical and Refining Company, which currently plates stainless steel waveguides for NRAO and supplies the C-27 gold plating bath.

Briefly, the waveguide is placed in a suitable jig and plating solution allowed to run through by gravity flow. The jig also has provisions for holding the inside anode. Small lacquer beads are applied to the anode wire to provide insulation from the cathode. This set-up has yielded waveguides with slightly higher loss than that commercially produced. Results are tabulated in Table I.

TABLE I

	WAVEGUIDE TYPE	WAVEGUIDE FINISH	TEST FREQUENCY (GHz)	LENGTH (Inches)	VSWR (dB)	ATTENUATION (dB/ft)
1	Baytron	Rhodium Plated Coin silver	89.30	6	20.5	1.70
2	NRAO Coin Silver	Coin silver, not degreased	89.30	6	16.9	2.50
3	NRAO Coin Silver	Coin silver, degreased	89.30	6	19.1	2.00
4	Stainless Steel	Gold plated stainless	89.30	6	14.0	3.50
5	Stainless Steel	Gold plate over copper plate	89.30	6	15.3	3.30
6	Stainless Steel	Gold plate over copper plate	89.30	6	16.5	2.70
7	Stainless Steel (ACR Plated)	Gold plate over nickel plate	89.30	6.5	17.4	2.21
8	Stainless Steel	Unplated				

NOTE: All waveguide tested is type WR10 (75-110 GHz), .100 x .050 inches

6. COSTS

Electroplating with gold presently costs NRAO roughly $2 per piece processed, based on labor and materials. Current gold prices average $120 per troy ounce; a five square inch part costs $.40 worth of gold when plated to a thickness of 1.5 microns. Labor and equipment account for the remaining costs. As the number of pieces plated increases, the cost per part will decrease, due to lower labor costs.

Electroforming represents a substantial saving over commercial fabrication. A recently completed set of (6) mandrels was electroformed at NRAO at a cost of $15 per mandrel, as compared to $60 per mandrel from a commercial fabricator for a previous set of similar mandrels.

7. REFERENCES

[1] Eastman Kodak Co., photofabrication techniques, Rochester, New York 14650.

[2] American Chemical and Refining Company, Inc., "C-27 Acid Gold Plating Process and #56 Strike", Waterbury, Connecticut 06714.

[3] Sel-Rex Corporation, "Cu Bath #1 Acid Copper Plating Process, Lectro-Nic 10-03 Bright Nickel Plating Process", Nutley, New Jersey 07110.

[4] Metals and Plastics Publications Inc., "Metal Finishing Guidebook and Directory", 41st Edition, Westwood, New Jersey, 1973.

[5] This bath is a standard tinplate bath with a bismuth addition to prevent "tin pest" (powdery coatings at low temperatures). It has been made up of high purity chemicals to yield a very pure tin-bismuth plate.

[6] Ashland Chemical Co., "Electropolish #1", Columbus, Ohio.

[7] Blum and Hogaboom, "Principles of Electroplating and Electroforming", 3rd Edition, New York, 1949.

[8] R. O. Hull and Company, Inc., Technical Bulletin "Hull Cell Plating Tests", Cleveland, Ohio.

[9] Metals and Plastics Publications Inc., "Metal Finishing Guidebook and Directory", 41st Edition, Westwood, New Jersey, 1973.

[10] Sel-Rex Corporation, "Cu Bath #1 Acid Copper Plating Process", Nutley, New Jersey 07110.

[11] Graham, A. Kenneth, "Electroplating Engineering Handbook", 2nd Edition, New York, 1962, pp.195-196.

[12] Metals and Plastics Publications, Inc., "Metal Finishing Guidebook and Directory", 41st Edition, Westwood, New Jersey, pp.229.

8. ACKNOWLEDGEMENTS

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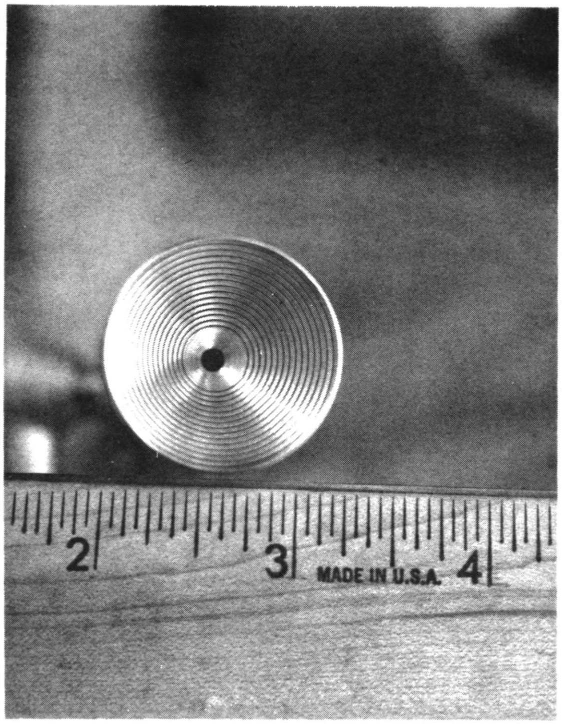

FIGURE 1 — Electroformed 85-95 GHz Conical, Corrugated Feed Horn for Use on the 36-ft Telescope at Tucson, Arizona

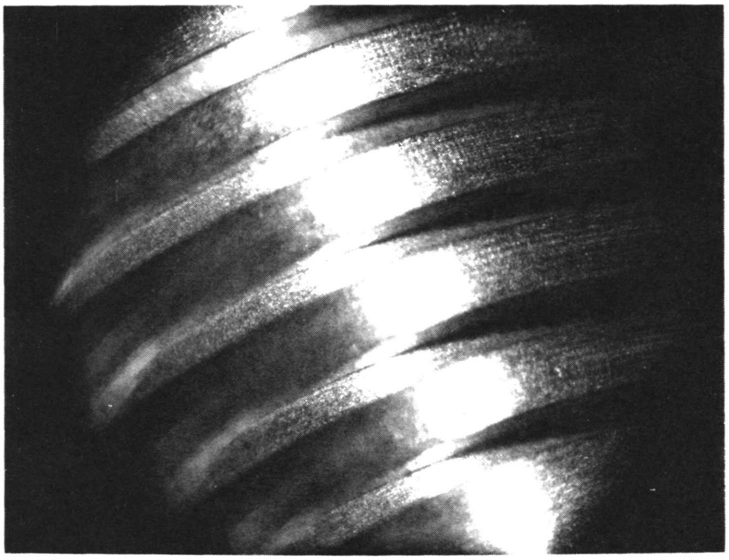

FIGURE 2 — Section of 85-95 GHz Feedhorn, 16X

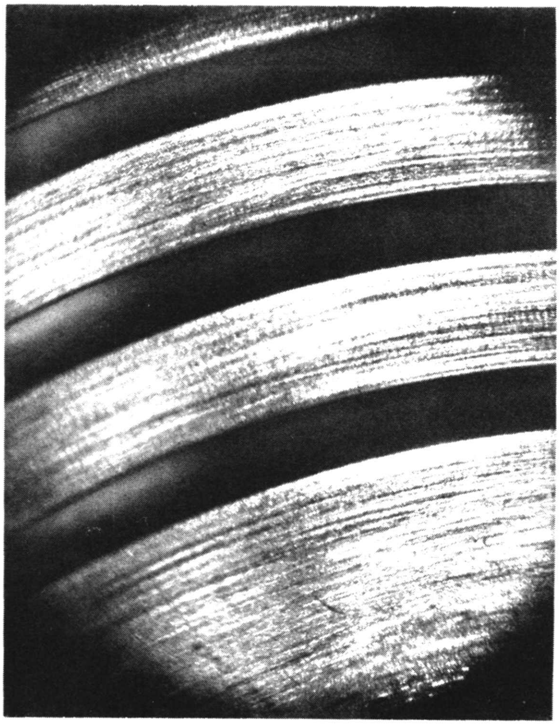

FIGURE 3 — Section of 85-95 GHz Feedhorn, 25X