

# *CHAPTER-I*



## *Introduction*

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## INDRODUCTION

### 1.1. Electrodeposition

Electrodeposition is one of the widely used coating techniques. It may be defined as the electrodeposition of an adherent metallic coating upon a substrate for the purpose of securing its surface different from those of the base metal. Generally, electroplating is performed with aqueous solution consisting of simple salts, complex or a fused salt medium.

Electroplating serves to improve the following properties of base metal.

- Protection from corrosion.
- Appearance.
- Superior hardness and better wear resistance.
- Lower contact resistance and increased reliability.
- Improved solderability.
- Better base for other finishings.
- Improved lubricity under pressure.
- Resistance to high temperature.
- Specific electrical and magnetic properties.
- Increased electrical conductivity.

The electrodeposition of metals and alloys invariably exhibit a crystalline microstructure and hence their properties mainly depend on the composition of the electrolyte and the operating conditions like pH, temperature, presence of additives and operation with or without agitation, etc.

Good adhesion of the coating requires an appropriate pretreatment of substrate, which is primarily an essential operation. Anodes used for plating may be of soluble or insoluble type, depending upon the nature of the electrolyte. Soluble anodes made of the same metal maintain their concentration by the subsequent dissolution of the anode. On the other hand, in order to maintain the bath concentration in the case of use of insoluble anodes, frequent addition of the metal salt is employed.

After the subsequent mechanical preparation, the article is degreased either with trichloroethylene or with acetone, followed by electrolytic cleaning in alkaline solution, thoroughly rinsed and immersed in plating solution for plating.

## **1.2. Electrodeposition of Metal from Solutions of Simple Salts**

The simple salts form hydrated cations in aqueous solution, thereby the concentration of metal ions, which can be discharged, will also be high. The deposition is explained on the basis of the "crystal growth theory" [1,2]

Metal salts do not exist in the solution in the simple state  $[M^{n+}]$  but have other ions and molecules associated with them. Each metal ion usually has a sheath of water molecules around it. These molecules do not affect the electrical charge on the metal ion. The hydrated metal ion is represented by  $M [H_2O]_x^{n+}$  Where x is the number of water molecules in the primary hydration sheath.

When deposition takes place [3] we have,

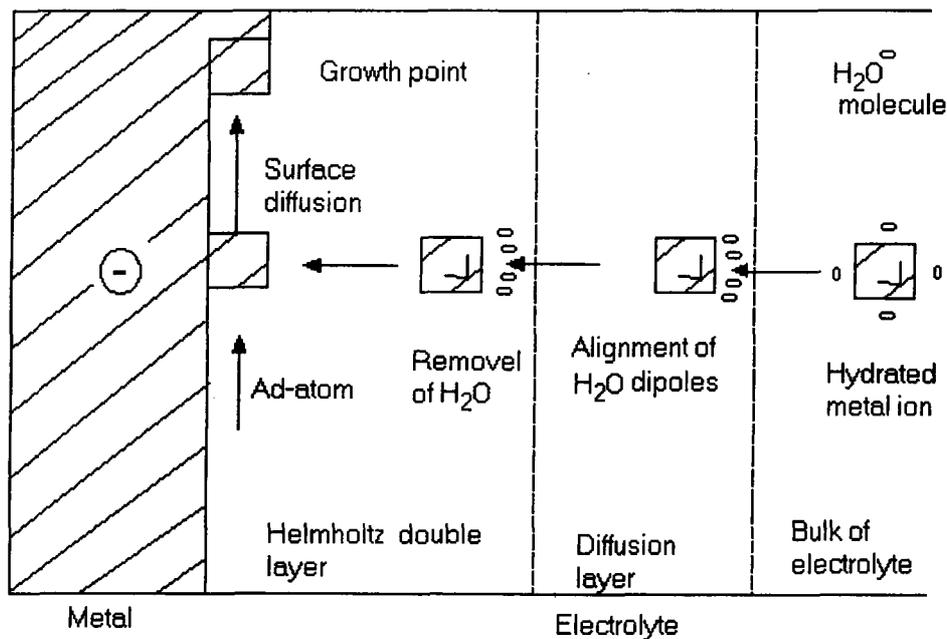
- Transport of hydrated metal ions to the cathode surface.

- Partial dehydration of the hydrate [the removal of water molecules being confined mainly to the external diffuse layer of the helmholtz layer and normally occurring in several steps].
- Adsorption of the partially hydrated ions at the cathode surface and diffusion along the surface to low energy position.

Complete dehydration followed by discharge



- Accommodation of the deposited atoms at active sites on the substrate, leading to the growth of the metal deposits Figure (1).



**Figure1: Sequence of events occurring during cathodic deposition.**

### 1.3. Metal Deposition from Solution of Complex Salts

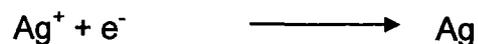
Metals such as copper, zinc, cadmium and silver are commonly deposited from cyanide baths. In addition to these baths, baths based on

pyrophosphate [4], thiosulphate [5], citrates [6], tartarates [7], nitriloacetates [8], are also used.

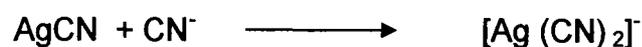
In these baths, the metal to be deposited are often present as the negatively charged complex ions, although dissociation equilibrium exists between these complex ions and the simple hydrated ions is extremely low because of the adequate high stability of the complexes. Various possibilities have been discussed for the discharged of metal ion  $M^{2+}$  from its complex as [9].

- The decomposition of the complex present in the electrolyte into its components.

For example

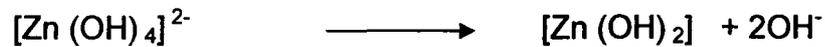


- The formation of a positively charged complex from the existing negative complex and the discharged of the positive complex as a whole. According to this, metal deposition would be a secondary process [10].



In a Similar manner,

Zinc deposition proceeds through  $Zn(OH)_2$  as follows.



Inhibition of these reactions produces a higher reaction overvoltage [11].

## **1.4. Gold plating**

### **1.4.1. Historical Background**

In 1942, with the emergence of the electronics industry and technologies and scientists evinced a renewed interest in gold electroplating. Requirements arose for heavy deposits of gold not requiring polishing or burnishing. Furthermore, it was necessary to deposit given thickness with accuracy and reproducibility. The 50's brought the rediscovery of solutions and techniques for thick, uniform and fine grained gold deposits and the introduction of modern bright acid and neutral solutions. Following this, in the 60's, acid gold and gold alloy systems were developed to produce deposits with specific physical properties such as ductility, corrosion and wear resistance, purity and so forth. During the period, the non-cyanide gold electrolytes were also reintroduced in bright and hard plating modifications.

Development in gold plating in the early 70's pointing the direction for the next decades are both chemical and technological. Further economics may be envisaged from the use of more highly alloyed gold deposits, which are the subject of much recent evaluation. In this case the possible

disadvantages of high contact resistance may be overcome by a final coating of pure gold.

Chemical developments are primarily directed toward increasing the speed of deposition, and increasing the levelling and throwing power of the baths. In modern plating machines, spots of gold 1.25 microns thick are deposited in under 2.5 seconds. Future progress will undoubtedly lead to baths capable of depositing gold at even higher speeds. Gold is electroplated not only for its psychological effects, but also because of its unique combination of physical and thermal properties.

#### **1.4.2. Properties of gold**

##### **Physical properties**

Atomic Number	79
Atomic weight	196.67
Naturally occurring isotope	197
Crystal structure	Face Centered Cubic, $a=4.07\text{\AA}$
Closest approach	$2.88\text{\AA}$
Density	$19.3\text{ g/cm}^3$
Atomic volume	$10.2\text{ cc/g-atom}$
Melting point	$1063^\circ\text{C}$
Boiling point	$2970^\circ\text{C}$
Latent Heat of Vaporization	$41.5\text{ cal/g}$

##### **Thermal properties**

Specific Heat	$0.031\text{ cal/g}^\circ\text{C}$
Coefficient of linear Expansion	$0.0000144/\text{C}^\circ$ (0-100°C)
Thermal Conductivity	$0.71\text{ cgs units}$ (20 °C)
Resistivity (18 °C)	$2.2 \times 10^{-6}\text{ ohm-cm}$
Temp. Coeff. Of Resistance (0-100 °C)	$0.004/\text{C}^\circ$

### **Chemical Properties**

Valency	1 and 3
Ionisation Potential	9 ev 18 ev
Heat of Formation of AuO	-12.0 Kcal/g.mole
Resistant to	fluorine, dry iodine, sulphur (100 °C), moist H <sub>2</sub> S
Attacked By	Sodium and potassium cyanide plus oxygen, aqua regia, chlorine, chlorine water, bromine and iodine in alcohol, selenic acid (above 230 °C)

#### **1.4.3. Introduction to electrolytes**

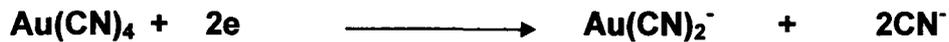
Gold, like silver, requires only a very small negative potential for reduction from the ionic to the metallic state; hence in solutions containing free ions, non-adherent immersion deposits are rapidly formed on base metal. Deposits from electrolytes of this nature are of large grain size with a tendency to "tree". Gold is therefore invariably plated from electrolytes in which the metal ions are complexed.

Gold plating has been carried out in alkaline cyanide electrolytes ever since the inception of commercial gold plating in the 1840's [12]. The alkaline cyanide bath has the limitations with respect to the deposition of hard alloy gold of constant colour because of rigid control of free cyanide becomes necessary. The codeposition of nickel, cobalt and other alloying constituents which were themselves complexed by the cyanide ion will try to take away some of the free cyanide ions in solution. Consequently, gold plating over the years became more of an art than any other plating system. Moreover, the picture became complicated due to the fact that the baths were frequently

prepared from gold chloride. In this case addition of sodium or potassium cyanide leads to the formation of auric cyanide



In alkaline solutions the auricyanide is reduced, slowly or rapidly, depending on the conditions, to the aurocyanide.



The reaction may well be more complex than indicated, but the end result is the same, namely, that a certain amount of auricyanide is likely to be present in baths prepared from the chloride, when solutions are prepared by simply dissolving gold anodically in potassium or sodium cyanide solution, when the aurocyanide is formed directly.



The mechanism may well be more complicated than shown, but this is unimportant. What is important is that for many years, both  $\text{Au(CN)}_2^-$  and  $\text{Au(CN)}_4^-$  were present in the baths prepared from gold chloride. This led to all sorts of confusing reports in the literature.

More recently, the industry has returned to non-cyanide baths and there is widespread interest in gold sulphite complex solutions [13], which offer some advantages in effluent control as well as good possibilities for alloy deposition.

#### 1.4.4. Electrolyte classification

Electrolyte classified into two types

- i) Cyanide electrolyte (three types)
- ii) Non-Cyanide electrolyte (one type)

### **i) Classification of cyanide electrolyte**

There are three types of cyanide based process,

- Alkaline cyanide gold electrolytes with no base metal additives [14]
- Neutral cyanide gold electrolytes [15]
- Acid cyanide gold electrolytes used with small concentrations of base metals [16]

### **Alkaline Cyanide Electrolytes**

Alkaline cyanide electrolytes may be used for the production of pure or alloy gold deposits. The most suitable classification, however, is on the basis of applicational areas i.e., colour gilding (jewellery) and industrial uses. Colour gilding is based entirely on alloy plating while industrial applications may call for pure or alloy gold deposits depending on the technological requirements. There is also an enormous difference in control of the two types of processes.

The deposition of colour gold remains much of an empirical art, in contrast to the close control necessary to meet present day specifications in the industrial gold plating field.

### **Ferrocyanide electrolytes**

In addition to the sodium or potassium gold cyanide electrolytes used for decorative plating, early workers employed "ferrocyanide" solutions. In general higher gold concentration, more vigorous agitation and higher temperatures will permit operation at higher current densities at high efficiency. The addition of trace quantities of metals such as arsenic, which do not form cyanide complexes is common, but such additions must be carefully

controlled otherwise the heat resistance of the deposit will be impaired. Actually, if such elements are not carefully controlled the deposit fall into the category of alkaline alloy golds.

For cyanaurate baths free of potassium cyanide, a definite potential must be reached before gold is deposited. Below this potential,  $\text{Au}(\text{CN})_4^-$  is being reduced to  $\text{Au}(\text{CN})_2^-$  and at more negative potentials direct reduction to metallic gold takes place. In actual practice the ferrocyanide solutions are operated at rather high voltages and current densities.

The ferrocyanide solutions have been used to deposit both 24 carat golds, and colour golds, particularly the latter, but this system is now rarely used.

The temperature of the alkaline cyanide gold baths is generally held within the range of 50-60°C with a pH of at least 10.0. The latter appears to have little effect on the current efficiency, but the degree of agitation and the gold concentration are important. Lee [17] reports that the plating efficiency is normally 90-100%. At low concentration is the region of about 1 gpl, the efficiency can be less than 20%, but when the gold content reaches about 3 gpl with good agitation, it is 100% at 0.2 A/dm<sup>2</sup>. A typical bath composition is given below:

$\text{KAu}(\text{CN})_2$	12 gpl
KCN	20 gpl
$\text{K}_2\text{HPO}_4$	20 gpl
$\text{K}_2\text{CO}_3$	20 gpl
Temperature	50-60 °C
Current density	0.1 – 0.5 A/dm <sup>2</sup>
pH	11 - 11.5

### ➤ **Electrolytes for pure gold deposits**

The pure alkaline systems have not changed much since the early 60's except for the application of ultrasonic [18], the use of KOH [19] an addition agent [20] and the use of ammonium gold cyanide [21] to minimize salt built-up in the bath, operational aspects of high purity gold plating baths in recent years have gradually more and more resembled those of high speed base metal electrolytes ie use of higher metal content and temperature, continuous purification as well as gold recovery from the rinses to give effective recovery of metal from the higher drag-out.

The gold is usually added as potassium gold cyanide and the concentration is generally strictly controlled. This is true for the conducting salt to ensure satisfactory current distribution and efficiency. The efficiency is usually close to 100 % at 60°C-70°C, current densities vary with the application, a typical figure being 0.5 A/dm<sup>2</sup>. In barrel work about 1/3 of the surface is being plated at any given time. So the current density for the full load will be 0.15-0.2A/dm<sup>2</sup>.

The deposit thickness is of the order 2-3 microns, but may be very much thicker if required; hence the structure of these deposits can be studied. The hardness of the high purity golds is of the order of 65 Knoop.

### ➤ **Electrolytes for bright alloy gold deposits**

In the area of alkaline alloy gold deposits, the bright to semi-bright deposits of Rinker [22, 23], Ostrow and Nobel [24] and Raub [25] involve the codeposition of silver, tin, and antimony.

The baths containing antimony found considerable use in the electronics industry, but the application to n-type transistors was actually much less than what the literature suggests.

Other references of alloy deposits from alkaline cyanide baths include claims that uranium and molybdenum have been codeposited with gold [26] and the Ni-Cu-Cd-Pd-Gold alloys can be electrodeposited [27]. Neither process has experienced any commercial success and because Pd forms a very stable cyanide complex, Pd-Au alloys cannot be codeposited on a production basis from baths replenished with potassium gold cyanide, contrary to claims that it is possible.

### **Neutral Electrolytes**

Neutral gold electrolytes in modern plating practice have been directed towards pure, rather than alloy baths, primarily due to the increasing importance of electronics as compared to decorative applications. There is, however, very little published data available. A typical composition is given below:

Gold as $\text{KAu}(\text{CN})_2$	10 - 20 gpl
Potassium citrate	20 gpl
Ethyl dihydrogen phosphate	30 – 60 gpl
Temperature	70 °C
Current density	0.1 – 0.3 $\text{A}/\text{dm}^2$
pH	6 - 8

Zimmerman and Brennerman [28] describe an essentially neutral solution, which deposits about 0.1% arsenic with the gold. They also

recommend the addition of 5 gpl of sodium thiosulphate. The preferred temperature is 55-72°C and the current density 0.1 A/dm<sup>2</sup>, the current efficiency being in the region of 93-100 %.

Many of the neutral baths contain alkali metal and ammonium citrates and/or phosphates, the latter groups include pyrophosphates also. In general, these baths are operated at elevated temperatures, with approximately 6-30 gpl of gold, good agitation and a pH of about 6.5. Under these conditions, the current efficiency is close to 100 %.

### **Acid Electrolytes**

The acid gold plating solutions may be classified in to the following categories,

- i) alloy gold solutions
- ii) pure gold solutions and
- iii) strike solutions.

And can be further sub-divided into solutions based on aurocyanide and auricyanide respectively.

The high purity acid gold baths are operated at temperature of 50°C or above in commercial practice. The gold content averages 8 gpl. Vigorous agitations are employed. The current density is normally 0.5 A/dm<sup>2</sup>, but may vary between 0.3-1.0 A/dm<sup>2</sup>. Increasing the gold content may use higher current densities. At 70-90 °C, with good agitation and a pH 5-6, the current efficiency is essentially 100 %, low gold concentrations, less vigorous agitation and low pH will reduce the current efficiency. Lower temperature will also reduce the current efficiency, but the deposit will generally be harder, probably due to the inclusion of organic materials in the deposits.

The acid alloy gold solutions are usually operated from room temperature upto about 35°C. For high speed application the temperature may be raised. The gold concentration is maintained at approximately 8.2 gpl although this is being no means mandatory. However, at this relatively low concentration, drag-out losses are minimized and maintained at a reasonable level.

A typical composition is:

Gold $\text{KAu}(\text{CN})_2$	8 gpl
Citric acid	40 gpl
Sodium citrate	40 gpl
pH	3 – 5
Temperature	Room
Current density	0.5 – 2.0 $\text{A}/\text{dm}^2$

The pH and degree of agitation affect the current efficiency considerably. Consequently, a pH as high as is consistent with good brightness is employed with good solution agitation by mechanical or other means.

The amount of base metal present in the solution and codeposited with the gold is also factor and has bearing on the current efficiency. With a low base metal concentration (100mg/l), a temperature of 35-40°C, good agitation, a pH of 4.5-5 and a current density of 1.0  $\text{A}/\text{dm}^2$ , the current efficiency will be in the order of 50%. However, if the pH is lowered to 3.5 and the temperature to 25°C, the efficiency will be much lower.

## **1.5. Non-Cyanide electrolytes**

One of the reactions the electrodeposition of gold was widely acclaimed in the 1800's was that this method of coating basis metals would eliminate the Hg poisoning hazards of fire gilding. However, what industry eventually settled down to using were solutions based upon potassium (I) gold cyanide also with free potassium cyanide. Such solutions, of course, were still poisonous. As early as 1845 Elener [29] suggested that non-cyanide gold electrolytes might have advantages. He mentions a  $\text{KAuCl}_4$  solution of ferrocyanide bath and a gold sulphite solution which he studied after von Seimens [30]. He has reported that a similar Ag bath could also be used. Woolrich [31] also suggested similar formulae in 1843.

The non-cyanide baths are of two types,

- High purity baths
- Alloy baths

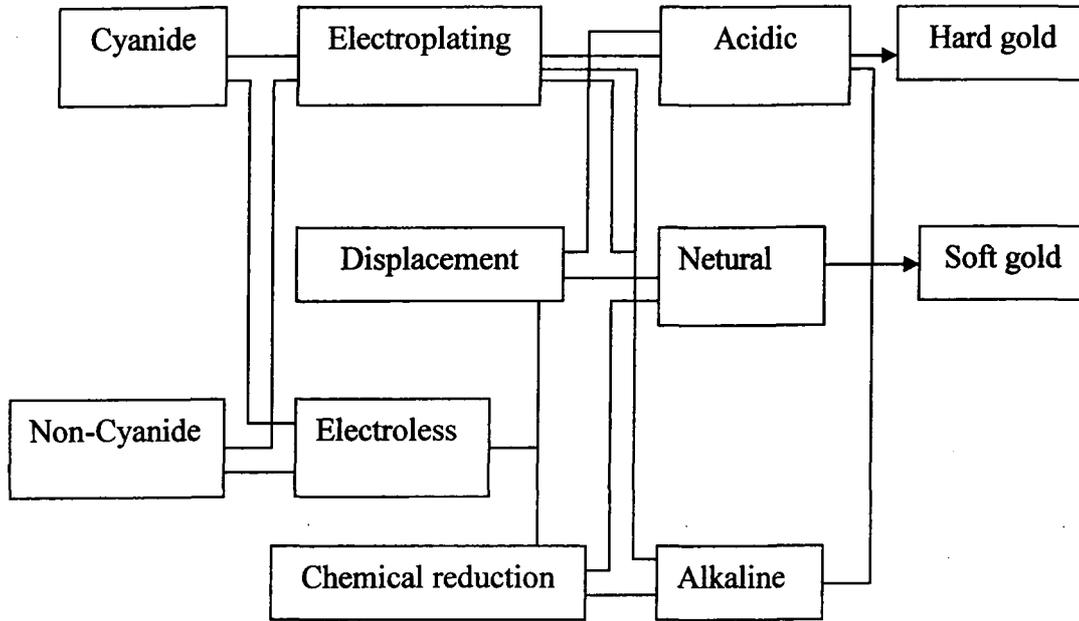
The high purity baths are generally operated at elevated temperatures in the order of 40-60°C, the gold concentration being 8-12 gpl.

### **1.5.1. Classification of non-cyanide gold plating Baths**

Gold plating baths can be classified into various categories depending on the gold salt used, the reaction mechanism, bath pH, and properties of the deposit obtained. The diagram shown in Fig.1.2 illustrates this classification.

The electrolytic cyanide-type baths include those operated at acidic, neutral, or alkaline pH's, and they can deposit either hard gold or soft gold. On the other hand, non-cyanide type baths can be operated only at neutral or alkaline pH's by either electrolytic or electroless mechanism, but the baths presently available can deposit soft gold only. Hard gold can be deposited

only from a cyanide-type electroplating bath at present, and neither a cyanide-type electroless hard gold plating bath nor a non-cyanide type electrolytic or electroless hard gold plating bath has yet been developed to the authors' knowledge.

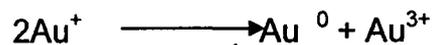


**Diagram.1.1 Classification of non-cyanide bath**

### 1.5.1.1. Sulfite Baths

#### Electroplating

The use of gold (I) sulfite complex,  $[\text{Au}(\text{SO}_3)_2]^{2-}$ , for electroplating gold has been known since 1842 [32]. Gold (I)-sulfite complex has been in use for many years as the source of gold in commercial noncyanide, electrolytic gold plating baths. The sulfite bath without stabilizing additives suffers from instability caused by the low stability constant of the sulfite complex itself, which is approximately equal to  $10^{10}$  as compared to  $10^{39}$  for the cyanide complex,  $[\text{Au}(\text{CN})_2]^-$ . Because of the low stability constant,  $\text{Au}^+$  ions are formed more readily from the sulfite complex than from the cyanide complex, and these ions undergo the disproportionation reaction,



forming a precipitate of metallic gold. To suppress this reaction, all commercially available sulfite baths contain proprietary stabilizing additive(s). The addition of a polyamine such as ethylenediamine is known to stabilize the sulfite bath through the formation of a mixed ligand gold complex [32, 33], which also makes it possible to operate the bath in a lower pH range of 5 to 8, rather than >8 for the bath containing no amine. Morrissey [34] found that simultaneous addition of ethylenediamine and nitrobenzene stabilizes the bath to such an extent that the bath can be operated at a pH as low as 4.0 to 6.5. The ability of the bath to function in the low pH range is significant because it enhances the compatibility with photoresists. More recently, 2,2'-bipyridine has been shown to stabilize the sulfite bath, presumably because it forms a complex with  $\text{Au}^+$  [35].

### **Electroless Plating**

The gold (I) sulfite complex has also been used to formulate electroless gold plating baths. Conventional reducing agents for electroless plating such as hypophosphite, formaldehyde, hydrazine, borohydride, and DMAB have been investigated for use with the sulfite complex [36-39]. More recently, less common reducing agents such as thiourea and its derivatives have been used successfully [40]. These systems require the addition of a stabilizer for practical use. For example, EDTA, triethanolamine, and NTA (nitrilotriacetic acid) have been reported to serve as the stabilizer [41,42]. These additives may form mixed ligand complexes of Au (I) with sulfite as ethylenediamine is dosed.

### 1.5.1.2. Thiosulfate Baths

#### Electroplating

The electroplating of gold from Au (I) thiosulfate complex has been known since as early as 1913 [33], but it has never been used for making a practical bath. In view of the fact that the stability constant of  $[\text{Au}(\text{S}_2\text{O}_3)_2]^{3-}$  is equal to  $10^{26}$ , which is orders of magnitude greater than that of the sulfite complex, the thiosulfate complex might be expected to be a viable alternative to the sulfite complex. The reason why the thiosulfate complex has not been used successfully for making a practical bath seems to be the instability of thiosulfate ion itself with respect to its disproportionation reaction:



Recently, an electrolytic gold plating bath using Au (I) thiosulfate complex and containing iodide ions as an additive has been reported. In this system, metallic gold is used as the anode, which dissolves into the bath during the plating to maintain the Au (I) concentration constant [43].

#### Electroless Plating

Prior to 1994, thiosulfate was used as a single complexing agent for Au (I) only in a galvanic displacement ("immersion") bath [44] and in an electroplating bath [45], while in 1994 Sullivan, Patel and Kohl [46] utilized the Au (I) thiosulfate complex to formulate an autocatalytic bath using ascorbic acid as the reducing agent. This bath was operated at a pH between 6.4 and 9.2 at room temperature. In this system the accumulation of free  $\text{S}_2\text{O}_3^{2-}$  ions produced by the reduction of  $[\text{Au}(\text{S}_2\text{O}_3)_2]^{3-}$  decreases the plating rate. Sullivan and Kohl [47] found that the periodic addition of  $\text{H}_2\text{O}_2$  removes the excess

$S_2O_3^{2-}$  ions to maintain a constant plating rate. However, this bath has only a short life (<2 hr) and hence needs to be improved to make it useful for industrial applications.

### **1.6. Characteristic of Electrodeposits**

Characteristic of electrodeposits, which are of importance are hardness, wear resistance, adhesion, corrosion resistance, porosity, tensile strength, internal stress.

#### **Hardness**

Hardness of the material is the resistance offered to permanent indentation or its resistance to plastic deformation. This is determined by measuring the indentation produced on deposit by a diamond point applied under a suitable load observed in a metallurgical microscope, using knoop indentation method. The Vickers micro hardness is calculated as,

$$H_v (\text{Kg/mm}^2) = 1.8454 \times P / (d+1)^2$$

Where, P is the load and d and l are constants

#### **Wear resistance**

Wear resistance of the electrodeposits are measured from the extent of metal removal from the plated surface when it is in contact with the hard material in motion. Wear is damage to a solid surface due to the relative motion between that surface and a contacting substrates or substances. It is a very complex phenomenon and usually involves progressive loss of materials.

**Adhesion**

Adhesion of the coating at the substrate/coating interface is a fundamental requirement of the electrodeposit and is tested by methods like bend test, scratch test, heat cycle test and tape test. For achieving proper deposit adhesion suitable pretreatment of the substrate is necessary.

**Thickness**

Thickness of the electrodeposits is ensured by means of weight gain in the coulometric method. Normally the thickness variation at various points of deposit surface should not be more than 10%

**Corrosion resistance**

Corrosion resistance is evaluated by either actual service test or by accelerated laboratory tests in which a corrosive salt solution is sprayed on the specimens under recommended conditions and by periodically observing for the appearance of corrosion spots.

**Porosity**

Porosity is of greater importance for coating which is more cathodic than the base metal and is determined by means of tests in which the chemical or electrochemical reactivity of the substance compared to the coating is the best parameters.

**Tensile strength**

Tensile strength and ductility of electrodeposition are evaluated by determining the fracture point of an elongated foil under applied load.

## **Internal stress**

Internal stress of electrodeposits can lead to lack of adhesion, peeling and cracking and this property is determined from the extent of bending of thin specimens as the electroplating operation goes on.

### **1.7. Advantages of non-cyanide gold plating**

- The gold sulfite process is that the deposits are bright
- Hard and very ductile, whereas the cyanide based acid (alloy) electrolytes yield deposits of limited ductility.
- Another important advantage is the good throwing power of the electrolytes.
- The sulfite are also attractive because of their non-toxicity
- Sulfite-based baths exhibit better resist compatibility compared to cyanide bath
- The sulfite systems are also attractive because of their non-toxicity as compared to the cyanide systems

### **1.8. Disadvantages of non-cyanide gold plating**

- The stability of the non-cyanide bath is low compared to cyanide bath

### **1.9. General applications of gold plating**

- In the electronics industry, gold plating is widely used to prepare of electrical contacts and wire bonding pads of semiconductor devices by taking advantage of the characteristics of high electrical conductivity, high reliability, and high corrosion resistance of gold.

- Gold has excellent corrosion resistance, particularly with respect to oxidation. It possesses low electrical resistivity, excellent solderability, weldability and infrared reflectivity. The appearance of gold and its alloy deposits ranges from pale yellow to orange red, offering highly desirable finishes for decorative applications.
- Gold is used in the aerospace industry because of its greatest values of infrared emissivity and reflectivity. This property helps man and instrument.
- In recent years, with the rapid progress of electronic devices, the development of "high density packaging technology" has become essential, and the gold-plating technology is expected to be compatible with this trend and capable of preserving the high reliability under the new circumstances.
- The chemical corrosion resistance of gold makes it a near-perfect material for construction of reactor vessels for production of chemicals. The good thermal properties and ease of producing 'drop condensation' makes gold the most scientific materials for heat exchangers.
- Watch cases and watch bands, writing instruments, spectacle frames, plumbing frames and jewellery and other related items are plated with gold for their decorative finishes.

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