Advanced Manufacturing Processes (AMPs)

Electroplating Process

by
Dr. Sunil Pathak
Faculty of Engineering Technology
sunilpathak@ump.edu.my

Chapter Description

- Aims
  - To provide and insight on Electroplating process (EP)
  - To provide details on why we need EP and its characteristics
- Expected Outcomes
  - Learner will be able to know about EP
  - Learner will be able to identify role of EP in todays sceneries
- Other related Information
  - Student must have some basic idea of conventional manufacturing and machining
  - Student must have some fundamentals on materials
- References

Neelesh Kumar Jain, **Sunil Pathak** (2016), “Chapter 30028: “Electrochemical Processing and Surface Finish” in **Comprehensive Materials Finishing** Vol. 3 (Volume Editor: Bakir Sami Yilbas; Editor-in-Chief: S. Hashmi) Elsevier Inc. Oxford (UK). (DOI: 10.1016/B978-0-12-803581-8.09182-7; online since 29 April 2016). (ISBN: 978-0-12-803581-8).

Introduction to Electroplating Process

- Electroplating or electrochemical deposition is the application of a metallic coating to an electrically conductive surface by electrolysis phenomenon. It involves passing an electric current through an electrolyte to reduce cations of the coating material and coat that material as a thin film on an electrically conductive workpiece surface.

- It is an economical technology to protect and enhance the functionality and surface properties of the workpiece. It imparts special or improved properties to the significant surfaces of a part or assembly and/or protecting or enhancing their function in their operating environment.

- Essentially any electrically conductive surface can be electroplated.

- The metals and alloy substrates electroplated on a commercial scale are cadmium, chromium, cobalt, copper, gold, indium, iron, lead, nickel, platinum, silver, tin, zinc, brass, bronze, many, lead-tin, nickel-iron, nickel-cobalt, nickel-phosphorus, tin-nickel, tin-zinc, zinc-nickel, zinc-cobalt, and zinc-iron etc.

Principle of Electroplating

Figure depicts schematic of a typical electroplating cell used for depositing copper using copper sulphate solution. It consists of four major components:

- **Direct current (DC) or pulsed DC supply unit:** for providing DC power supply between cathode and anode. Usually a rectifier or motor generator is used as DC source to supply the current in the electroplating cell. The means of regulating the voltage and current maintain their values at the chosen levels.
- **Cathode and its positioning means:** The substrate material (i.e. workpiece) on which plating is to be done is made as cathode. Its positioning means ensures its position remains fixed in the in the plating solution and contact with the DC power supply is maintained.
- **Anode:** The coating material which is to be plated or deposited is made as anode.
- **Platers:** Electrolyte solution is referred as platers. Generally, salt solutions are used as platers.

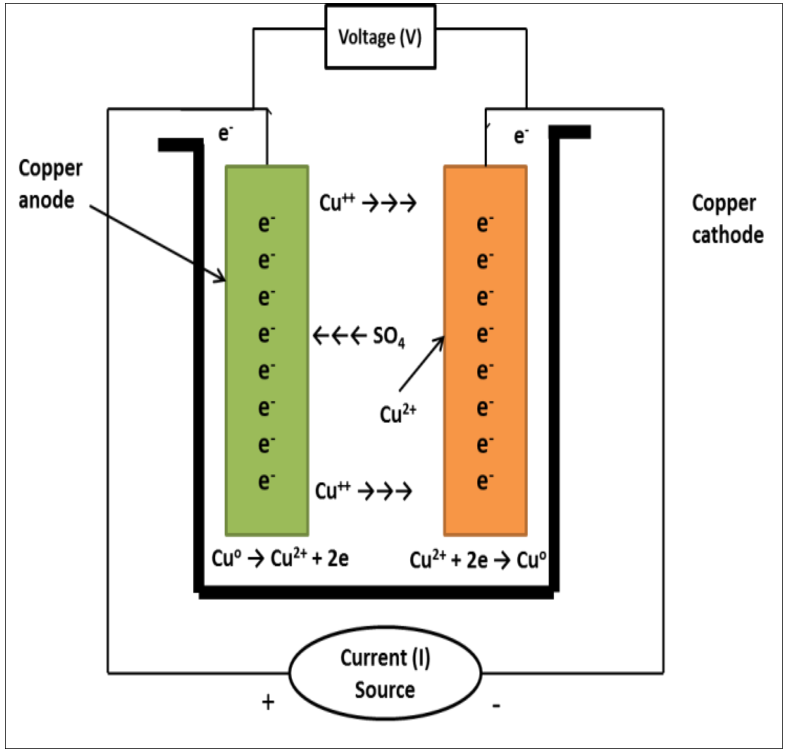


Fig: Schematic of a typical electroplating cell.

Principle of Electroplating (Conti…)

- In an electroplating process, the deposition reactions at cathode are referred as reduction reactions since electrons are consumed reducing the valence states of the ions involved.
- The reactions occurring at anode are oxidation reactions in which electrons are liberated and atoms are ionized increasing their valence states. Electrochemical reactions are reversible reactions and independent of each other.
- They are governed by the condition of material balance i.e. electrons liberated at the anode must be equal to the number of electrons consumed at the cathode.
- For depositing copper using copper sulphate solution, the aqueous solution of electrolyte contains positively charged copper ions and negatively charged sulphate ions.
- When DC power is supplied, copper from the anode dissolves into the solution leaving two electrons and forming positively charged copper ions (i.e. $Cu \leftrightarrow Cu^{++} + 2e$) which migrate towards the cathode where they are deionized and are deposited as copper atoms on the anode.

The sulphate ions remain unchanged in quantity during the electrolysis, $Cu^{2+} + 2e \leftrightarrow Cu$ (atom)

The overall reaction at the anode is the oxidation of water, $2H_2O \leftrightarrow 4H^+ + O_2 + 4e$

Principle of Electroplating (Conti…)

Under the influence of an applied potential, rearrangement of ions near the electrode surface results in an electrical double layer called the *Helmholtz double layer*, followed by the formation of a diffusion layer as shown in Fig.

These two layers combined are known as *Gauy-Chapman layer*. Their process sequence is as follows:

- **Migration:** The hydrated metal ions in the solution migrate towards the cathode under the influence of the applied current as well as by diffusion and convection.
- **Electron transfer:** At the cathode surface, a hydrated metal ion enters the diffused double layer where the water molecules of the hydrated ion are aligned. Then the metal ion enters the Helmholtz double layer where it is deprived of its hydrate envelope.
- The dehydrated ion is neutralized and adsorbed on the cathode surface.
- The adsorbed atom then migrates or diffuses to the growth point on the cathode surface.

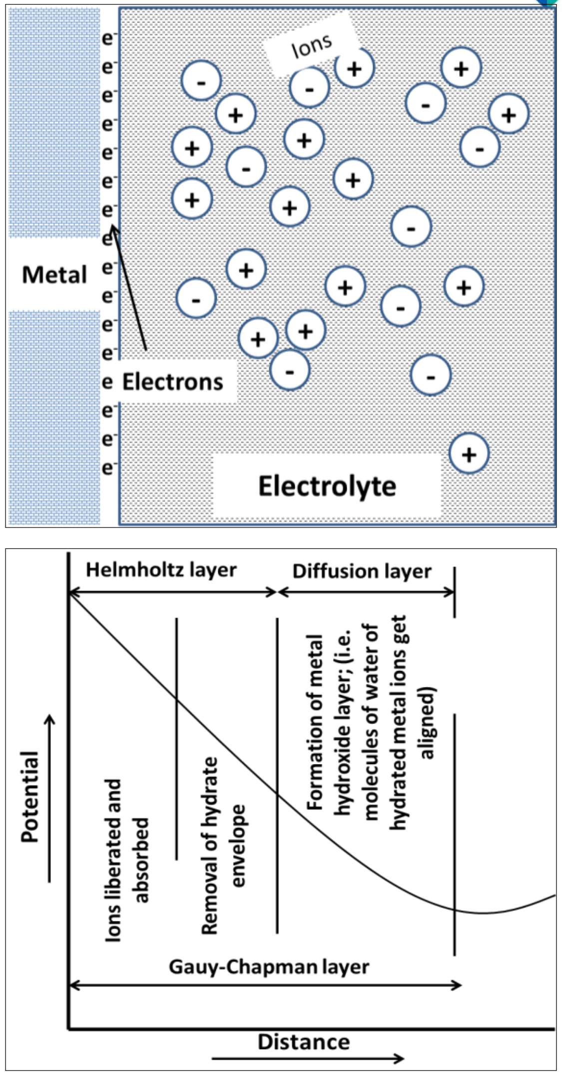


Fig. (a) Schematic of ion migrations; (b) graphical representation of Gauy-Chapman layer.

Factors affecting quality of deposition

Factors affecting deposition quality

Electrolyte related parameters
- *Type*
- *Composition*
- *Concentration*
- *Conductivity*
- *Temperature*
- *pH value*
- *Impurities*

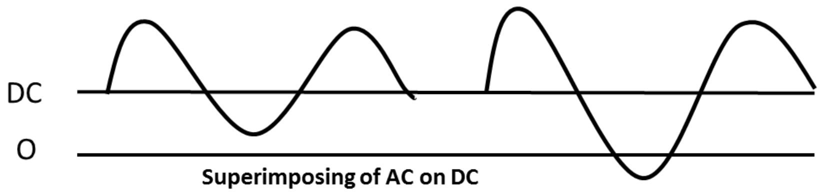
Current characteristics
- *Current source*
- *Type of waveform*
- *Applied voltage*

Electrode properties
- *Density*
- *Electrical conductivity*
- *Valency of dissolution*
- *Electrode potential*
- *Corrosion resistance*

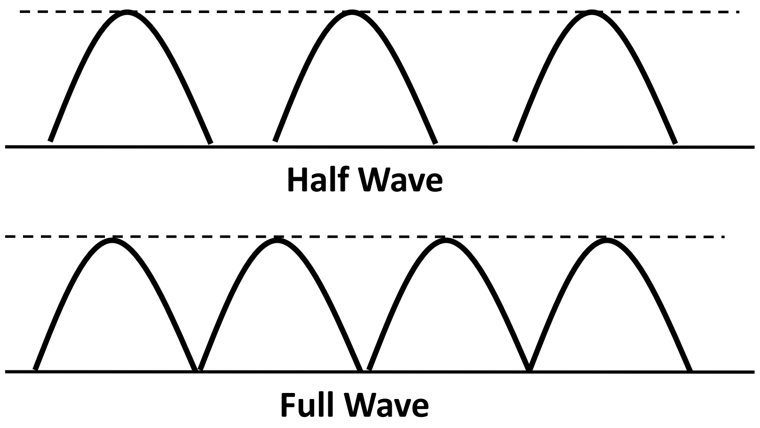
Electroplating process Parameters
- *Inter-electrode gap*
- *Deposition time*
- *Deposition thickness*
- *Deposition composition*
- *Additives*
- *Agitation*

Effects of current characteristics

Different types of current and their sources are used for electroplating. Selection of current source depends on the specific requirements and desired surface quality of the end product. Earlier, alternating current (AC) superimposed on direct current (DC) (Fig.) was used as the current source for electroplating applications.



(a)



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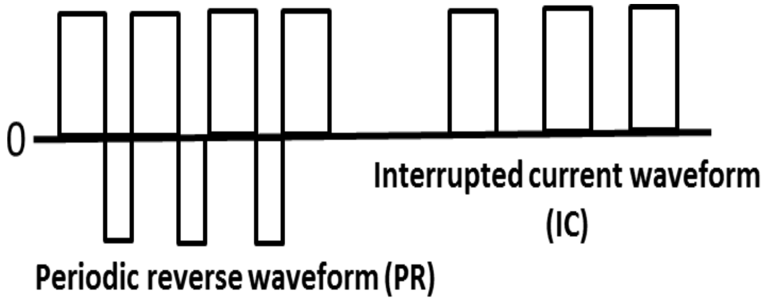
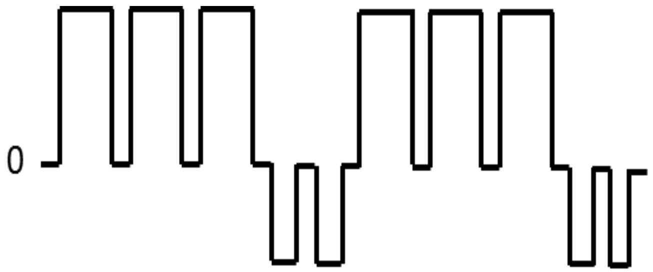


(c)



Pulsed pulse reverse

(d)

Fig. Schematic of different types of electrical waveforms.

Effects of current characteristics

Deposition quality of some metal and alloy depositions was found to be superior while using pulsed DC than that using constant DC. Some of the advantages of pulse electroplating are:

- Faster deposition rate due to increased permissible current densities
- Denser deposition (i.e. lesser porosity)
- Higher purity of deposition, less tendency for impurities to be included in the deposition
- Smoother and finer-grained deposition
- Reduced need or elimination of addition agents
- Less hydrogen evolution thus providing better surface finish and very less hydrogen embrittlement
- Decreased stress in deposition
- Increased Ni or Co contents in alloy-hardened gold deposition with less polymer formation

Effects of electrolyte parameters

- Electrolyte parameters such as its type, composition, concentration, conductivity, temperature, flow rate, pH value and impurities greatly affect deposition quality in the electroplating process.
- Type of electrolyte (i.e. salt based, acidic or alkaline and passivating or non-passivating) is selected on the basis of physical, mechanical and electrochemical properties of the electrode material.
- Role of the electrolyte composition in electroplating is to facilitate generation and movement of the ions which are to be deposited on the cathodic workpiece and to provide supporting ions.

Its other functions are

(i) stabilize the electrolyte;

(ii) improve electrolyte solution conductivity;

(iii) to prevent excessive polarization and passivation of the anode; and

(iv) to provide compatibility with the desired plating conditions.

Effects of electrolyte parameters (Conti…)

Supporting ions reduces the current shared by the metallic ions or complexes thus making convection (agitation) a more significant factor.

Electroplating is mainly dominated by two factors namely

(i) dissolution of the freshly deposited metal atoms on the substrate; and

(ii) formation and absorption of metals hydroxides on the electrode surface.

A lower pH value favors the dissolution of freshly deposited material and depresses formation and absorption of the metallic hydroxides. Whereas, higher pH value favors the formation and absorption of metal hydroxides and depresses the dissolution of the freshly deposited metal atoms.

Selection of deposition material

Deposition characteristics	Metal	Applications
Corrosion resistance	Zn, Cd	Sacrificial coatings, fasteners, hardware fittings
	Sn	Food containers
	Ni, Cr	Food processing equipment requiring wear resistance
Wear resistance	Ni, Cr, E-Ni,	Aerospace, space, hydraulics
	Rh, Au and Au	Electronic contacts
High temperature oxidation resistance	Cr, Rh, Pd, Pt	Avionics
Diffusion barrier	Au, Ni	Electronic devices
Decorative	Cu/Ni/Cr	Household appliances, automotive trim
	Ag, Au, Rh	Jewelry
Reflectors	Ag, Rh, Cr	Visible light reflectors
	Au	Infra-red reflectors
Soldering, bonding	Pb, Sn, Pb, Cu, Ag, Au	Containers, printed circuits and other electronic
	Sn, Cd, Ni	Assemblies and chassis
Electroforms	Ni, Cu, Fe, Cr, Co	Radar plumbing, screens, bellows, containers, molds
Dielectrics	Al,Ti,Ta	Condensers, capacitors coatings

Selection of deposition material (Cont…)

Deposition characteristics	Alloy	Applications
Corrosion and wear resistance	Ni-P, Sn-Ni, Sn-Pb	Avionics, computer hard disks, printed circuits boards, electronic assemblies, assemblies and chassis, bearings, corrosion resistant coatings, solderable coatings
Decorative and wear resistance	Au-Co, Au-Ni	Jewelry hardened gold alloy deposition for electronic contacts, components with high wear rate
Electroforms and decorative	Co-Ni	Molds for plastics, screens, bellows, containers
Decorative	Ni-Fe, Cu-Zn, Cu-Sn	Rubber bonding, antique, household appliances, automobile accessories

Selection of deposition material (Cont…)

Deposition characteristics	Copper deposition	Nickel deposition	Chromium deposition	Nickel and chromium deposition	Remarks
Thickness range (μm)	12.5-500	12.5-500	12.5-500	12.5-500	Grinding required over 200 μm thickness
Hardness (HV)	60-150	200-300	850-950	850-950	Indicates abrasive wear resistance
Corrosion resistance	Very poor	Very good	Poor	Very good	Minimum 50 μm thickness of Ni is required
Low friction anti-stick	Poor	Poor	Excellent	Excellent	Indicates adhesive wear resistance
Resistance to impact	Medium	Very good	Medium	Very good	Thin coats and soft substrates prone to damage
Max. working temp. (^{o} C)	50	650	650	650	----
Covering complex shapes	Medium	Medium	Very poor	Medium	----
Non-toxicity	Excellent	Very good	Very good	Very good	-----
Cost for given thickness	Low	Medium	High	Very High	Depends on shape and size
Typical applications	Lubricant in forming, Heat sink, Selective case hardening	Below or in place of Cr in corrosive condition, Printing surfaces	Moulds, Tools, Valves, Rams, Pistons, Shafts, Gauges, Dies, Saw blades	Marine cranes, Hydraulic rams, Mine roof supports, Print rolls	------

Advantages

- Improved corrosion resistance
- Improved wear resistance
- Excellent finish and shining
- Hazardless process
- Pollution-free process
- No hydrogen embrittlement
- No effect on fatigue life

Limitations

- High capital cost
- Coating on internal diameters cannot be done
- More time consuming process
- Plating may not be uniform

Applications

Electroplating is used in many diverse industries including home appliances, jewelry, automotive, aircraft, aerospace, and electronics for both decorative and engineering applications. Some of the worth mentioning application areas are:

- ✓ Decoration: Coating a more expensive metal onto a base metal surface in order to improve the appearance. Applications are jewellery, furniture fittings, hardware and tableware.
- ✓ Protection: Corrosion-resistant coatings such as chromium plating of automobile parts and domestic appliances, zinc and cadmium plating of nuts, screws and electrical components.
- ✓ Wear-resistant coatings such as nickel or chromium plating of bearing surfaces and worn shafts and journals.
- ✓ Electroforming: Manufacture of sieves, screens, dry shaver heads, record stampers, moulds and dies.
- ✓ Enhancement: coatings with improved electrical and thermal conductivity, solderability, reflectivity etc.
- ✓ Other applications of electroplating include salvage of mismachined or worn out parts and other types of reworking as well as material savings.

Dr Sunil Pathak, PhD - IIT Indore (MP) India
Senior Lecturer
Faculty of Engineering Technology
University Malaysia Pahang, Kuantan Malaysia
https://www.researchgate.net/profile/Sunil_Pathak4
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