BMM3643 Manufacturing Processes
Surface Treatments

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Chapter Synopsis

This chapter will expose students to various surface modification operations that commonly performed such as mechanical surface treatments, coating operation, thermal spray operation, physical and chemical vapor deposition, ion implantation and electroplating. Surface treatments may be necessary in order to ensure that its surfaces have certain properties and characteristics.

Chapter Information

Lesson Objectives:

Surface Treatments

Lesson Objective:

At the end of this lecture, students should be able to understand and explain the following:

- Analyze the fundamental of surface treatments, coatings and design guidelines cleaning processes
- Evaluate the mechanical surface treatment, mechanical plating and cladding, case hardening, PVD, CVD and electroplating.

Introduction

- Surface treatments are done in order to:
  - Improve resistance to wear, erosion and indentation
  - Control friction (sliding surfaces of tools, etc.)
  - Reduce adhesion (electrical contacts)
  - Improve lubrication
  - Improve resistance to corrosion and oxidation
  - Improve fatigue resistance
  - Rebuild surfaces
  - Modify surface texture (appearance, dimensional accuracy)
  - Impart decorative features (colour)

Mechanical Surface Treatments

- **Shot Peening** is the mechanical working of metals by means of hammer blows or by blasting with shot (i.e. small balls of cast steel, glass, or ceramic).
- It tends to expand the surface of the cold metal, thereby relieving tensile stresses and/or inducing compressive stresses.
- Peening also encourages strain hardening of the surface metal.

Mechanical Surface Treatments

- **Laser peening** is the process of hardening or peening metal using a powerful laser.
- Laser peening can impart a layer of residual compressive stress on a surface that is four times deeper than that attainable from conventional shot peening treatments.
- Laser peening is often used to improve the fatigue resistance of highly stressed critical turbine engine components, and the laser (or component) is typically manipulated by an industrial robot.

Mechanical Surface Treatments

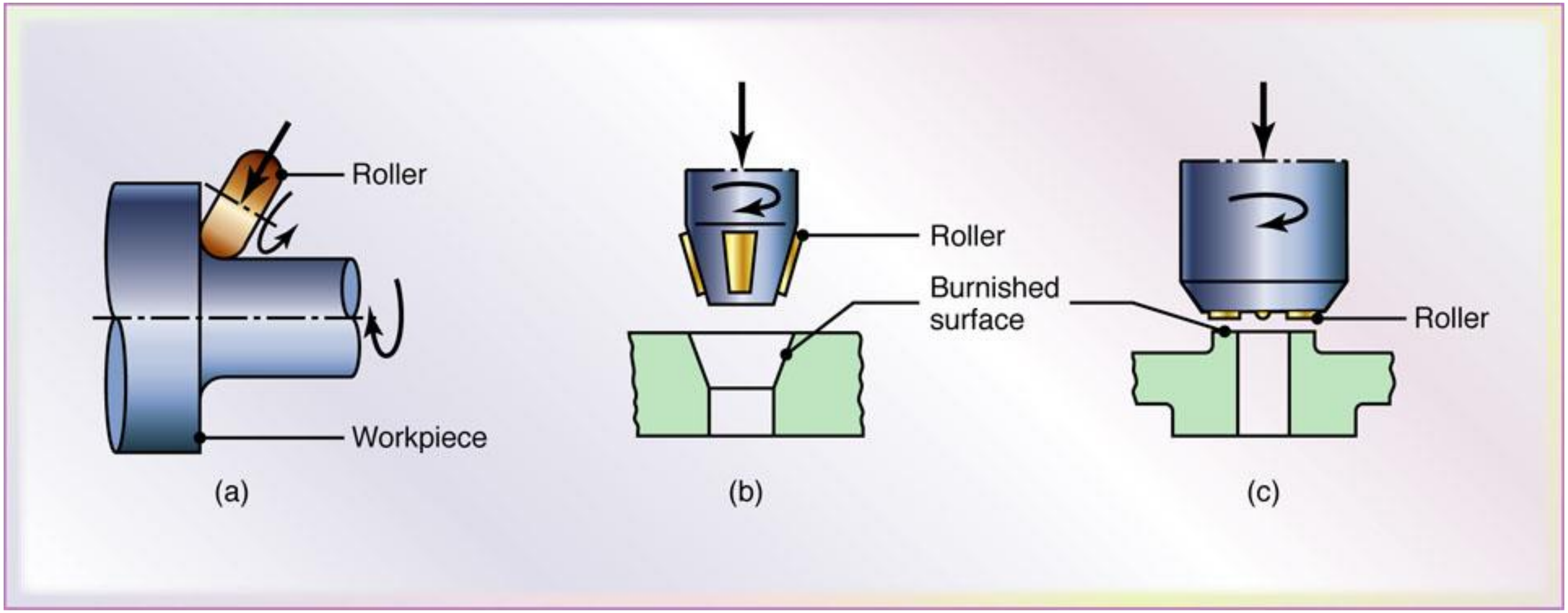
- **Ultrasonic Peening (or Ultrasonic Impact Treatment) –** this process uses a hand tool based on a piezoelectric transducer.
- The energy generated from these high frequency impulses is imparted to the treated surface through the contact of specially designed steel pins.
- These frequencies range between 27 kHz and 55 kHz, with the displacement amplitude of the resonant body of between 22 and 50 micrometres.

Mechanical Surface Treatments

Roller burnishing

- In this process, also called *surface rolling*, the surface of the component is cold worked by a hard and highly polished roller or set of rollers.
- This process is used on various flat, cylindrical, or conical surfaces.

Roller Burnishing



Burnishing tools and roller burnishing of (a) the fillet of a stepped shaft to induce compressive-surface residual stresses for improved fatigue life; (b) a conical surface; and (c) a flat surface.

Mechanical Surface Treatments

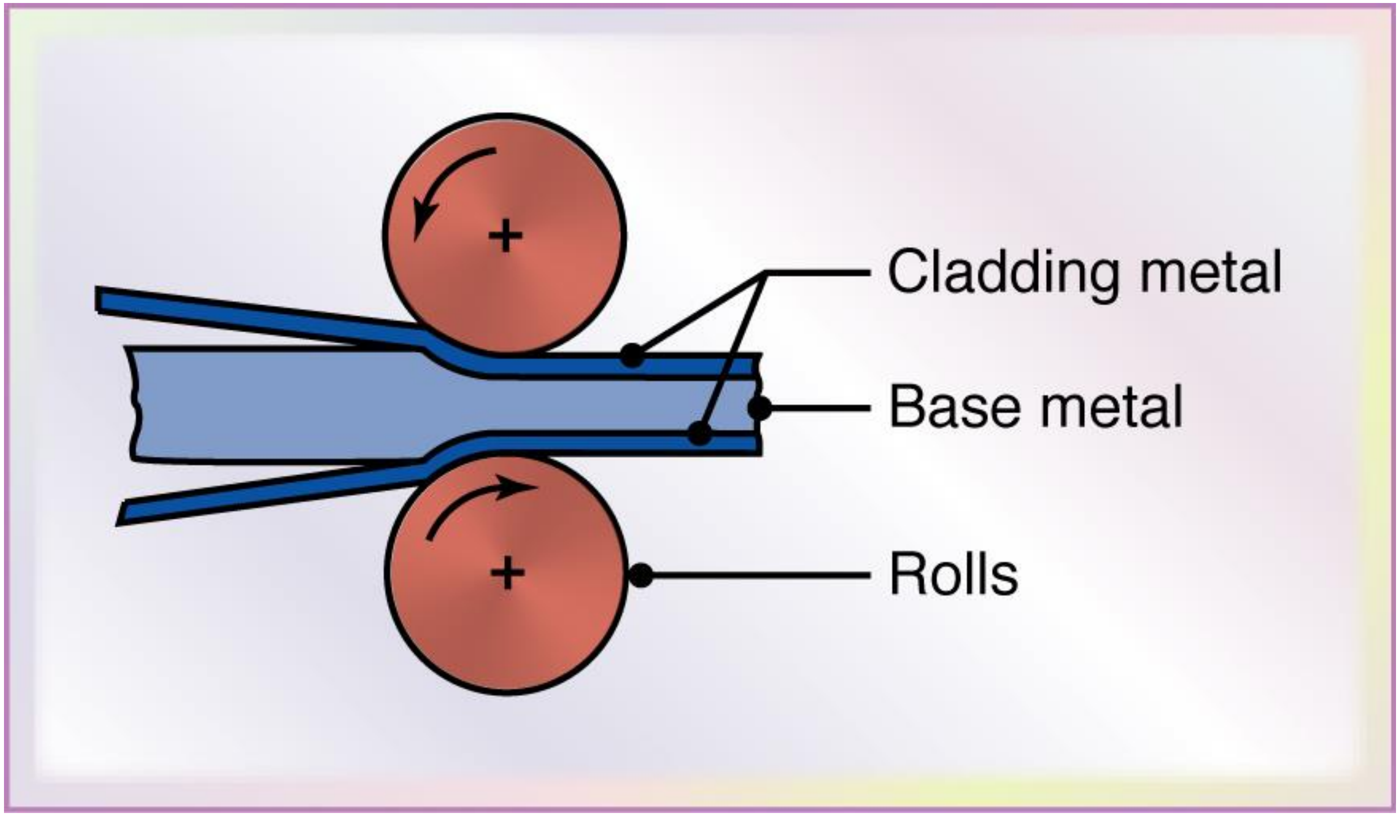
Roller burnishing

- Internal cylindrical surfaces also are burnished by a similar process, called **ballizing** or **ball burnishing**.
- In this process, a smooth ball (slightly larger than the bore diameter) is pushed through the length of the hole.

Mechanical Plating and Cladding

- Mechanical plating – also called coating, fine particles are compacted over the workpiece surfaces by glass, ceramic, etc.
- Cladding – metals are bonded with a thin layer of corrosion-resistant metal through the application of pressure using rolls (cold welding or roll bonding)

ROLL BONDING



Schematic illustration of the roll bonding or cladding process.

Case Hardening

- **Case hardening** is the process of hardening the surface of a metal, by infusing elements into the material's surface, forming a thin layer of a harder alloy.
- Some methods of case hardening include:
  - carburizing,
  - carbonitriding,
  - cyaniding,
  - nitriding,
  - flame hardening
  - induction hardening

Outline of Heat Treatment Processes for Surface Hardening

TABLE 4.1

Outline of Heat Treatment Processes for Surface Hardening

Process	Metals hardened	Element added to surface	Procedure	General characteristics	Typical applications
Carburizing	Low-carbon steel (0.2% C), alloy steels (0.08–0.2% C)	C	Heat steel at 870–950 °C (1600–1750 °F) in an atmosphere of carbonaceous gases (gas carburizing) or carbon-containing solids (pack carburizing). Then quench.	A hard, high-carbon surface is produced. Hardness 55 to 65 HRC. Case depth < 0.5–1.5 mm (< 0.020 to 0.060 in.). Some distortion of part during heat treatment.	Gears, cams, shafts, bearings, piston pins, sprockets, clutch plates
Carbonitriding	Low-carbon steel	C and N	Heat steel at 700–800 °C (1300–1600 °F) in an atmosphere of carbonaceous gas and ammonia. Then quench in oil.	Surface hardness 55 to 62 HRC. Case depth 0.07 to 0.5 mm (0.003 to 0.020 in.). Less distortion than in carburizing.	Bolts, nuts, gears
Cyaniding	Low-carbon steel (0.2% C), alloy steels (0.08–0.2% C)	C and N	Heat steel at 760–845 °C (1400–1550 °F) in a molten bath of solutions of cyanide (e.g., 30% sodium cyanide) and other salts.	Surface hardness up to 65 HRC. Case depth 0.025 to 0.25 mm (0.001 to 0.010 in.). Some distortion.	Bolts, nuts, screws, small gears

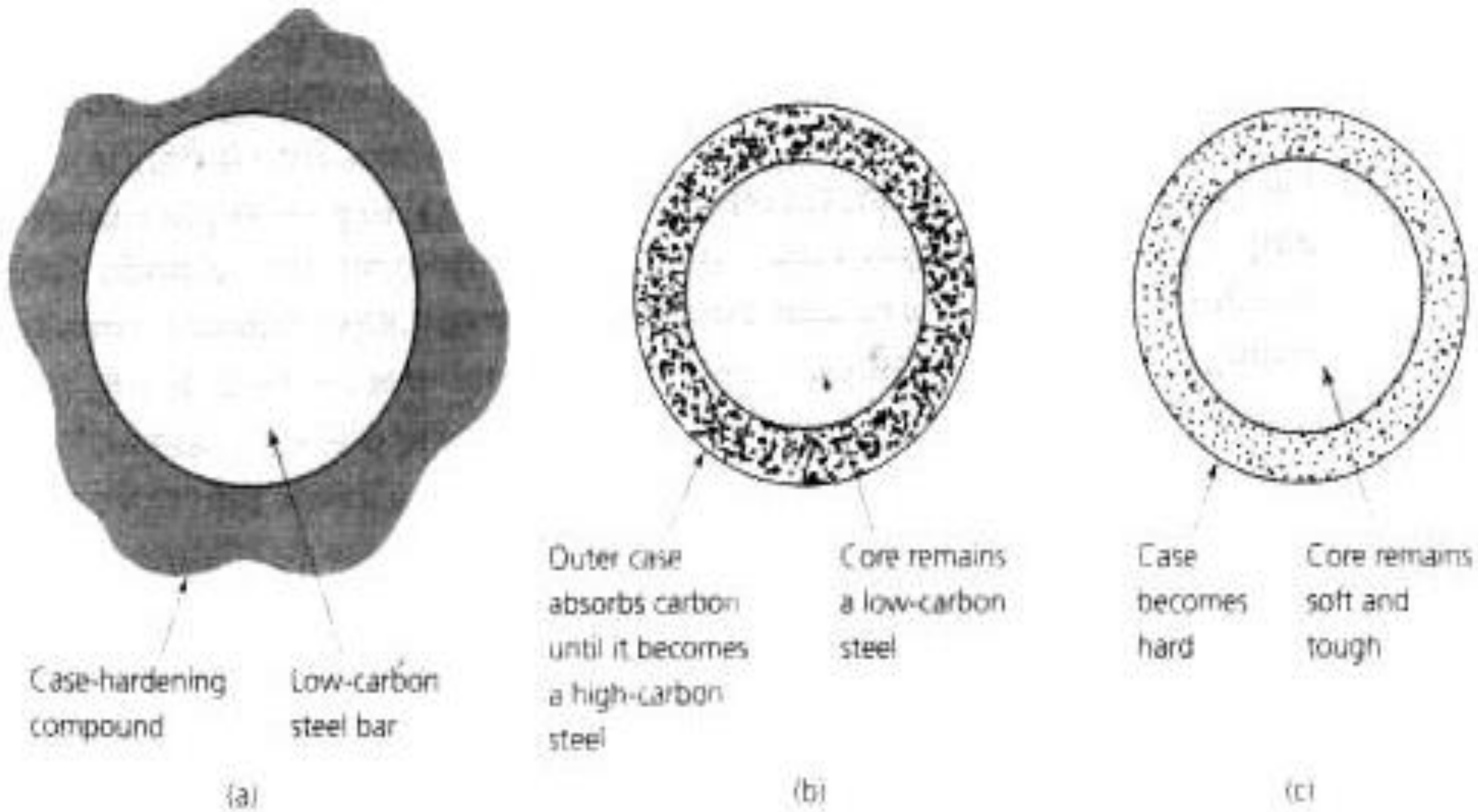
Outline of Heat Treatment Processes for Surface Hardening (cont.)

TABLE 4.1

Outline of Heat Treatment Processes for Surface Hardening

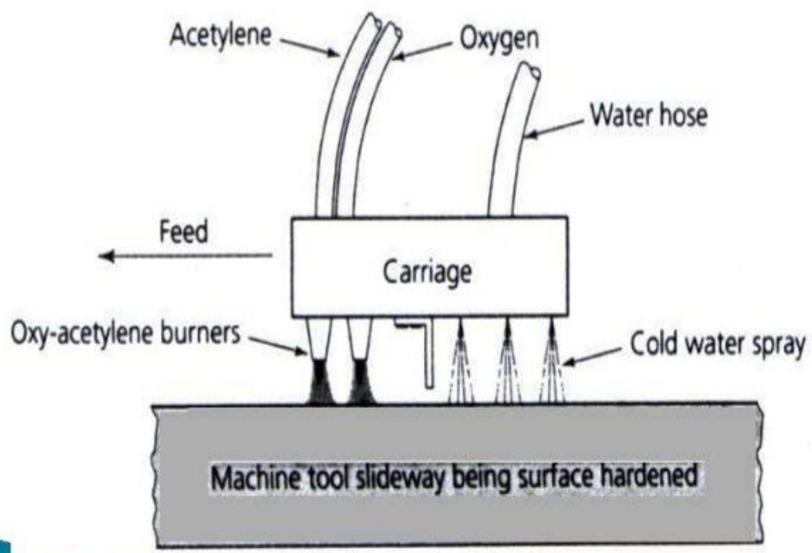
Process	Metals hardened	Element added to surface	Procedure	General characteristics	Typical applications
Nitriding	Steels (1% Al, 1.5% Cr, 0.3% Mo), alloy steels (Cr, Mo), stainless steels, high-speed tool steels	N	Heat steel at 500 –600 °C (925 –1100 °F) in an atmosphere of ammonia gas or mixtures of molten cyanide salts. No further treatment.	Surface hardness up to 1100 HV. Case depth 0.1 to 0.6 mm (0.005 to 0.030 in.) and 0.02 to 0.07 mm (0.001 to 0.003 in.) for high speed steel.	Gears, shafts, sprockets, valves, cutters, boring bars, fuel-injection pump parts
Boronizing	Steels	B	Part is heated using boron-containing gas or solid in contact with part.	Extremely hard and wear resistant surface. Case depth 0.025 –0.075 mm (0.001 –0.003 in.).	Tool and die steels
Flame hardening	Medium-carbon steels, cast irons	None	Surface is heated with an oxyacetylene torch, then quenched with water spray or other quenching methods.	Surface hardness 50 to 60 HRC. Case depth 0.7 to 6 mm (0.030 to 0.25 in.). Little distortion.	Gear and sprocket teeth, axles, crankshafts, piston rods, lathe beds and centers
Induction hardening	Same as above	None	Metal part is placed in copper induction coils and is heated by high frequency current, then quenched.	Same as above	Same as above

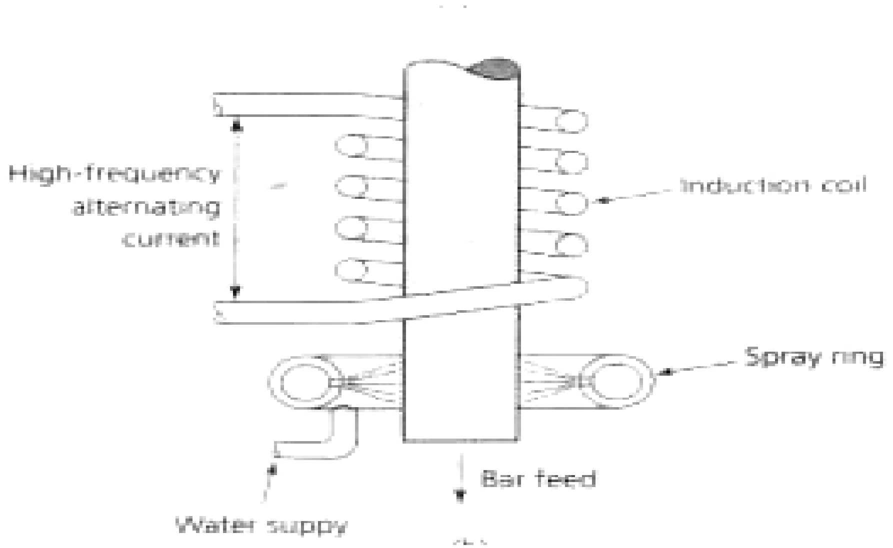
Case Hardening



(a) carburizing; (b) after carburizing; (c) after quenching component from a temperature above 780^{o}C

Surface Hardening





(a) flame hardening

(b) induction hardening

Physical vapour deposition (PVD)

- **Physical vapour deposition (PVD)** is a process of depositing thin films by the condensation of a vaporized form of the material onto various surfaces (e.g., onto semiconductor wafers).
- 3 basic types of PVD processes are (1) evaporative (vacuum) deposition, (2) sputtering and (3) ion plating.

Physical vapour deposition (PVD)

Vacuum deposition

- In vacuum deposition (or evaporation), the metal is evaporated at a high temperature in a vacuum and is deposited on the substrate (which is usually at room temperature or slightly higher for improved bonding).
- In **arc deposition** (PV/ARC), the coating material (cathode) is evaporated by several arc evaporators using highly localized electric arcs.
- **Pulsed-laser deposition** is a more recent related process in which the source of energy is a pulsed laser.

Applications of PVD

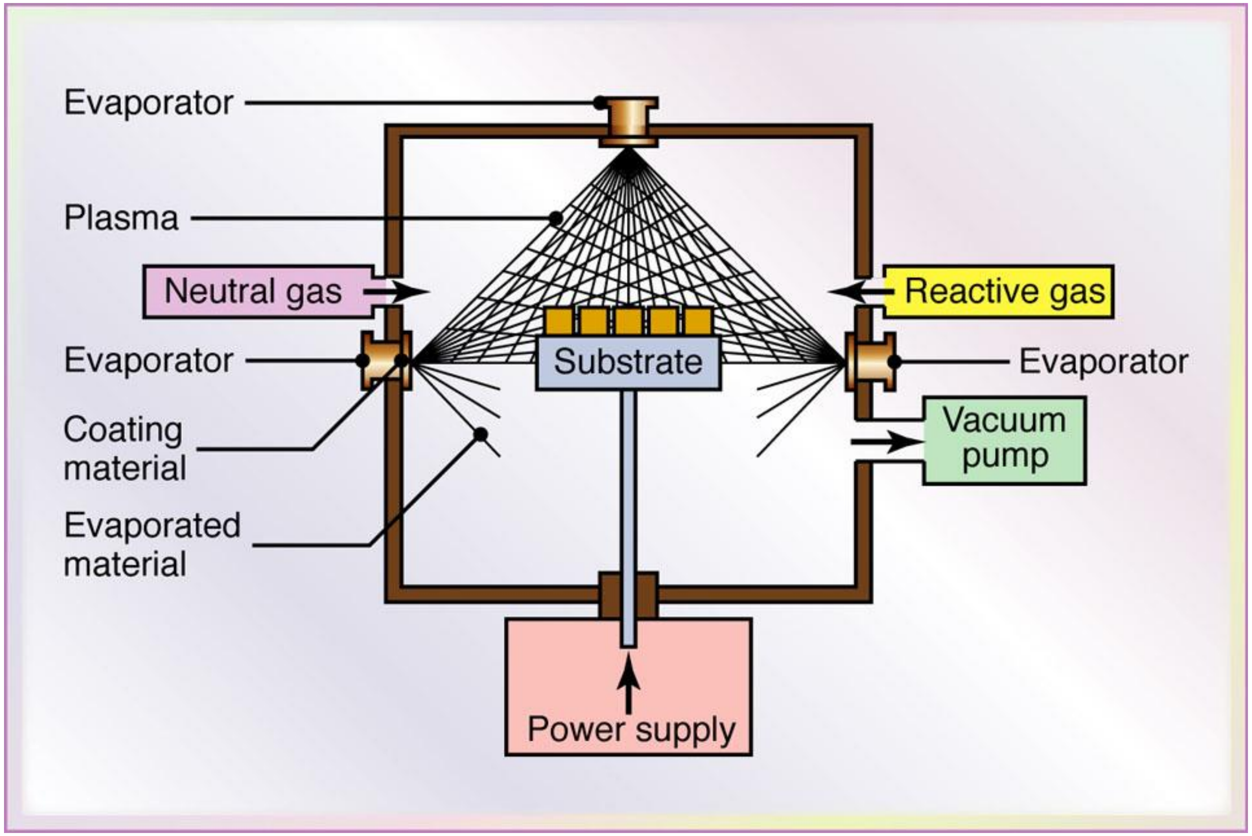
- Decorative coatings on plastic and metal parts such as trophies, toys, pens and pencils, watchcases, and interior trim in automobiles
- Antireflection coatings of magnesium fluoride (MgF_2) onto optical lenses
- Depositing metal to form electrical connections in integrated circuits
- Coating titanium nitride (TiN) onto cutting tools and plastic injection molds for wear resistance

Processing Steps in PVD

- All physical vapor deposition processes consist of the following steps:
  1. Synthesis of coating vapor
  2. Vapor transport to substrate
  3. Condensation of vapors onto substrate surface
- These steps are generally carried out in a vacuum chamber, so evacuation of the chamber must precede PVD process

PVD: Evaporative Deposition

- **Evaporative deposition** - the material to be deposited is heated to a high vapor pressure by electrically resistive heating in high vacuum.



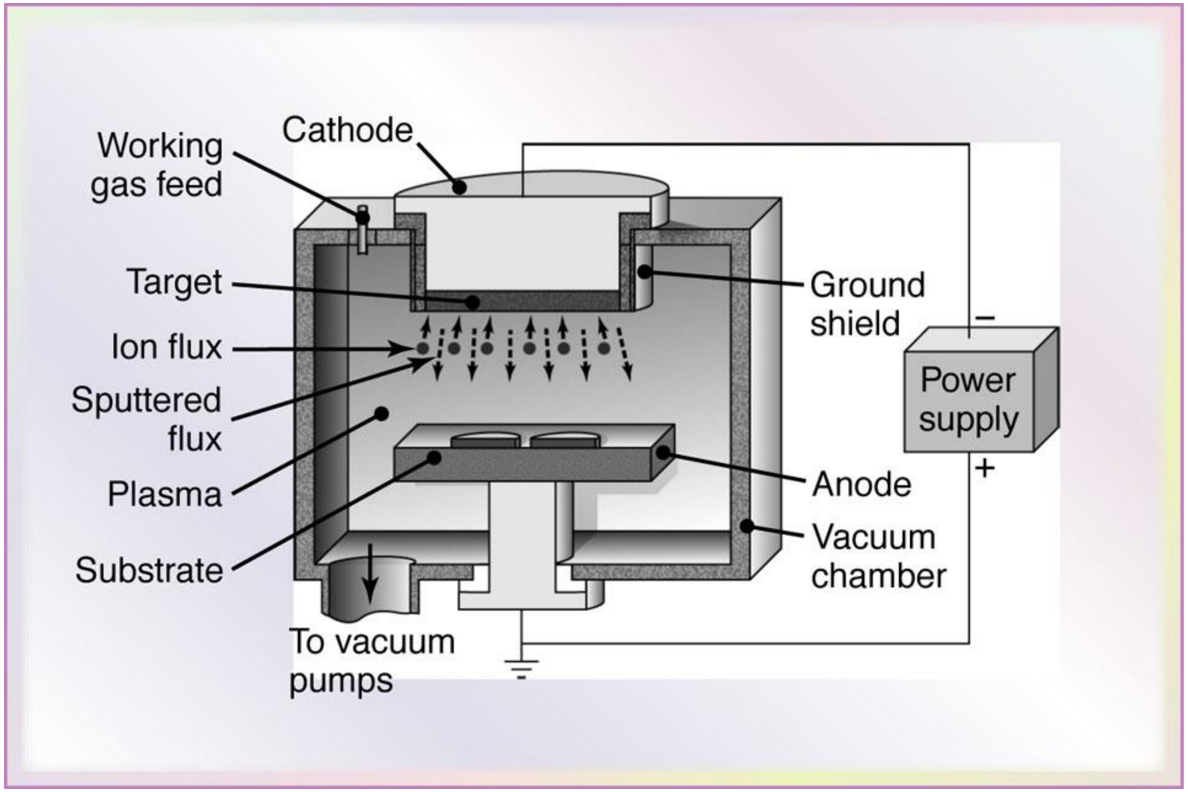
PVD: Sputtering

Sputtering

- In sputtering, an electric field ionizes an inert gas (usually argon).
- The positive ions bombard the coating material (cathode) and cause sputtering (ejecting) of its atoms.
- These atoms then condense on the workpiece, which is heated to improve bonding.

PVD: Sputtering

- **Sputter deposition** -a glow plasma discharge (usually localized around the target by a magnet) bombards the material sputtering some away as a vapor.



PVD: Sputtering

Sputtering

- In **reactive sputtering**, the inert gas is replaced by a reactive gas (such as oxygen) in which case the atoms are oxidized and the oxides are deposited.
- Carbides and nitrides also are deposited by reactive sputtering.
- **Radio-frequency** (RF) sputtering is used for nonconductive materials, such as electrical insulators and semiconductor devices.

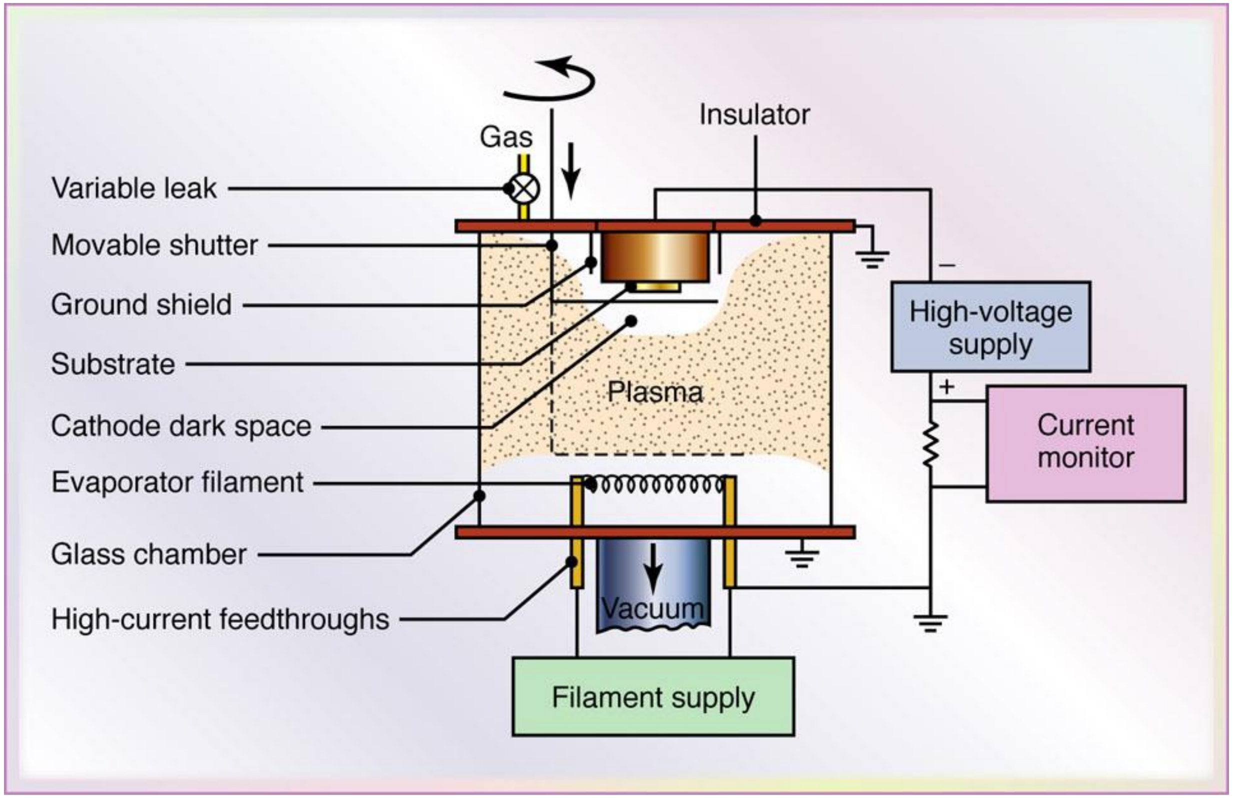
PVD: Ion Plating

Ion plating

- Ion plating is a generic term that describes various combined processes of sputtering and vacuum evaporation.
- An electric field causes a glow discharge, generating a plasma.

PVD: Ion Plating

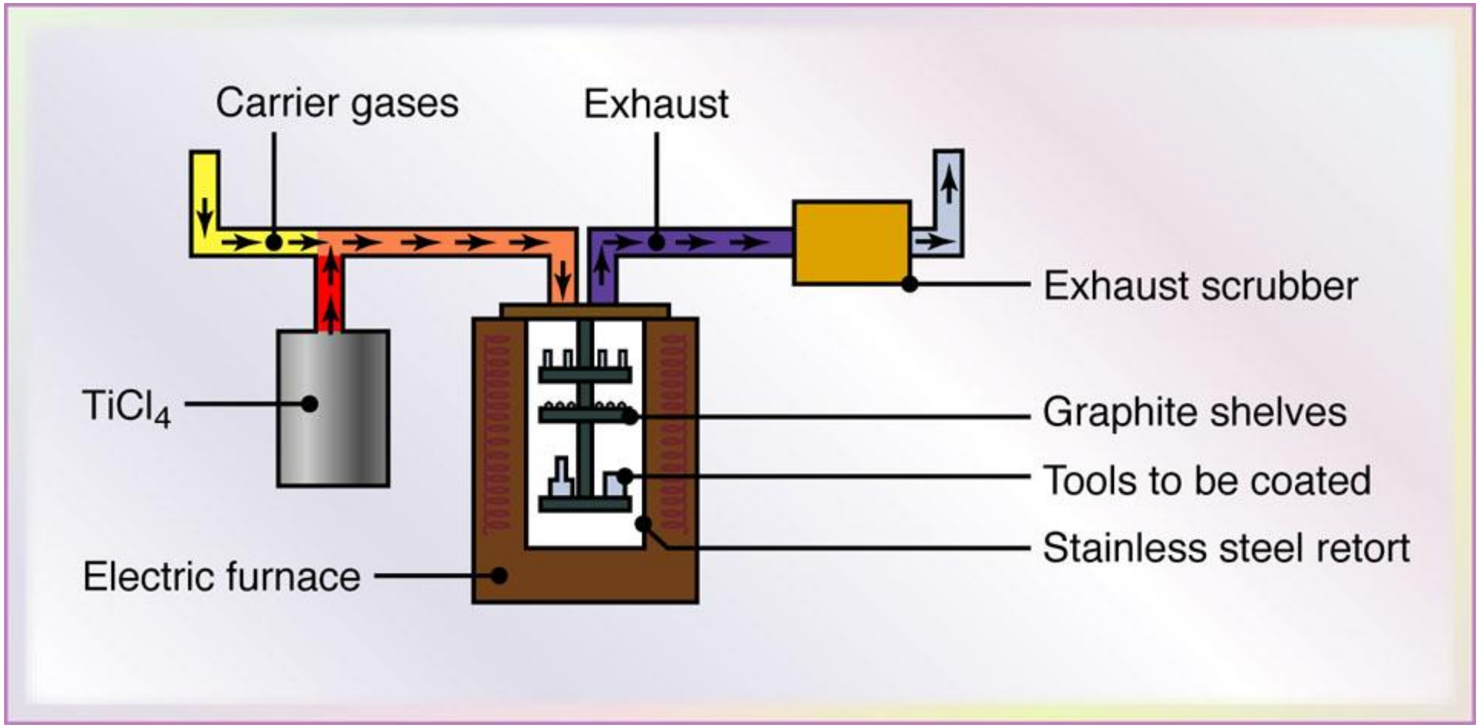
- **Ion plating** – describes various combined processes of sputtering and vacuum evaporation.



Chemical vapor deposition (CVD)

- **Chemical vapor deposition (CVD)** is a chemical process used to produce high-purity, high-performance solid materials.
- The process is often used in the semiconductor industry to produce thin films.
- In a typical CVD process, the wafer (substrate) is exposed to one or more volatile precursors, which react and/or decompose on the substrate surface to produce the desired deposit.
- Frequently, volatile by products are also produced, which are removed by gas flow through the reaction chamber.

Chemical-Vapor-Deposition Process



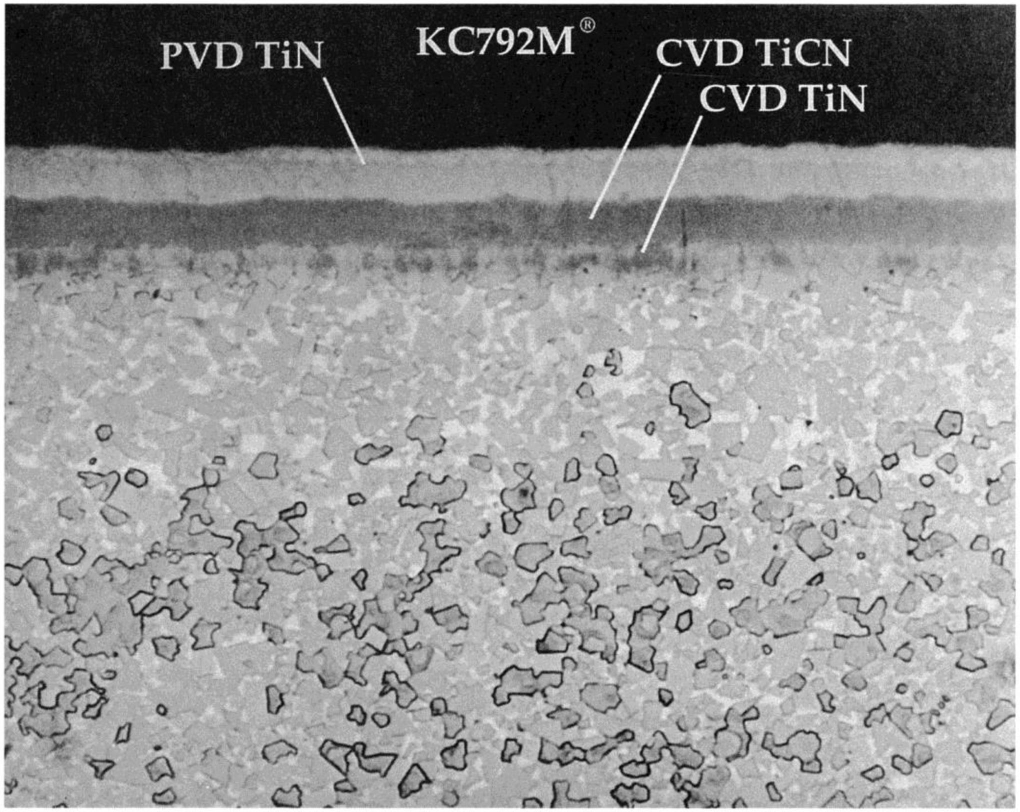
Schematic illustration of the chemical-vapor-deposition process. Note that parts and tools to be coated are placed on trays inside the chamber.

Applications of CVD

- Industrial metallurgical processes
  - Mond process to reduce nickel from its ore
- Coated carbide tools
- Solar cells
- Refractory metals on jet engine turbine blades
- Integrated circuit fabrication
- Other applications for resistance to wear, corrosion, erosion, and thermal shock

PVD and CVD

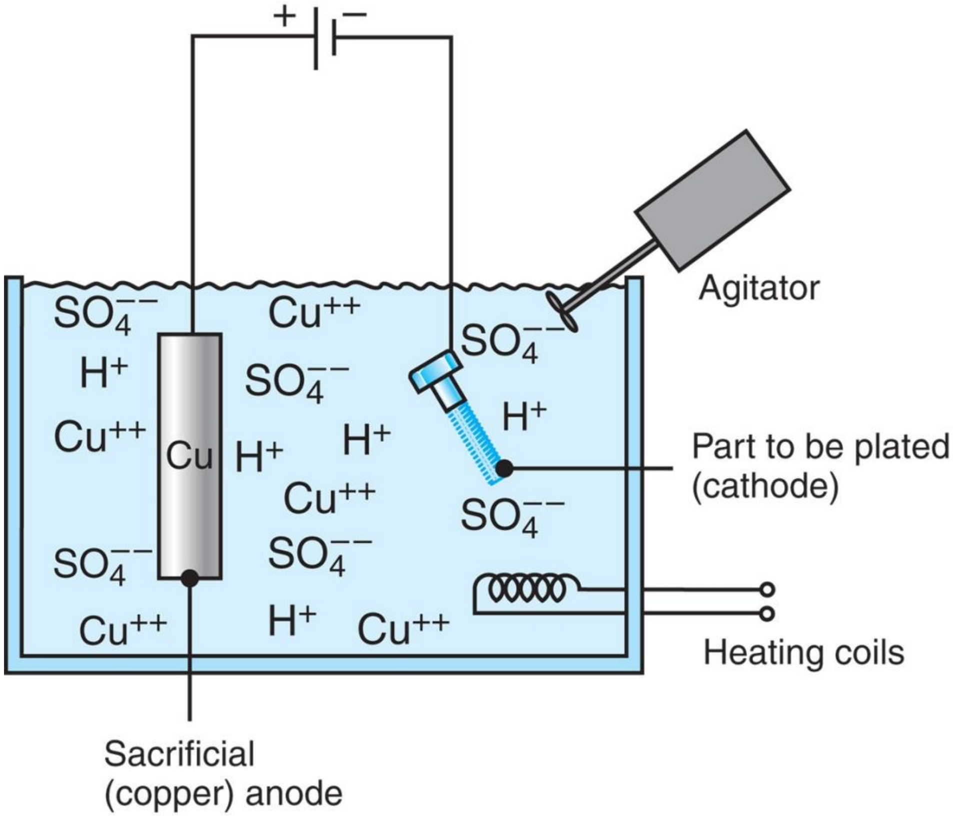
- Photomicrograph of cross section of a coated carbide cutting tool using CVD and PVD



Electroplating Process

- Also known as electrodeposition because the process involves depositing a thin layer of metal onto the surface of a work piece (substrate). An electric current is used to cause the desired reaction.
- For examples: A layer of gold is to be electrodeposited onto metal jewellery to improve the appearance of the piece. The plating metal (gold) is connected to the anode (positively charged electrode) of the electrical circuit, while the jewellery piece is placed at the cathode (negatively charged electrode). Both are immersed in a specially developed electrolytic solution (bath).
- At this point, a DC current is supplied to the anode, which oxidizes the metal atoms in the gold and dissolves them into the bath. The dissolved gold ions are reduced at the cathode and deposited (plated) onto the jewellery piece. Factors that impact the final plating result include:
  1. the chemical composition and temperature of the bath
  2. the voltage level of the electric current
  3. the distance between the anode and the cathode
  4. the electrical current application's length of time

ELECTROPLATING PROCESS



(a)

(b)

(a) Schematic illustration of the electroplating process. (b) Examples of electroplated parts. *Source*: Courtesy of BFG Manufacturing Service.

Theoretical Electroplating Equation

- Faraday's laws can be summarized:

  $$V = C\,I\,t$$

  where V = volume of metal plated, mm^3 (in^3); C = plating constant which depends on electrochemical equivalent and density, mm^3/amp-s; $I\,t$ (current x time) = electrical charge, amps-s
- C indicates the amount of plating material deposited onto the cathodic workpart per electrical charge

Principal Electroplating Methods

- *Barrel plating* - performed in rotating barrels - suited to plating many small parts in a batch
- *Rack plating* – racks of copper wire formed into shapes to hold parts and conduct current to them - used for parts that are large, heavy, or complex
- *Strip plating* – continuous strip is pulled through the plating solution by means of a take-up reel – suited to high production

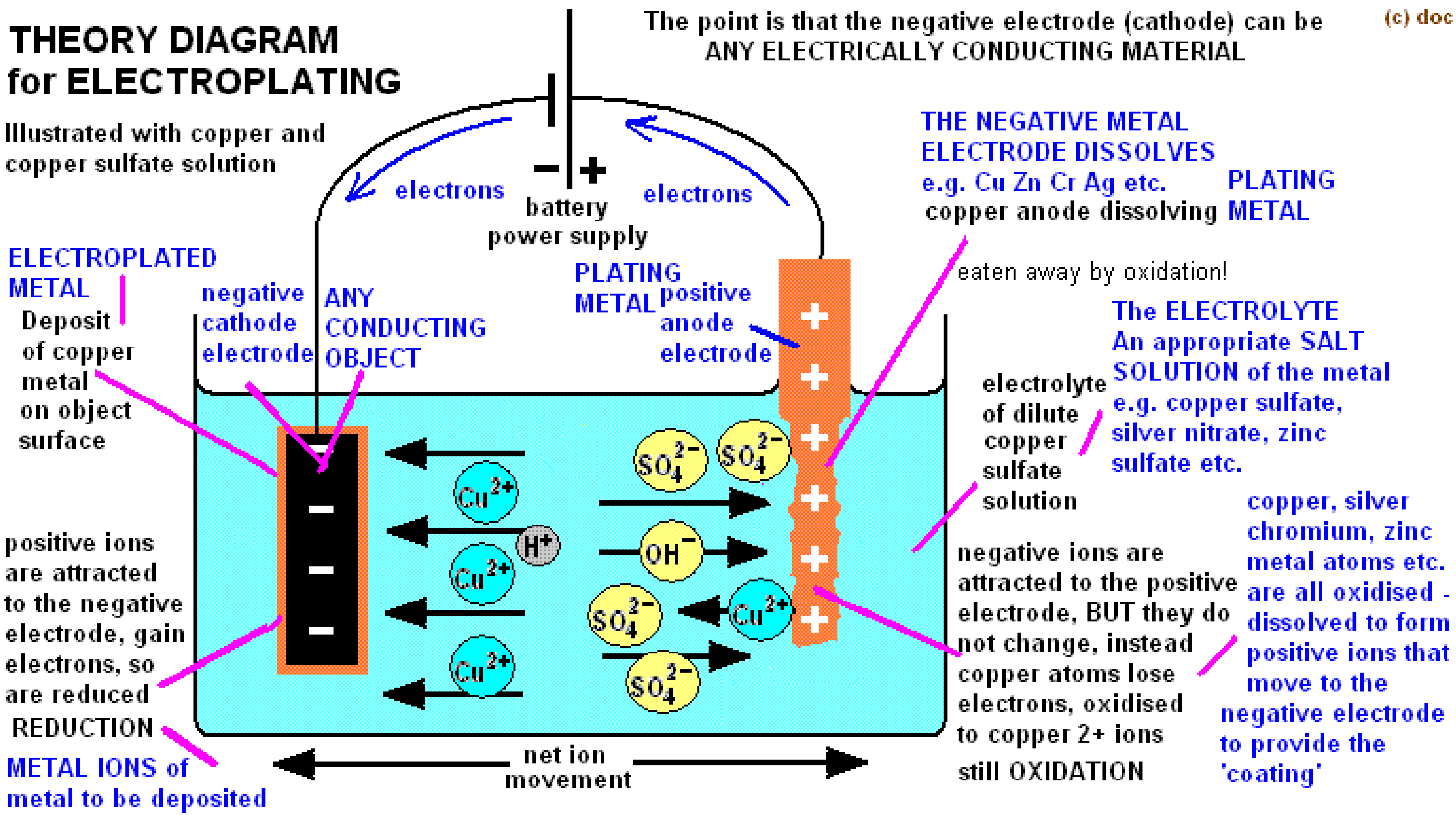
Common Coating Metals

- Zinc - plated on steel products such as fasteners, wire goods, electric switch boxes, and sheetmetal parts as a sacrificial barrier to corrosion
- Nickel - for corrosion resistance and decorative purposes on steel, brass, zinc die castings, etc.
  - Also used as base coat for chrome plate
- Tin - widely used for corrosion protection in "tin cans" and other food containers

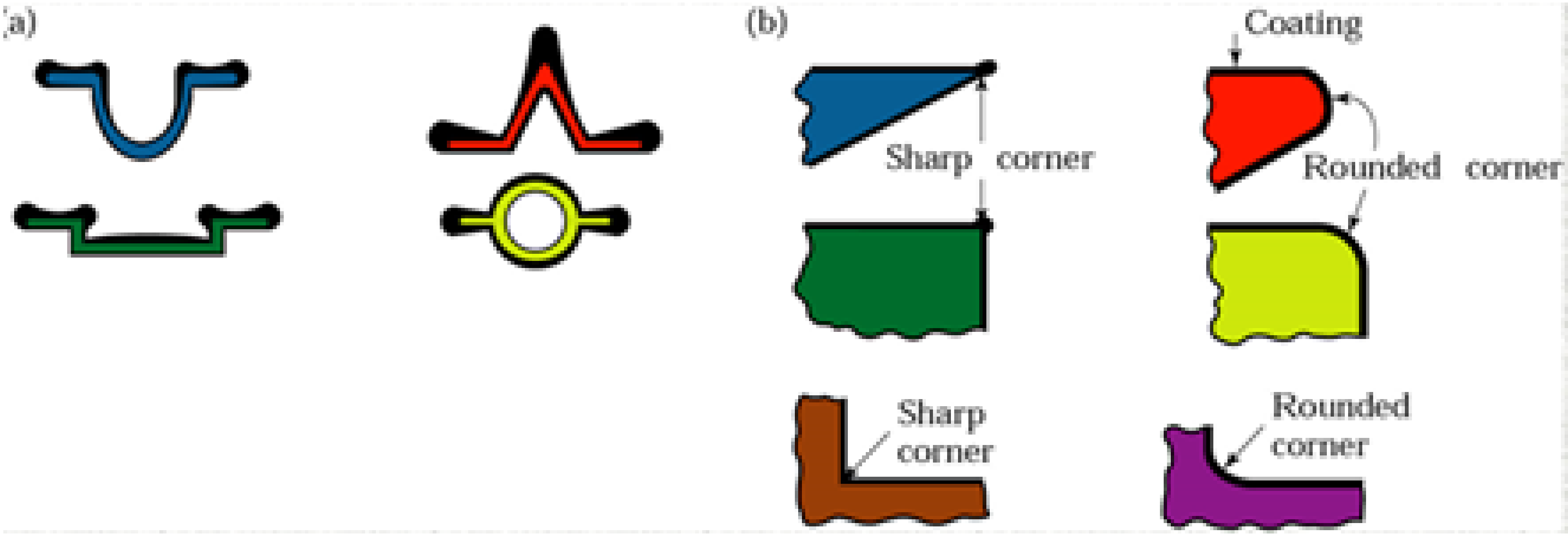
More Coating Metals

- Copper - decorative coating on steel and zinc, either alone or alloyed as brass
  - Also important in printed circuit boards
- Chromium - decorative coating widely used in automotive, office furniture, and kitchen appliances
  - Also one of the hardest electroplated coatings for wear resistance
- Precious metals (gold, silver) - plated on jewelry
  - Gold is also used for electrical contacts

THEORY DIAGRAM FOR ELECTROPLATING



DESIGN GUIDELINES



(a) Schematic illustration of non-uniform coatings (exaggerated) in electroplated parts. (b) Design guidelines for electroplating; note that sharp external and internal corners should be avoided for uniform plating thickness.

End of chapter
Surface Treatments