Surface coating methods

Processes, equipment and coating properties

Lecture notes based on Chapter 2

Gaseous, solution and thermal deposition routes

Based on the supplied chapter, printed pages 7–32

Classification of surface processes

Gaseous state: CVD, PVD and ion-assisted methods.

Solution state: chemical, electrochemical and sol-gel routes.

Molten or semi-molten routes: lasers, thermal spray and welding.

Solid-state processes form a fourth family. The chapter gives friction surfacing as an example.

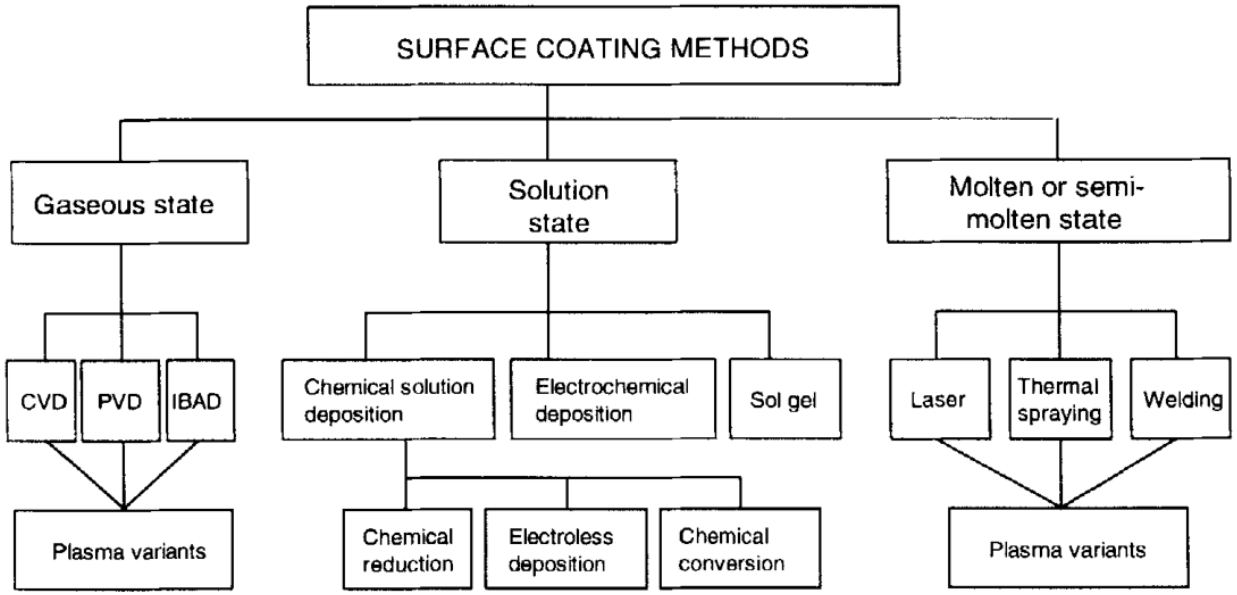


Figure 2.1 · Classification used in the chapter

Source: Chapter 2, pp. 7–8, 31

Thickness and temperature constraints

Required thickness eliminates unsuitable routes early.

Substrate temperature limits protect heat treatment and dimensional accuracy.

Part size, recesses and access affect equipment choice and coverage.

The plotted ranges are illustrative, not universal process limits.

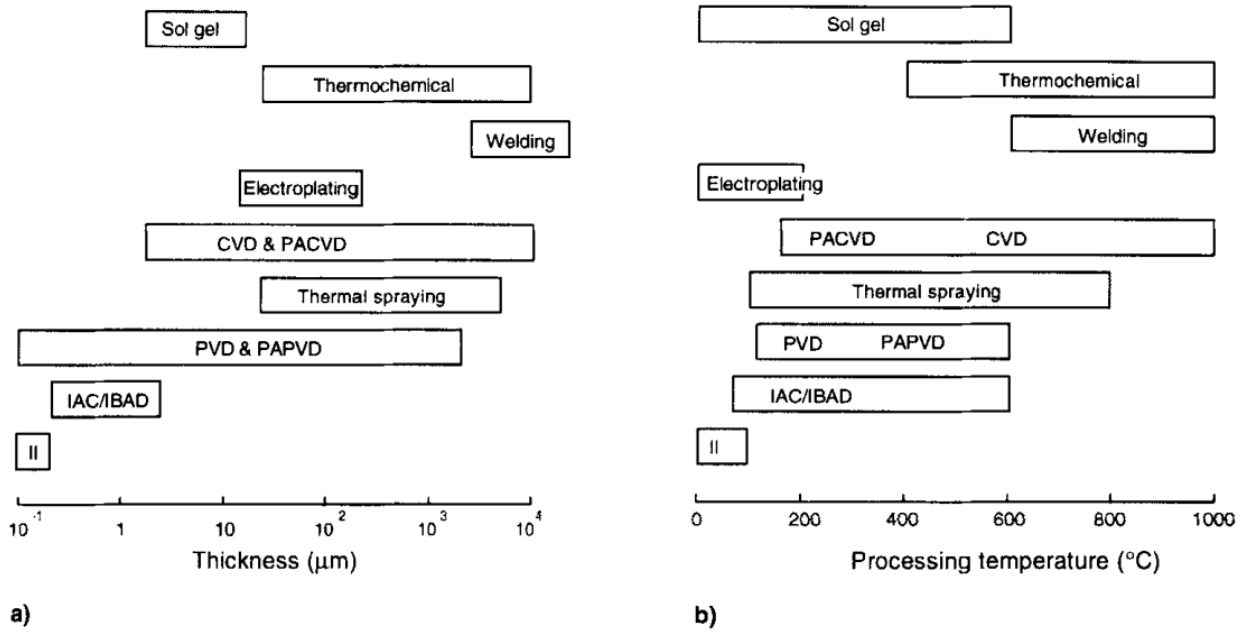


Figure 2.2 · Indicative ranges from the source

Source: Chapter 2, pp. 8–10

Plasma assistance and film growth

Ion bombardment cleans and heats the surface before deposition.

During growth, bombardment promotes atomic mobility and can densify the film.

Pressure and homologous temperature T/T_m influence morphology.

Plasma assistance can reduce the bulk temperature needed for dense films.

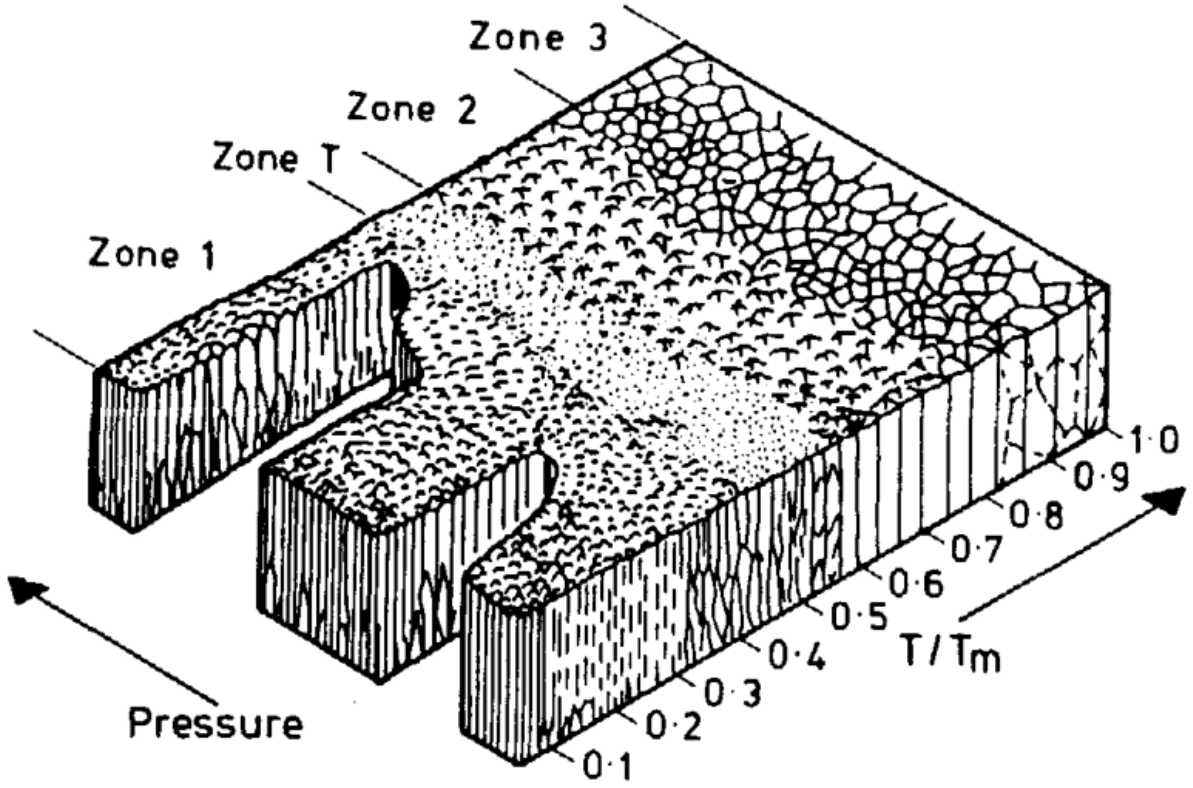


Figure 2.3 · Thornton structure-zone schematic

Source: Chapter 2, pp. 11–12

Chemical vapour deposition

Volatile precursors enter a reaction chamber and react at the heated surface.

Reactant delivery, surface reaction and exhaust removal sustain growth.

TiN and TiC tool coatings illustrate the hot-wall route.

Dense, adherent films and recess coverage are strengths. High temperature can restrict substrates.

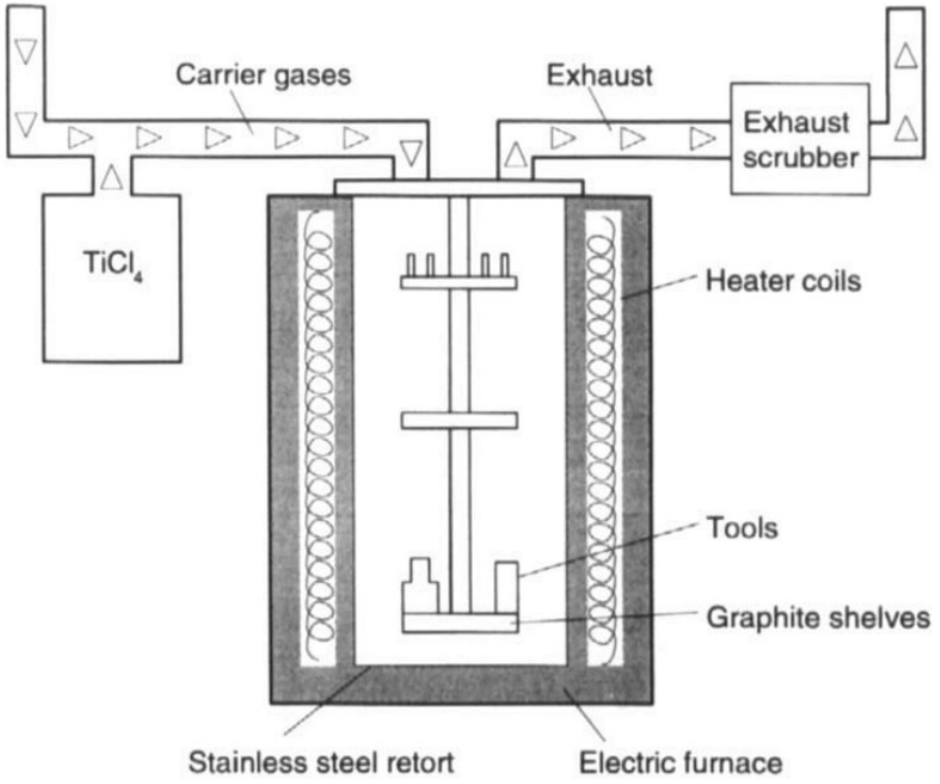


Figure 2.4 · Hot-wall CVD reactor

Source: Chapter 2, pp. 13–15

CVD variants

Pressure routes: normal-pressure and low-pressure CVD.

Activation: electron, laser, hot filament or plasma assistance.

Precursor and growth routes: metal-organic CVD, vapour-phase epitaxy and atomic-layer epitaxy.

Chemical vapour infiltration extends deposition into porous structures.

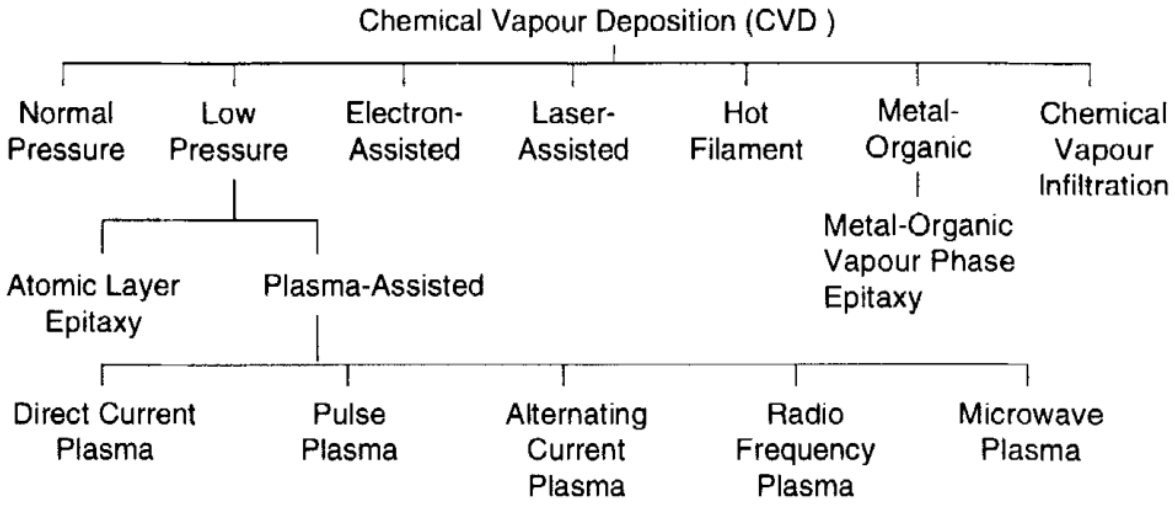


Figure 2.5 · CVD derivatives named in the source

Source: Chapter 2, pp. 13–15

CVD transport and interface reactions

Reactants and by-products cross a boundary layer.

Surface reactions determine nucleation and microstructure.

Temperature also changes the coating and substrate after deposition begins.

Interdiffusion can form intermediate phases at the interface.

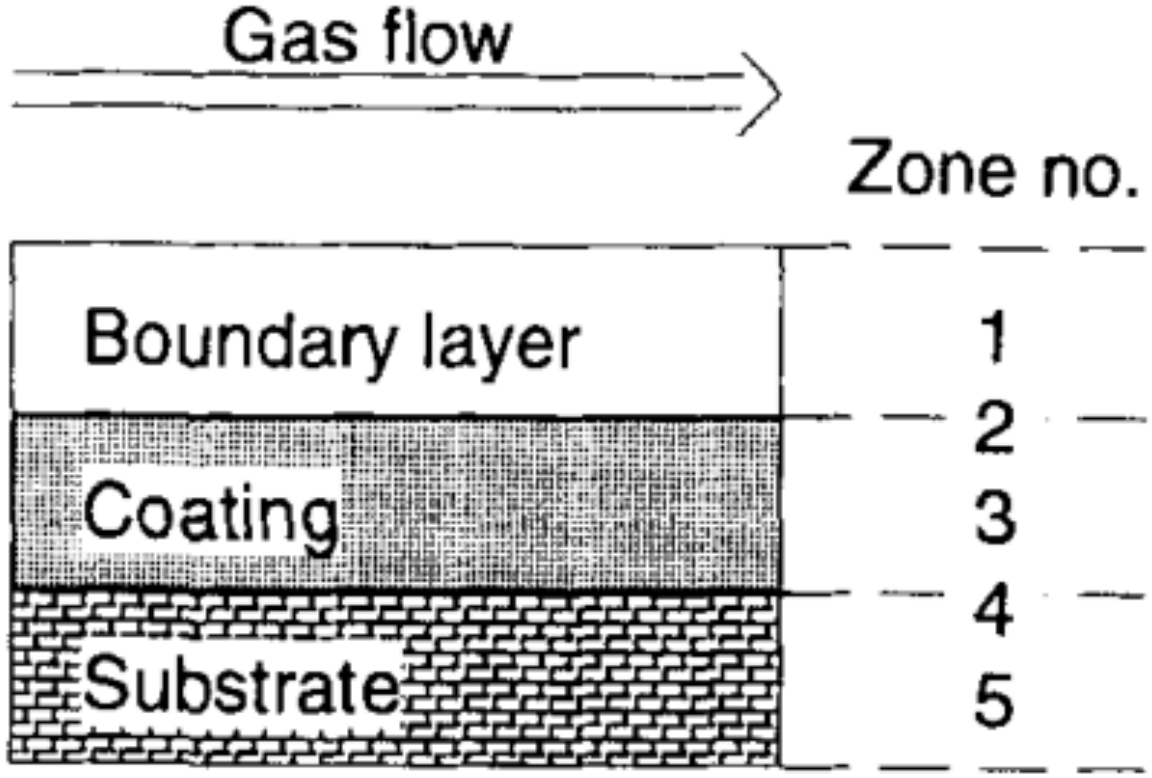


Figure 2.6 · Gas, coating and substrate reaction zones

Source: Chapter 2, pp. 14–15

Physical vapour deposition families

PVD atomises or vaporises material from a solid source.

Evaporation uses resistive, inductive, electron-beam or arc sources.

Sputtering uses diode, magnetron, ion-beam or triode arrangements.

Plasma-assisted PVD includes ion plating and ion-assisted coating.

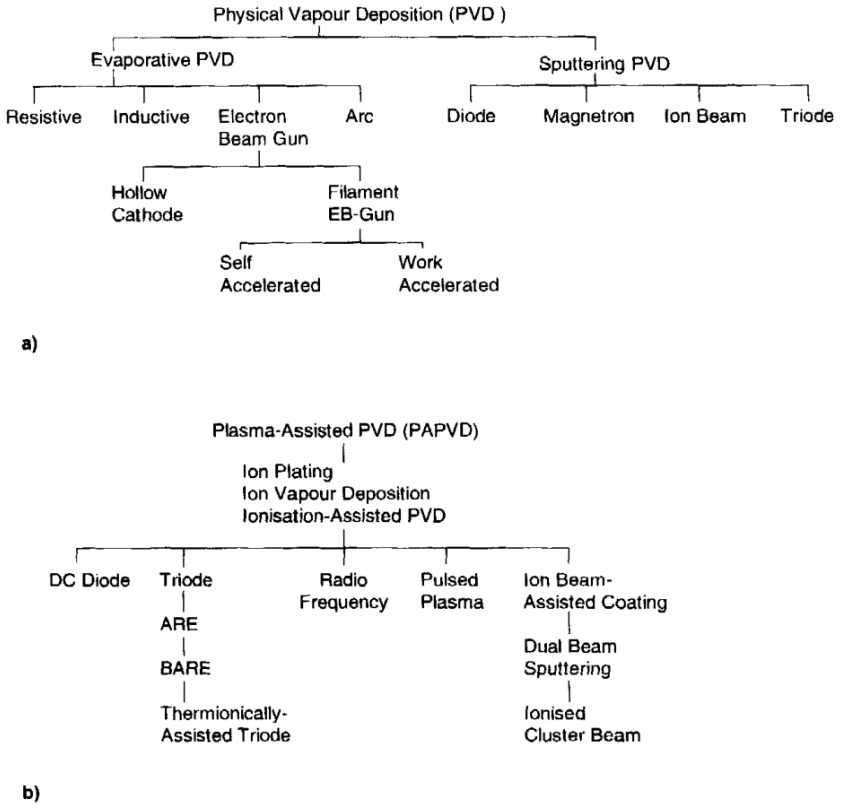


Figure 2.7 · PVD sources and plasma derivatives

Source: Chapter 2, pp. 15–16

Ion plating and surface bombardment

A negatively biased component attracts positive ions from a plasma.

Argon bombardment first removes surface contamination.

Evaporated material then enters the plasma and deposits with added energy.

Sputtering, intermixing and redistribution influence adhesion and density.

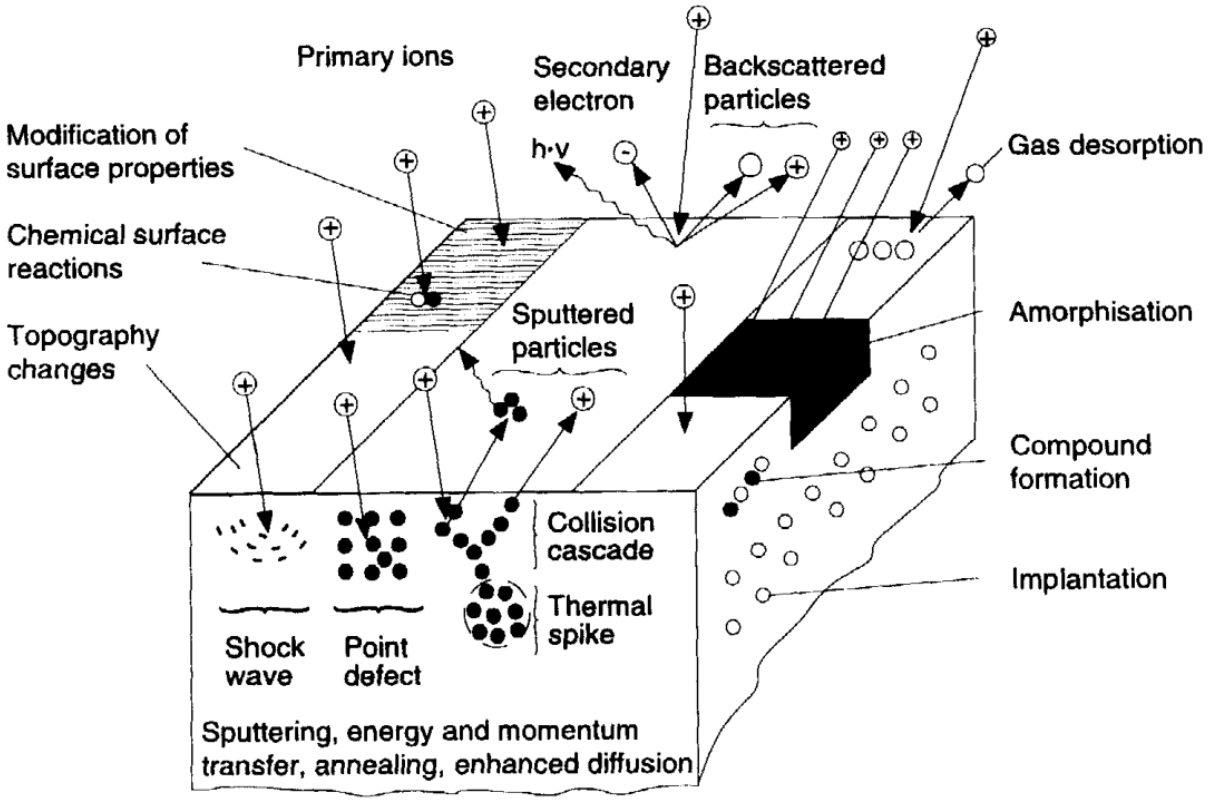


Figure 2.8 · Ion–surface interactions

Source: Chapter 2, pp. 17–18

ARE, BARE and enhanced triode systems

Activated reactive evaporation (ARE) raises ionisation using an additional electrode.

Biased ARE (BARE) combines activation with substrate bias.

A thermionic triode adds electrons from a heated filament.

The aim is stronger control of the energy and flux reaching the growing film.

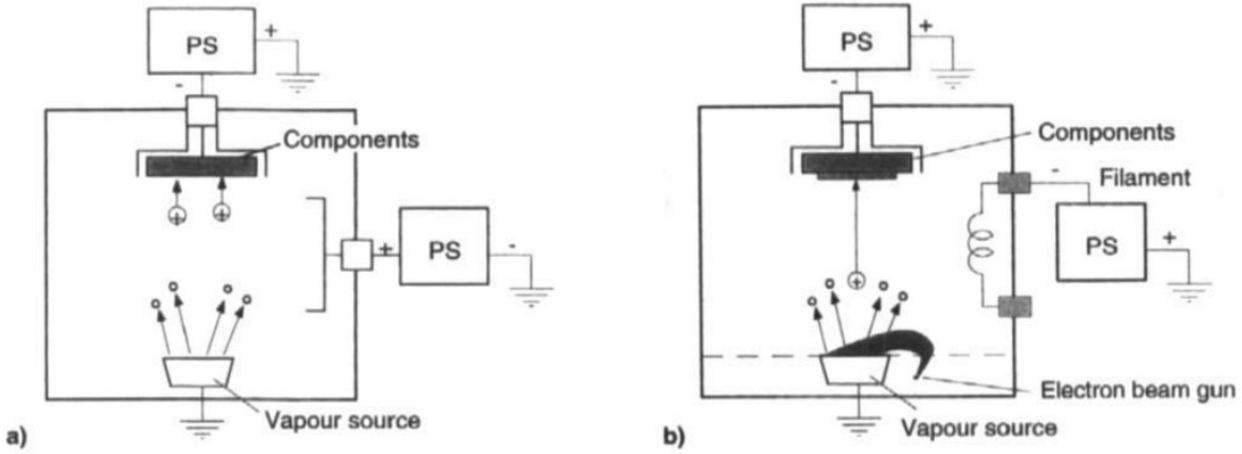


Figure 2.9 · BARE and thermionic triode layouts

Source: Chapter 2, pp. 17, 19

Resistance and induction evaporation

Resistance evaporation passes current through a refractory boat or holder containing the source material.

The chapter lists aluminium, copper, silver and lead as examples.

Induction heating couples energy into the melt and can reduce reactions with the crucible.

Titanium and aluminium illustrate materials for which reduced container interaction can be useful.

Source: Chapter 2, pp. 18, 20

Electron-beam evaporation

An electron beam concentrates heat at the evaporation source.

The chapter distinguishes self-accelerated, work-accelerated and hollow-cathode guns.

A beam passing through the chamber can also enhance ionisation.

A hollow-cathode discharge confines a plasma in a tube to generate the electron beam.

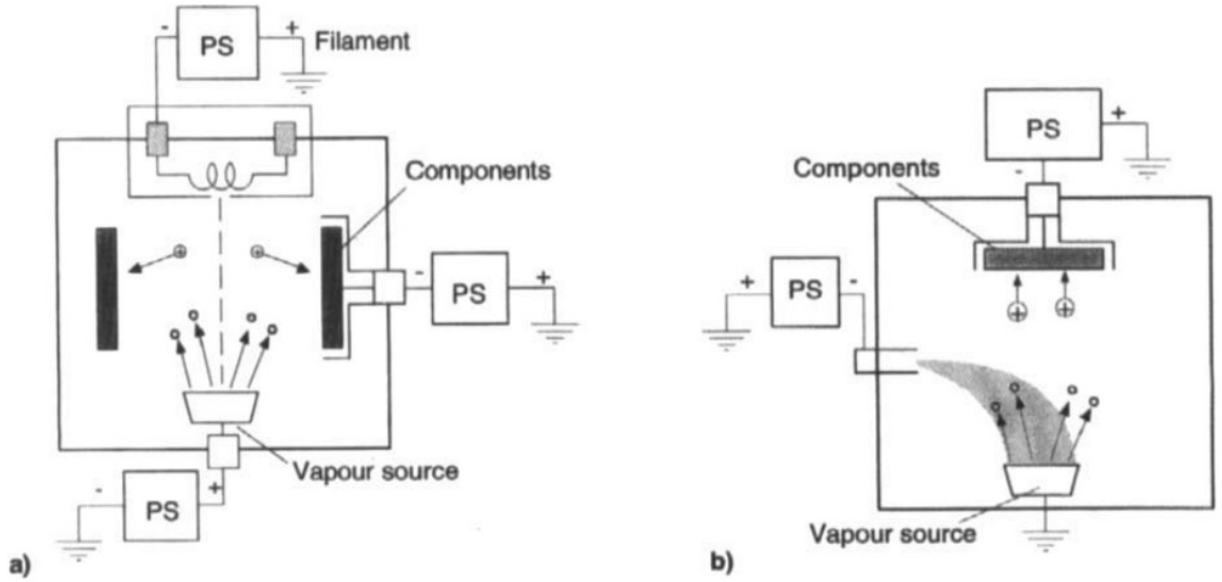


Figure 2.10 · Work-accelerated and hollow-cathode guns

Source: Chapter 2, pp. 18–20

Arc evaporation

An electrical arc erodes and vaporises the source material.

The depositing flux has a high degree of ionisation.

Sources can operate in different orientations.

Ejected droplets can create macroparticles and surface defects.

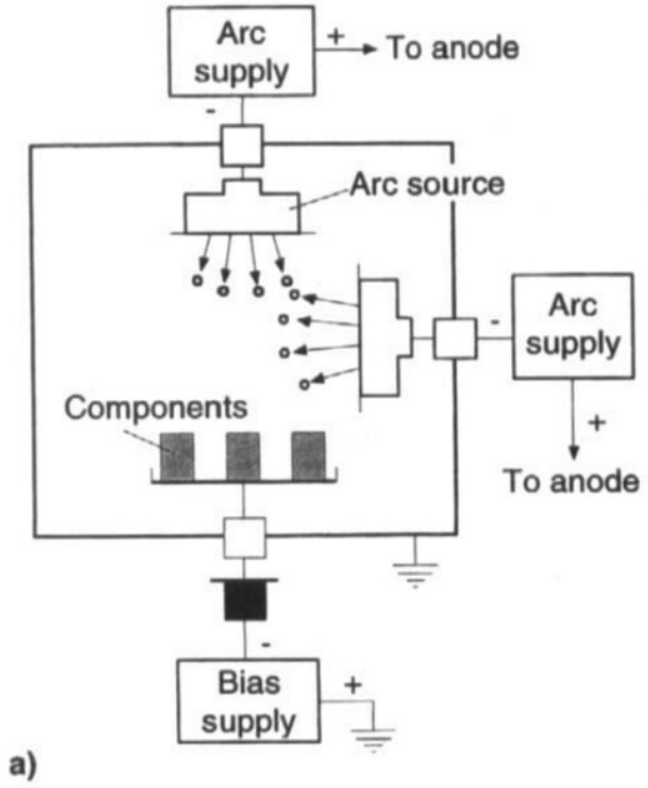


Figure 2.11a · Arc-source coating arrangement

Source: Chapter 2, pp. 20–21

Sputtering and magnetron sources

Argon ions and energetic neutrals eject atoms from a target by momentum transfer.

Magnetic confinement increases bombardment near the target.

Unbalanced magnetrons extend plasma into the deposition volume.

Alloy deposition is possible, but composition still requires process control.

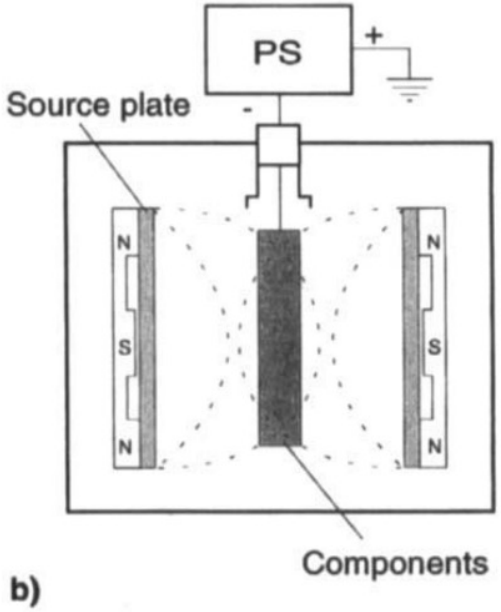


Figure 2.11b · Double-magnetron arrangement

Source: Chapter 2, pp. 17, 20–21

Ion implantation

Electrical acceleration drives ions beneath the substrate surface.

The modified region is part of the substrate, without a separate deposited film.

Nitrogen, titanium, carbon and yttrium are examples in the chapter.

Beam implantation and pulsed plasma-immersion routes provide different geometries.

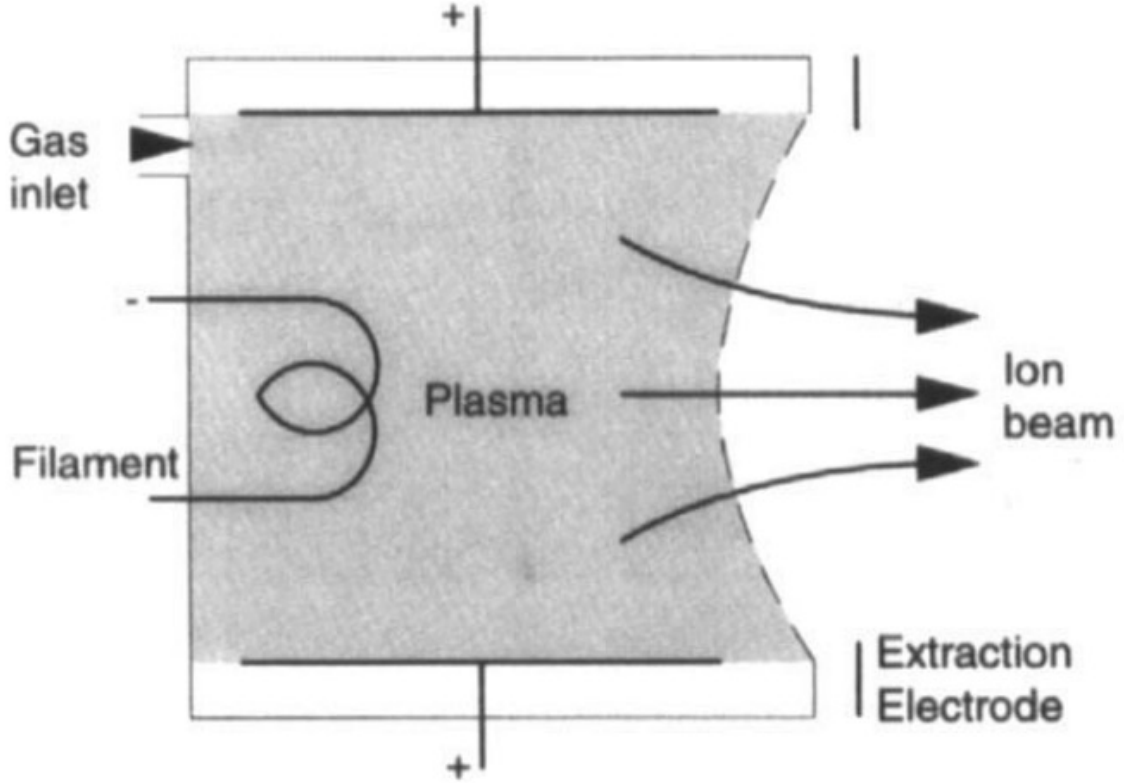


Figure 2.12 · Ion-source schematic

Source: Chapter 2, pp. 21–22

Ion stitching and ion-beam mixing

Stitching implants through a thin coating–substrate interface to improve bonding.

Mixing redistributes coating and substrate atoms through collision processes.

The chapter describes initial layers up to about 50 nm for mixing.

Both methods act on an existing layer or interface.

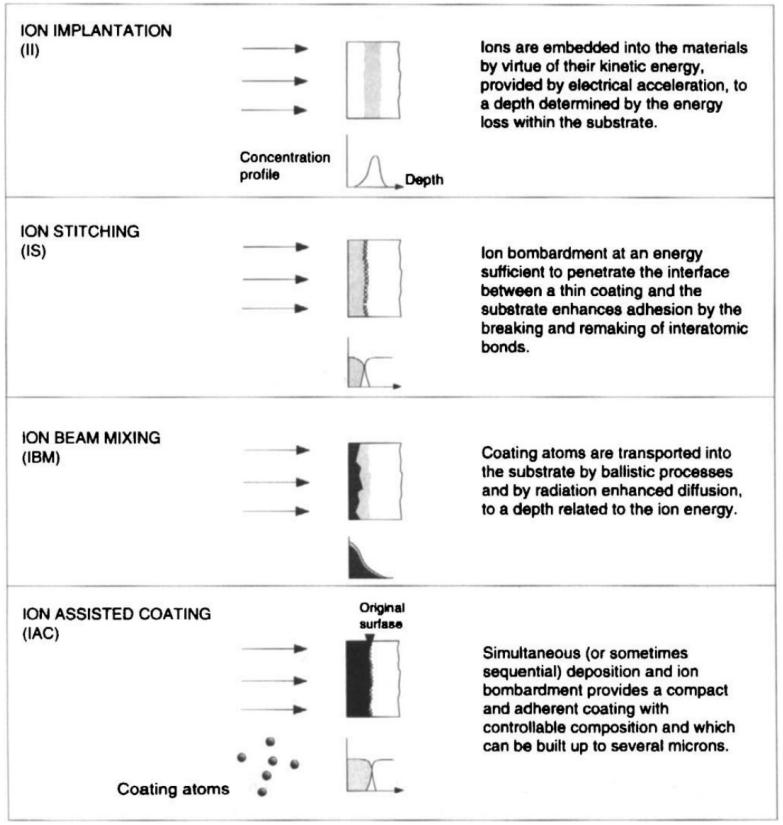


Figure 2.13 · Four ion-beam treatment modes

Source: Chapter 2, pp. 22–23

IBAD and reactive ion-assisted coating

Ion-beam assisted deposition (IBAD) combines deposition with ion irradiation.

Ion-assisted coating (IAC) is an alternative name used in the chapter.

Reactive ions give reactive IBAD (RIBAD).

Reactive ion-assisted coating (RIAC) can combine initial mixing with subsequent deposition and implantation.

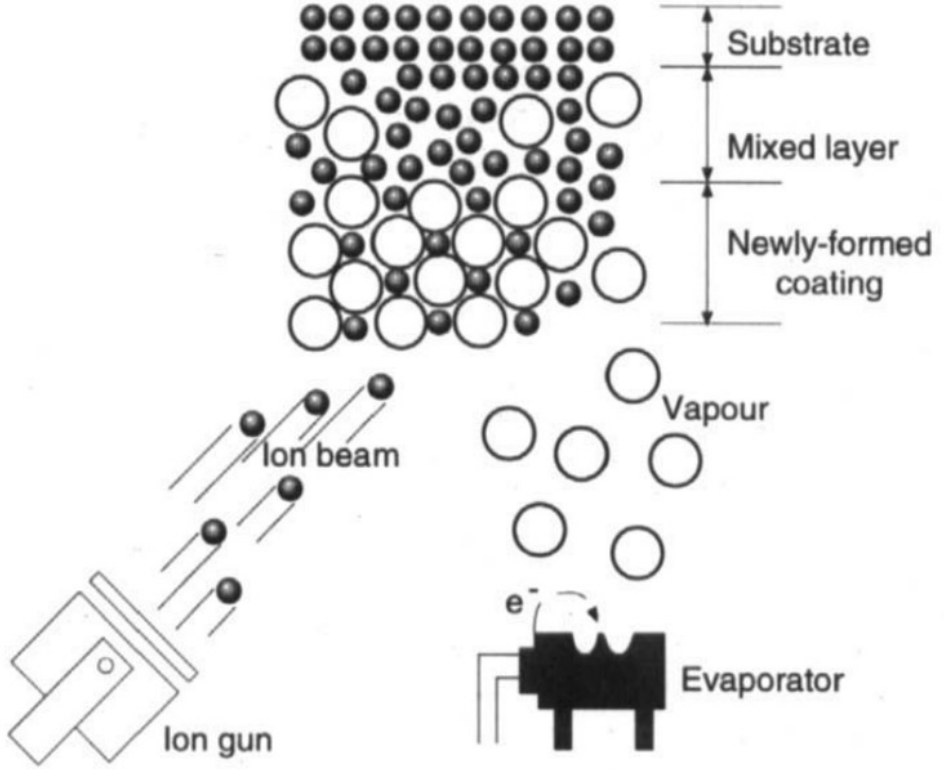


Figure 2.14 · Ion-assisted coating arrangement

Source: Chapter 2, pp. 23–24

Chemical reduction from solution

A reducing agent converts dissolved metal ions into metal.

The chapter describes spraying metal-ion and reducing-agent solutions onto a surface.

Silver, gold and copper can form coatings on metals or plastics.

Adhesion can be poor, so surface preparation and substrate compatibility matter.

Source: Chapter 2, pp. 24–25

Electroless and composite deposition

Autocatalytic deposition localises the reduction reaction at a catalytic surface.

Electroless nickel commonly contains phosphorus or boron derived from the reducing agent.

Dispersed SiC, WC, alumina or diamond particles can reinforce the deposit.

Graphite, PTFE or calcium fluoride additions can provide solid lubrication.

Source: Chapter 2, pp. 25

Chemical conversion coatings

A solution reacts with the substrate to form a compound layer.

Phosphating forms amorphous or crystalline phosphate layers.

Phosphate pretreatment supports paint protection and can aid running-in.

Chromating improves corrosion protection and paint adhesion on several metals.

Source: Chapter 2, pp. 25–26

Electrochemical deposition

An external current drives metal deposition onto the cathodic workpiece.

The electrolyte carries ions between electrodes.

Faraday’s laws relate deposited mass to charge and chemical equivalent.

Thickness depends on current, time, efficiency and coated area.

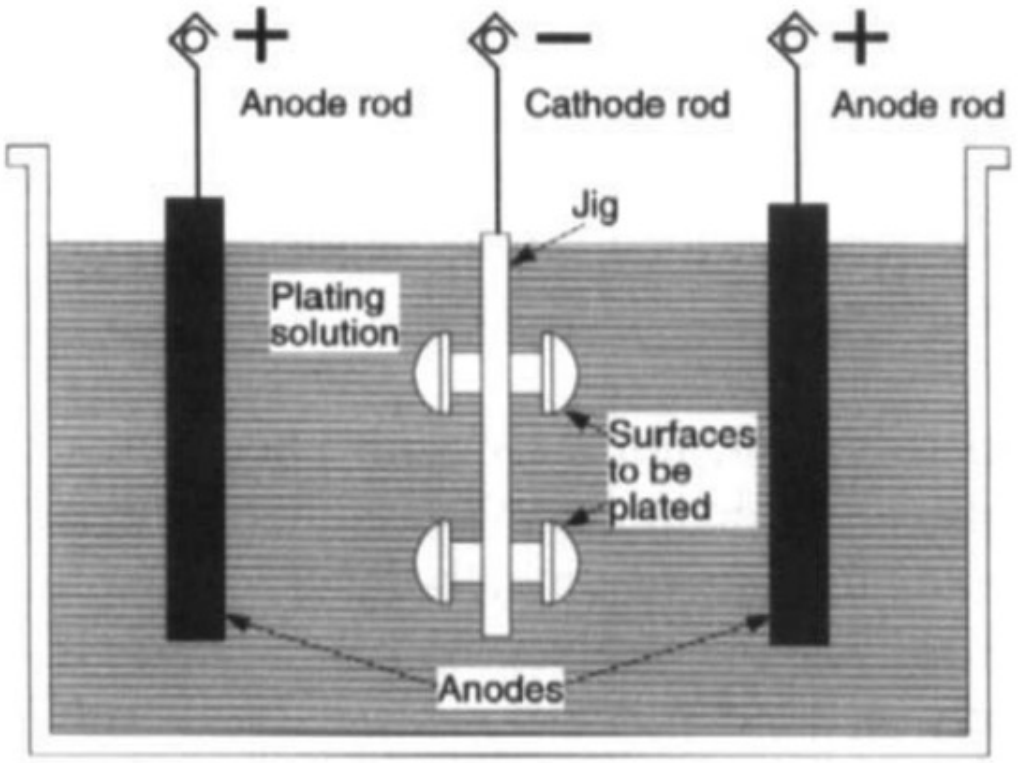


Figure 2.15 · Electroplating cell

Source: Chapter 2, pp. 26

Electroplated metals and alloys

Examples include brass, bronze, Co–Ni, Fe–Ni and Sn–Ni.

Zinc on steel provides sacrificial galvanic protection.

Decorative chromium may be a thin layer over nickel or copper/nickel.

Thicker hard-chromium deposits serve abrasion and lubricant-retention needs.

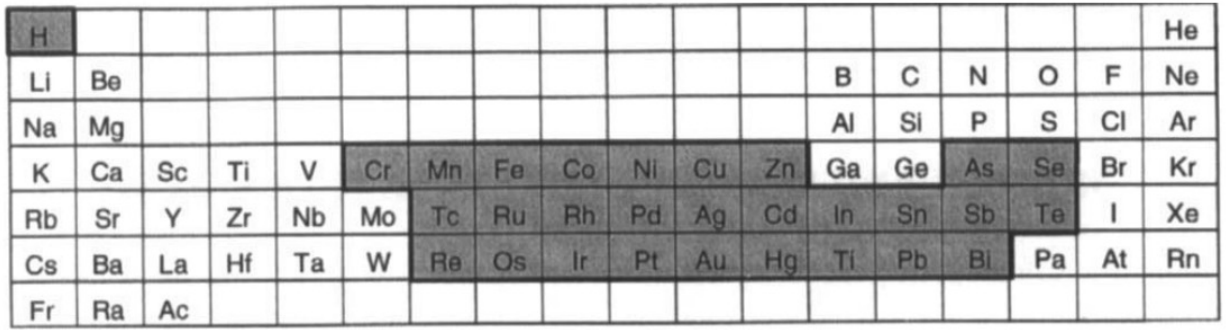


Figure 2.16 · Aqueous-deposition region in the source

Source: Chapter 2, pp. 26–27

Sol-gel coatings

A sol contains colloidal particles dispersed in a liquid.

Dipping or spinning distributes the sol over the substrate.

Aggregation and gelation produce a network, followed by drying.

Firing converts the gel to a ceramic film. Porosity depends on processing.

Source: Chapter 2, pp. 27–28

Laser surface treatments and coatings

Heating supports transformation hardening or annealing without adding material.

Surface melting refines or homogenises structure and can seal the surface.

Alloying mixes added material with the surface. Cladding builds a deposited layer.

Laser CVD, laser PVD and laser-ablation deposition use laser energy to assist film formation.

Source: Chapter 2, pp. 28

Thermal spraying and HVOF

A hot gas stream heats feedstock and projects it onto the substrate.

Arc and flame spraying include metallising with zinc or aluminium.

Higher-energy routes include plasma spray, detonation gun and high-velocity combustion spray.

HVOF uses combustion to accelerate powder toward the surface.

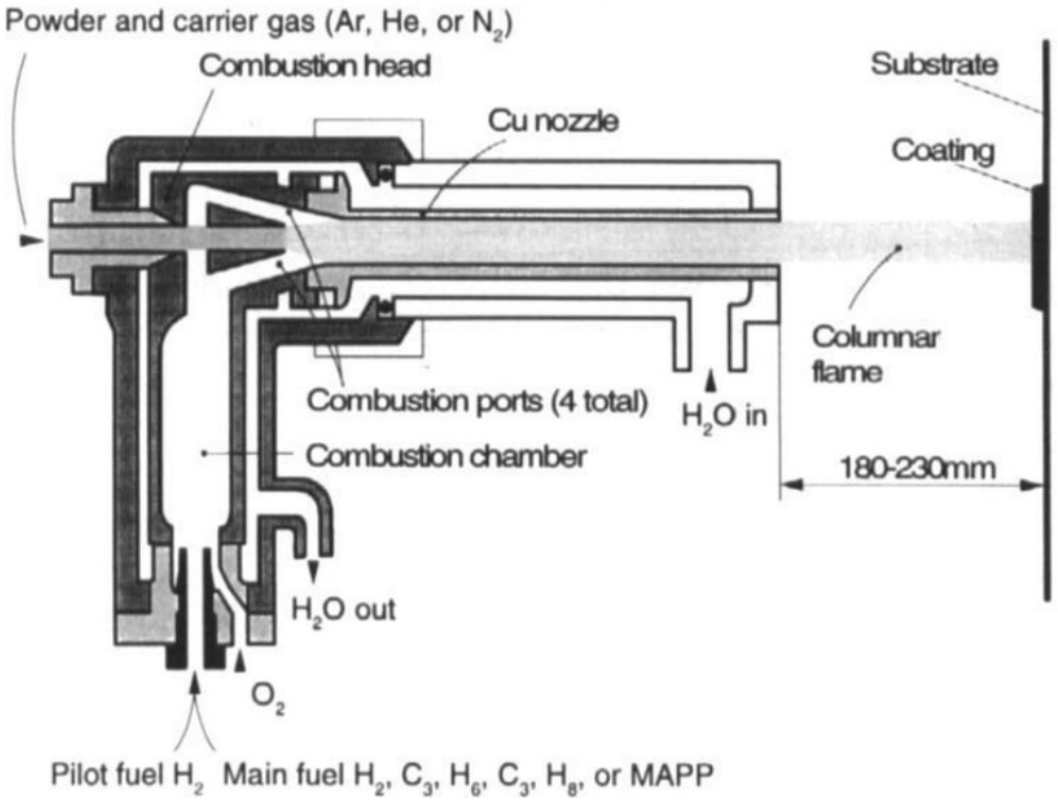


Figure 2.17 · High-velocity oxy-fuel spray layout

Source: Chapter 2, pp. 29

Weld hard-facing

Oxyacetylene and arc welding deposit metals or metal–ceramic composites.

Fusion creates a metallurgical bond and can alter the substrate.

Carbides in Fe-, Co- or Ni-based matrices resist abrasive wear.

The chapter gives a typical deposited thickness of 1.5–6 mm.

Electro-spark deposition

Short, high-current pulses transfer anode material to a cathodic substrate.

Local micro-welding creates a fused, metallurgical bond.

Low total heat input can keep the bulk substrate near ambient temperature.

Slow coverage and difficult access to holes, corners and rough surfaces limit use.

Source: Chapter 2, pp. 30–31

Friction surfacing

A rotating consumable rod presses against the substrate.

Frictional heating creates a hot plasticised zone at the contact.

Relative traverse transfers a layer and bonds it in the solid phase.

The chapter gives deposit thicknesses of 0.2–2.5 mm and a dense, fine microstructure.

Source: Chapter 2, pp. 31

Processing controls coating properties

Identical chemistry can give different wear behaviour after different deposition routes.

Morphology, boundaries and residual stress affect hardness, toughness and adhesion.

Microcracked chromium can retain lubricant.

Segmented thermal barriers and dense PVD tool coatings need different structures.

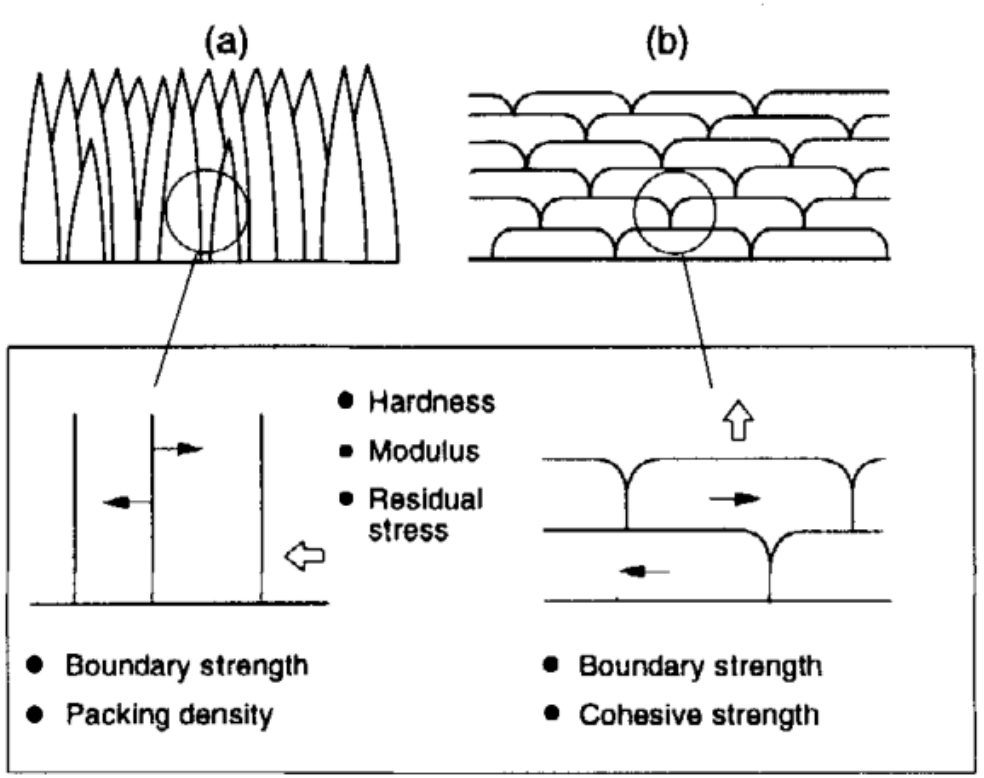


Figure 2.18 · Vapour-grown and sprayed structures

Source: Chapter 2, pp. 31–32

Process selection and review

Route	Main mechanism	Selection concern
CVD / PVD	Chemical reaction / vapour transfer	Temperature, geometry, stress
Ion methods	Implantation or assisted growth	Depth, ion dose, interface
Solution routes	Reduction or surface reaction	Bath chemistry, preparation
Spray / weld / laser	Particle impact or local fusion	Heat input, structure, dilution
Friction surfacing	Plastic flow and solid-phase bond	Access, force and traverse

Review: How do thickness, substrate temperature and part geometry narrow the choice?

Source: Chapter 2, pp. 7–32