Unlock Delicate Materials:
chemical & laser-based techniques: fragile mat. e.g. glass/thin films for microelectronics/medical devices

Conquer Hardness:
readily machine superalloys, ceramics, diamonds unlike traditional processes

Non-traditional Machining:
Processes that remove materials by various techniques involving mechanical, thermal, electrical, or chemical energy (or combinations) but **do not use a sharp cutting tool** in the conventional sense

→ micromachining, aerospace industry, rapid prototyping

Pros: enables higher production complexity & material selection
conquer hardness

Longer Tool Life:
some eliminate direct tool contact, reducing wear/tear/production costs

Complex Features:
non-contact methods to create sharp corners/thin walls, impossible w/ traditional tools.

Micro-Precision:
tolerances in micro range e.g. microfluidic devices / intricate turbine blades

Electric Energy

Electrochemical Machining (ECM):
Utilizes a shaped tool electrode & electrolyte flow to dissolve workpiece, replicating tool shape; anodic dissolution: mat from workpiece (+) → cathode tool (−) in an electrolyte bath; flow carries off depleted mat.

Advantages
High Precision, Stress-Free Machining, Hard Mat. Compatibility (e.g. Ti), Environ. F.

Limitations
Limited M.C. (conductive mat.), Electrolyte Maintenance, Tool Wear.

Electrochemical Deburring (ECD):
Utilizes same method as ECM to remove burrs & sharpe edges.

Advantages
High Speed, Precision, Versatility (mat. & structure), E.F.

Applications
Medical Devices (surgical tools), Electronics Industry.

Electrochemical Grinding:
Combines ECM w/ abrasive action: abrasive slurry flow btwn tool electrode (as a grinding wheel) & workpiece.

Advantages vs traditional grinding
Faster Mat. Removal, ↑ Efficiency, Wide M.C.

Mechanical Energy

Ultrasonic Machining (USM):
A piezoelectric transducer converts electrical energy into high frequency vibrations, which are transferred through a slender tool immersed in an abrasive slurry - erodes material through chipping & grinding

Advantages
Material Versatility (hard mat.), Complex Geometries (thin walls), Minimal Heat Generation (preserves prop.), Environmentally friendly.

Disadvantages
Slower Process, Tool Wear

Waterjet Cutting (WJC):
Pressured water (up 55,000 psi) is focused through a narrow nozzle, directly eroding workpiece material through erosion & fatigue.

Advantages:
Material Versatility, Clean Cutting, Complex Geometries, Environmentally Friendly

Limitations:
Lower Accuracy, Water Consumption, Safety Precautions

Abrasive Waterjet Cutting (AWJC):
An abrasive feeder introduces fine-grained particles into conventional WJC, eroding wider range of mat. w/ higher efficiency

Advantages over WJC:
↑ Cutting Power/Speeds, Mat. Compatibility

Considerations
Surface Finish, Abrasive Selection, Cost

Abrasive Jet Machining (AJM):
Like AWJC, but uses gas (compressed air) instead of water & uses Al_2O_3 & SiC as abrasive parts.
→ chipping / grinding

Advantages:
Ultra Precise (smaller nozzle), Wider Mat Compatibility, Minimal Heat Gen., Environ. F.

Limitations:
Slower Cutting Speed (Lower P), Limited Depth of Cut (efficiency ↓), Cost

Thermal Energy Processes (TEPs):

Leverages heat / light to vaporize / melt / erode materials: hard / brittle / exotic mat.

Electric Discharge Machining (EDM):

Utilizes rapidly recurring electrical discharges (sparks) btwn. 2 electrodes separated by a dielectric fluid → melts / vaporizes workpiece into shape of tool electrode

Variations:

Die Sinking EDM (DSEDM):

most common, employs shaped tool electrode for complex 3D features

Advantages:

Complex 3D Geometries, Hard M.C., Minimal Contact

Challenges:

Electrode Wear, Surface Finish, Heat-Affected Zone (HAZ: affect props.)

Wired EDM (WEDM):

Utilizes a thin, electrically charged wire (brass or copper) as tool electrode, guided by CNC.

Advantages:

Ultra-Precise Machining (2D narrow cuts), Complex Geometry (profiles & angles), Hard M.C., Min. Contact / stress.

Challenges:

Wire Breakage, Slower Process, Surface Finish.

Micro EDM (MEDM):

Miniature tool electrodes (down to 20 microns) & specific formulated dielectric fluids.

Advantages

Unmatched Precision, Hard M.C., Minimal HAZ, Non-contact Machining.

Challenges:

Complex Setup / Expertise, Slower Process, Tool / Electrode Wear.

Plasma Arc Machining (PAM):

Utilizes constricted, high-velocity jet of ionized gas (plasma) gen. by an electric arc → melts & remove mat. (11,000°C ~ 30,000°C)

Advantages:

Material Versatility (most conductive Mat & some non-cond), Fast Cutting Speeds, Clean Cutting, Non-Contact Mfg.

Challenges:

HAZ, Surface Finish, Safety Concerns

Laser Beam Machining (LBM):

Utilizes a highly focused laser beam to deliver intense thermal energy: melts / vaporize / ablates

Operations:

Laser Cutting:

high-power laser for cutting

Laser Engraving:

low-power laser for texturing surfaces

Laser Abrasion:

remove thin layers / surface cleaning

Laser:

Light Amplification by Stimulated Emission of Radiation

- converts electrical energy into a highly coherent light beam
- monochromatic (single wavelength), highly collimated (light rays are almost perfectly parallel).

Advantages:

Unmatched Precision, Material Versatility, E.F., Non-Contact Machining

Challenges:

High initial investment, HAZ, Safety Concerns

Electron Beam Machining (EBM):

Employs a highly focused beam of electrons, melting / vaporizing mat.

Advantages:

Unmatched Precision, Exceptional Material Versatility, Minimal HAZ, Deep Drilling Capabilities

Challenges:

High Initial Investment, Vacuum Environment, Safety Concerns

Chemical Machining (CHM):

Employs chemical solutions (etchants) to selectly dissolve unwanted materials.

→ etching rate: chemical comp., temp., & agitation

Steps:

1. Design & Preparation
2. Masking: apply photoresist
3. Pattern Transfer: expose w/ photomasks
4. Etching: etchant bath dissolves mat.
5. Demasking & Cleaning: remove residual etchants
6. Inspection & Finishing

Variations

Maskant-Based CHM:

resist material (protective maskant) to shield / protect wanted areas from etchant bath

Etchants:

potent chemical solution that selectively dissolves unwanted mat.; typically acidic / alkaline / oxidizing

Types:

Acidic (for metals, $FeCl_3$ / HNO_3)

Alkaline (metals / non-Ms)
$NaOH$ → silicone, KOH → glass

Oxidizing (semiconductors)
H_2O_2 & H_2SO_4 mixtures

Maskant:

Liquid Photoresist: (light-sensitive, patterned through photolithography) & high resolution

Film Mask: pre-cut film made of polymer; for simple shape / large vol. mfg.

Enamels / Spray: brushed / sprayed liquid resists; flexible & good adhesion

Solid Maskants: sheet mat. (rubber / plastic) for thick sections / complex geom.

Photochemical Machining (PCM):
employs light-sensitive resists for pattern transfer w/ photolithography

Electropolishing:
removes material smoothly through electrochemical processes.