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SMART SENSOR TECHNOLOGIES

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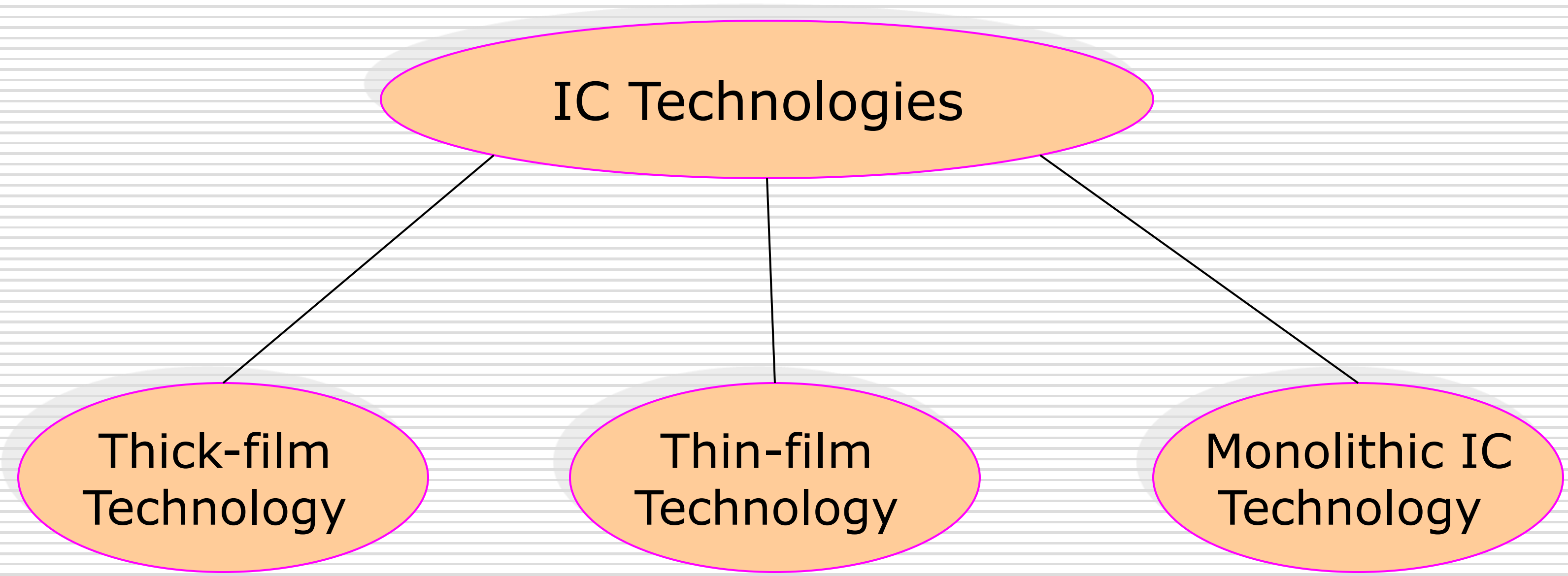
Smart Sensor Technologies

- IC Technologies
  - Originally developed for producing micro-electronic components and circuits
  - If sensor is an electrical or electronic device (e.g. piezo-resistive strain gauge or P-N junction temperature sensor), then the complete sensor can be produced using IC technologies alone.

- Micromachining Technologies
  - *Originally developed for producing micro-mechanical components and systems*
  - *Used only for producing sensing elements in the form of a micro-mechanical structure or a micro-electro-mechanical system (MEMS).*

2.1 IC Technologies & Capabilities



Capabilities
- R, C & L
- Conductors
- Sensor elements
- Sensor supports

Capabilities
- R & C
- Conductors
- Sensor elements

Capabilities
- R & C
- Diodes & transistors
- Conductors
- Sensor elements

2.2 Thick-Film Technology

Process : Print → Dry → Fire → Trim → Finish

Materials: Substrate + Paste or Ink + Printing screen

Paste : Suspended particles of selected material

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Dispersed in an organic solvent

\+

Glass frit

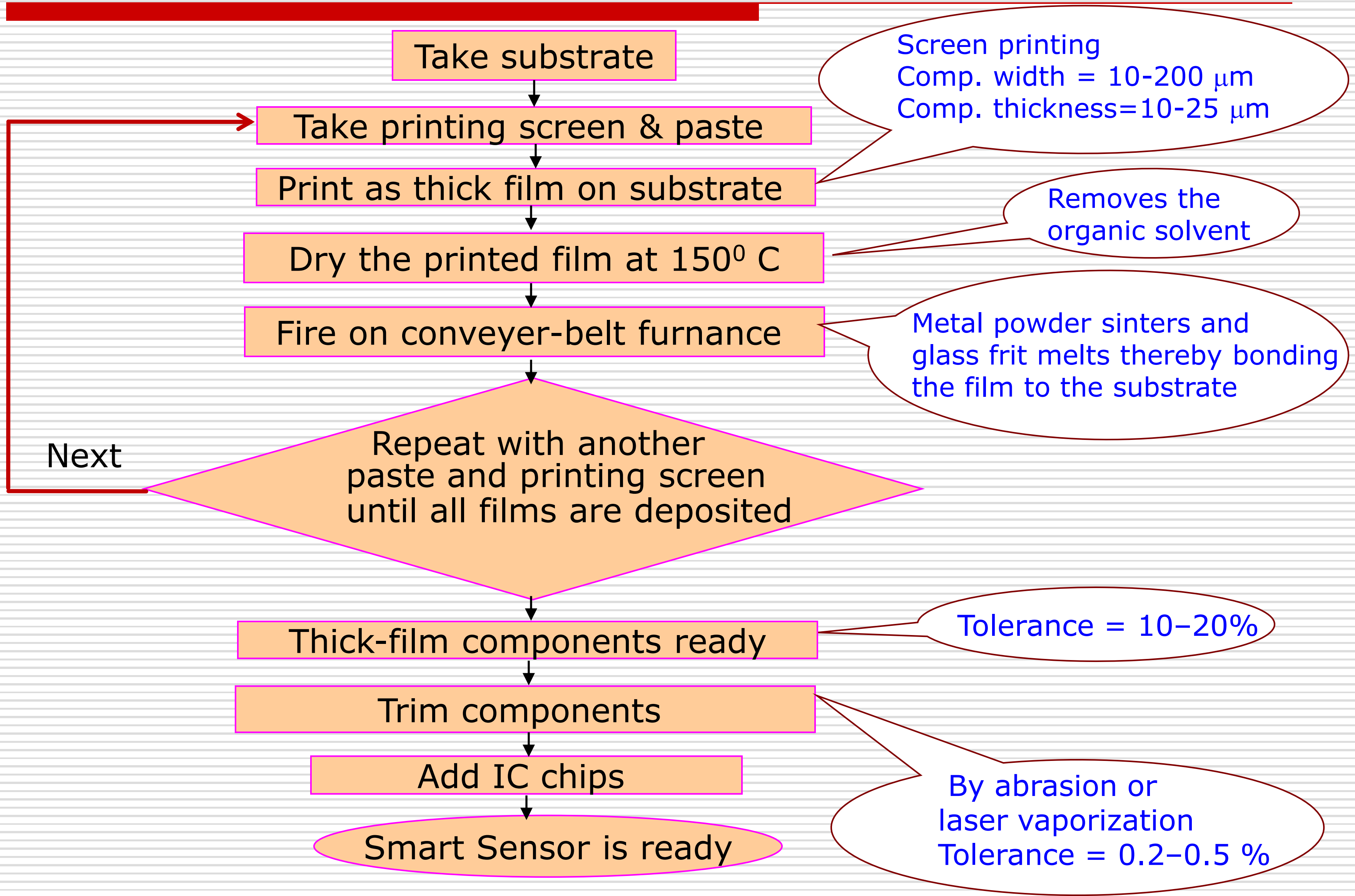
Particle Materials

- **Conductive** → For interconnections & small inductances
- **Resistive** → For resistances and sensors
- **Dielectric** → For capacitors and some sensors
- **Other materials** → For some sensors and sensor supports

Thick-Film Pastes & Substrates

- Low-Temperature Pastes
  - Melting Point: Less than 250 ^{0}C
  - Substrate : Plastic materials
    Glass fibre with epoxy
    Anodized aluminum
- Medium-Temperature Pastes
  - Melting Point: 500 – 600 ^{0}C
  - Substrate: Low carbon steel with porcelain enamel coating
- High-Temperature Pastes
  - Melting Point: 800 – 1000 ^{0}C
  - Substrate : Ceramic

Thick-Film Process



Thick-Film Sensor Elements
(successfully developed / manufactured)

❑ Temperature Sensors	:	Film RTD, film thermistor, film thermocouple
❑ Pressure Sensors	:	Film diaphragms & film capacitors Piezo-electric & piezo-resistive pastes
❑ Light Sensors	:	Photo-conductive pastes
❑ Magnetic Sensors	:	Magneto-resistive pastes
❑ Humidity Sensors	:	Organic polymer based pastes
❑ Gas Sensors	:	Metal-oxide pastes

Advantages of Thick Film Technology

- Almost any material can be deposited as a thick film
- Low-value resistances and high-value capacitances possible
- Small inductances possible
- Special features of thick-film sensors
  - Can withstand high temperatures
  - Allow large voltage / current excitation
  - Heaters can be integrated
  - Economically competitive for low-volume production

Limitations of Thick Film Technology

- Active components cannot be produced
- Size of thick-film components is very large as compared to thin-film components
- Not suitable for medium and large scale production

2.3 Thin-Film Technology

- **Film thickness:** 1 – 25 μm
- **Process:** Deposit thin-film by vacuum evaporation or other similar technique
- **Patterns:** By masking
- No printing, drying, firing and trimming

Substrate

- High–purity **alumina**
- Low–alkalinity **glass**
- **Silicon**
- **Silicon oxide**

Deposition Techniques

- Vacuum evaporation
- Spin casting
- Sputtering or cathodic deposition
- Reactive growth
- Chemical vapour deposition
- Plasma deposition

Thin-Film Materials

- For conductors: Aluminium or gold
- For resistors: Nichrome
- For dielectrics: Silicon dioxide
- For sensors (examples)
  - Strain gauge: Nichrome, polycrystalline silicon
  - RTD: Platinum
  - Conductivity sensor: Platinum
  - Gas sensors: Zinc oxide
  - Piezoresistive pressure sensor: Nichrome, polycrystalline silicon
  - Magnetoresistive magnetic sensor: Nickel, Cobalt, Iron alloys
  - Thermo-anemometric flow sensor: Gold

Thin-Film Components

- Thin-film resistors
- MOS capacitors
- Thin-film conductors
- Thin-film sensors

Advantages of Thin-Film Technology

- Almost any metal can be deposited as thin film
- Miniaturization
- Suitable for adding resistances, capacitances and sensors to monolithic IC
- Suitable for low and medium volume production

Limitations of Thin Film Technology

- Active components cannot be produced
- Size of thin-film components is very large as compared to monolithic IC components
- Not suitable for high-volume production

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Monolithic IC Technology

- Processes: Epitaxial growth
  Silicon-oxide layer formation
  Photolithographic etching
  Planar diffusion of dopants
  Metallization (vacuum evaporation of aluminium)
  Stitch bonding
- Substrate: Wafer of silicon (less used are Ge and GaAs)
- Dimensions: Sub-micrometric, nano-metric
- Capability: R, C, diodes, transistors, conductors, and silicon sensors

Monolithic IC Process: Steps

Step I: Epitaxial growth

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Step II: Isolation diffusion

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Step III: Base diffusion

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Step IV: Emitter diffusion

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Step V: Metallization

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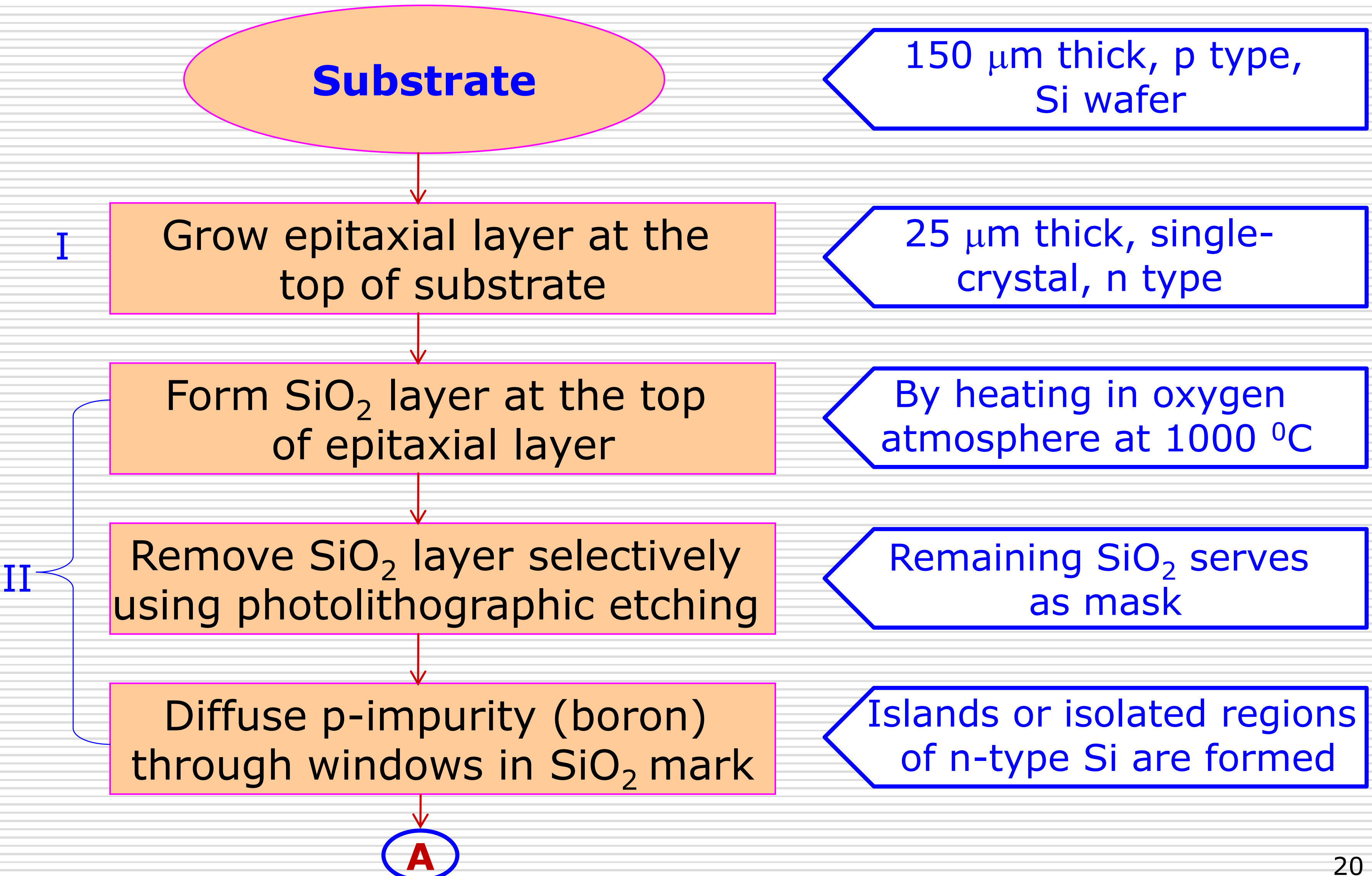
Step VI: Packaging (optional)

Monolithic IC Process: Flowchart



Monolithic IC Process: Flowchart (contd…)

A

III

Form second SiO_2 layer at the top

Open second set of windows in SiO_2 layer (mask)

Diffuse p-impurity through openings in mask

The regions are:
base of transistors,
anode of diodes,
resistances

IV

Form third SiO_2 layer at the top

Open third set of windows in SiO_2 layer (mask)

Diffuse n-impurity phosphorus through openings in mask

The regions are:
emitter of transistors,
cathode of diodes,
contact regions

(Contd…)

B

Monolithic IC Process: Flowchart (contd…)

B

V

- Form fourth SiO_2 layer at the top
- Open fourth set of windows in SiO_2 layer (mask) — *For metallic contacts to make inter-component & external connections*
- Deposit aluminium layer over entire surface (penetrates into openings) and remove unwanted portions — *Using vacuum Evaporation of Al*

VI

- Scribe wafer to separate individual chips (ICs) — *Using diamond-tipped tool*
- Mount chip on ceramic wafer and attach to a suitable header
- Connect terminal pads on IC to Package leads by stitch bonding — *Using Al or gold wire*

Packaged Chip

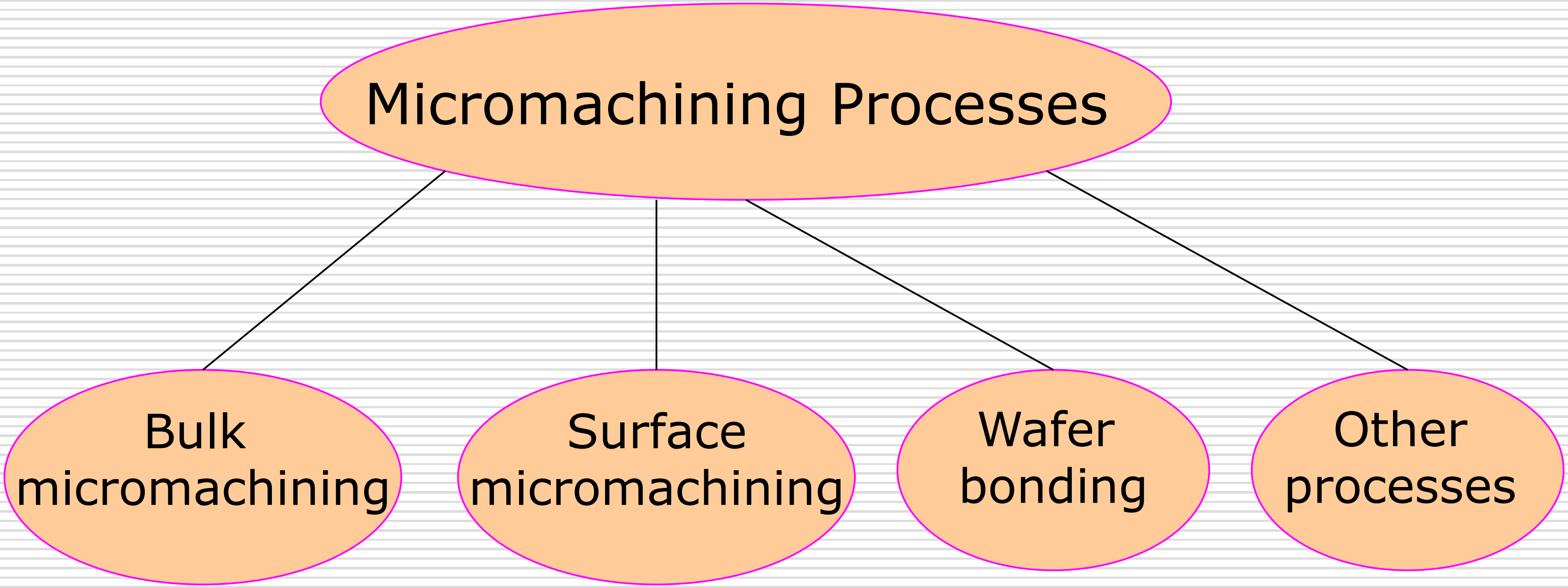
Advantages of Monolithic IC Technology

- Both active and passive devices
- Miniaturization: very high density of devices
- Suitable for large, very large and ultra large scale integration
- Silicon sensors made alongwith integrated circuit on same chip
- High repeatability (consistency)
- Very cheap if produced in high volumes

Limitations of Monolithic IC Technology

- Sensors of silicon only
- Resistances in medium-range only
- Resistances have large temperature coefficient
- Capacitors of small values only
- Capacitors have some shortcomings
- Too expensive for low-volume production

2.5 Micromachining Technologies



Bulk Micromachining

- Significant amounts of material are removed by chemical etching from relatively thick substrate
- Substrate is usually silicon crystal; sometimes glass, quartz, germanium or gallium arsenide is used
- Substrate (wafer) is etched on single side or both sides
- Etching done with masks and etchants solutions
- Masking by photolithographic etching technique
- Etching processes:
  a) Isotropic etching
  b) Anistropic etching

Etching Processes for Bulk Micromachining

(a) Isotropic Etching

- Etchants used have the same etching rate for all crystallographic orientations of silicon wafer (crystal)
- Common Etchants: Sulfur hexafluoride (SF6) and Hydrogen fluoride (HF)
- Common Structures Produced: Cantilever, semi-spherical cavity

(b) Anistropic Etching

- Etchants used have different etching rates for different crystallographic orientations of silicon wafer (crystal)
- Common Etchants: Ethylene-diamine pyrocatechol (EDP) and potassium hydroxide (KOH)
- Common Structure Produced: Diaphragm

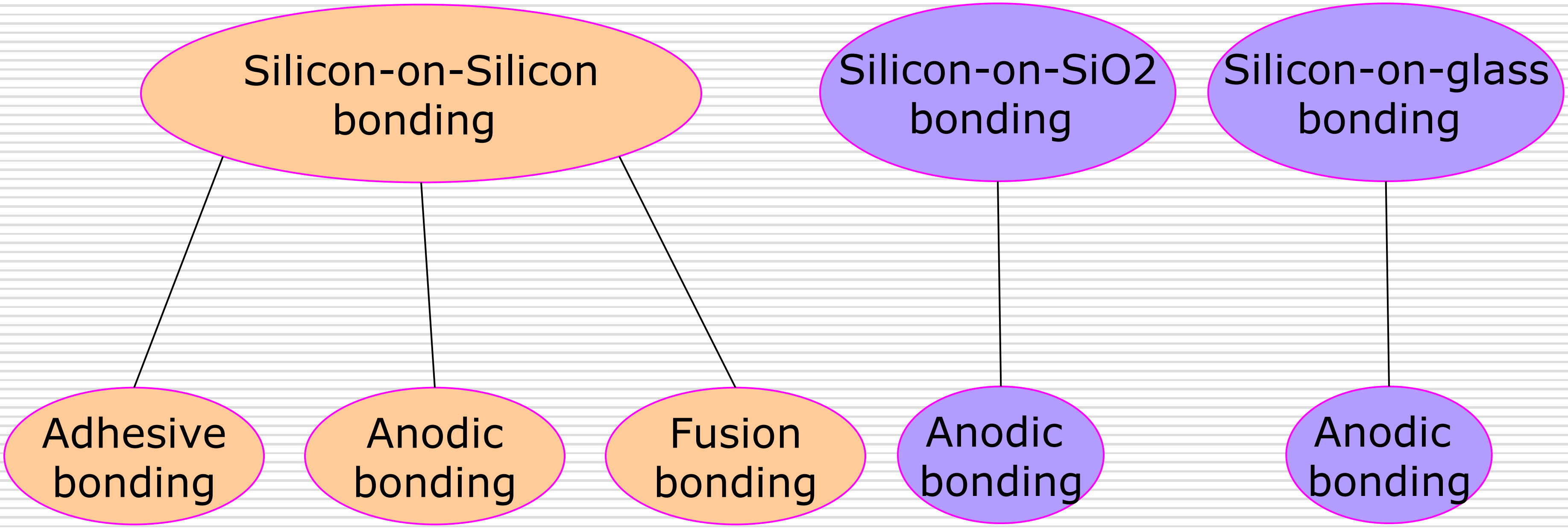
Surface Micromachining

- 3-dimensional structures built by stacking layers
- Layers are deposited using vacuum evaporation or other process and removed using chemical etching
- All etching and depositing processes are carried out on one surface only
- Layers used:
  a) Structural layers: Retained in the final structure
  b) Sacrificial layers: Sacrificed during the process
- Intricate structures produced by using two types of layers
- Substrate is usually Si; sometimes glass is used
- Silicon oxide and silicon nitride used for masking

Wafer Bonding

Used for bonding two silicon wafers or two materials to produce complex structures:

- Silicon-on-silicon bonding
- Silicon-on-silicon dioxide bonding
- Silicon-on-glass bonding



Other Micromachining Processes

- LIGA (Lithographie Galvonoformung Abformung) process
- DRIE (Deep Reactive Ion Etching) process
- Plasma etching
- Micro-milling