EE 407
Microwave Enginering

Lecture 27-28

Microwave Integrated Circuits

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Microwave Integrated Circuits (MIC's):

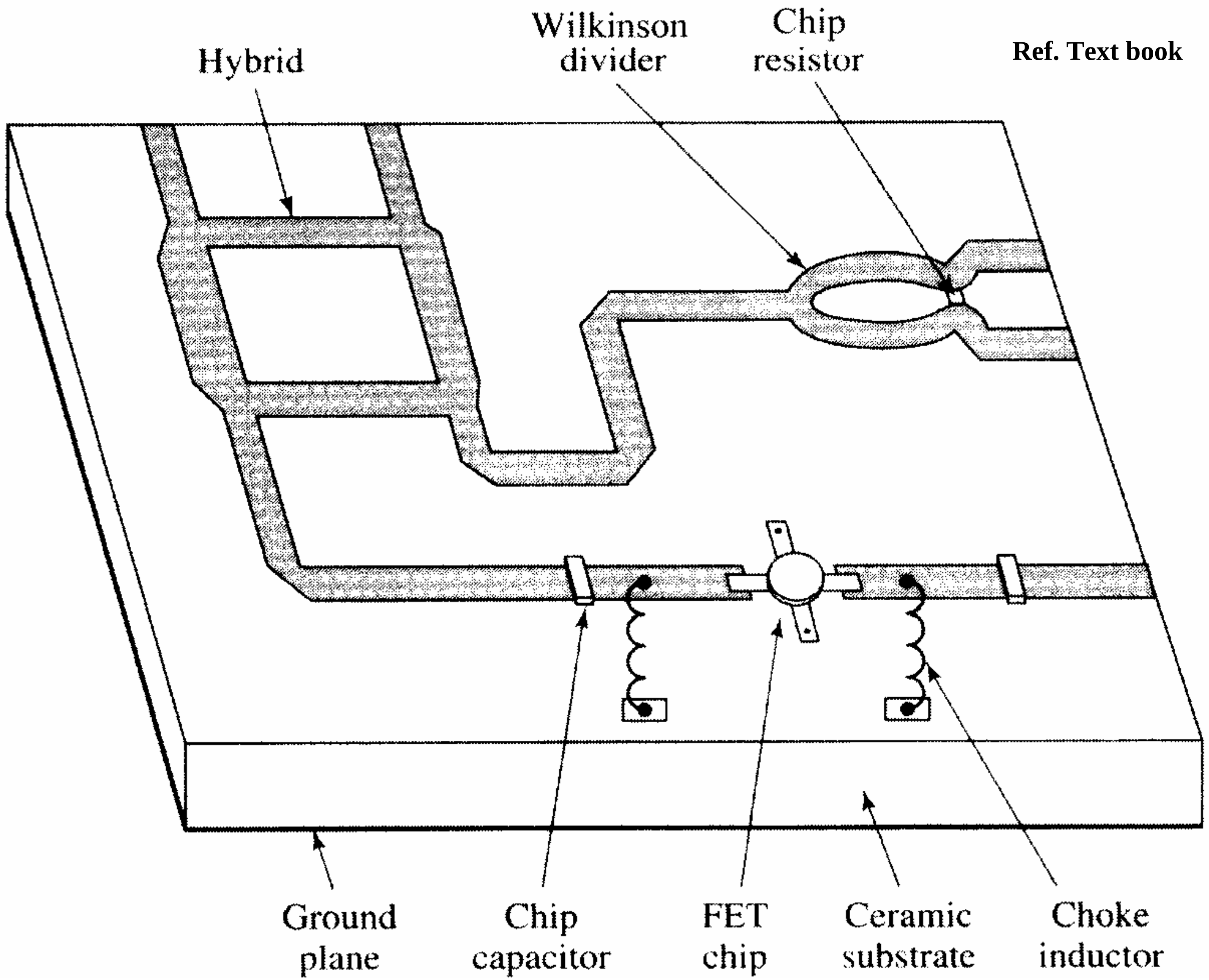
- There are three types of circuit elements that either are used in chip form or are fabricated in MIC. They are:
  - **Distributed** transmission lines (microstrip, strip, etc.)
  - **Lumped** elements (R, L. and C)
  - **Solid** state devices (FETs, BJTs, diodes, etc.)

Two Types of MIC's are:

- **Hybrid Microwave Integrated Circuits (HMICs):** where solid state devices and passive elements (both lumped and distributed) are bonded to its dielectric substrate. The passive elements are fabricated using thick or thin film technology.

  (a) **Standard Hybrid MIC's:** Standard hybrid MIC's use a single-level metallization for conductors & transmission lines with discrete circuit elements (such as transistors, inductors, capacitors, etc.) bonded to the substrate. This type of MIC use a very mature single-layer metallization technique to form RF components.

A typical standard hybrid MIC is shown in the figure.

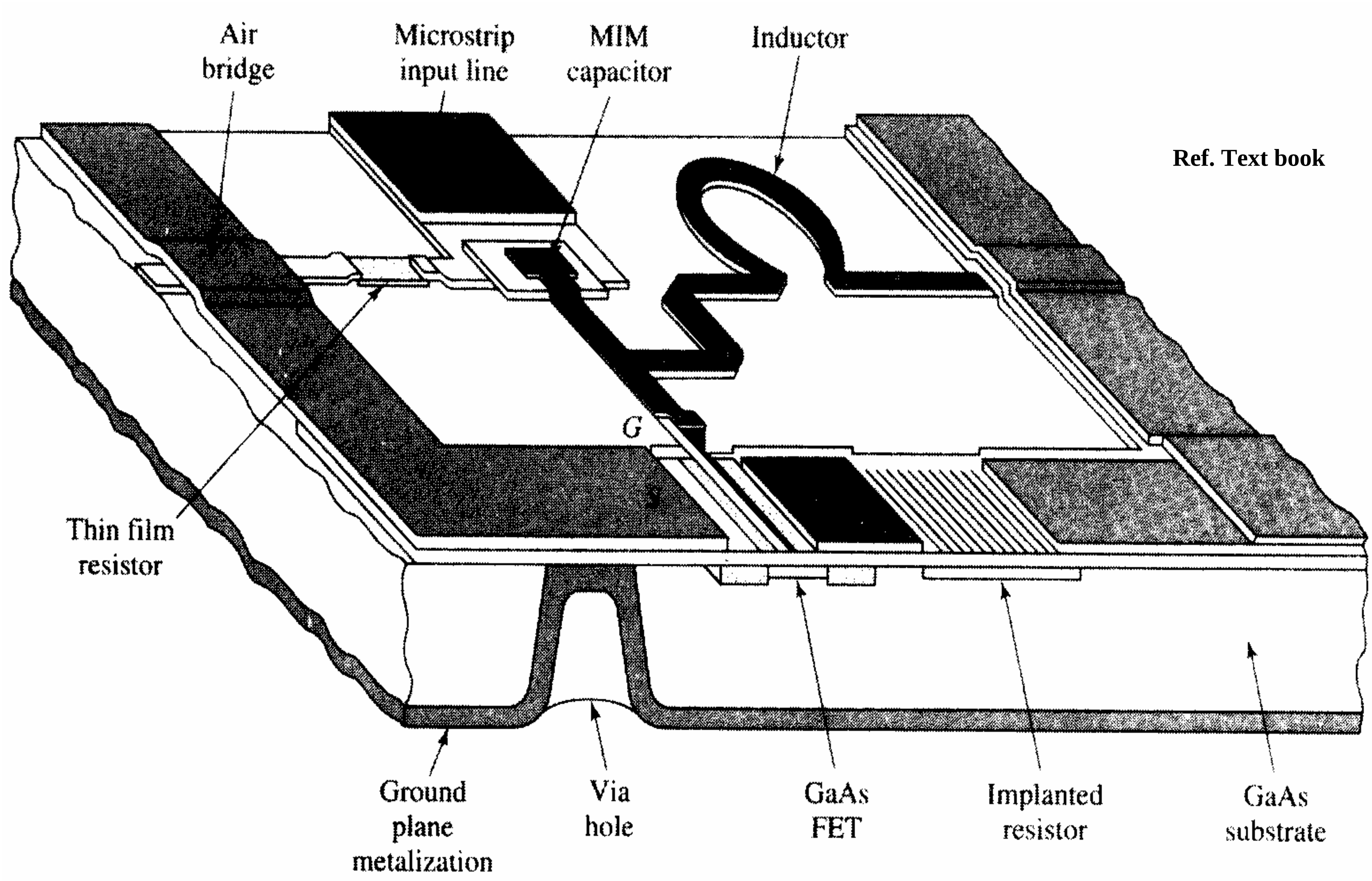


(b) Miniature Hybrid MIC's: use multi-level processes in which passive elements (inductors, capacitors, resistors, transmission lines, etc.) are batch deposited on the substrate whereas the semiconductor devices (transistors, diodes, etc.) are bonded on the substrate surface.

- These circuits are smaller than hybrid MIC's but are larger than MMIC's; therefore miniature hybrid circuit technology can be also called quasi-monolithic.
- The advantages of miniature hybrid compared to standard hybrid circuits are: (i) Smaller size, (ii) Lighter weight, (iii) Lower loss.
- But as frequency is increased thinner substrates are required, resulting in smaller sized circuits; for example, 1-20 GHz require substrate thickness of 0.635-0.254 mm

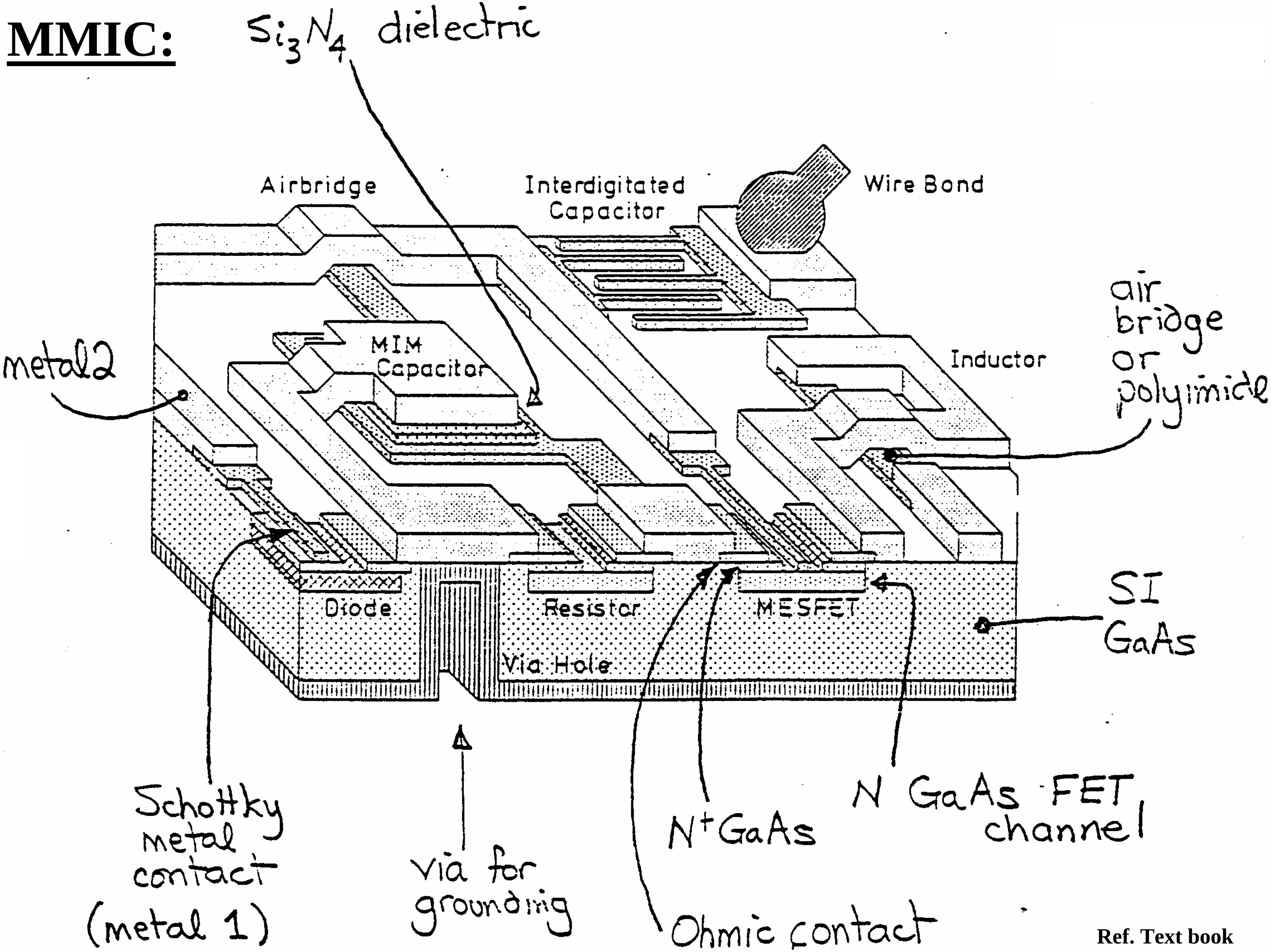
- **Monolithic Microwave Integrated Circuits** (MMICs): is a type of circuit in which all active and passive elements as well as transmission lines are formed into the bulk or onto the surface of a substance by some deposition scheme as epitaxy, ion implantation, sputtering, evaporation, diffusion.
- RF/MW MMIC circuits are important as :
  - The trend in advanced microwave electronic systems is toward increasing integration, reliability, and volume of production with lower costs.
  - The new millimeter-wave circuit applications demand the effects of bond-wire parasitics to be minimized and use of discrete elements to be avoided.
  - New developments in military, commercial and consumer markets demand a new approach for mass production and for multi-octave bandwidth response in circuits.

<u>MMIC</u>: A typical Monolithic MIC. One example of a MMIC is are 2-40 GHz distributed amplifier with a gain of 4 dB.



Ref. Text book

MMIC:



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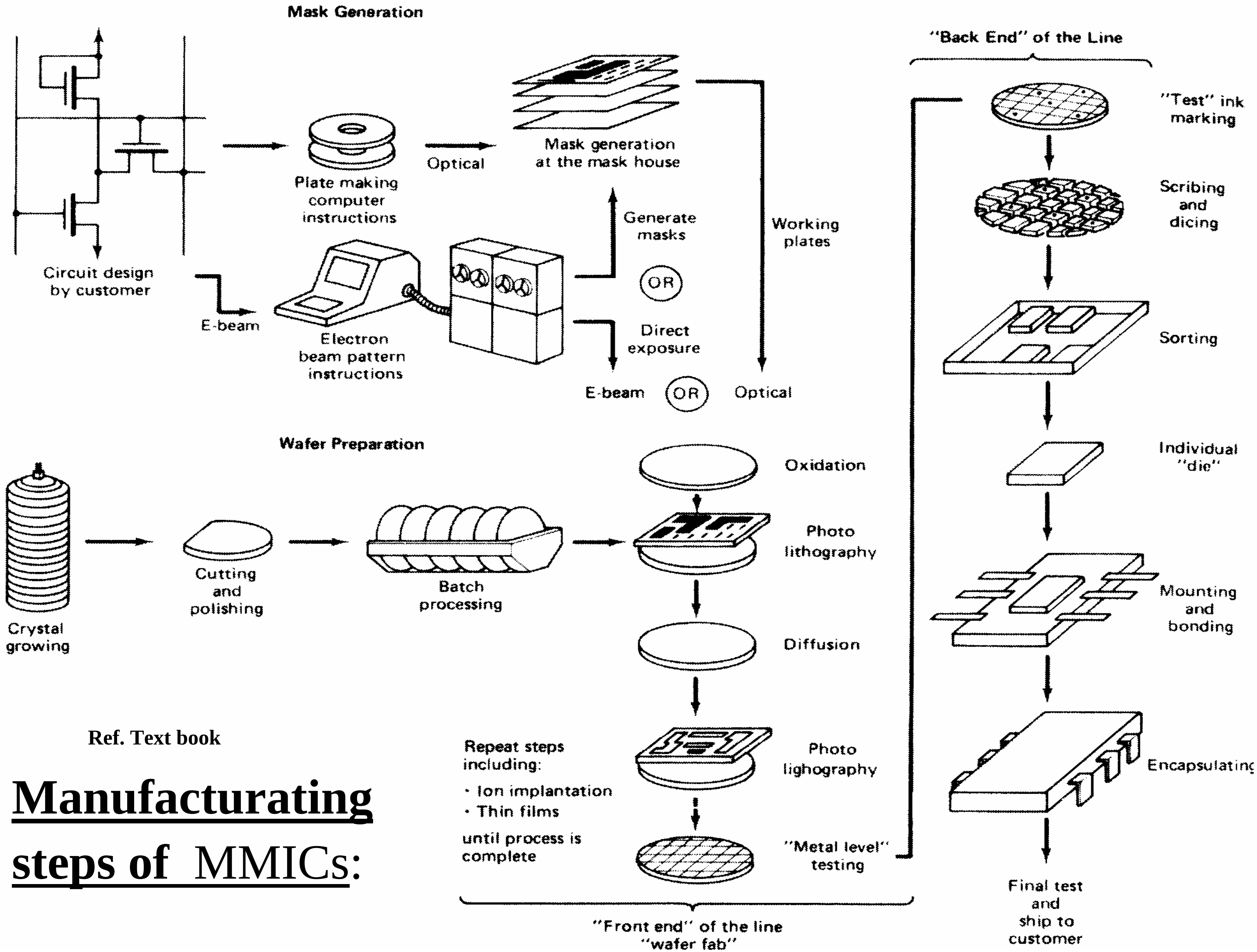

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Manufacturating steps of MMICs:

Materials used as substrate in MMIC's: for comparison

Property	Si	Si or Sapphire	GaAs	InP
Resistivity(Ω-cm)	10^3 - 10^5	>10^{14}	10^7 - 10^9	10^7
Dielectric constant	11. 7	11.6	12.9	14
Mobility (cm^2/V-s)*	700	700	4300	3000
Saturation velocity (cm/s)	9x 10^6	9 X 10^6	1.3 X 10^7	1.9 X 10^7
Radiation Hardness	Poor	Poor	Very good	Good
Density (g/cm^3')	2.3	3.9	5.3	4.8
Thermal Conductivity (W/cm-°C)	1.5	0.46	0.46	0.68

- **Hybrid versus Monolithic** Microwave Integrated Circuits: Important areas that MMIC has advantage over HMIC are, Cost, Size and weight, Design flexibility, Circuit tweaking, Broadband performance, Reproducibility, Reliability.

- **Materials used in MIC's:**
  - **Substrate material:** features for an ideal substrate are,
    (1) justifiably low cost, suitable dielectric thickness and permittivity to allow useful frequency range and achievable impedance values
    (2) negligible dielectric loss which means to a low 'tan δ'
    (3) good substrate surface finish (0.05-0.1 μm) free of voids to keep conductor
    (4) loss low with good metal-film adhesion
    (5) good mechanical strength and thermal conductivity

Types and properties of MIC Substrate Materials:

Types of Material	Surface Roughness (μm)	Tan δ @ 10 GHZ (x 10^{-4})	Relative dielectric Constant, ε_r	Thermal Conductivity (KW/cm-°C)	Dielectric Strength (KV/cm)(x10^3)	MIC Applications
Alumina (99.5%)	2 - 8	1 - 2	10	0.3	4	Microstrip lines
Sapphir	1	1	9.3 – 11.7	0.4	4	Microstrip lumped elements
Glass	1	20	5	0.01	-	Lumped elements
Beryllia	2-50	1	6.6	2.5	-	Compound substrate
GaAs	1	6	12.9	0.46	0.35	MMICs, microstrips
Si	1	10-100	12	1.5	0.30	MMICs
Quartz	1	1	3.8	0.01	10	Microstrips

- **Dielectric Materials** : features for ideal dielectric are,
  (1) Reproducibility and High breakdown voltage
  (2) Low loss tangent and Process ability
- **Conductor Materials** : features for ideal conductor are,
  (1) High conductivity
  (2) High coefficient of thermal expansion
  (3) Low resistance at RF/microwaves
  (4) Good adhesion to the substrate
  (5) Good etch ability and solder ability
  (6) Easy to deposit or electroplate
- **Resistive Films** : features for ideal resistive film are,
  (1) Good stability
  (2) Low Temperature Coefficient *of* Resistance (TCR)
  (3) Sheet resistivity in the range *of* 10-2000 Ohm/square

Types and Properties of MIC Dielectric Materials:

Types of Material	Relative dielectric Constant, ε_r	Dielectric Strength (V/cm)(x10^5)	Microwave Q	MIC Deposition Technique
SiO	6-8	4	30	(E)*
SiO_2	4	100	100-1000	(D)*
Si_3N_4	7.6	100	-	(S)*
Al_20_3	7-10	40	-	(A)*, (E)
Ta_20_5	22-25	60	100	(A), (E)

- ***Anodization (A), Deposition (D), Evaporation (E), Sputtering (S) and Vapor phase epitaxy (VPE)**

  (*Same* ***for next Table)***

Types and Properties of MIC Conductor Materials:

Types of Material	Surface Resistivity	Skin Depth @ 2 GHz (μm)	Adherence to dielectric	MIC Deposition Technique
Gold (Au)	3.0	1.7	Poor	(E), (P)
Aluminum	3.3	1.9	Poor	(E)
Chromium	4.7	2.7	Good	(E)
Tantalum (Ta)	7.2	4.0	Good	(EB)*, (S)*
Molybdenum	4.7	2.7	Fair	(EB), (S)
Tungsten (W)	4.7	2.6	Fair	(S), (E)