Materials for

IC Chips, Semiconductors & Electrical Devices

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Integrated circuits

- An integrated circuit (IC), sometimes called a *chip* or *microchip.*
- It is a *semiconductor* wafer on which thousands or millions of tiny resistors, capacitors, and transistors are fabricated.
- An IC can function as an amplifier, oscillator, timer, counter, computer memory, or microprocessor.

Brief History

- 1940'S – Initial stage.
- 1945's – Bell labs established a group to develop a semiconductor replacement for vacuum tubes.
- 1947's – Transistor invented.
- 1951's – Junction transistors invented.
- 1958's – Integrated circuits invented.

Scale of integration

- Small scale integration (SSI) (3-30 gates/chip)
- Medium scale integration (MSI) (30-300 gates/chip)
- Large scale integration (LSI) (300-3000 gates/chip)
- Very large scale integration (VLSI) (more than 3000)
- Ultra large scale integration (ULSI)

Types of IC's

- Analog IC's
- Digital IC's
- Mixed signal IC's

- Analog circuits are circuits dealing with signals free to vary from zero to full power supply voltage.
- This stands in contrast to digital circuits, which almost exclusively employ "all or nothing" signals: voltages restricted to values of zero and full supply voltage, with no valid state in between those extreme limits.

ANALOG IC

- When the input and output relationship of a circuit is linear, linear ICs are used. Input and output can take place on a continuous range of values.
- Example operational amplifiers, power amplifiers, microwave amplifiers multipliers etc.

DIGITAL IC

- When the circuit is either in on-state or off-state and not in between the two, the circuit is called the digital circuit. ICs used in such circuits are called the ***digital ICs***.
- They find wide applications in computers and logic circuits.
- Example logic gates, flip flops, counters, microprocessors, memory chips etc.

MIXED INTEGRATED CIRCUITS

- IC's which contain both analog and digital ic's are mixed integrated circuits.
- Examples include intel processor, qualcom processor etc.

Wafer preparation

Silicon shaping:
- Removal of ends
- Surface grinding
- Grounding of flats
- Slicing of ingots
- Lapping
- Edge contouring

Chemical etching
Polishing
Chemical cleaning

Silicon shaping:

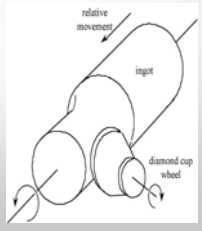
- Silicon is a hard & brittle material.
- Industrial grade diamond is the most suitable material for shaping & cutting silicon.

Removal of ends:

- Remove seeds and tang ends.
- Metallurgical grade silicon (MGS).
- Cutting is done using a circular saw.

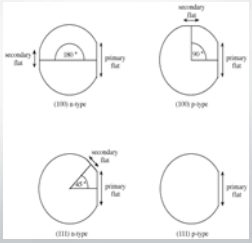
Surface grinding:

- Rotating diamond grinding tool.
- X-ray diffraction techniques.



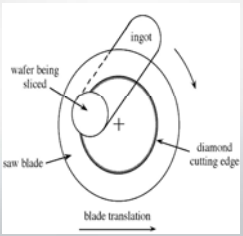
Grounding of flats:

- Primary flats
- Secondary flats



Slicing of ingots:

- Inner diameter sawing
- Diamond saw

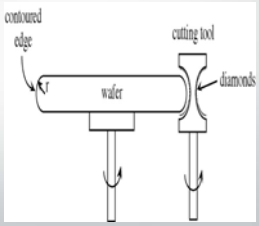


Lapping:

- The wafer flatness produced at this step is better than 2 micro meter.
- Mixture of AL_2O_3 & glycerin.

Edge contouring:

- Diamond tool.
- Prevents defects.
- Helps in smooth deposition of photoresist.



Chemical etching:

- **Acid etching:**
- acid bath
- etchant
- **Alkali etching:**

$$Si + HNO_3 + 6\,HF \rightarrow H_2SiF_6 + HNO_2 + H_2O$$

$$HNO_3 + HNO_2 \rightarrow N_2O_4 + H_2O$$

$$N_2O_4 \rightarrow 2\,NO_2$$

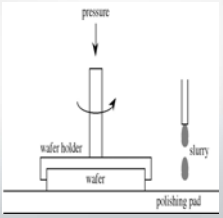
$$Si^0 + 2\,NO_2 + 2\,H_2O \rightarrow Si(OH)_2 + 2\,HNO_2$$

$$Si(OH)_2 \rightarrow SiO_2 + H_2$$

mixture of NaOH:H2O or KOH:H2O

Polishing:

- For smooth surface
- Batch wafer process
- Single wafer process
- Slurry



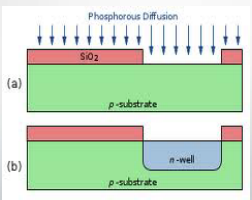
Chemical cleaning:

- Silicon wafers are cleaned chemically to remove organic films, heavy metals
- Aqueous solution of NH_4OH-H_2O_2, HCL-H_2O_2.

IC fabrication techniques:

- Diffusion and ion implantation
- Oxidation and film deposition
- Epitaxial growth
- Lithography
- Etching
- Photo resist
- Deposition

Diffusion & ion implantation



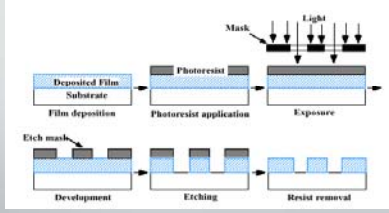
Oxidation & film deposition

- Oxides are grown or deposited on the surface of the wafer
- Film deposition:
  - thermal oxides
  - dielectric layers
  - polycrystalline oxides
  - metal films

Epitaxial growth

- The growth of ultra pure layer of crystalline silicon.
- Approx 3% of silicon wafer.
- Contaminate free for the subsequent construction of transistor.

lithography, Deposition, Etching & photo resist



Advantages

- Small size
- Low weight
- Easy replacement
- High speed
- High temperature tolerance

Disadvantages

- Lack of flexibility
- High power requirements

Applications

- Automobiles
- Appliances
- computers

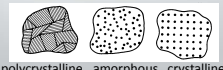
Conclusion

- Modern computing, communication, manufacturing and transport system including the internet, all depends on the existence of integrated circuits.

Semiconductor Materials

What is a Semiconductor?

- Low resistivity => "conductor"
- High resistivity => "insulator"
- Intermediate resistivity => "semiconductor"
  - conductivity lies between that of conductors and insulators
  - generally crystalline in structure for IC devices
    - In recent years, however, non-crystalline semiconductors have become commercially very important

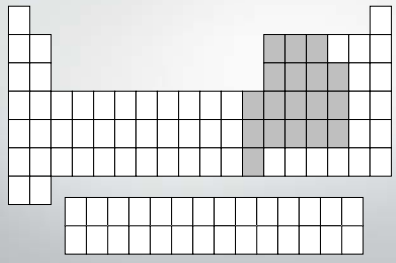


polycrystalline amorphous crystalline

What is a semiconductor?

- Any class of solids whose electrical conductivity is between that of a conductor and that of an insulator in being nearly as great as that of a metal at high temperatures and nearly absent at low temperatures

Semiconductor materials



Semiconductor materials

Examples:

IV: C, Si, Ge

III-V: GaAs, GaN, InP, AlSb, GaAlAs, GaInN

II-VI: ZnSe, CdTe

Group

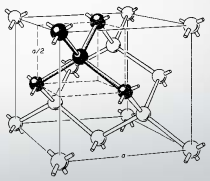
	III	IV	V	VI
	B	C	N	
II	Al	Si	P	S
Zn	Ga	Ge	As	Se
Cd	In	Sn	Sb	Te
Hg				

Application

- Applications
  - Anything in which you want to control the flow of current (transistors, amplifiers, microprocessors, etc.)
  - Devices for producing light
  - Radiation detectors

Semiconductor Crystalline Structure

- Semiconductors have a regular crystalline structure
  - for monocrystal, extends through entire structure
  - for polycrystal, structure is interrupted at irregular boundaries
- Monocrystal has uniform 3-dimensional structure
- Atoms occupy fixed positions relative to one another, but are in constant vibration about equilibrium



Physical Structure-semiconductors

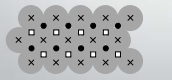
Basic lattice
Face-centered cubic
(fcc)

Diamond structure

Si, Ge

Zincblende

GaAs, InP, ZnS,...



× A
● B
□ C

Zincblende: ABCABC...

Wurtzite: ABABAB...

About 10^{22} atoms in each cm^3.

- **Semiconductors** are not as effective conductors as metals. However, they have higher mobility at room temperature and higher temperatures. This means that an electrical current can travel through them much faster.
- The high mobility of semiconductors makes them best basic materials for use in advanced electronics and communications. they are used to fabricate chips for every electronic device, including computers, cell phones, iPods and GPSs.

The procedure to make the chips is complex and requires very well controlled air conditions with low concentrations of dust particles and other impurities

Current research

- researchers announced they had created a computer chip that melded silicon components with brain cells. Electrical signals from the brain cells could be transmitted to the electronic silicon components of the chip, and vice versa. The hope is to eventually create electronic devices to treat neurological disorders

- A neuro-chip (It is a chip designed for the interaction with neuronal cells)
- Application : Present applications are neuron research. Future applications (still in the experimental phase) are retinal implants or brain implants.

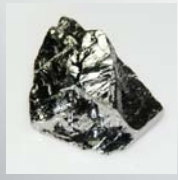
silicon

- Silicon (Si) is one of the most important semiconductors today because it has a very low occurrence of defects.

- Silicon is the element to thank for the computer we're using to read these words. A crucial component in microelectronics and computer chips.

Silicon Valley gets its name from the silicon used in computer chips.

germanium



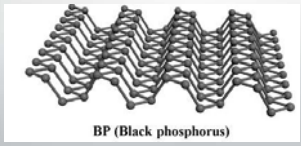
- This type of semiconductor was used in many early devices from radar detection diodes to the first transistors
- Not as widely used these days as better semiconductor materials are available

Gallium arsenide

- Gallium arsenide is The second most widely used type of semiconductor after silicon
- However it is a brittle material and has a lower hole mobility than silicon
- It is also relatively difficult to fabricate and this increases the cost of GaAs devices

Developments in Semiconductor Materials

- BLACK PHOSPHORUS SEMICONDUCTOR



BP (Black phosphorus)

BLACK PHOSPHORUS SEMICONDUCTOR

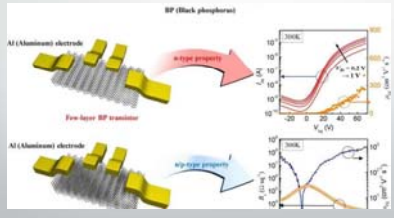
- Researchers have created a high performance transistor using black phosphorus (BP).
- With the BP crystal, it is discovered that we can change its thickness and/or the contact metals and that will determine if it is high performance n-type, p-type, or ambipolar (function as both n- or p-type) material.

BLACK PHOSPHORUS SEMICONDUCTOR

- The BP crystals can operate as both n-type and p-type or something in between, but don't require extrinsic doping !!.
- This means that instead of having to fabricate a silicon-arsenic crystal sandwiched between silicon-boron crystals, a transistor can have a single, lightweight, pure black phosphorus logic chip.

BLACK PHOSPHORUS SEMICONDUCTOR

- Instead of doping to make an n- and p-type material, both n- and p-type BP can be put all together on one chip just by changing its thickness and the contact metal used.



BLACK PHOSPHORUS SEMICONDUCTOR

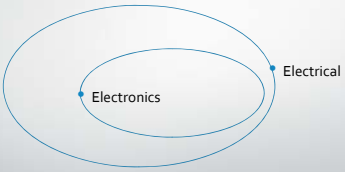
Properties

- High carrier mobility
- Can operate at low voltages
- Reduced power consumption(Energy Efficient)
- Thinner than the Si semiconductors

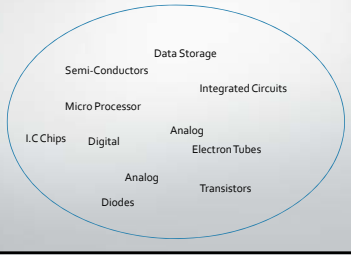
Why not in use?

- No large scale manufacturing technology available for such a thinner semiconductor.
- Thin layers can be made only from scraping bulk crystalline BP samples
- At present, BP isn't ready for commercial use and its potential has just started to be recognized. If it continues to perform in further tests, it should be strong a contender as a chip material for future technology.

Electronic materials



Electronic Materials

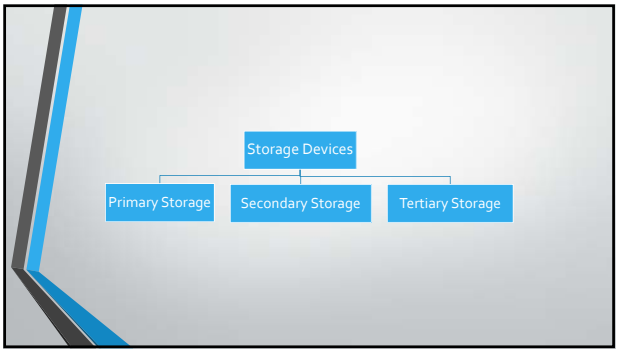


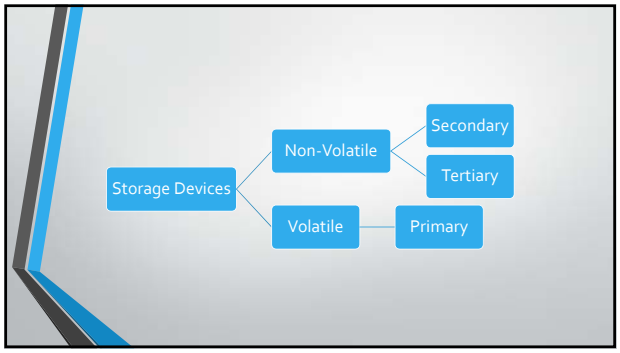
Electrical

- Flow of electrons

Electronics

- Controlling the flow of electrons



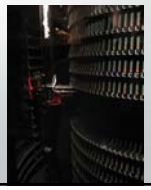


Volatile Storage Device

- Continuous power supply is required to maintain data
- Data can be accessed very fast (Order of Nano seconds)
- Dynamic-RAM needs data to be rewritten regularly
- Static-RAM stores data as long as power is supplied
- Very Expensive

Non-Volatile Storage Devices

- Once data is stored, power need not be supplied
- Secondary Storage has a speed of order of mille seconds(Slower)
- Tertiary storage is much slower
- In expensive



Other Storage Devices

- Vacuum Tubes- Cathode Ray Tubes, Out Dated, Expensive
- Electro Acoustic Memory-Uses sound waves on materials like mercury to store data; Volatile
- Optical Tapes-Uses patterns an plastic sheets to cipher data
- Phase change Memory – Phase change material with X-Y addressable memory; Resistance values to interpret data
- Holographic Data Storage- stores information optically inside crystals or photopolymers
- Molecular Memory – Information is stored on polymers as an electric charge