ECN 101

Introduction to Electronics and Communication Engineering

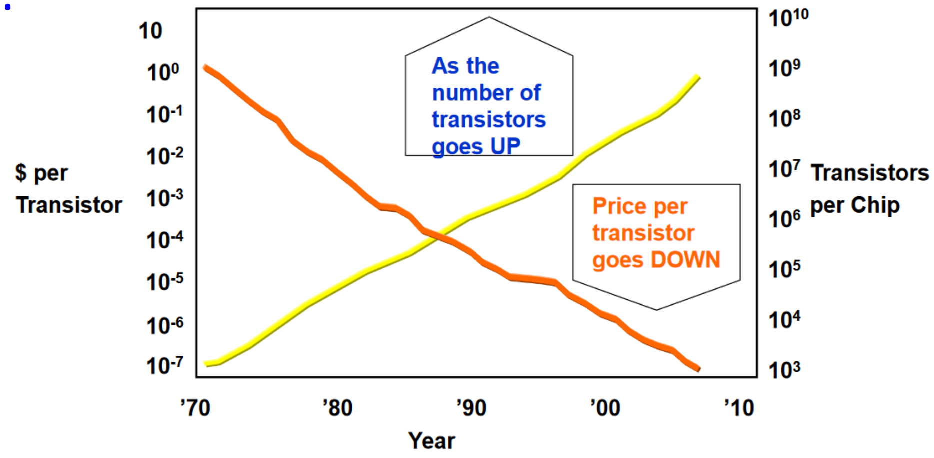
Review

Extremely important part of our life today.

Electronic devices

Communication among the devices

Electronics is about controlling electrons.



The story of electronics is the story of conquest of the electron.

History

Pre-electronics era

Pre-20th century,
Almost no electronics in common man's life

Electricity, Magnetism and technologies based on that

Vacuum tube electronics

Vacuum tube diode and triode invention,

Facilitated the invention of the first computer

Transistor era

The semiconductor era

Start with the birth of solid state triode - transistor

History – pre-electronics era

- Electron – Around 1000 BC, an unknown greek observed
  - When a piece of cloth was rubbed over an elektron (an amber), it attracted hairs, wheat chaff, feathers – unknown force

- In 600 BC – a farmer in a small town named magnesia noted that a rock lodestone invisibly attracts fragments of iron and stone chips containing iron – that's how the term magnet came about.

- Chinese compass invention, 220 BCE
  - 1000 AD – Advanced version of compass, went to Europe through Arab traders
  - One of the four greatest inventions of ancient China (paper, printmaking, gunpowder)

- Renaissance in Europe: 15^{th} – 17^{th} century (after the fall of Constantinople) – scientific method
  - Hypothesis – model – experiment (repeatable)

- 1600, William Gilbert, Britain
  - Probably the first experimental physicist
  - Published six volumes titled – About the magnet
  - Published his observations about electric and magnetic field – some right, some wrong

- 1663, Otto von Guericke, Germany
  - Produced static charge by rubbing a piece of cloth over a sulfur ball
  - Didn't know what to do with it, a method of generating and storing static electricity

History – pre-electronics era

- 1729, Stephen Fray, Britain
  - Discovered conductivity of material
  - Flower boy experiment
- 1733, Charles DU Fay, France
  - Discovered different polarity of different charges
  - Same type of charges repel, opposites attract.
- 1745, Pieter van Musschenbrock, Netherlands
  - Invention of electric charge storage device, capacitor by sticking two metal foils on inside and outside of a jar
- Benjamin Franklin (1706-1790), US
  - After observing discharge across two charged spheres – hypothesized that thunder is infact discharge of static electricity stored in cloud layers
  - He invented the lightening rod – the houses at that time used to be made from wood, the lightening would burn these houses. He invented the lightening rod which could capture the electricity discharge from the clouds.
  - Lightening rod – a rod at the roof-top and a copper wire connected to it which goes right upto the ground.

History – pre-electronics era (quantitative understanding)

- 1789, Charles Augustin de Coulomb, France
  - Coulomb's law of electrostatics
  - First quantitative success in understanding electrical sciences

- 1757, Bioelectricity was discovered by a French botanist (in a catfish)

- 1772, same thing was observed by a British officer posted in India (eel)

- Galvani, Italy – electrical stimulus moved the frog's leg.

- 1800, Alessandro Volta produced a continuous current by connecting two different metals via an electrolyte
  - Voltaic pile which was named as battery

- 1807, Humphry Davy, Royal Institution London
  - Created sustained light between two terminals of a battery – by bringing the terminals closer
  - Developed electrochemistry – electrolysis, electroplating, resulting in discovery of new materials.

History, pre-electronics era (quantitative understanding)

- 1820, Hans Oersted, Denmark
  - Demonstrating current flow through a wire to his students
  - Observed that a nearby compass was deflected because of the current. If the current is turned off – the compass comes back to the normal state
  - Could the electricity and magnetism be related?

- 1820, André-Marie Ampère, France
  - Two parallel current carrying wires
  - Attracted each other when the current was flowing in the same direction, repelled each other if the current was flowing in the opposite direction in both wires.
  - The forces were due to magnetic field created by wires and Oersted’s compass was also getting deflected because of that only.
  - Developed the mathematical model to describe the relation between electric current and magnetism.

- 1821, Faraday, London
  - Started his career at a bookbinder’s shop
  - Invented first prototype motor – published single author paper
  - Shifted to do electrochemistry experiments – pioneer in that field as well
  - Worked on batteries, electrolysis, electroplating
  - Played key role in discovering the ring structure of benzene.
  - Also explained the mechanism of Voltaic pile

History, pre-electronics era (quantitative understanding)

- After Humphry Davy, Faraday became the new director of the Royal Institution London in 1829.
- The principle of electric generator was also discovered by Faraday when he observed that motion of a magnet inside an electric coil generated current in the coil

- Also Faraday
  - Discovered electrical induction
  - In his later years, just out of intuition, he hypothesized that light could be made of oscillating electric and magnetic fields.
  - Thus connection between electromagnetism and light was discovered
  - **Never applied for a patent**
  - **Unresolved question: how magnetic and electric fields were transmitted through space, could not formulate it.**

- James Clark Maxwell, born on 1831 Scotland
  - Had exception mathematical ability since early age
  - Lord Kelvin suggested him to study the works of Faraday
  - Made right predictions about the rings of the Saturn at early age
  - After an elaborate discussion with Faraday, Maxwell put together ideas of Faraday, Ampere, Gauss etc. and after 11 years came up with Maxwell's equations
  - Initially 20 equations were there, later British scientist Heavyside condensed them into 4.
  - This quantitative work was the pinnacle of the science in 19th century – took almost three centuries from the time of Gilbert.

History, pre-electronics era

- James Clark Maxwell, contd..
  - Maxwell's equation could explain all electric and magnetic phenomena observed till that time.
  - Existence of electromagnetic waves was predicted, the speed could also be calculated.
  - Also predicted the existence of electromagnetic waves beyond the realm of the light waves.
  - German physicist Heinrich Hertz experimentally verified the existence of these electromagnetic waves after 11 years.

- Heinrich Hertz, 1888
  - Created radio waves
  - Observed that the radio waves are essentially the same as light waves.
  - Then Gamma rays, microwaves, X-Rays etc. were discovered.
  - And thus electromagnetic spectrum was discovered.
  - After the advent of quantum mechanics in 1920s, more fundamental understanding of electromagnetics was reached.

After these discoveries and mathematical formulation were done – a solid foundation was built upon which the electronics rests.

Albert Einstein adorned his office walls with the portraits of three scientists:

1. Isaac Newton
2. Michael Faraday
3. James Clark Maxwell

Pre-electronics era, technological innovations

- Telegraph
  - Morse

- Telephones
  - Elisha Gray, 1870s
  - Alexander Graham Bell, 1876

- 1890s
  - People all around the world started finding applications of the electromagnetic fields.
  - Guglielmo Marconi – using an antenna attached to a high flying kite, demonstrated the transmission of electromagnetic waves upto 3 km.
  - Indian Scientist J.C. Bose, Russian scientist Popov

- The AC-DC war between Edison and Westinghouse
  - AC had the advantage that the voltage can be stepped up and down, unlike DC
  - Hence better for transmission
  - Tesla

History, J.C. Bose

- J C Bose

Achievements of Sir J. C. Bose in the field of communication
(In a Nutshell)

- Sir J. C. Bose invented the Mercury Coherer (together with the telephone receiver) used by Guglielmo Marconi to receive the radio signal in his first transatlantic radio communication over a distance of 2000 miles from Poldhu, UK to Newfoundland, St. Johns in December 1901. Guglielmo Marconi was celebrated worldwide for this achievement, but the fact that the receiver was invented by Bose was totally concealed. Read Bose's original paper on the receiver device.
- In 1895, Sir J. C. Bose gave his first public demonstration of electromagnetic waves, using them to ring a bell remotely and to explode some gunpowder. He sent an electromagnetic wave across 75 feet passing through walls and body of the Chairman, Lieutenant Governor of Bengal. (I am in process of ascertaining how this experiment is placed in context of works by other scientists towards demonstrating remote transmission of EM waves).
- Sir J. C. Bose holds the first patent worldwide to invent a solid-state diode detector to detect EM waves. The detector was built using a galena crystal. Have a look at Bose's patent and wait for an interesting article on the same soon.
- Sir J. C. Bose was a pioneer in the field of microwave devices. His contribution remains distinguished in the field and was acknowledged by the likes of Lord Kelvin, Lord Rayleigh, etc. Read what people thought about J. C. Bose. Refer to [1,2] to study the work of J. C. Bose in the field of microwave.

- Refs:
  - http://web.mit.edu/varun_ag/www/bose.html
  - http://web.mit.edu/varun_ag/www/bose_real_inventor.pdf

Ref: https://ethw.org/w/images/8/87/Routray.pdf

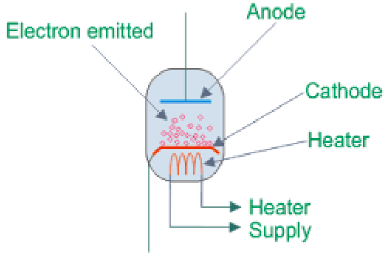
History – vacuum tube electronics era, 20th century

- The first decade saw the invention of vacuum tube

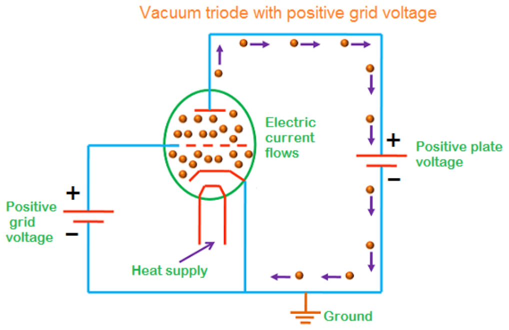
- John Ambrose Fleming (UK), 1904
  - He developed a device he called an "oscillation valve" (because it passes current in only one direction). The heated filament, was capable of thermionic emission of electrons that would flow to the plate (or anode) when it was at a positive voltage with respect to the heated cathode. Electrons, however, could not pass in the reverse direction because the plate was not heated and thus not capable of thermionic emission of electrons.

  - It worked as a very important part in radio communication – for AC to DC conversion

  - This is considered to be the birth of electronics.



- Lee De Forest (US), 1906
  - Invented triode
  - Besides anode and cathode, it had a third terminal as well (grid) which controls the flow of the electrons
  - It acted like amplifier – a key component in communication



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Technological innovations: vacuum tube technology

- Diode
  - Rectifier
- Triode
  - Amplifier
- Radio communication technology
- Television
- Radar
- Computer

Electronics in 20th century

- Then came photoelectric effect and quantum theory
  - Our fundamental understanding of nature was revolutionized.
  - Planck, Einstein, Bohr, De Broglie, Heisenberg, Schrödinger and Dirac.

- Then came world wars
  - The development of electronics saw huge jump
  - Due to the world wars there was a big need of computers for war related tasks like code breaking.

Ref: https://ethw.org/w/images/8/87/Routray.pdf

History – the transistor era (solid state electronics)

- Transistor
  - Switching
  - Amplification

- The solid-state electronics goes back to the invention by Ferdinand Braun of the solid-state rectifier in 1874.
  - His work centered around the solid-state rectifier using a point contact based on lead sulfide.

- With the need for high frequency applications, the idea of point contact made a comeback.

- 1920s onwards, understanding of quantum mechanics played an important role in developing solid state electronics.

- Without QM, a good understanding of solids (metals, semiconductors, insulators) would have been impossible. – Electronic band structure came about due to that reason only.

- Development of the quantum theory of solids led by Peierls, Wilson, Mott, Franck, and others, largely in England – electron conductivity in metals.

History – the transistor era (solid state electronics)

- Mervin Kelly, at Bell Labs, decided in 1936 that he should start a solid-state device group.
- It is interesting to note that by 1938, two Germans (Pohl and Hilsch) described a solid amplifier made using potassium bromide that had three metal leads.
  - However, this device turned out to have too low an operating frequency. Also, it was not a device that could be used in any true sense for electronics.
- By 1940, Russell Ohl had done a great deal of work, along with others at Bell Labs, in an attempt to understand silicon crystals.
  - Ohl learned that depending on how you prepared single crystals of silicon, you could get either n- or p-type silicon.
- Ohl actually was able to make a sample in which the top part was a p-type region and the bottom was n type, and he found that when light was shone on it, it actually developed a voltage.
  - Solar cell
- Ohl’s piece was given to Brattain to remeasure it the voltage when light is shown over the sample.
- Impurities that were responsible for n-type and p-type character of material

History – the transistor era (solid state electronics)

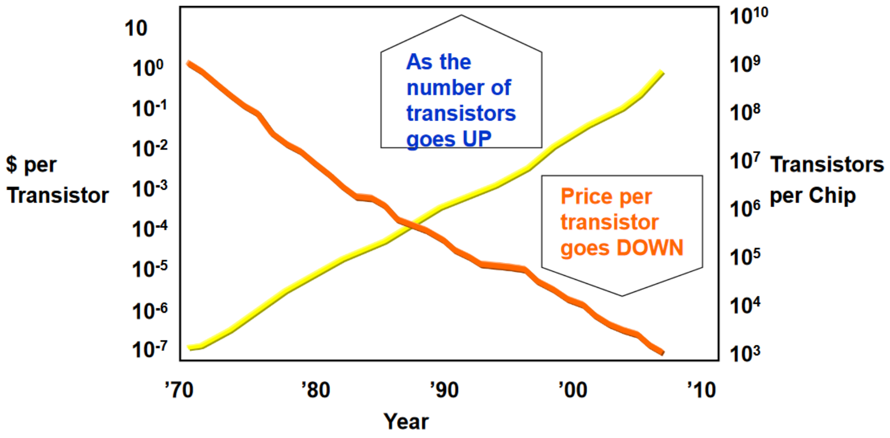
- Post WW II, the solid state group was again re-constituted.
  - Bardeen made important contributions to understand field effects transistor.
- The Field-Effect idea: the field can tune the conductivity of the material.
- By simple calculations, he showed how even a small concentration of surface states can screen the field from the interior.
- Bardeen and Brattain started attempts to clean the surface
- In Nov 1947, the transistor was improved in Dec 1947.
- In June 1948, they had a press conference with the circuit made from transistor and voices being amplified over it.

History – the transistor era (integrated circuits)

- An IC is a set of electronic circuits on one small flat piece (or "chip") of semiconductor material,0 normally silicon.

- The integration of large numbers of tiny transistors into a small chip results in circuits that are orders of magnitude smaller, faster, and less expensive than those constructed of discrete electronic components.

- Integrated circuits were made practical by mid-20th-century technology advancements in semiconductor device fabrication.
  - Since their origins in the 1960s, the size, speed, and capacity of chips have progressed enormously
  - 1968 – Intel was founded.



Moore's law and Scaling

Number of transistors would double every 18 months.

The transistor era - integrated circuits summary

- **Transistor being fabricated on one small piece of semiconductor.**

- **SSI** - Small Scale integration
  - less than 100 components (about 10 gates)

- **MSI** - Medium Scale integration
  - less than 500 components (more than 10 but less than 100 gates)

- **LSI** - Large Scale integration
  - components b/w 500 and 300000 (more than 100 gates)

- **VLSI** - Very Large Scale integration
  - it contains more than 300000 components per chip

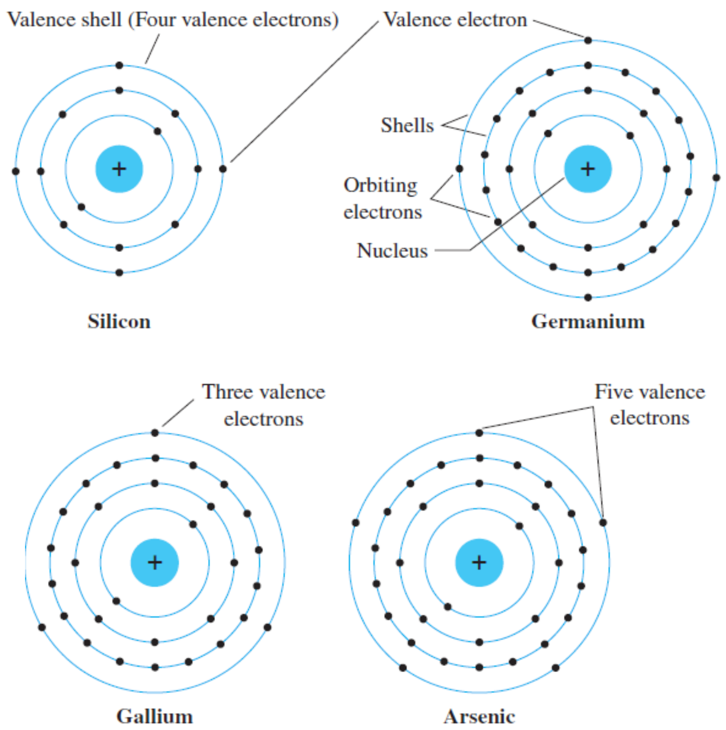
Introduction to semiconductor devices

- Electron – fundamental particle with unit negative charge.
    - Roughly the radius of an electron is 1 fm while that of an atom is 1 Angstrom.

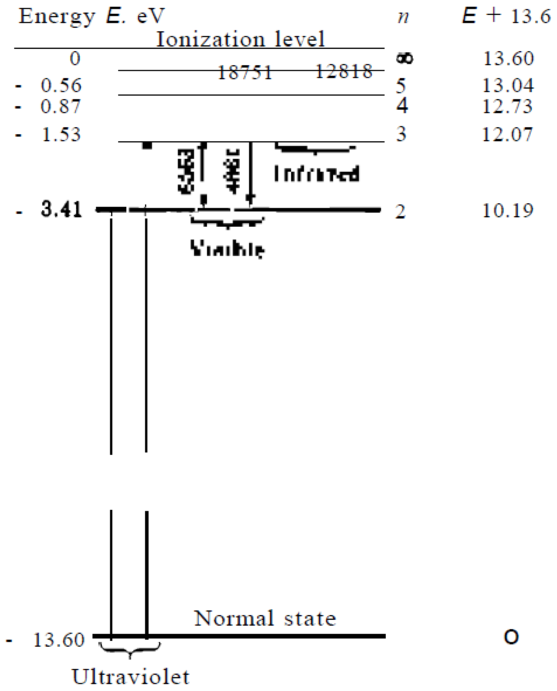
- What is as semiconductor: conductivity between metal and insulators
    - Conductivity of metals: 10^{7} $(\Omega\text{-m})^{-1}$ [Metals conduct both heat and electric current]
    - Conductivity of metals: 10^{-10} $(\Omega\text{-m})^{-1}$
    - Conductivity of metals: 10^{-6} to $10^{4}(\Omega\text{-m})^{-1}$

- Why semiconductors to make devices
    - We need controlled flow of electrons
    - Conductors allow continuous flow of electrons
    - Insulators disallow electron flow.
    - Semiconductors' flow of electron can be tuned and controlled.

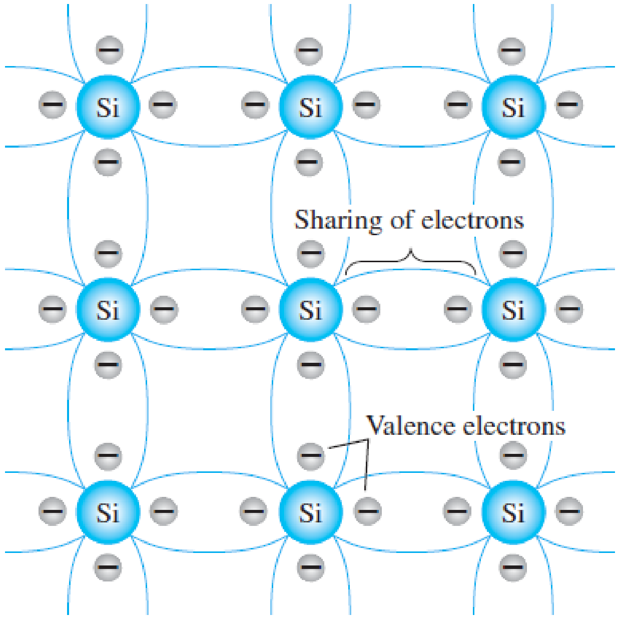
- Semiconductors
    - Covalent bonds
    - Si, Ge, GaAs



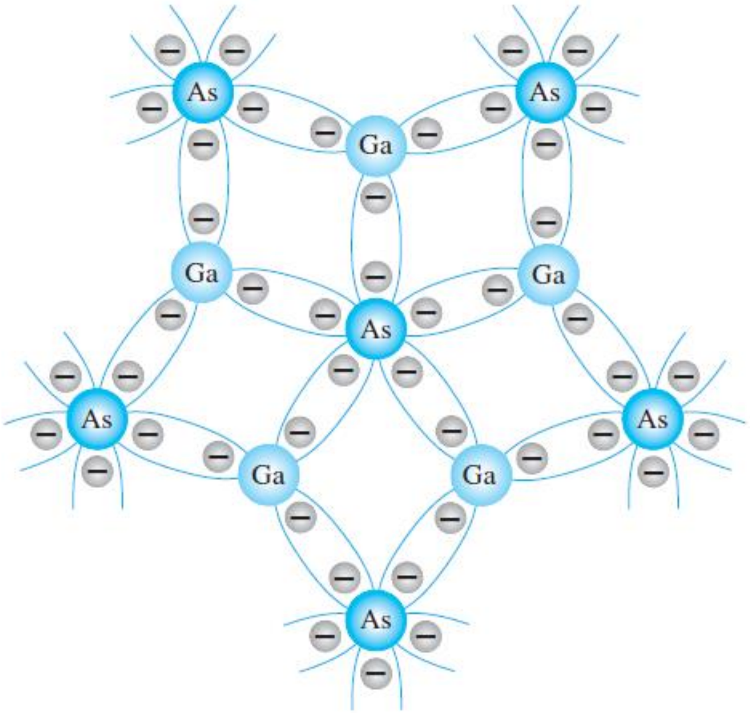
Photoelectric effect
Quantum mechanics



Atomic energy levels (hydrogen atom)



Covalent bonding in Si crystal



Covalent bonding in GaAs crystal

What happens when lots of such atoms come close to each other.