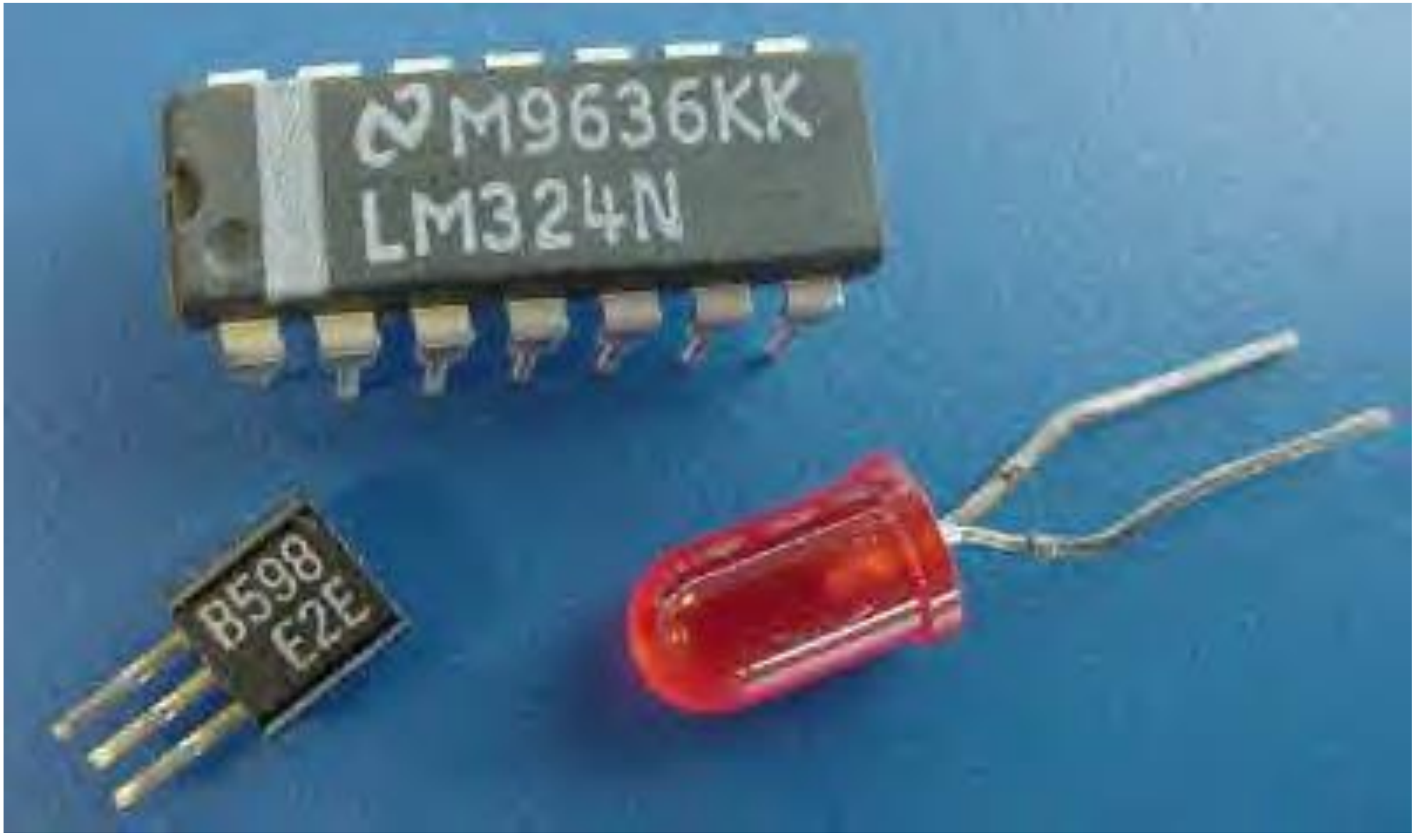
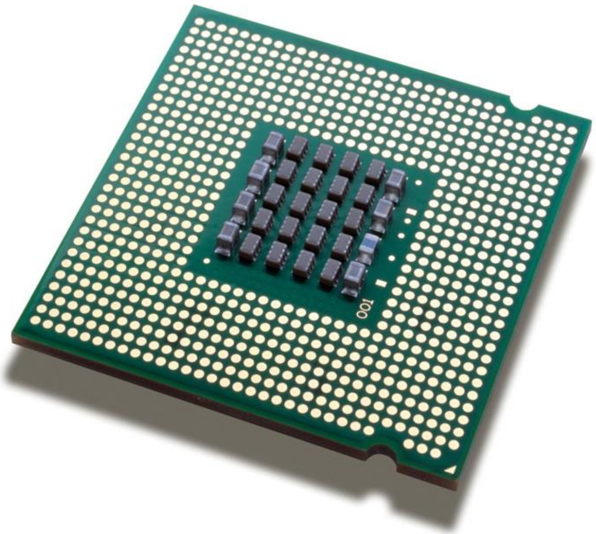
Mathematics and Science in Schools in Sub-Saharan Africa

SEMICONDUCTORS



What is a Semiconductor?

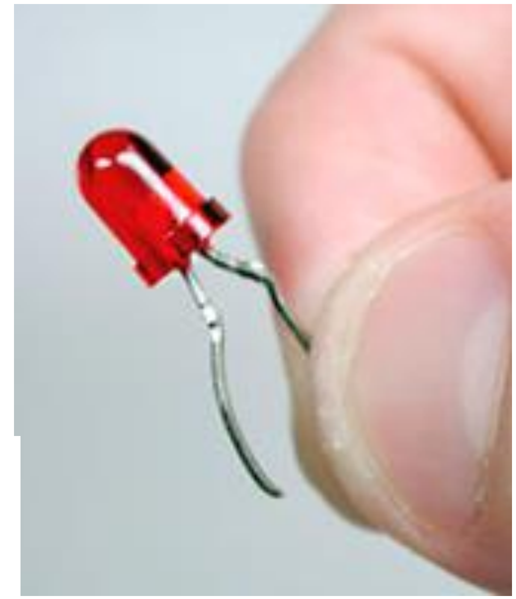
What is a Semiconductor?



Microprocessors

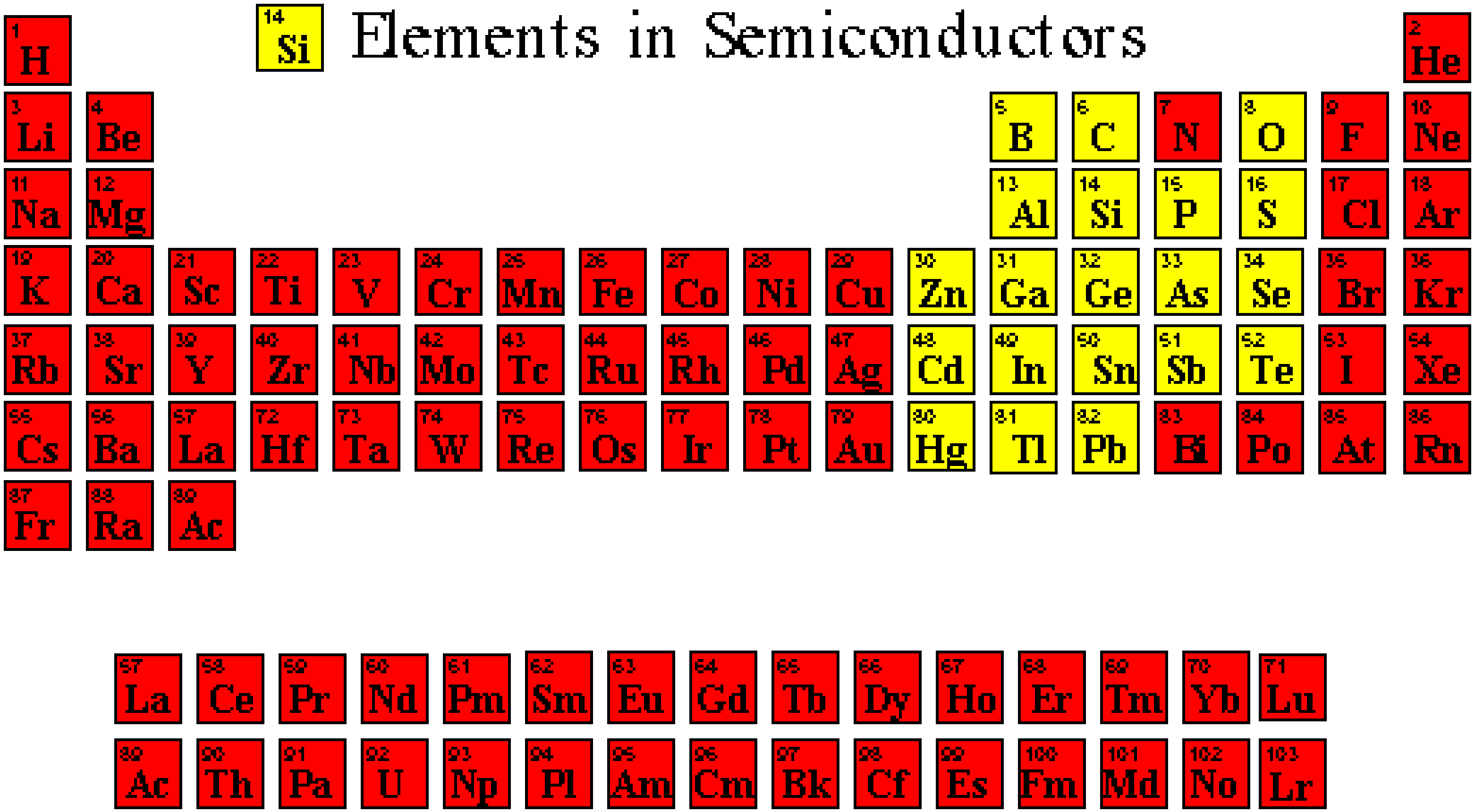
Transistors

Capacitors

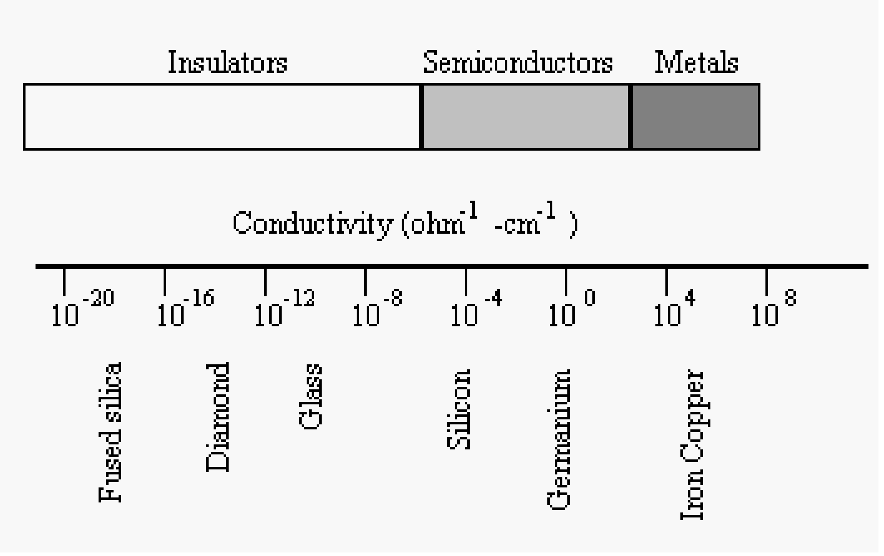


LED

Elements in Semiconductors

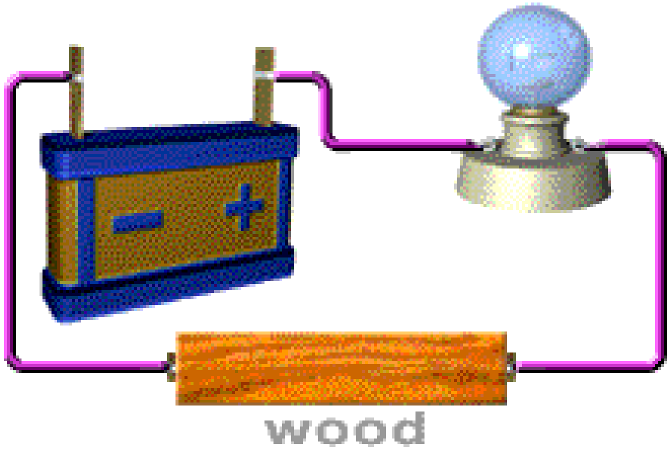


Range of Conduciveness



The semiconductors fall somewhere midway between conductors and insulators.

Range of Conduciveness



Semiconductors have special electronic properties which allow them to be insulating or conducting depending on their composition.

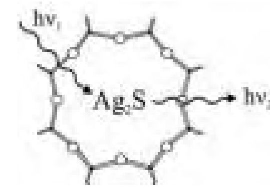
1824

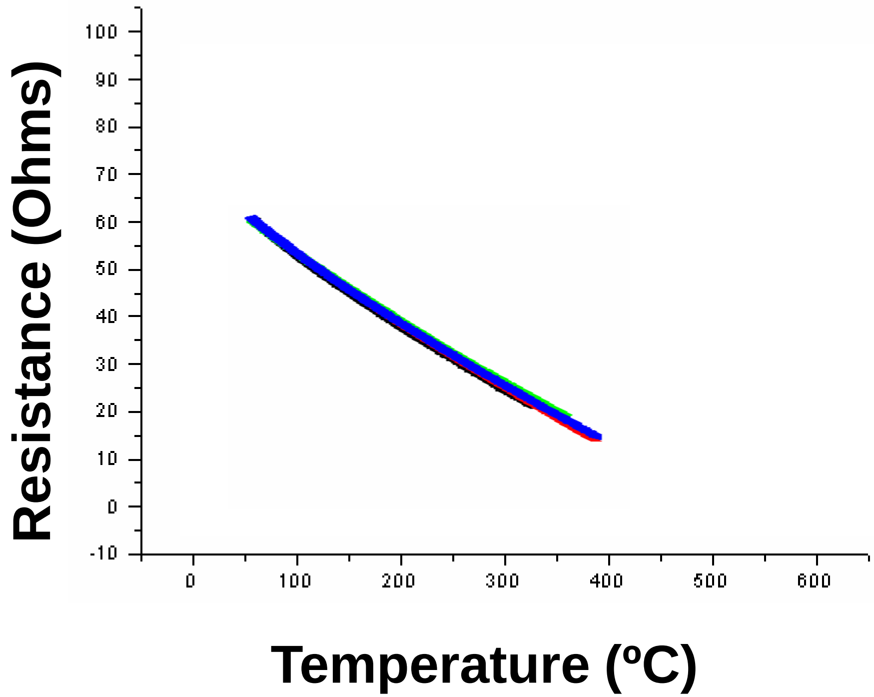
John Jacob Berzelis

First to isolate and identify silicon.
Remains little more than a scientific curiosity until the 1900s.

Michael Faraday

1833

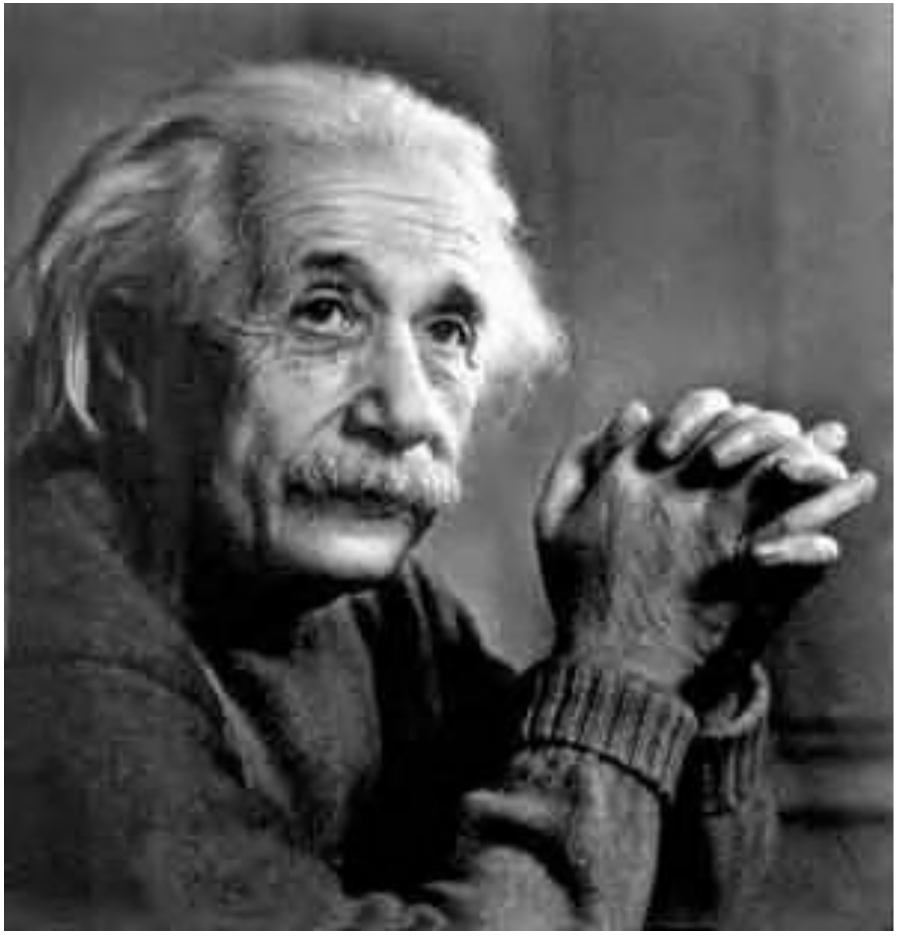




Discovers that electrical resistively decreases as temperature increases in silver sulfide.

This is the first investigation of a semiconductor.

Lab: Metals vs. Semiconductors



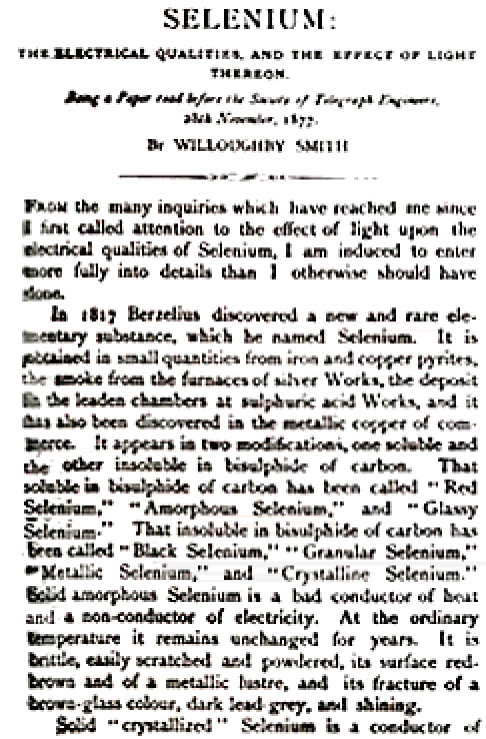
Lab: Metals vs. Semiconductors

Data Chart

Temperature	Copper	Germanium
0ºC	*31Ω*	*5.2Ω*
25ºC	*33Ω*	*4.2Ω*
50ºC	*37Ω*	*1.2Ω*
75ºC	*41Ω*	*0.63Ω*
100ºC	*44Ω*	*.029Ω*

1873

William Smith



SELENIUM:

THE ELECTRICAL QUALITIES, AND THE EFFECT OF LIGHT THEREON.

Being a Paper read before the Society of Telegraph Engineers, 28th November, 1877.

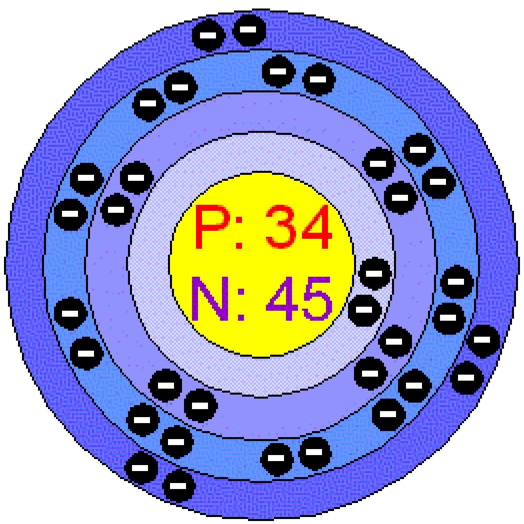
By WILLOUGHBY SMITH

FROM the many inquiries which have reached me since I first called attention to the effect of light upon the electrical qualities of Selenium, I am induced to enter more fully into details than I otherwise should have done.

In 1817 Berzelius discovered a new and rare elementary substance, which he named Selenium. It is obtained in small quantities from iron and copper pyrites, the smoke from the furnaces of silver Works, the deposit in the leaden chambers at sulphuric acid Works, and it has also been discovered in the metallic copper of commerce. It appears in two modifications, one soluble and the other insoluble in bisulphide of carbon. That soluble in bisulphide of carbon has been called "Red Selenium," "Amorphous Selenium," and "Glassy Selenium." That insoluble in bisulphide of carbon has been called "Black Selenium," "Granular Selenium," "Metallic Selenium," and "Crystalline Selenium." Solid amorphous Selenium is a bad conductor of heat and a non-conductor of electricity. At the ordinary temperature it remains unchanged for years. It is brittle, easily scratched and powdered, its surface red-brown and of a metallic lustre, and its fracture of a brown-glass colour, dark lead-grey, and shining.

Solid "crystallized" Selenium is a conductor of

Discovers the photoconductivity of selenium and invents a selenium photometer.

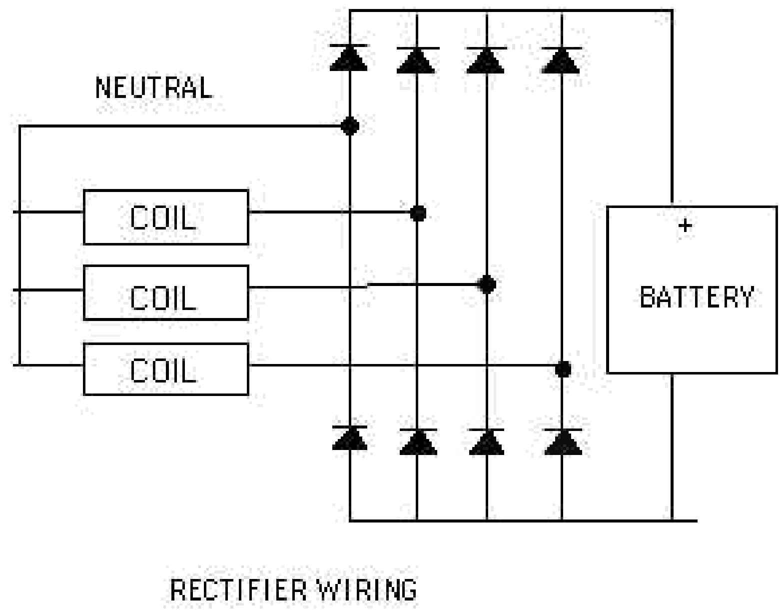

P: 34
N: 45

1874

Ferdinand Braun

The first semiconductor device was born.

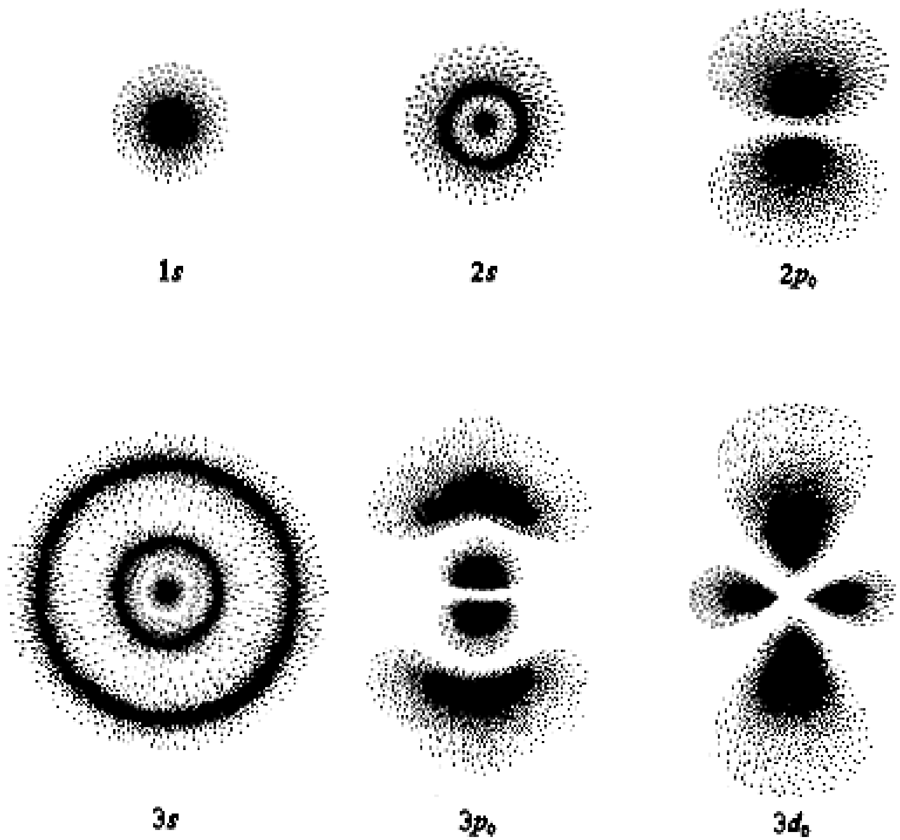
Radio receivers required a device called a rectifier to detect signals.

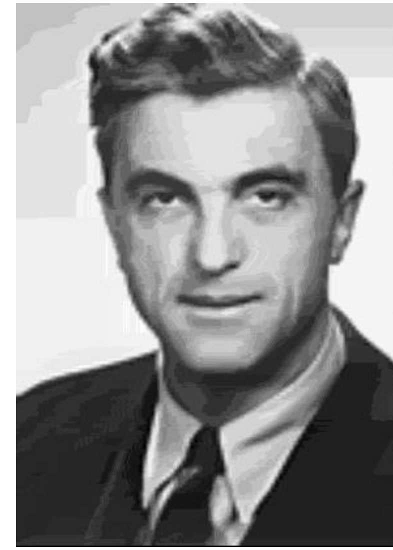


He used the rectifying properties of the galena crystal, a semiconductor material composed of lead sulfide, to create the cat's whisker diode for this purpose.

1927

Sommerfeld

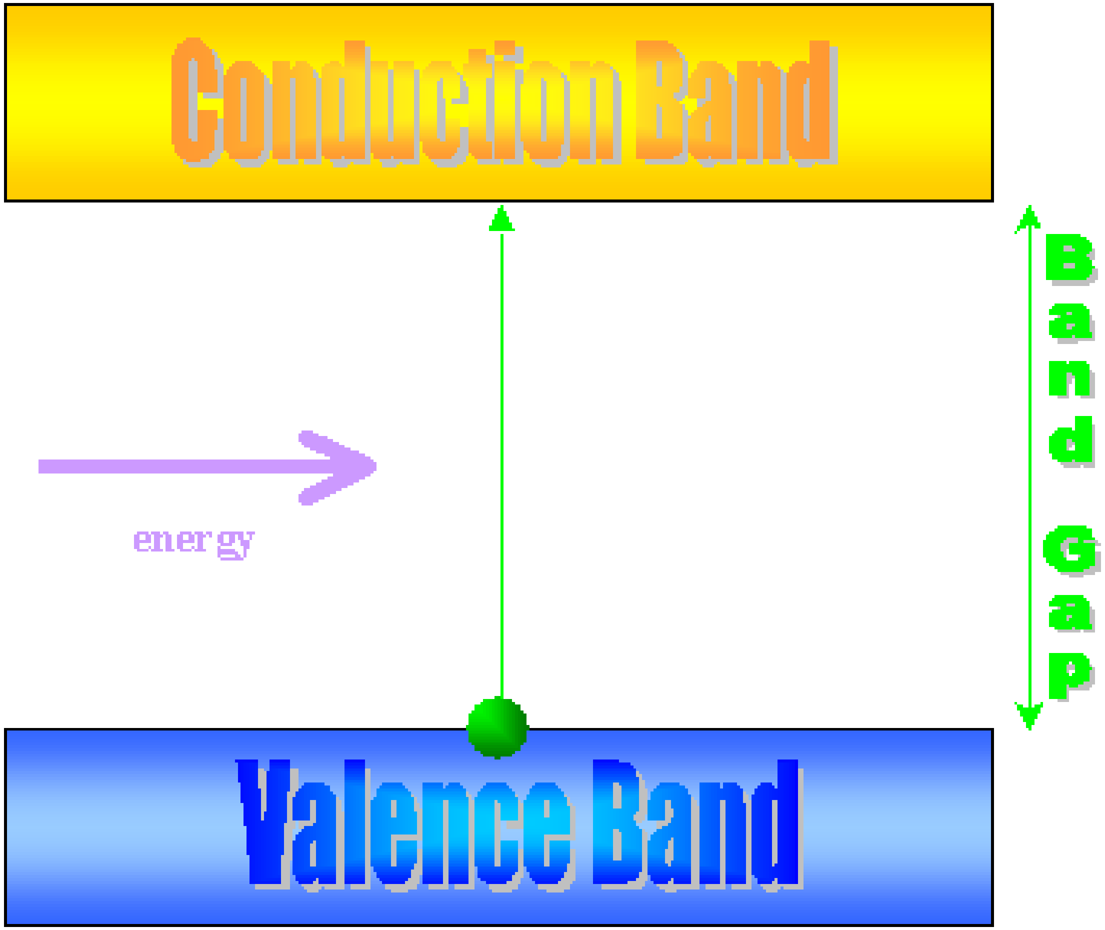




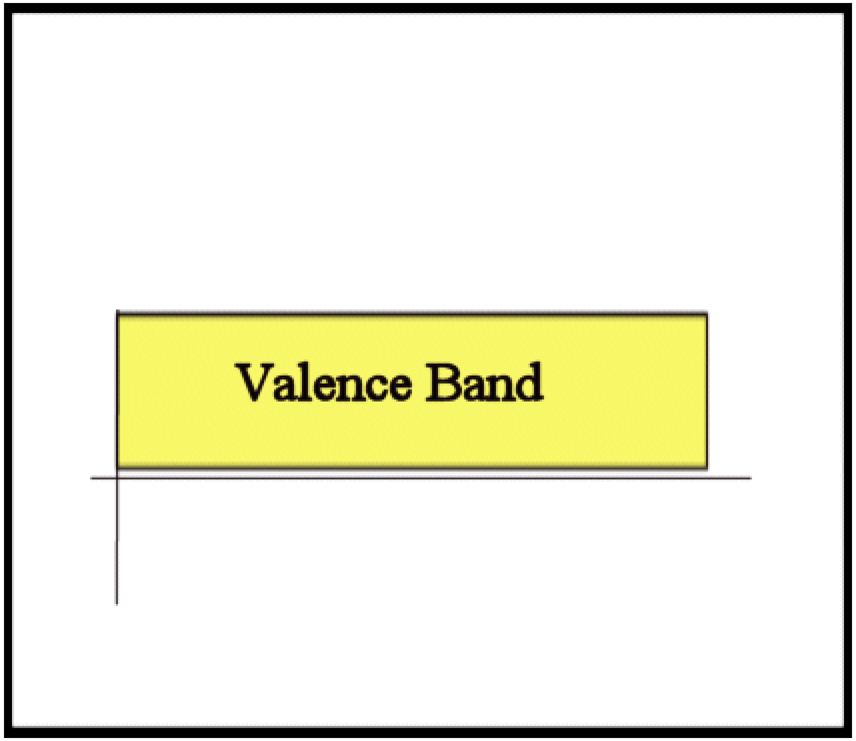
Bloch

Applied quantum mechanics to solids, helping explain the conduction of electricity in semiconductors.

Scientific Principle of Conduction



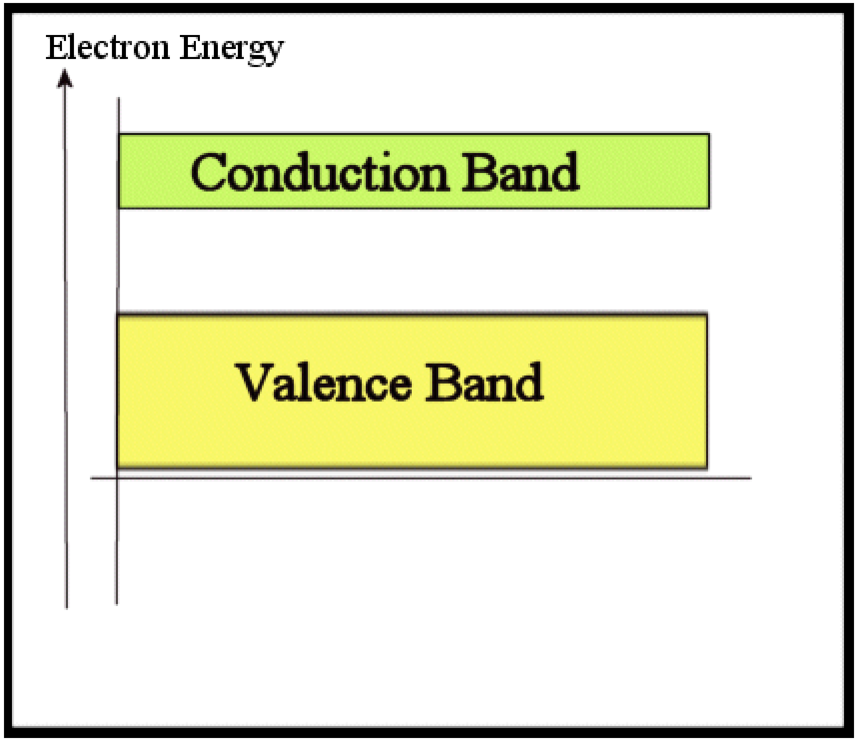
Valence Band



The highest occupied energy band is called the valence band.

Most electrons remain bound to the atoms in this band.

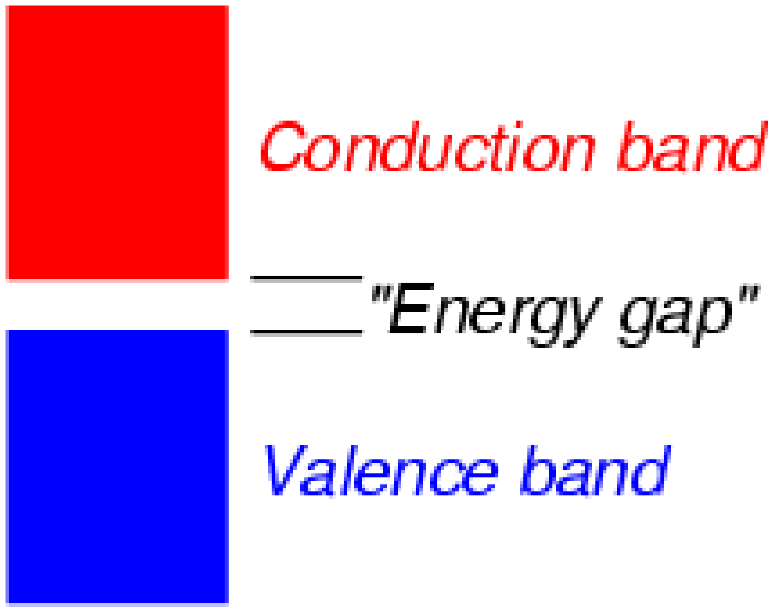
Conduction Band



The conduction band is the band of orbitals that are high in energy and are generally empty.

It is the band that accepts the electrons from the valence band.

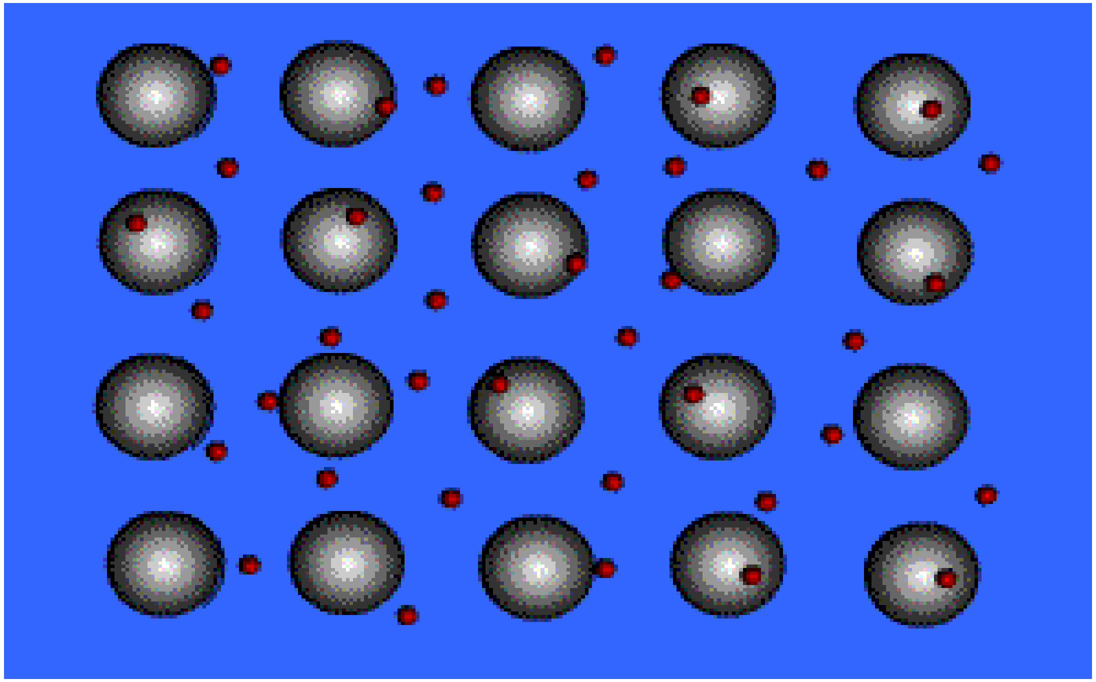
Energy Gap



The "leap" required for electrons from the Valence Band to enter the Conduction Band.

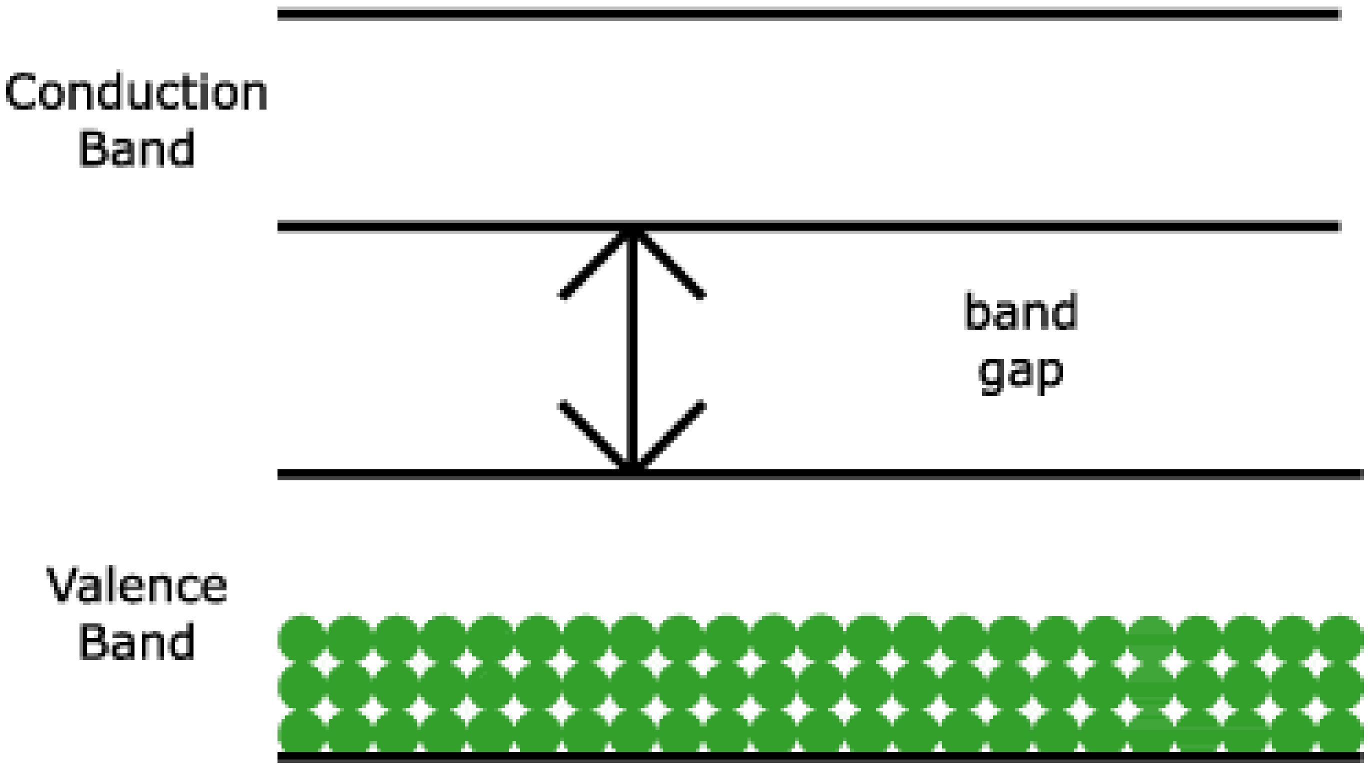

Conduction Band
Band Gap
Valence Band
LongIslandExchange.com

Conductors



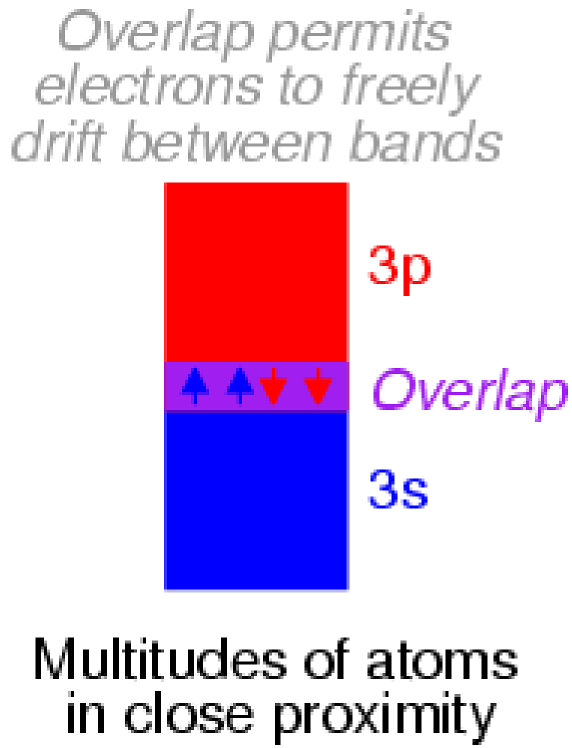
In a conductor, electrons can move freely among these orbitals within an energy band as long as the orbitals are not completely occupied.

Conductors



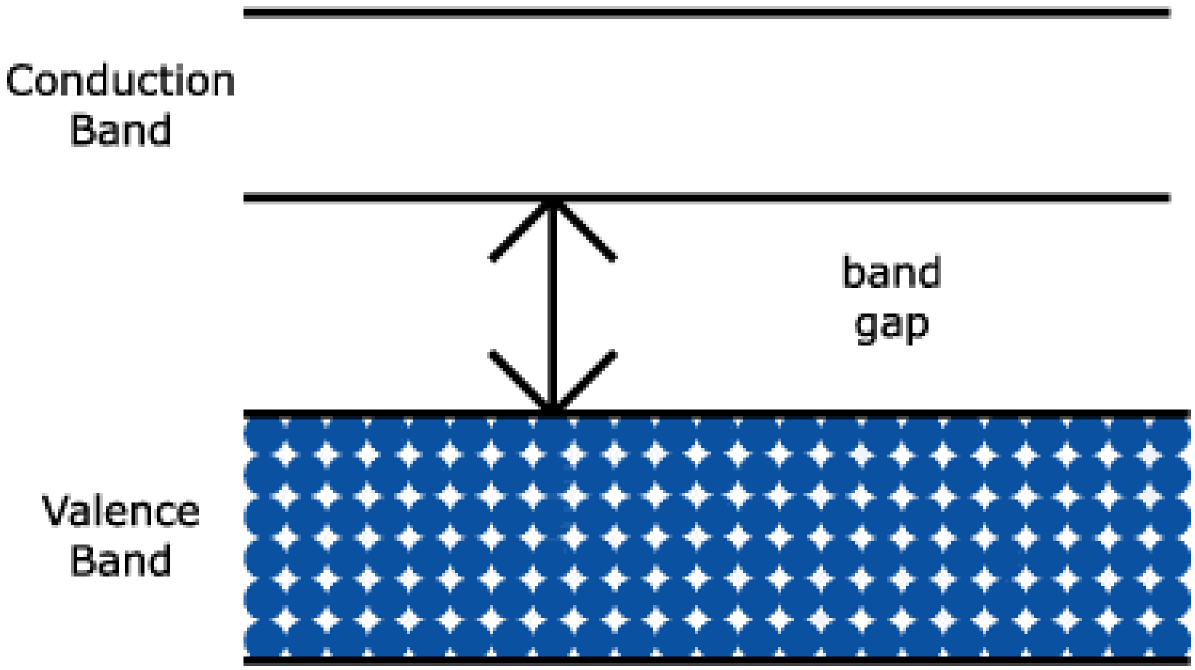
In conductors, the valence band is empty.

Conductors



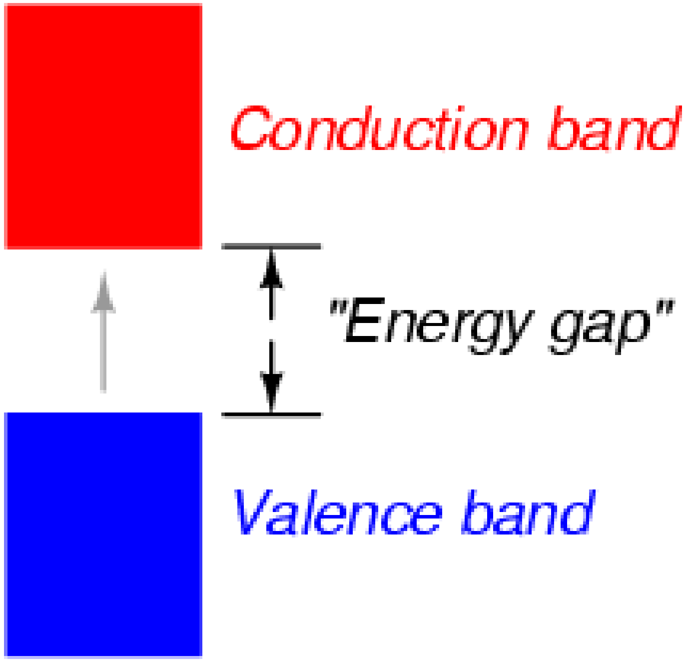
Also in conductors, the energy gap is nonexistent or relatively small.

Insulators



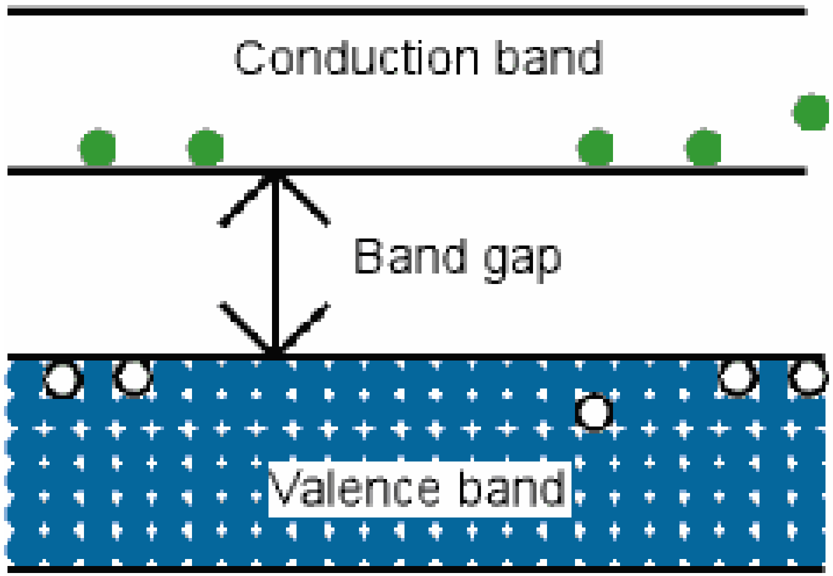
In insulators, the valence band is full.

Insulators



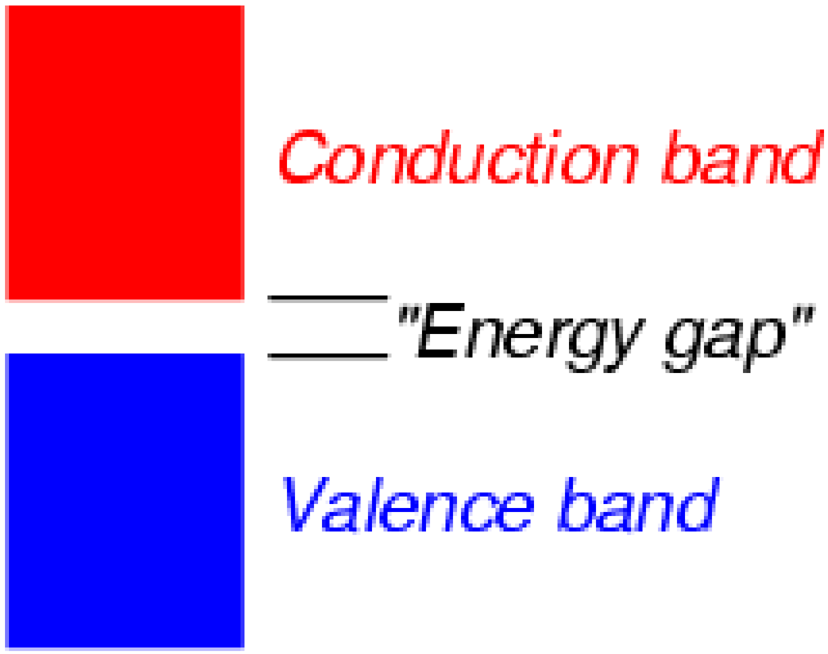
Also in insulators, the energy gap is relatively large.

Semiconductors



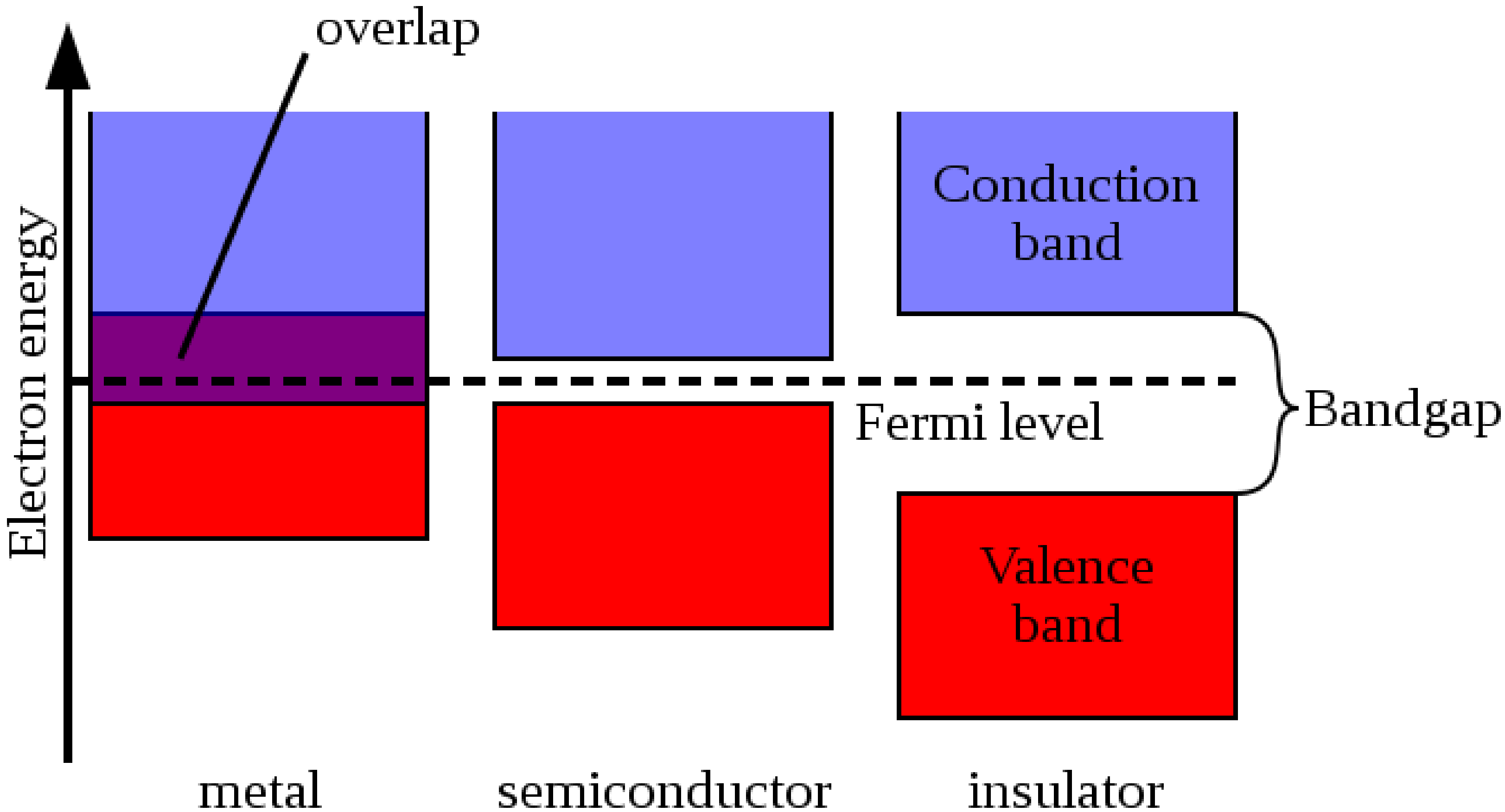
In semiconductors, the valence band is full but the energy gap is intermediate.

Semiconductors



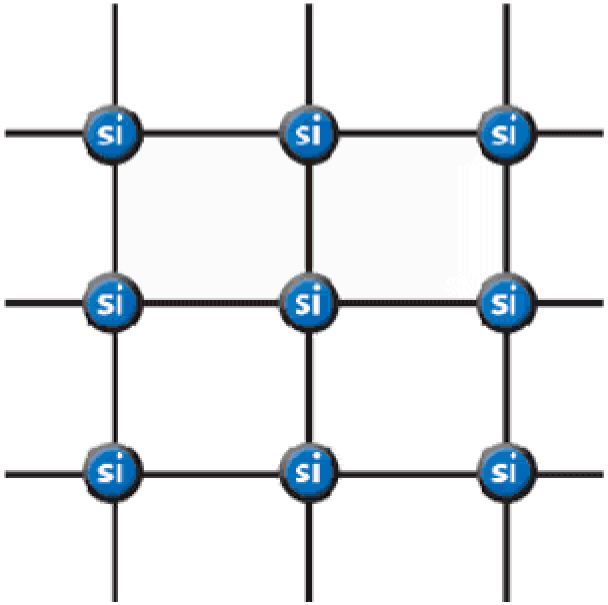
Only a small leap is required for an electron to enter the Conduction Band.

Band Diagrams



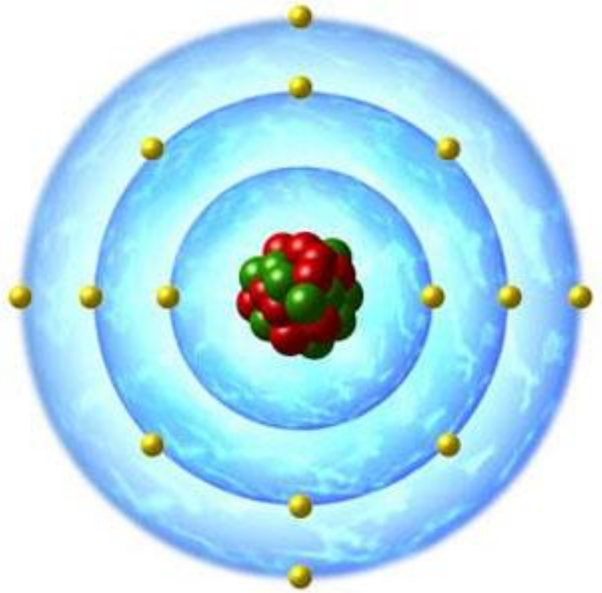
Silicon

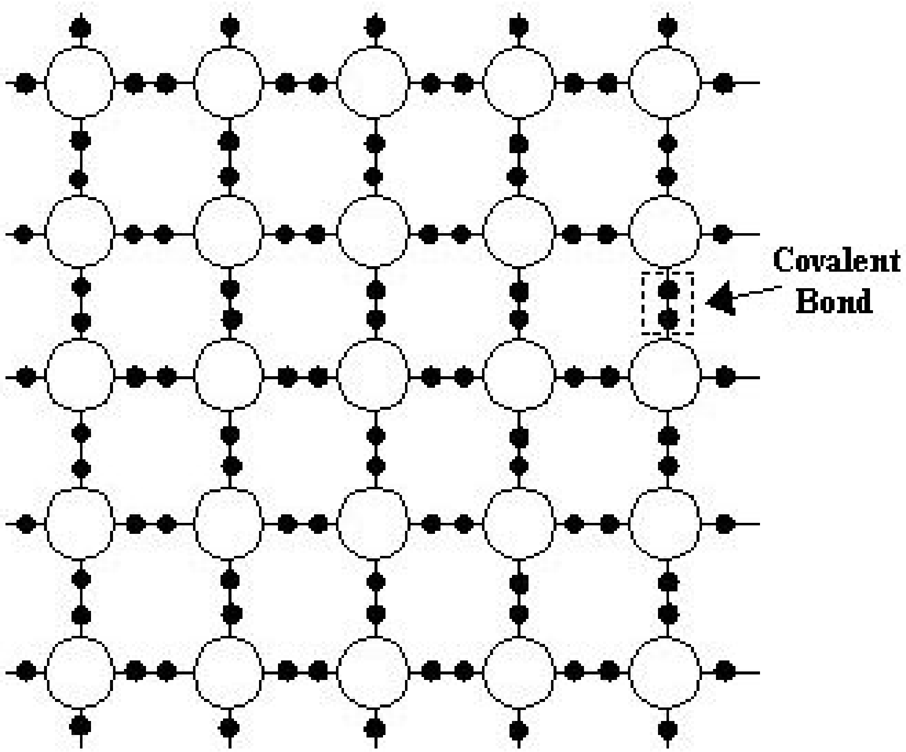

5 B Boron 2.34
6 C Carbon 2.62
7 N Nitrogen 1.251
13 Al Aluminum 2.70
14 Si Silicon 2.33
15 P Phosphorus 1.82
31 Ga Gallium 5.91
32 Ge Germanium 5.32
33 As Arsenic 5.72


Si
Si
Si
Si
Si
Si
Si
Si
Si

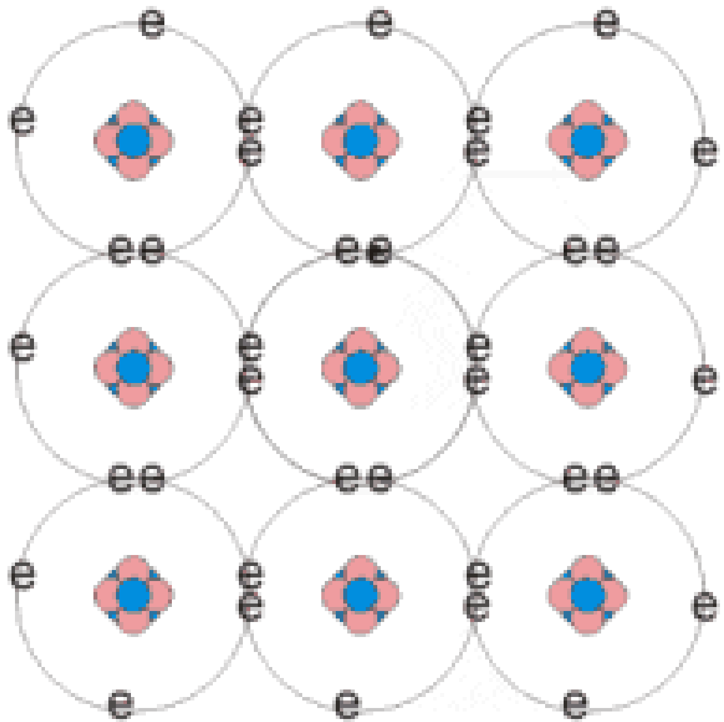
Silicon is a very common element, the main element in sand & quartz.

Silicon's Arrangement



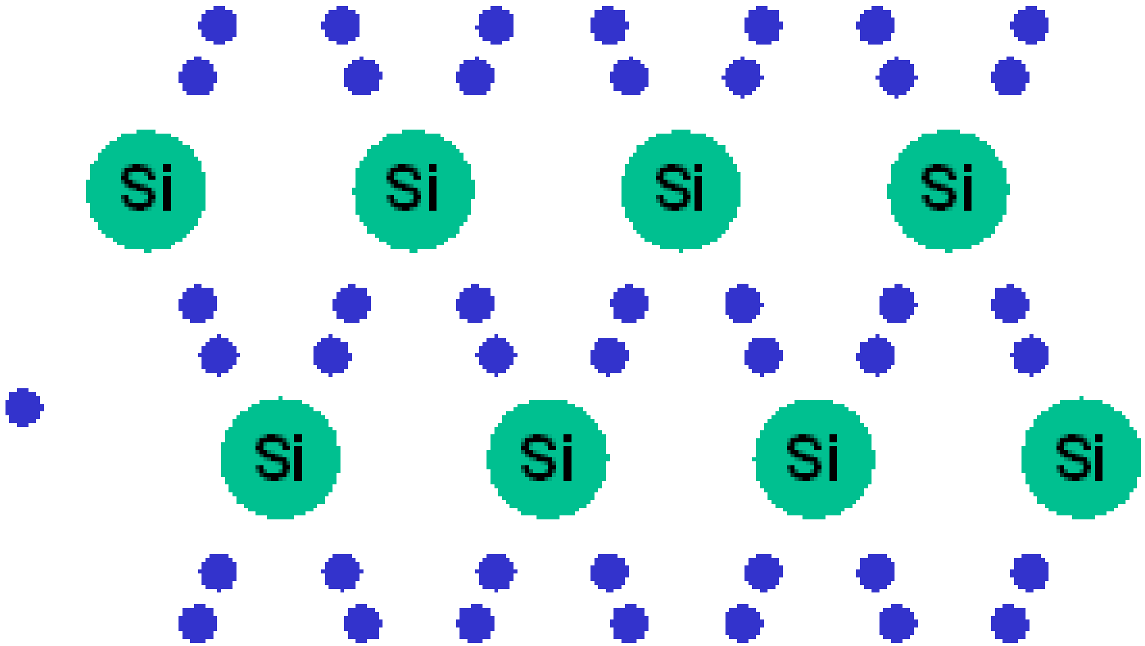


Intrinsic Silicon



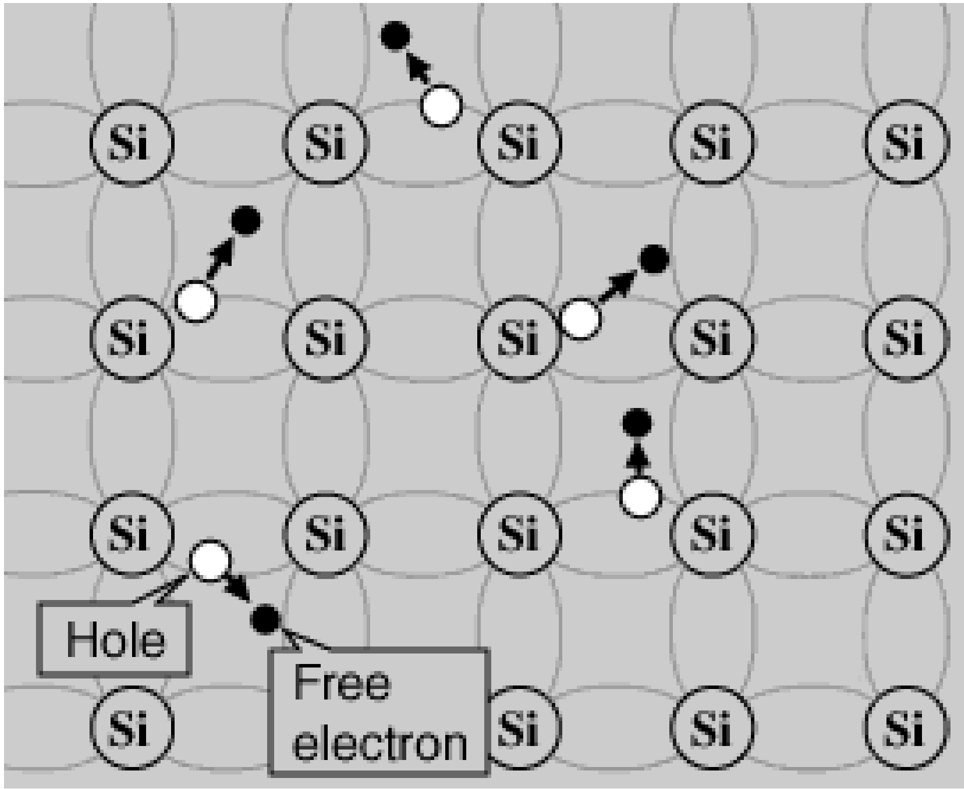
A silicon crystal is different from an insulator.

Intrinsic Silicon



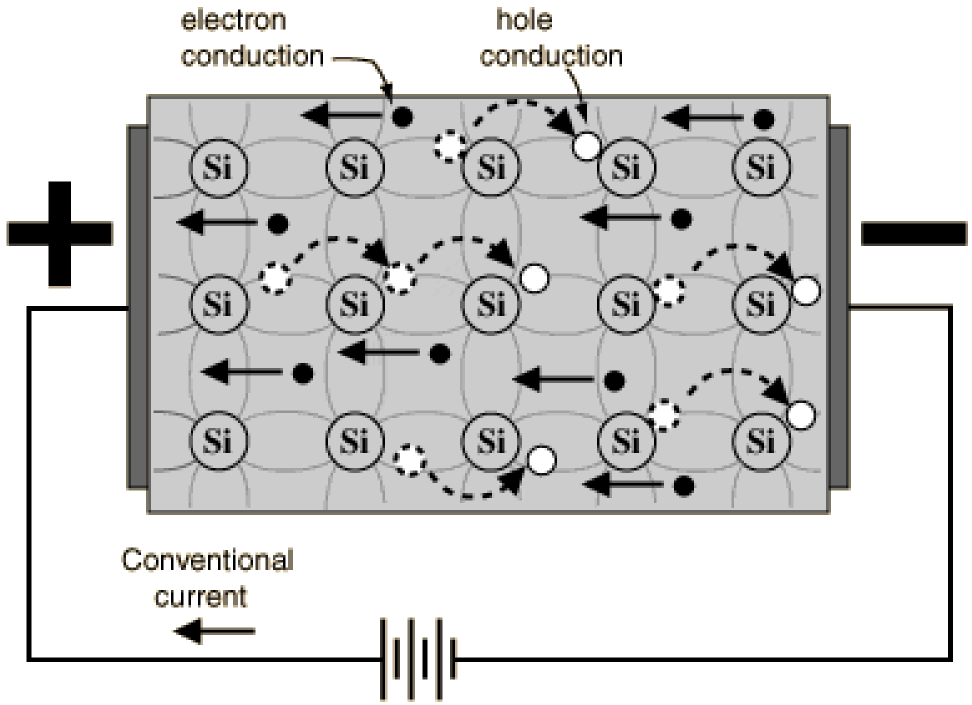
At any temperature above absolute zero temperature, there is a finite probability that an electron in the lattice will be knocked loose from its position.

Intrinsic Silicon



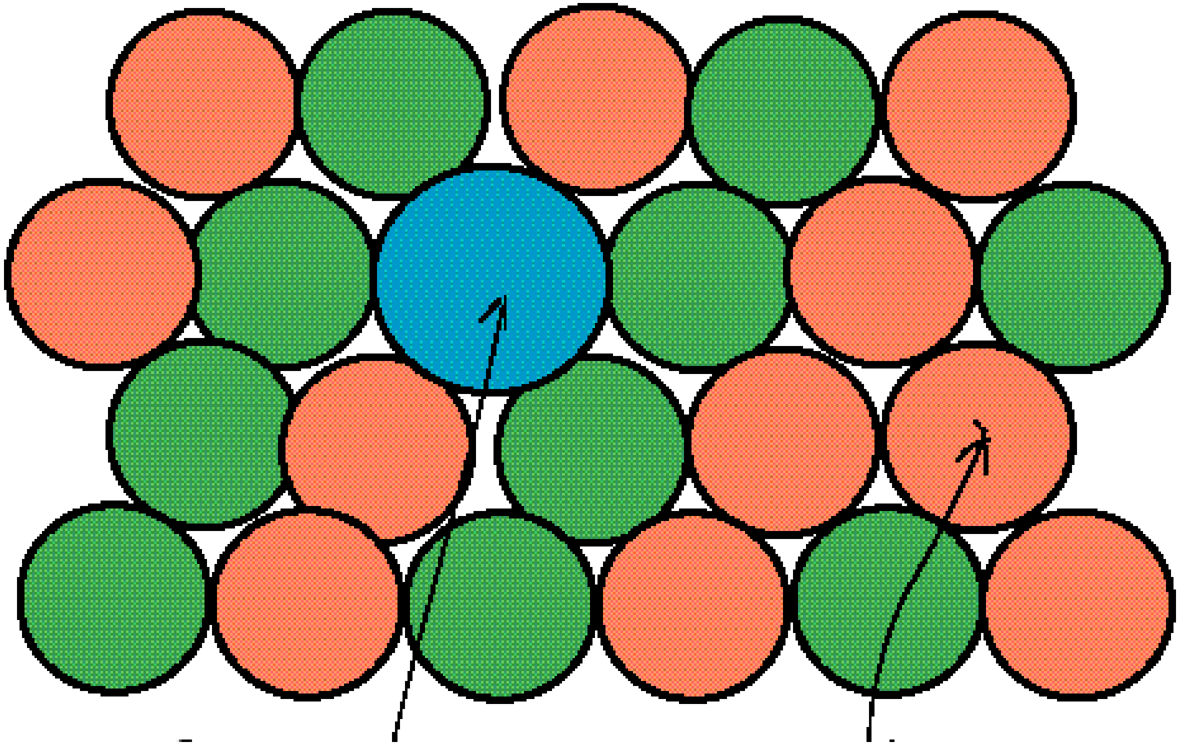
The electron in the lattice knocked loose from its position leaves behind an electron deficiency called a "hole".

Current Flow

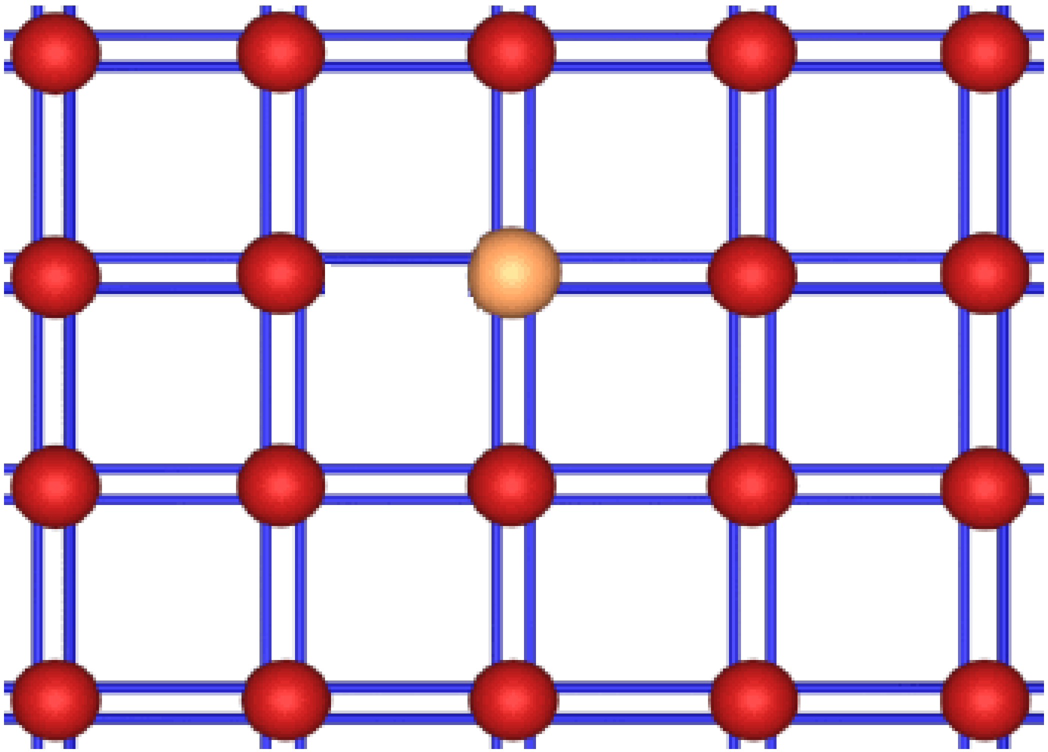


If a voltage is applied, then both the electron and the hole can contribute to a small current flow.

Impurity

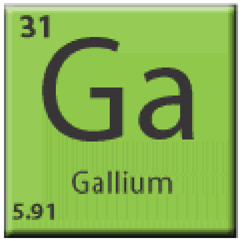


Doping



Doping (adding an impurity) can produce 2 types of semi-conductors depending upon the element added.

P-Type Doping

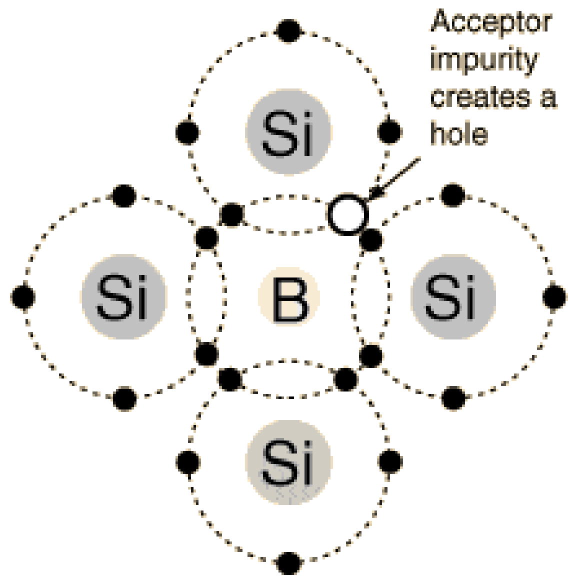


In P-type doping, boron or gallium is the dopant.

hydrogen 1 **H** 1.0079																		helium 2 **He** 4.0026
lithium 3 **Li** 6.941	beryllium 4 **Be** 9.0122												boron 5 **B** 10.811	carbon 6 **C** 12.011	nitrogen 7 **N** 14.007	oxygen 8 **O** 15.999	fluorine 9 **F** 18.998	neon 10 **Ne** 20.180
sodium 11 **Na** 22.990	magnesium 12 **Mg** 24.305												aluminium 13 **Al** 26.982	silicon 14 **Si** 28.086	phosphorus 15 **P** 30.974	sulfur 16 **S** 32.065	chlorine 17 **Cl** 35.453	argon 18 **Ar** 39.948
potassium 19 **K** 39.098	calcium 20 **Ca** 40.078		scandium 21 **Sc** 44.956	titanium 22 **Ti** 47.867	vanadium 23 **V** 50.942	chromium 24 **Cr** 51.996	manganese 25 **Mn** 54.938	iron 26 **Fe** 55.845	cobalt 27 **Co** 58.933	nickel 28 **Ni** 58.693	copper 29 **Cu** 63.546	zinc 30 **Zn** 65.39	gallium 31 **Ga** 69.723	germanium 32 **Ge** 72.61	arsenic 33 **As** 74.922	selenium 34 **Se** 78.96	bromine 35 **Br** 79.904	krypton 36 **Kr** 83.80
rubidium 37 **Rb** 85.468	strontium 38 **Sr** 87.62		yttrium 39 **Y** 88.906	zirconium 40 **Zr** 91.224	niobium 41 **Nb** 92.906	molybdenum 42 **Mo** 95.94	technetium 43 **Tc** [98]	ruthenium 44 **Ru** 101.07	rhodium 45 **Rh** 102.91	palladium 46 **Pd** 106.42	silver 47 **Ag** 107.87	cadmium 48 **Cd** 112.41	indium 49 **In** 114.82	tin 50 **Sn** 118.71	antimony 51 **Sb** 121.76	tellurium 52 **Te** 127.60	iodine 53 **I** 126.90	xenon 54 **Xe** 131.29
caesium 55 **Cs** 132.91	barium 56 **Ba** 137.33	57-70 *	lutetium 71 **Lu** 174.97	hafnium 72 **Hf** 178.49	tantalum 73 **Ta** 180.95	tungsten 74 **W** 183.84	rhenium 75 **Re** 186.21	osmium 76 **Os** 190.23	iridium 77 **Ir** 192.22	platinum 78 **Pt** 195.08	gold 79 **Au** 196.97	mercury 80 **Hg** 200.59	thallium 81 **Tl** 204.38	lead 82 **Pb** 207.2	bismuth 83 **Bi** 208.98	polonium 84 **Po** [209]	astatine 85 **At** [210]	radon 86 **Rn** [222]
francium 87 **Fr** [223]	radium 88 **Ra** [226]	89-102 * *	lawrencium 103 **Lr** [262]	rutherfordium 104 **Rf** [261]	dubnium 105 **Db** [262]	seaborgium 106 **Sg** [266]	bohrium 107 **Bh** [264]	hassium 108 **Hs** [269]	meitnerium 109 **Mt** [268]	ununnilium 110 **Uun** [271]	unununium 111 **Uuu** [272]	ununbium 112 **Uub** [277]		ununquadium 114 **Uuq** [289]				

*Lanthanide series	lanthanum 57 **La** 138.91	cerium 58 **Ce** 140.12	praseodymium 59 **Pr** 140.91	neodymium 60 **Nd** 144.24	promethium 61 **Pm** [145]	samarium 62 **Sm** 150.36	europium 63 **Eu** 151.96	gadolinium 64 **Gd** 157.25	terbium 65 **Tb** 158.93	dysprosium 66 **Dy** 162.50	holmium 67 **Ho** 164.93	erbium 68 **Er** 167.26	thulium 69 **Tm** 168.93	ytterbium 70 **Yb** 173.04
* *Actinide series	actinium 89 **Ac** [227]	thorium 90 **Th** 232.04	protactinium 91 **Pa** 231.04	uranium 92 **U** 238.03	neptunium 93 **Np** [237]	plutonium 94 **Pu** [244]	americium 95 **Am** [243]	curium 96 **Cm** [247]	berkelium 97 **Bk** [247]	californium 98 **Cf** [251]	einsteinium 99 **Es** [252]	fermium 100 **Fm** [257]	mendelevium 101 **Md** [258]	nobelium 102 **No** [259]

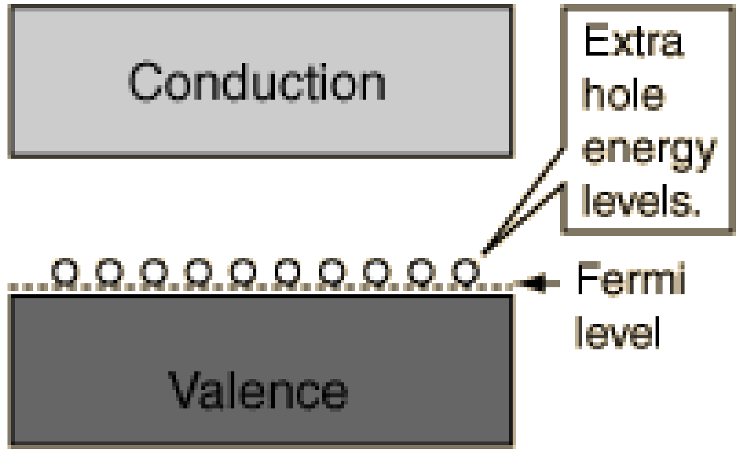
P-Type Doping



Boron and gallium each have only three outer electrons.

When mixed into the silicon lattice, they form "holes" in the lattice where a silicon electron has nothing to bond to.

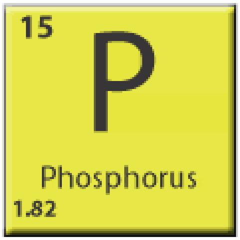
P-Type Doping



The absence of an electron creates the effect of a positive charge, hence the name P-type.

Holes can conduct current. A hole happily accepts an electron from a neighbor, moving the hole over a space. P-type silicon is a good conductor.

N-Type

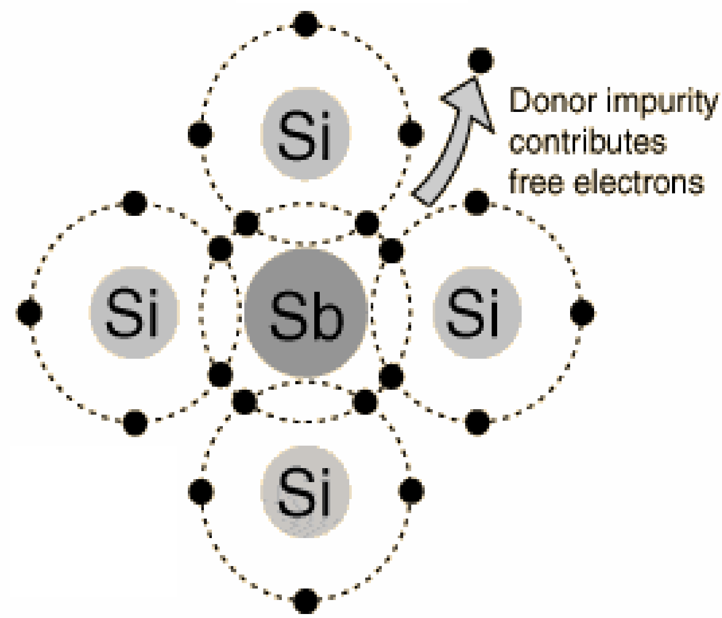


In N-type doping, phosphorus or arsenic is added to the silicon in small quantities.

hydrogen 1 H 1.0079																		helium 2 He 4.0026
lithium 3 Li 6.941	beryllium 4 Be 9.0122												boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180
sodium 11 Na 22.990	magnesium 12 Mg 24.305												aluminium 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948
potassium 19 K 39.098	calcium 20 Ca 40.078		scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80
rubidium 37 Rb 85.468	strontium 38 Sr 87.62		yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29
caesium 55 Cs 132.91	barium 56 Ba 137.33	57-70 *	lutetium 71 Lu 174.97	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]
francium 87 Fr [223]	radium 88 Ra [226]	89-102 * *	lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	ununnilium 110 Uun [271]	unununium 111 Uuu [272]	ununbium 112 Uub [277]		ununquadium 114 Uuq [289]				

*Lanthanide series	lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04
* *Actinide series	actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]

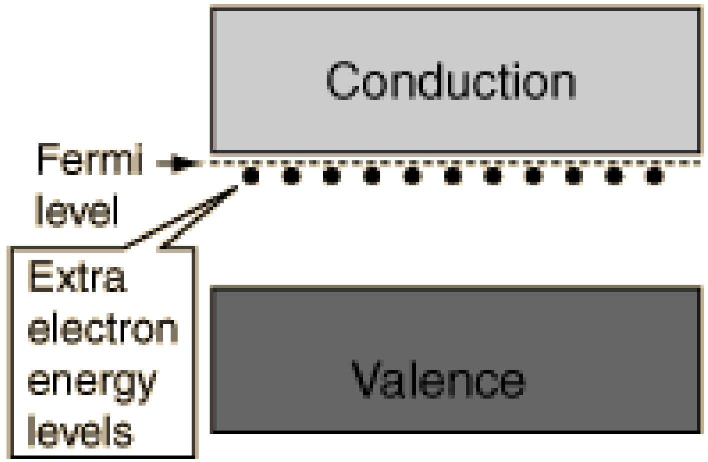
N-Type



Phosphorus and arsenic each have five outer electrons, so they're out of place when they get into the silicon lattice.

The fifth electron has nothing to bond to, so it's free to move around.

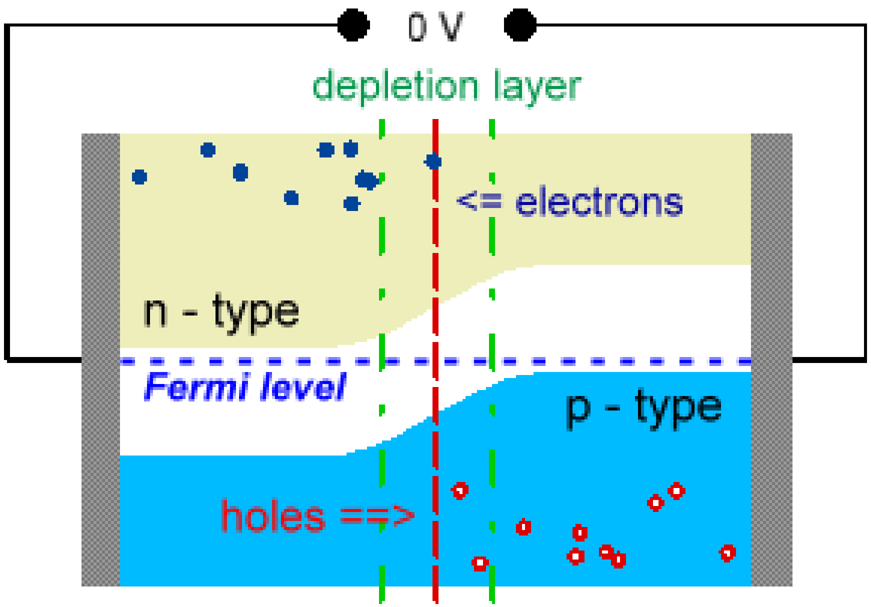
N-Type

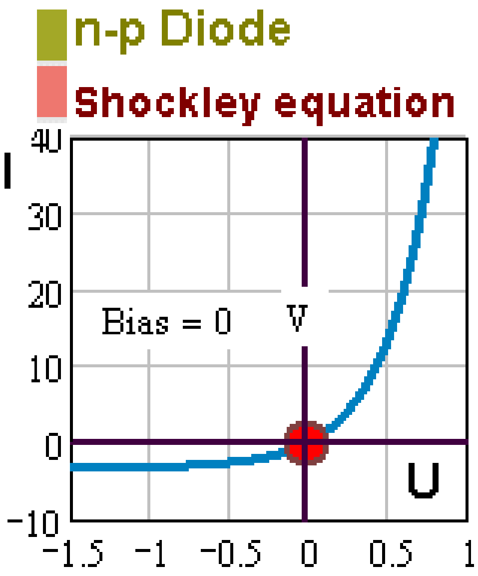


It takes only a very small quantity of the impurity to create enough free electrons to allow an electric current to flow through the silicon. N-type silicon is a good conductor.

Electrons have a negative charge, hence the name N-type.

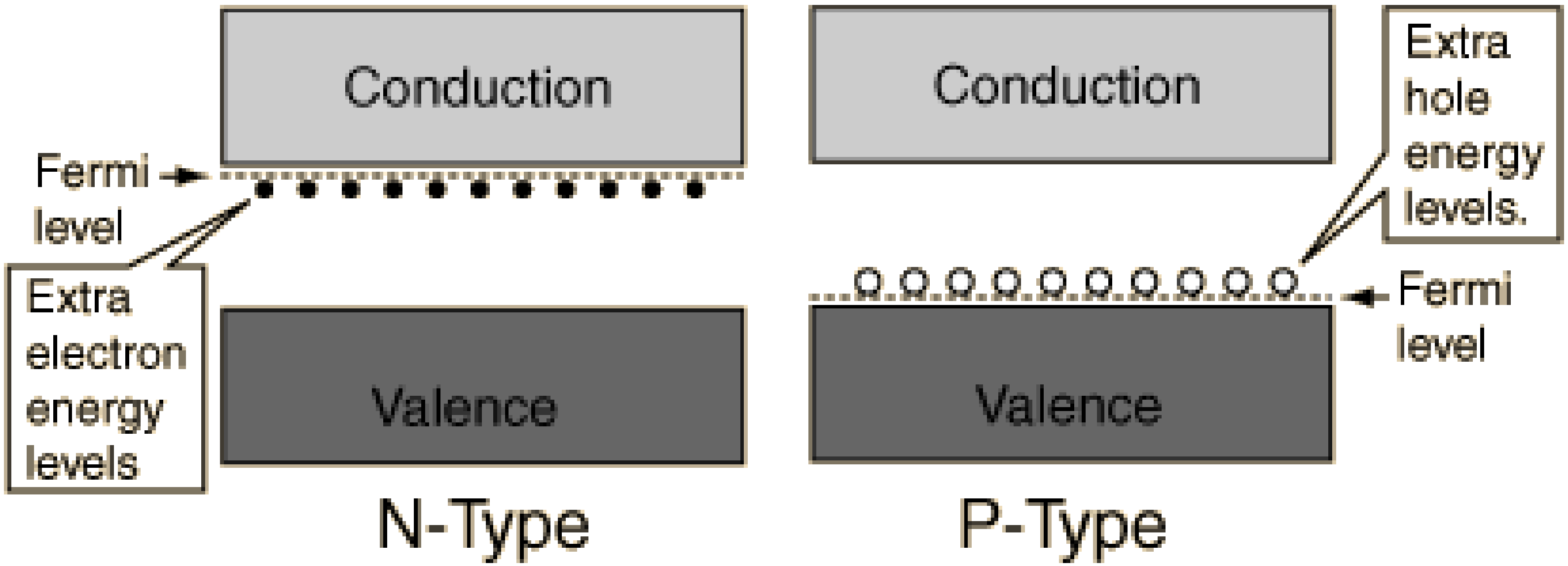
P-N Junction





We create a p-n junction by joining together two pieces of semiconductor, one doped n-type, the other p-type.

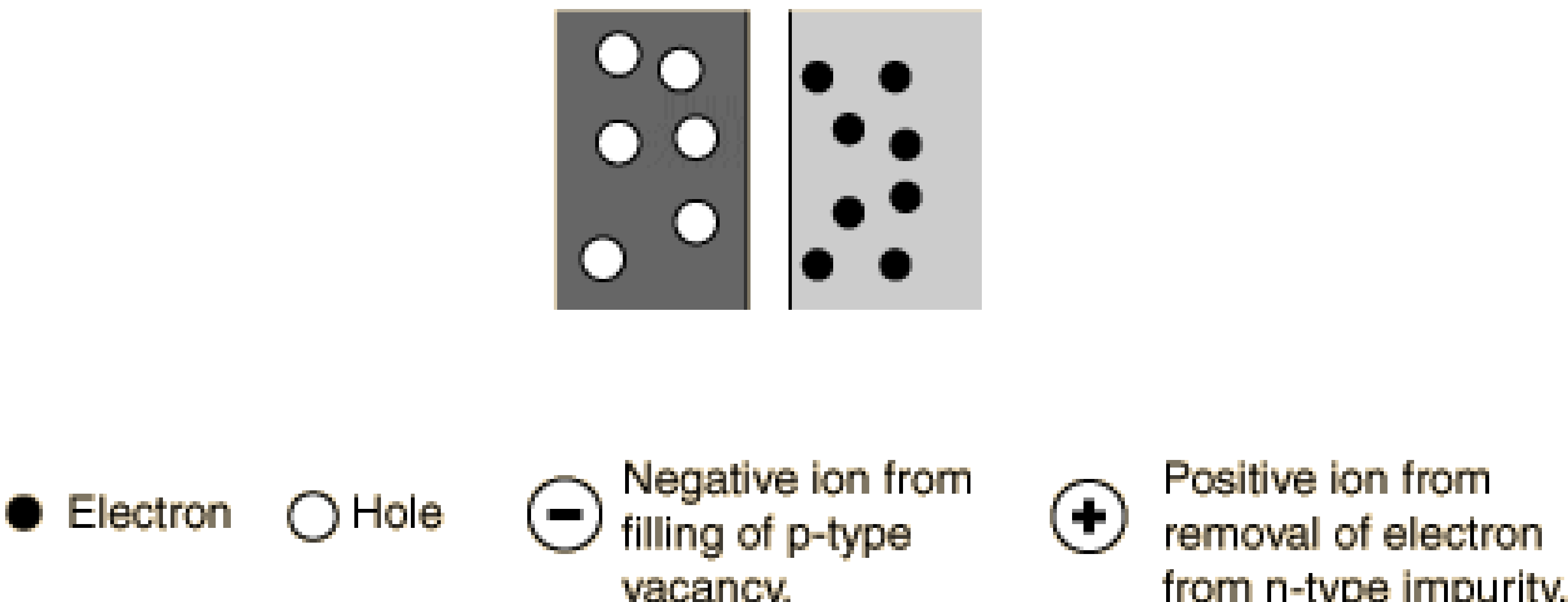
P-N Junction



In the n-type region there are extra electrons and in the p-type region, there are holes from the acceptor impurities .

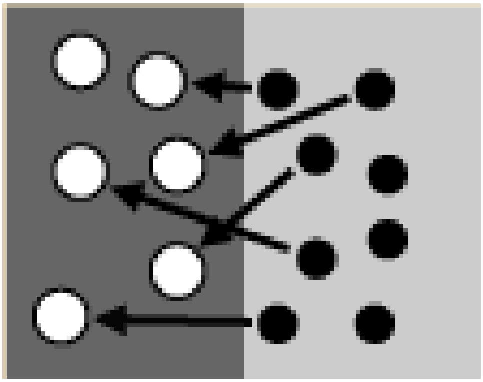
P-N Junction

In the p-type region there are holes from the acceptor impurities and in the n-type region there are extra electrons.



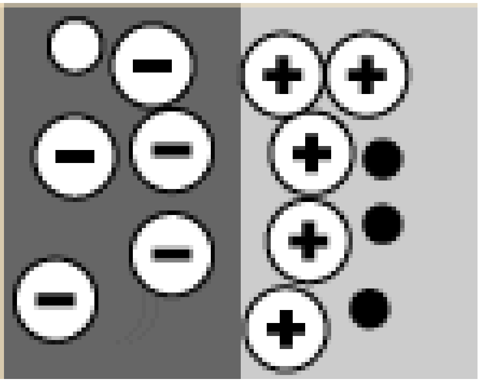
P-N Junction

When a p-n junction is formed, some of the electrons from the n-region which have reached the conduction band are free to diffuse across the junction and combine with holes.



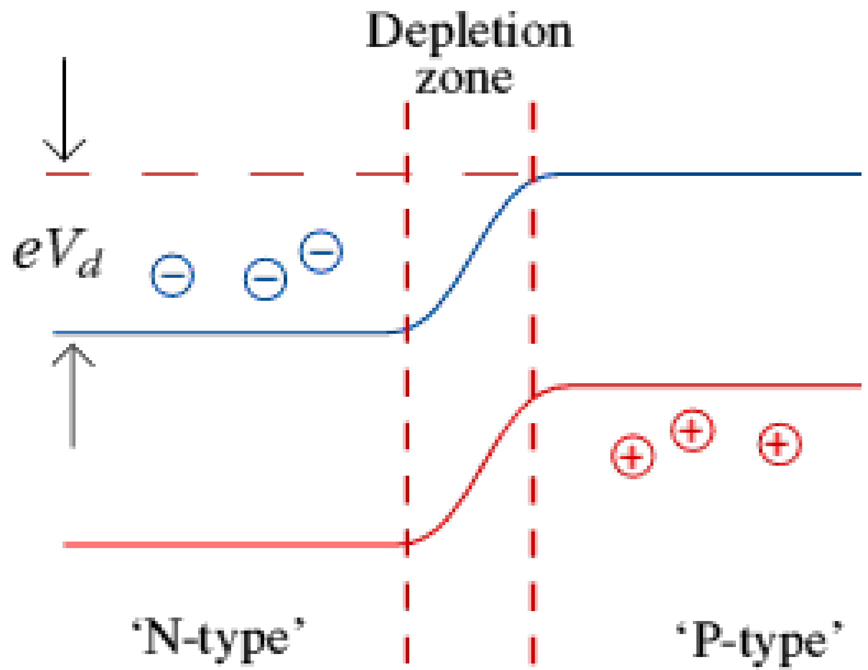
P-N Junction

Filling a hole makes a negative ion and leaves behind a positive ion on the n-side.



A space charge builds up, creating a depletion region.

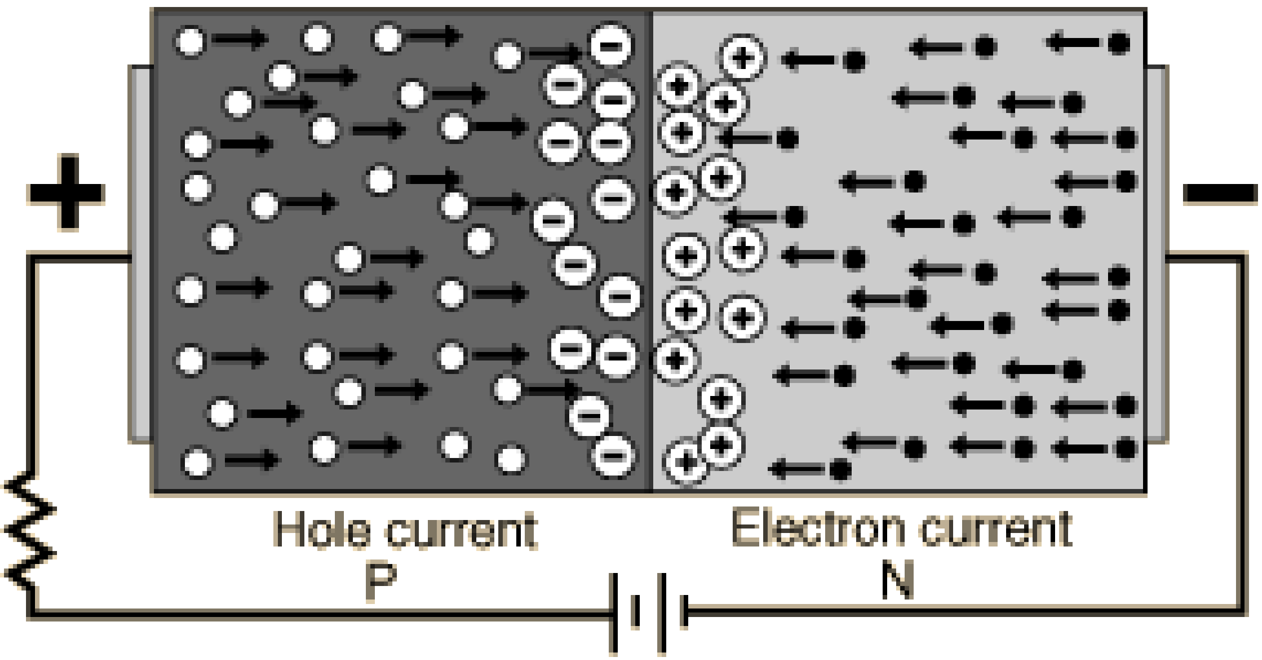
P-N Junction



This causes a depletion zone to form around the junction (the join) between the two materials.

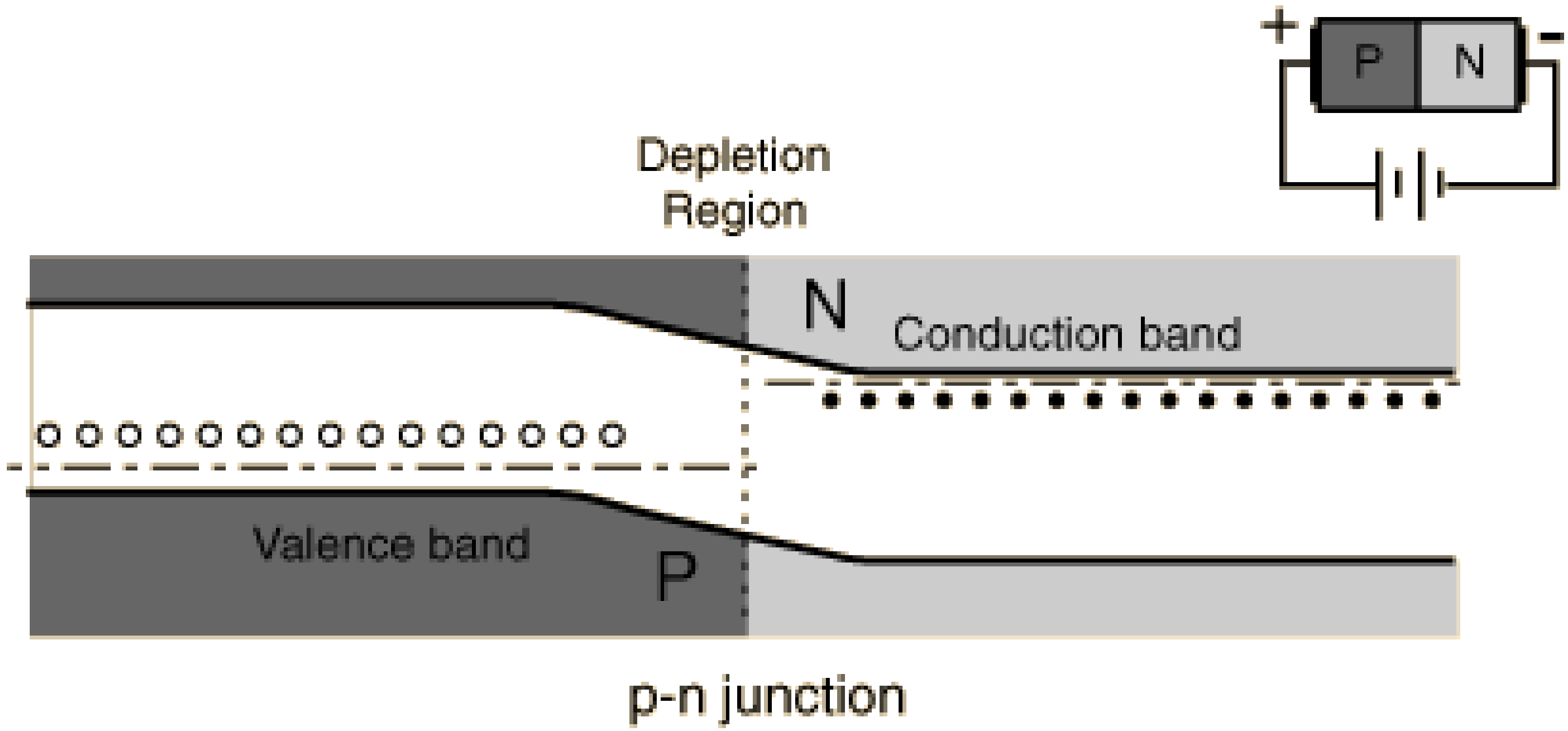
This zone controls the behavior of the diode.

Forward Biasing



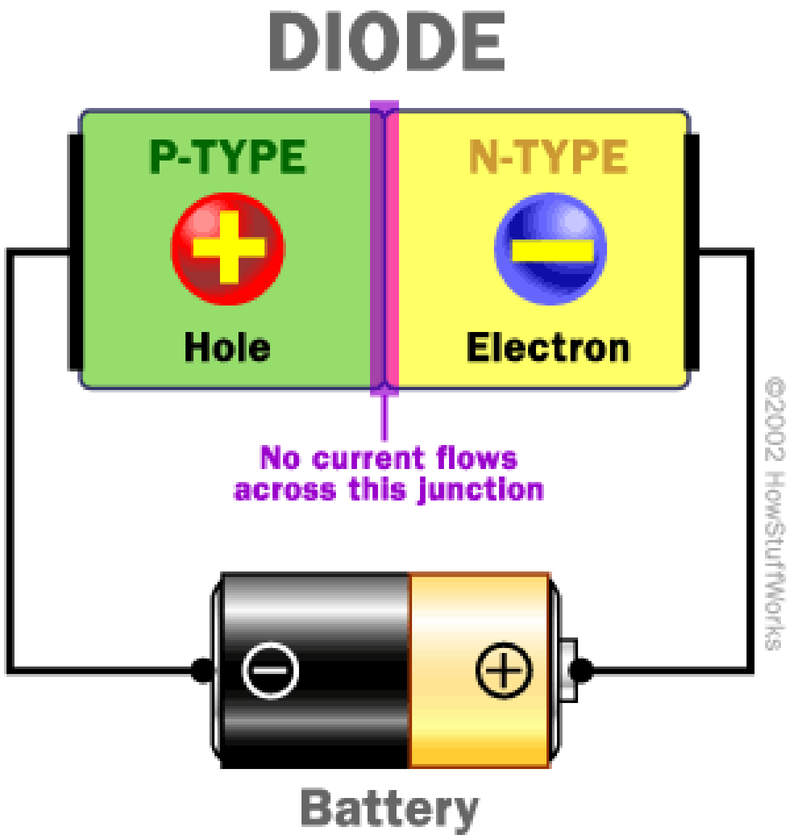
Forward biasing the p-n junction drives holes to the junction from the p-type material and electrons to the junction from the n-type material.

Forward Biasing



At the junction the electrons and holes combine so that a continuous current can be maintained.

Diode



A diode is the simplest possible semiconductor device.

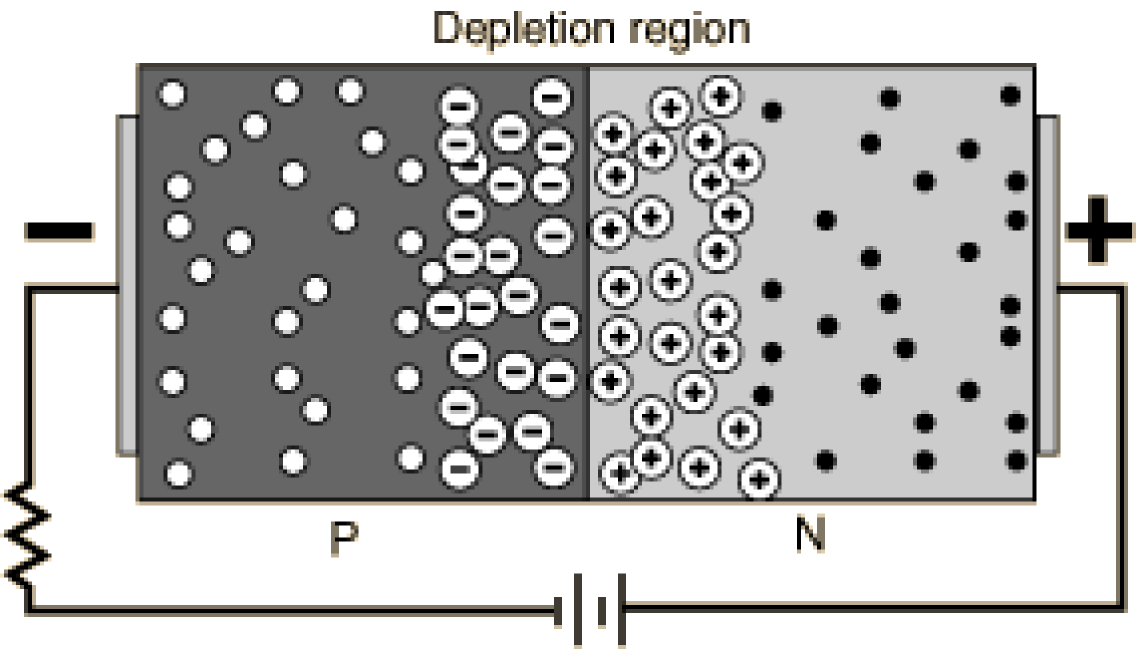
One Way Electric “Turnstile”

A diode allows current to flow in one direction but not the other.

Jumping

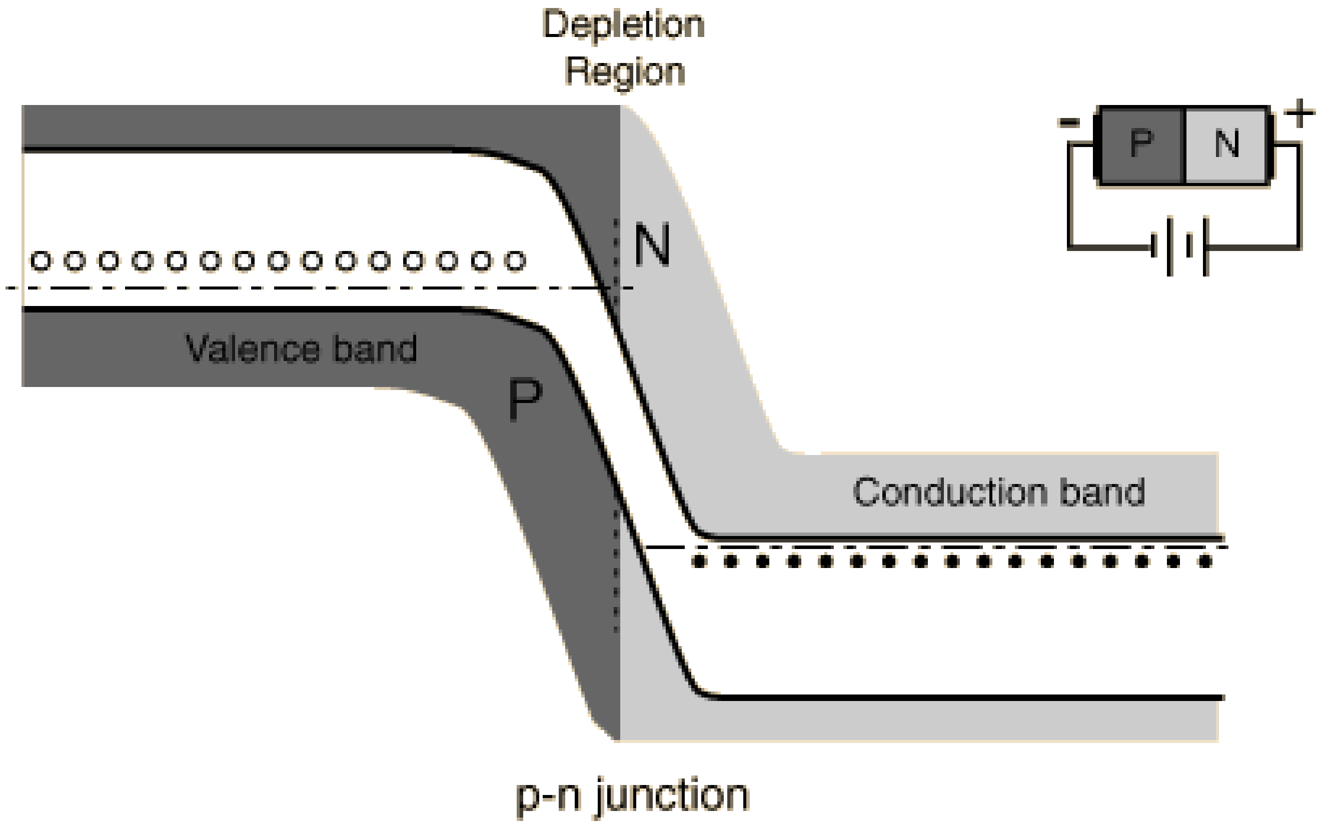
If you apply enough reverse voltage, the junction breaks down and lets current through.

Reverse Biasing



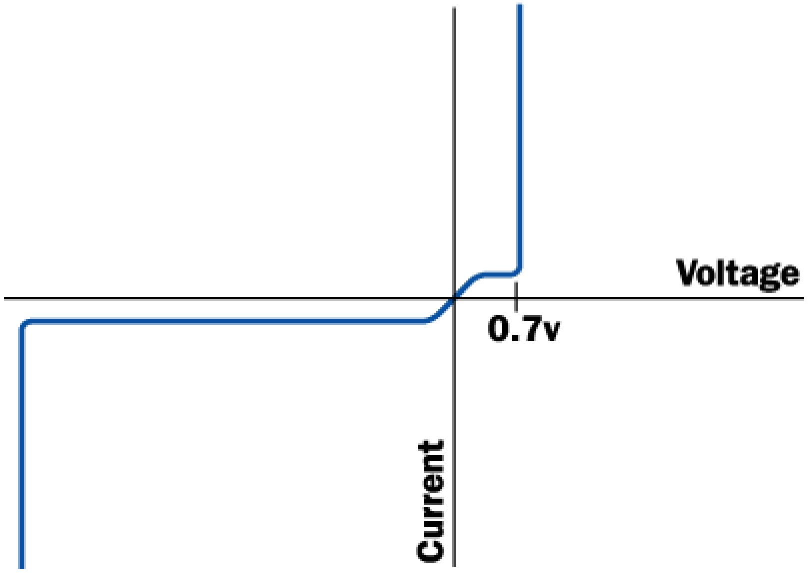
The application of a reverse voltage to the p-n junction will cause a transient current to flow as both electrons and holes are pulled away from the junction.

Reverse Biasing



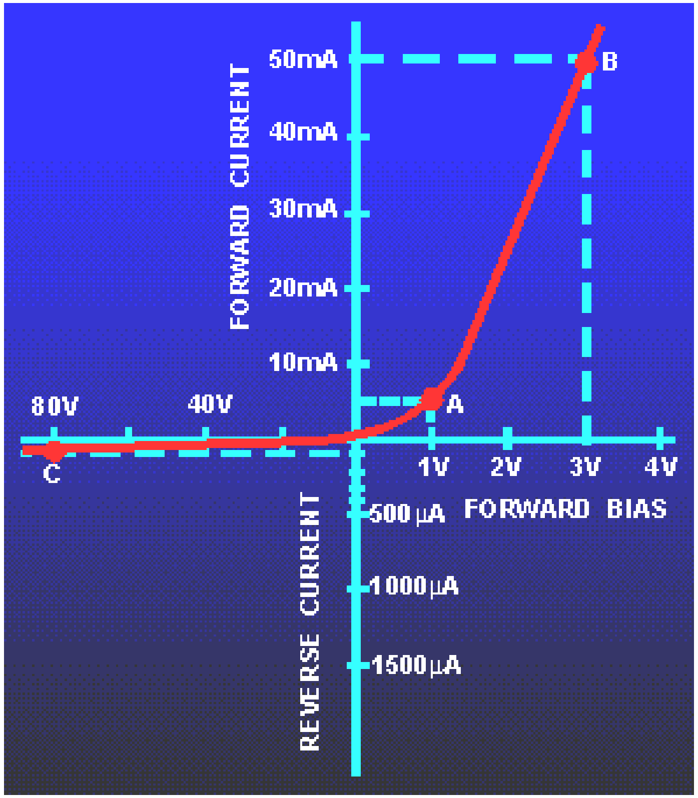
When the potential formed by the widened depletion layer equals the applied voltage, the current will cease except for the small thermal current.

When forward-biased, there is a small amount of voltage necessary to get the diode going. In silicon, this voltage is about 0.7 volts.



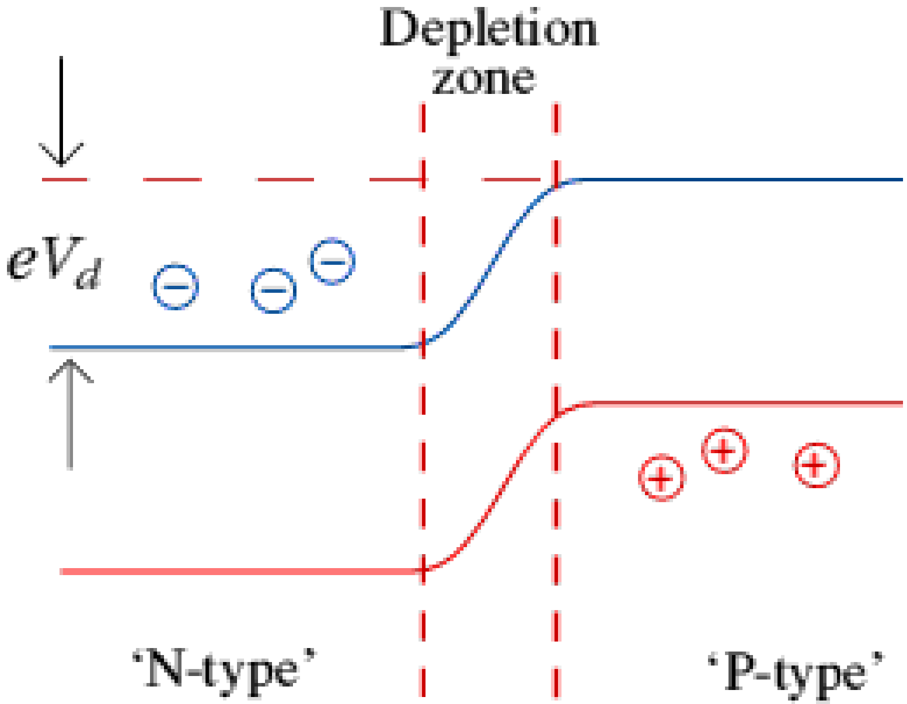
This voltage is needed to start the hole-electron combination process at the junction.

Diode Characteristic



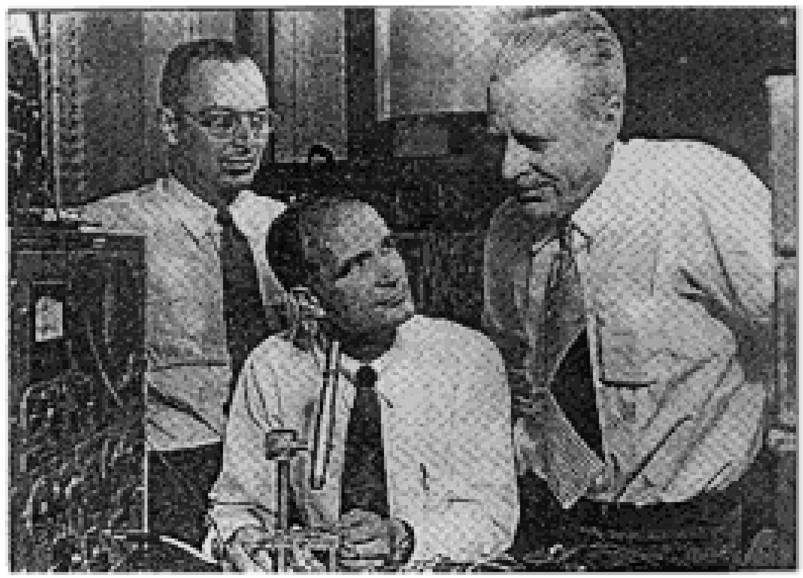
When reverse-biased, an ideal diode would block all current. A real diode lets perhaps 10 microamps through -- not a lot, but still not perfect.

Diode Characteristic



Usually, the breakdown voltage is a lot more voltage than the circuit will ever see, so it is irrelevant.

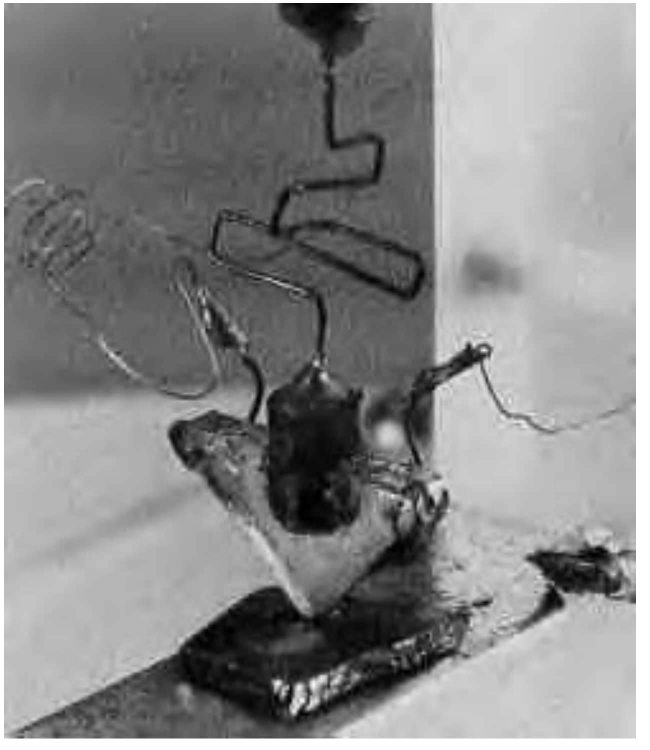
1947



John Bardeen, William Shockley and Walter Brattain

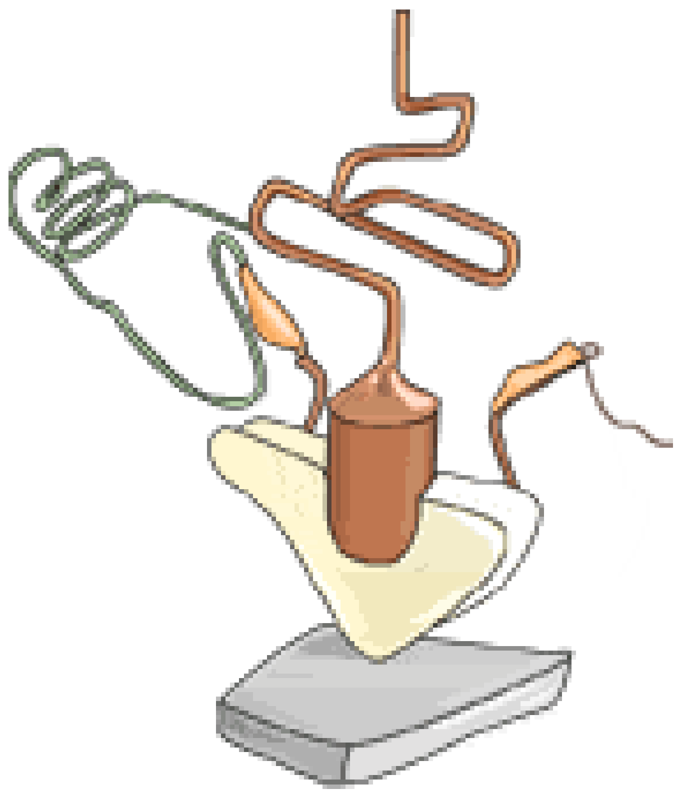
Working at Bell Telephone, they were trying to understand the nature of the electrons at the interface between a metal and a semiconductor (germanium).

First Transistor

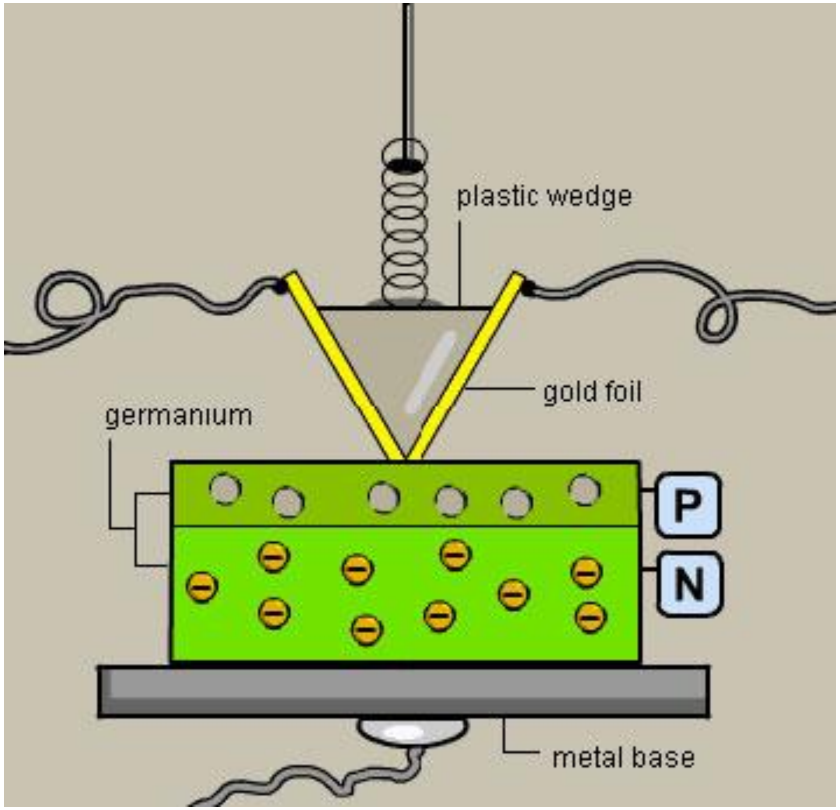


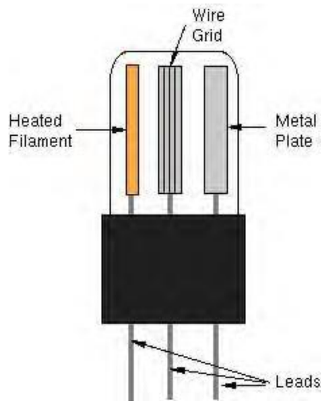
It consisted of a plastic triangle lightly suspended above a germanium crystal which itself was sitting on a metal plate attached to a voltage source.

A strip of gold was wrapped around the point of the triangle with a tiny gap cut into the gold at the precise point it came in contact with the germanium crystal.



The germanium acted as a semiconductor so that a small electric current entering on one side of the gold strip came out the other side as a proportionately amplified current.



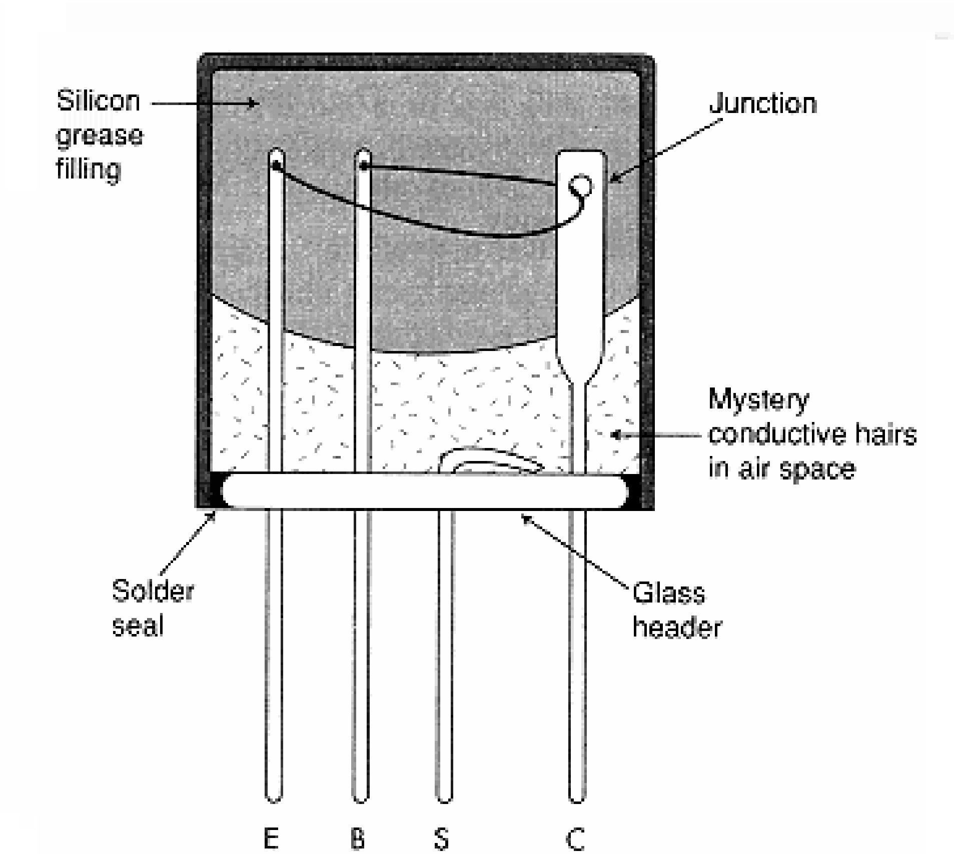


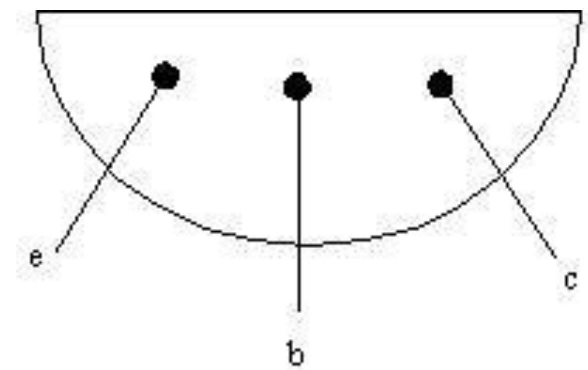
Transistors didn't need time to "warm up" like the heaters in vacuum tube circuits.

Transistor

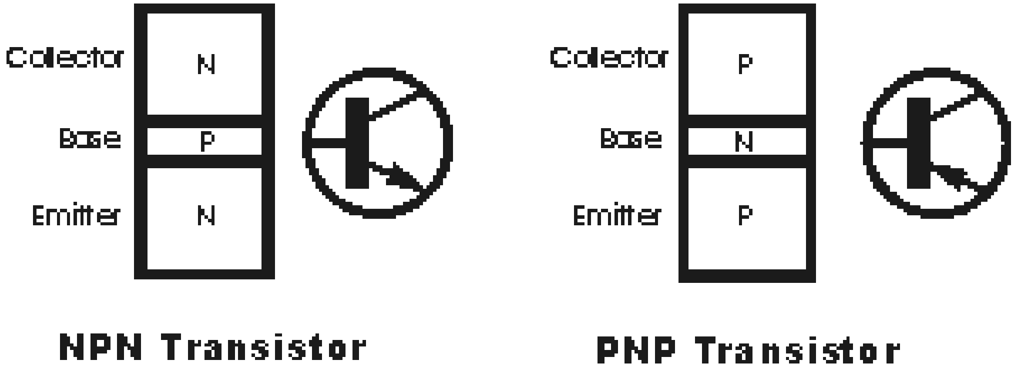
A transistor is a semiconductor device commonly used to amplify or switch electronic signals.

The transistor is a three terminal device and consists of three distinct layers.

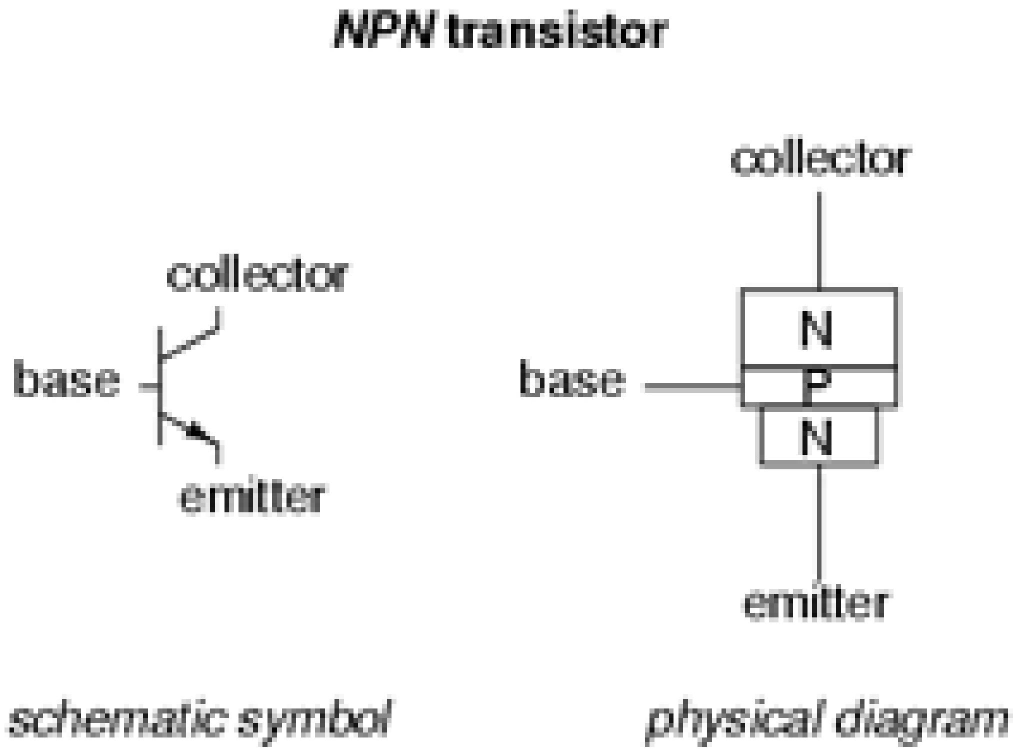




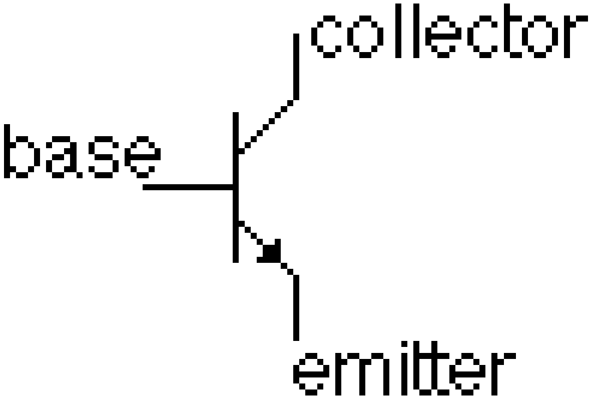
Two of them are doped to give one type of semiconductor and the there is the opposite type, i.e. two may be n-type and one p-type, or two may be p-type and one may be n-type.



They are designated either P-N-P (PNP) types of N-P-N (NPN).

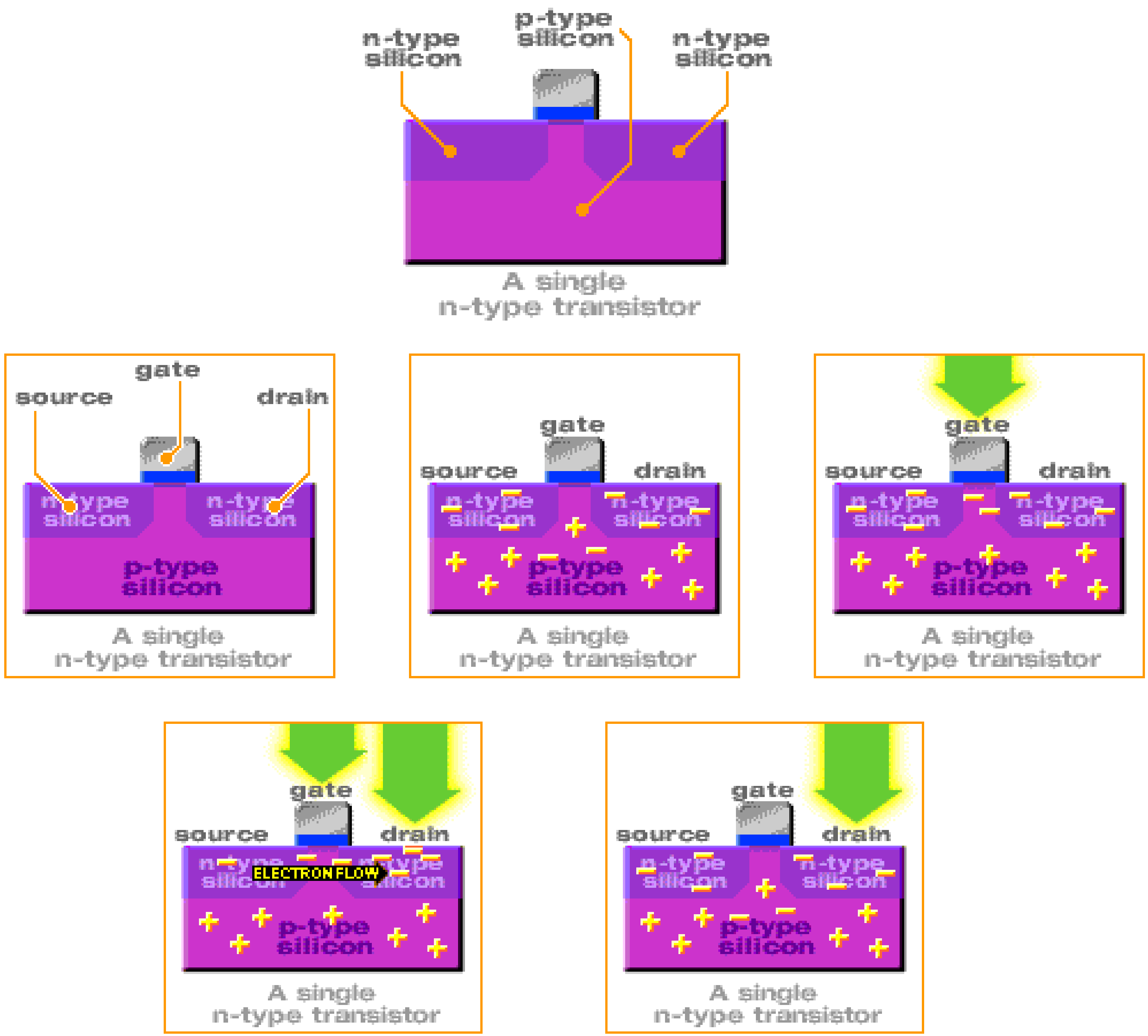


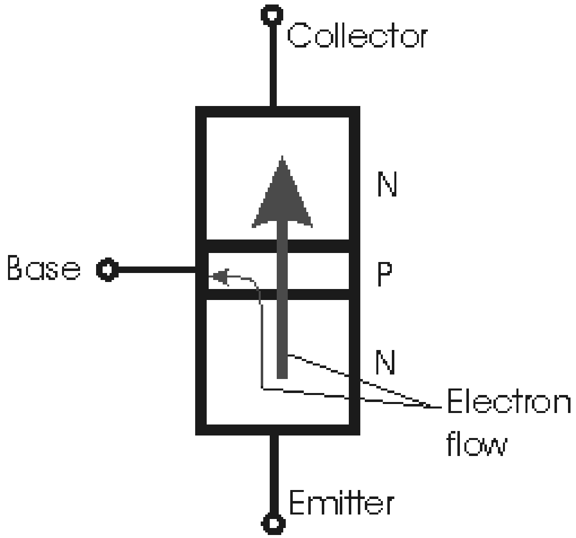
When discussing NPN transistors the N-Type semiconductor material on one side of the wafer is designated an emitter and it is most often connected to a negative electrical current.



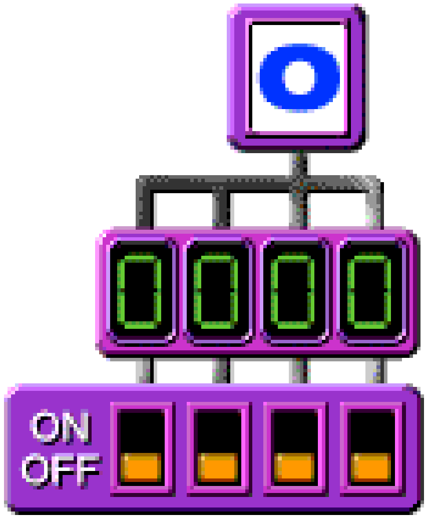
The P-Type material in the middle is the base.

The N-Type material on the other side of the base is called the collector.


n-type silicon
p-type silicon
n-type silicon
A single n-type transistor
gate
source
drain
n-type silicon
n-type silicon
p-type silicon
A single n-type transistor
gate
source
drain
n-type silicon
n-type silicon
p-type silicon
A single n-type transistor
gate
source
drain
n-type silicon
n-type silicon
p-type silicon
A single n-type transistor
gate
source
drain
ELECTRON FLOW
p-type silicon
A single n-type transistor
gate
source
drain
n-type silicon
n-type silicon
p-type silicon
A single n-type transistor



Collector
N
Base
P
N
Electron
flow
Emitter



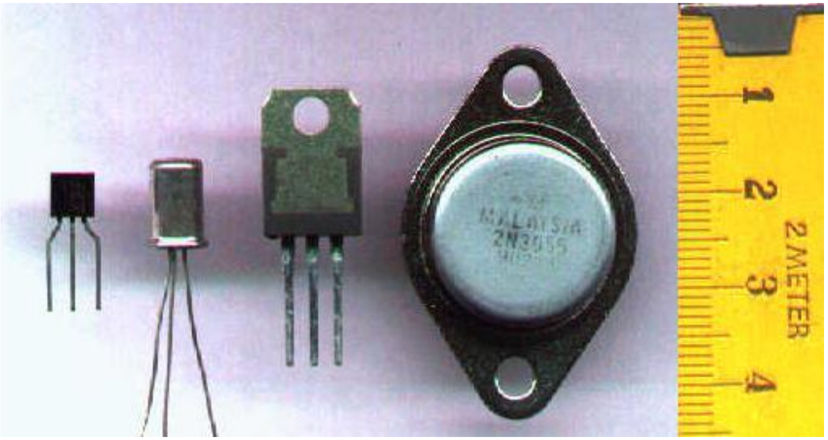
ON
OFF

Transistor Advantages

Highly automated manufacturing processes, resulting in low per-unit cost.

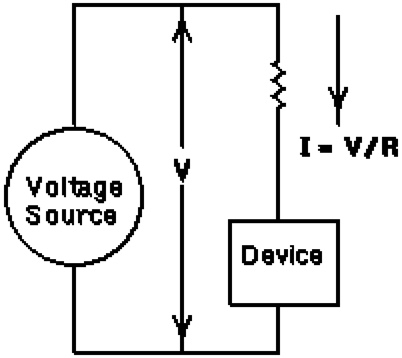
Extremely long life.

Higher reliability and greater physical ruggedness.

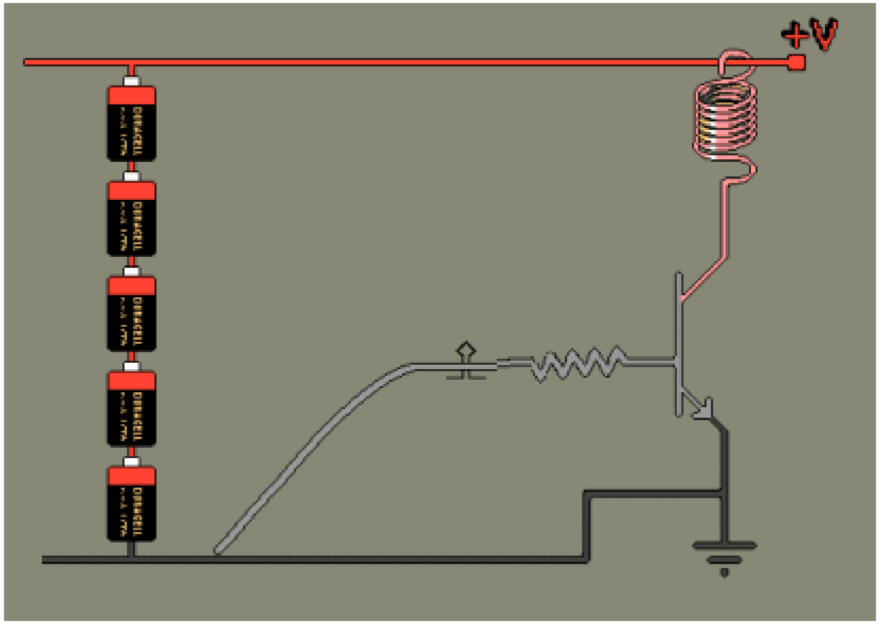


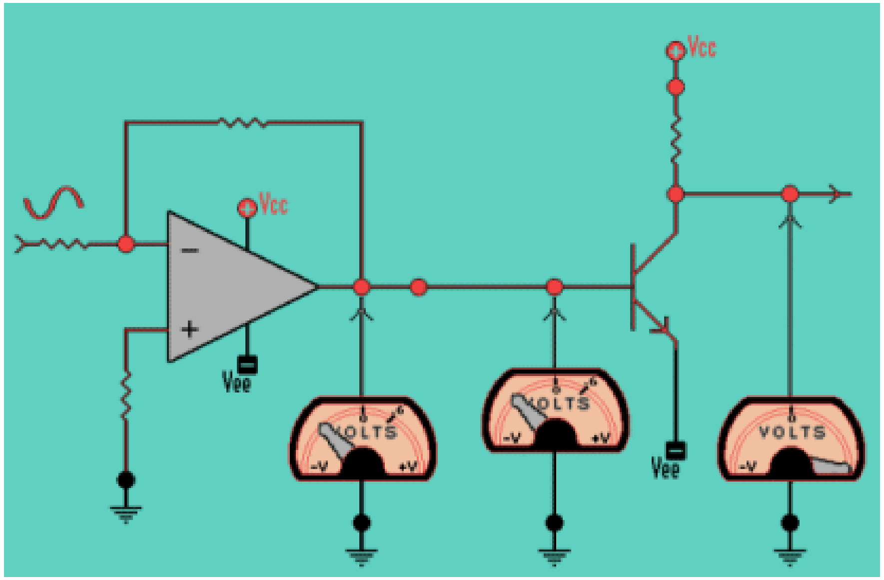
Small size and minimal weight, allowing the development of miniaturized electronic devices.

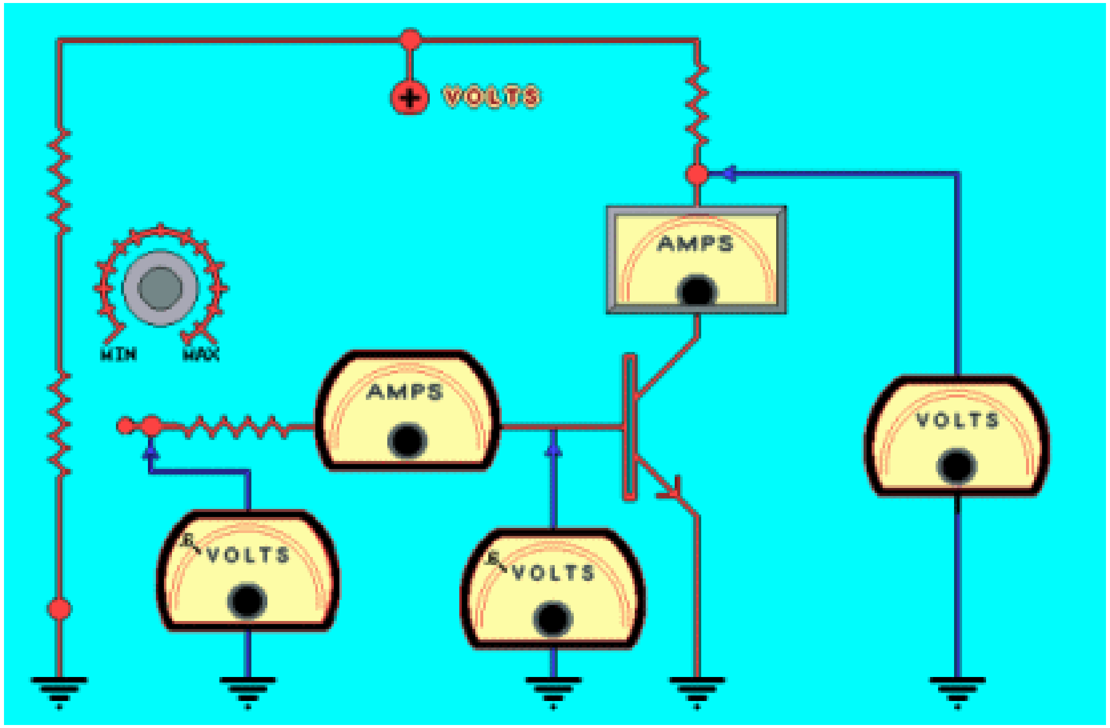
Lower possible operating voltages, making transistors suitable for small, battery-powered applications.



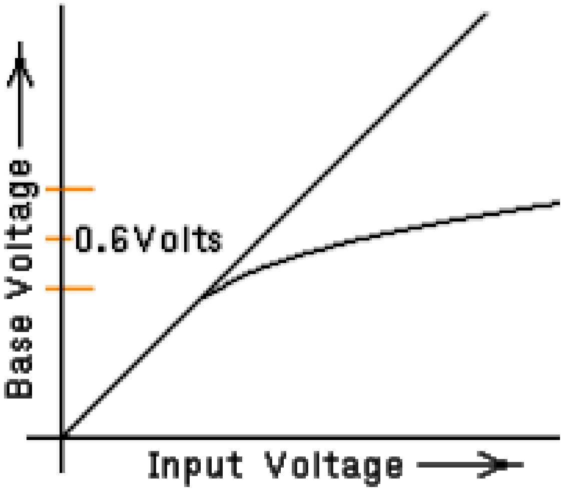
Voltage to Current Convertor





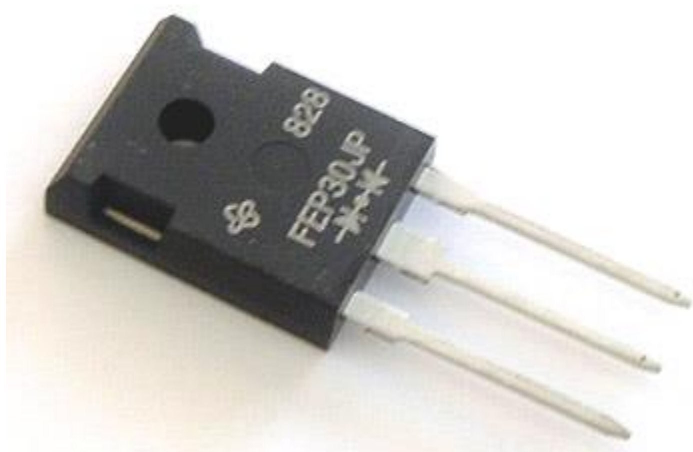


VOLTS
AMPS
MIN
MAX
AMPS
VOLTS
VOLTS
VOLTS



Base Voltage
0.6Volts
Input Voltage

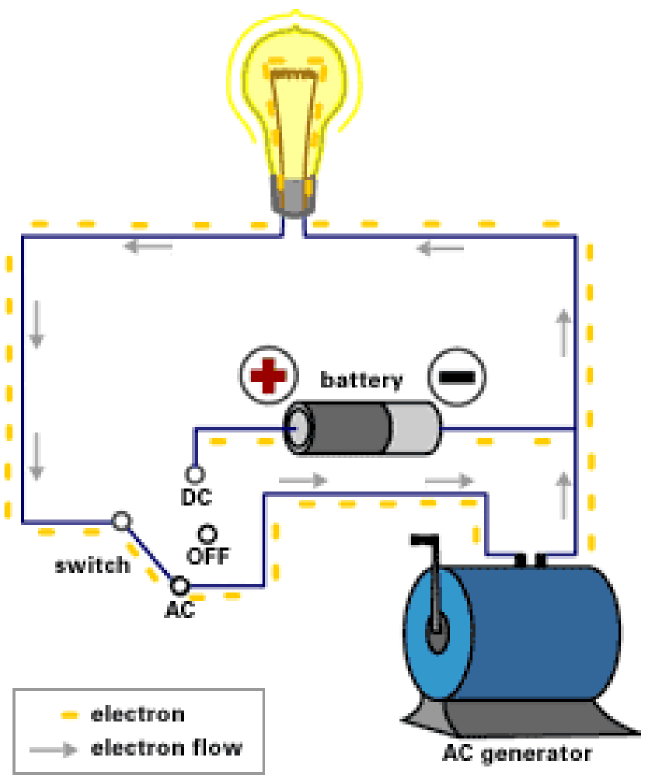
Rectifiers

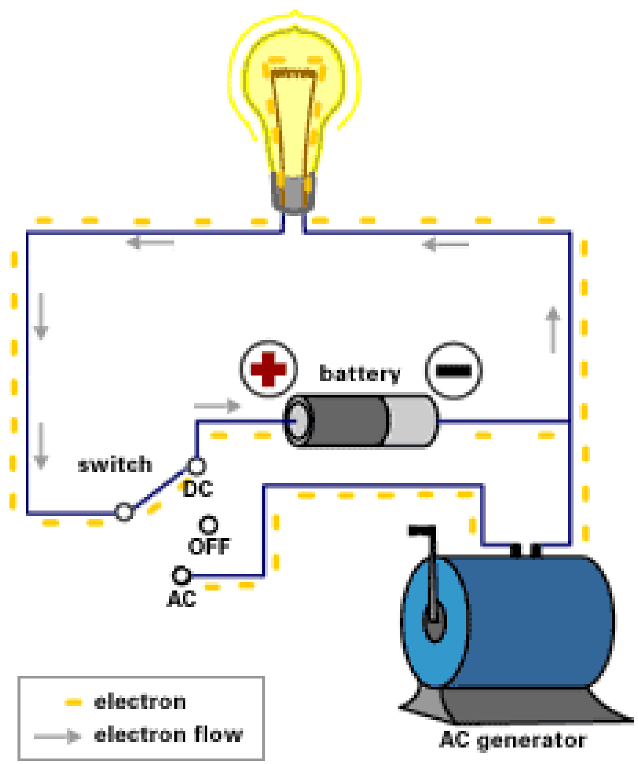


The most popular application of the diode.

Most electronics need a direct current to function, but the standard form of electricity that is transmitted to homes is alternating current.

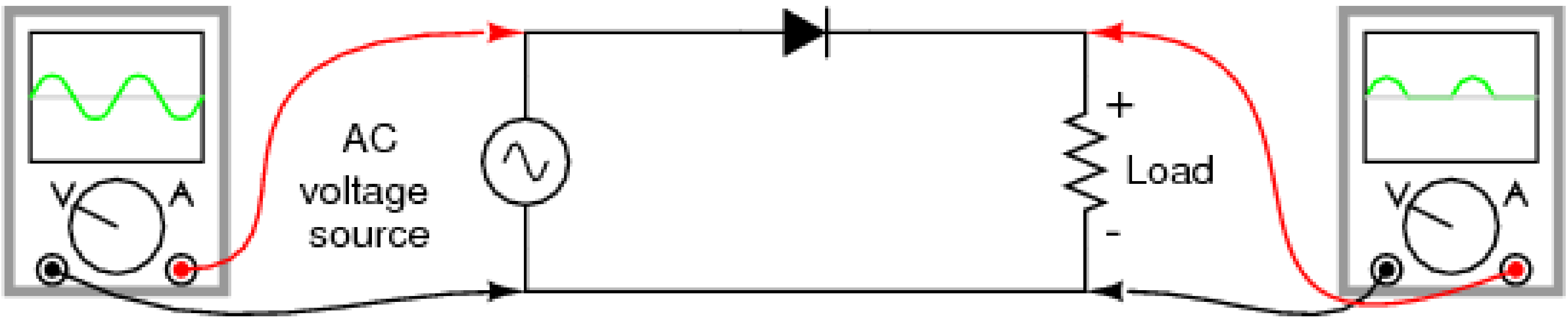
Rectifiers are needed to change the alternating current





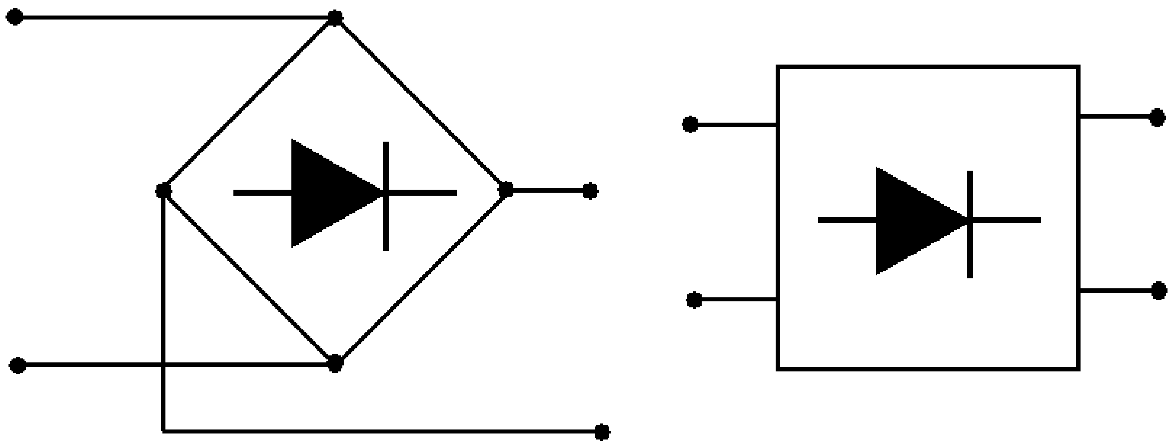
into direct current inside the electronics so that they can function correctly.

Rectification



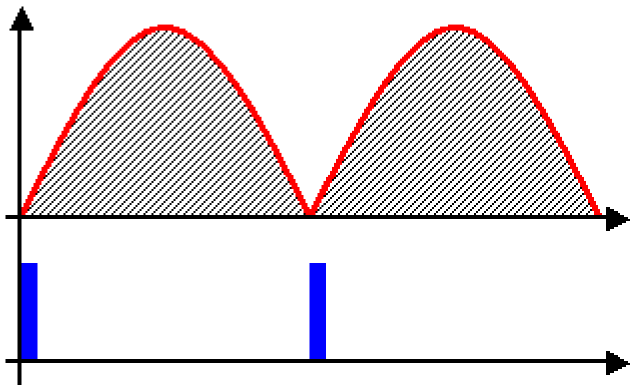
is the conversion of alternating current (AC) to direct current (DC).

Rectifiers



This involves a device that only allows one-way flow of electrons, which is exactly what a semiconductor diode does.

Half-Wave Rectifiers



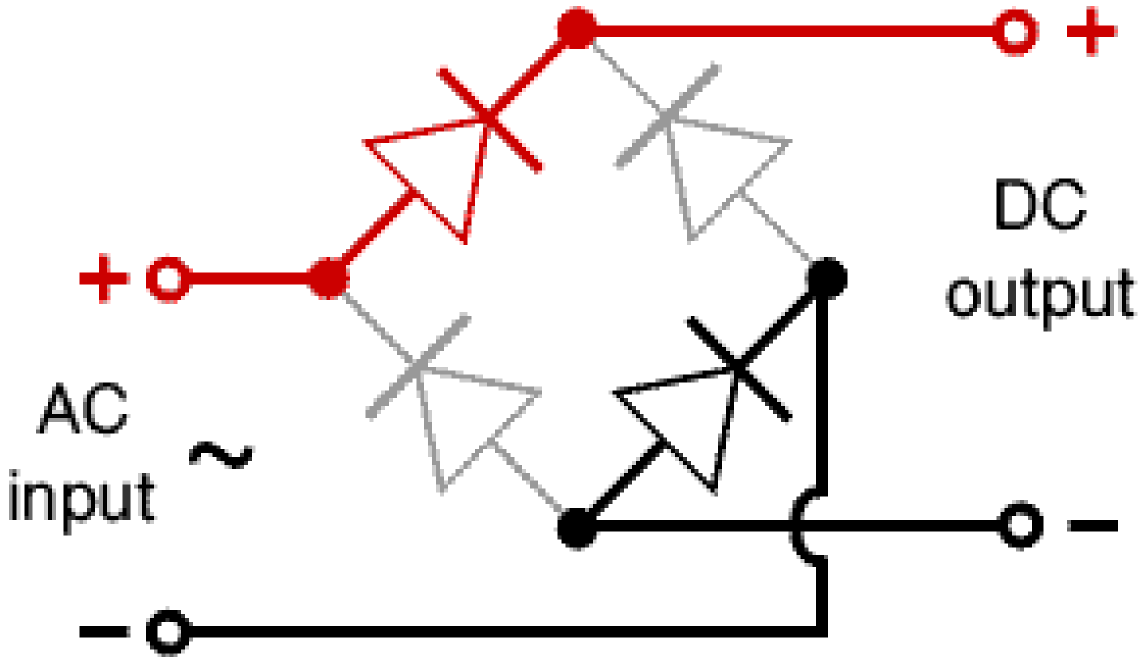
The simplest kind of rectifier circuit is the half-wave rectifier.

It only allows one half of an AC waveform to pass through to the load.

Half-wave rectification is a very simple way to reduce power to a resistive load.

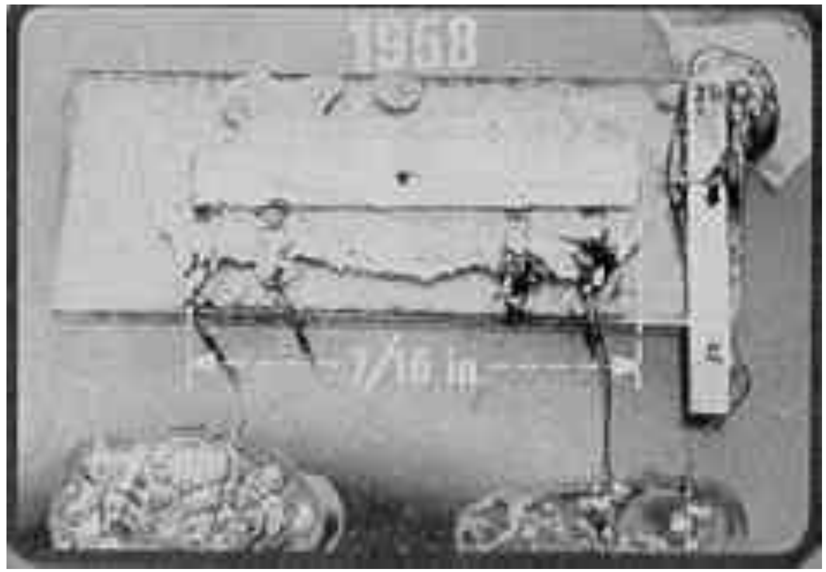
Some two-position lamp dimmer switches apply full AC power to the lamp filament for "full" brightness and then half-wave rectify it for a lesser light output.

Bridge Rectifiers



The invention of the transistor or semiconductor was probably the most important development that lead to the personal computers amazing growth and what we know of as modern day computers.

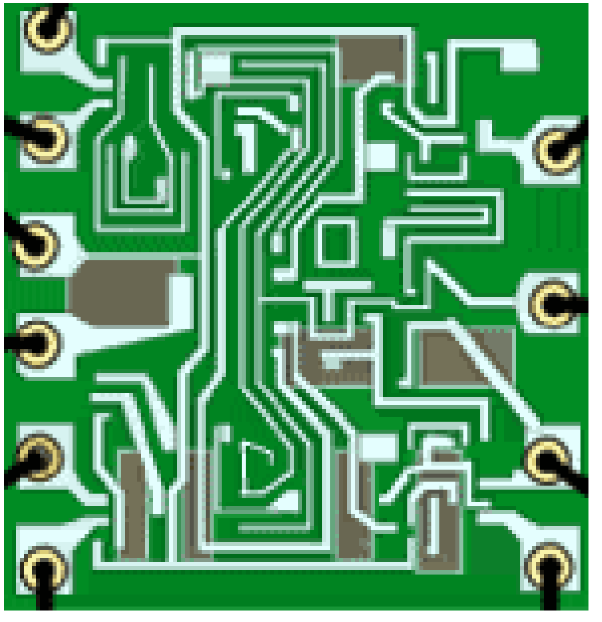
1959



The First I.C.

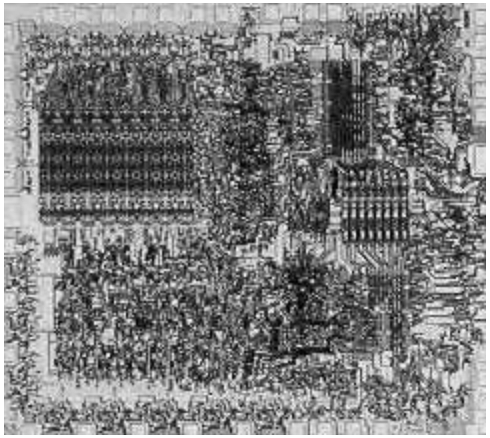
Jack Kilby at Texas Instruments and Robert Noyce at Fairchild Camera, came up with a solution to the problem of large numbers of components, and the integrated circuit was developed.

Instead of making transistors one-by-one, several transistors could be made at the same time, on the same piece of semiconductor(a silicon wafer).



Not only transistors, but other electric components such as resistors, capacitors and diodes could be made by the same process with the same materials.

1970

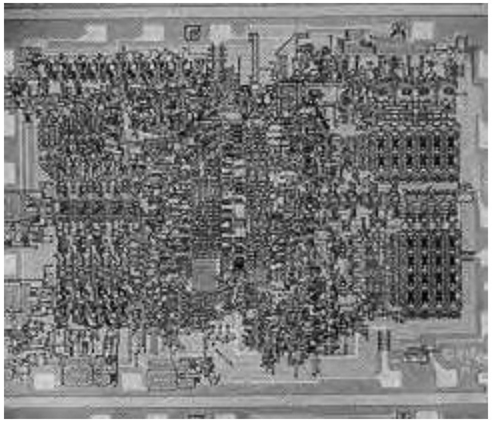


4004

4–bit unit

8080

8–bit processor



First microprocessor invented at Intel.

First commercial MPU in 1975.

1981

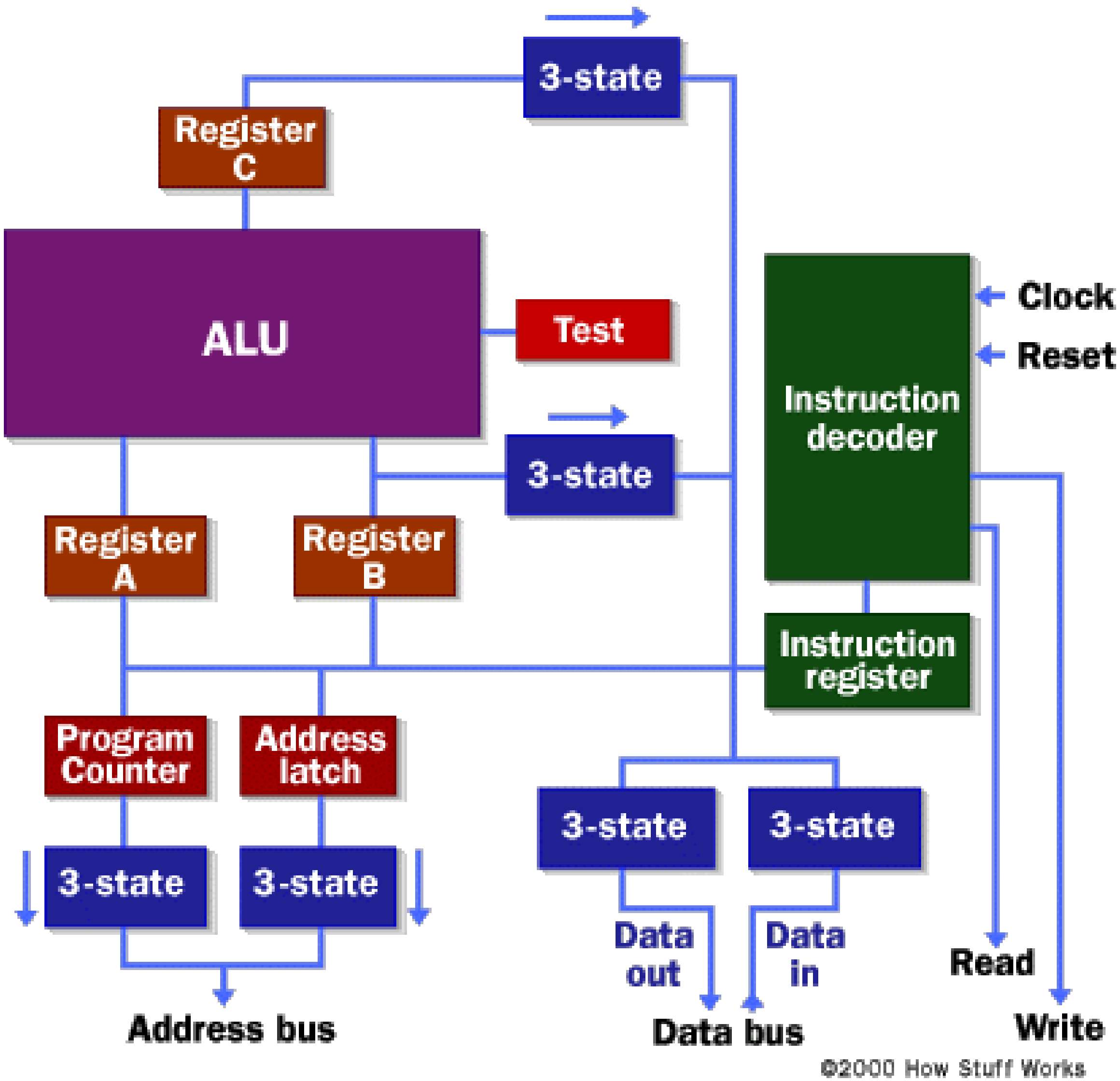
The IBM PC model 5150 was announced at a press conference in New York on August 12, 1981 and became available for purchase in early Fall 1981.

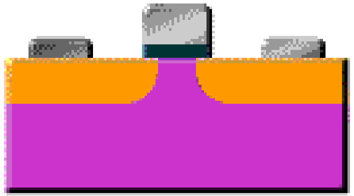
The base model retailed for $2880!

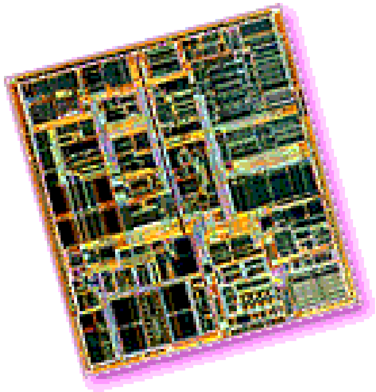
This included 64 kilobytes of RAM and a single-sided 160K 5.25" floppy drive.

The IBM PC was powered by a 4.77 MHz Intel 8088 processor.

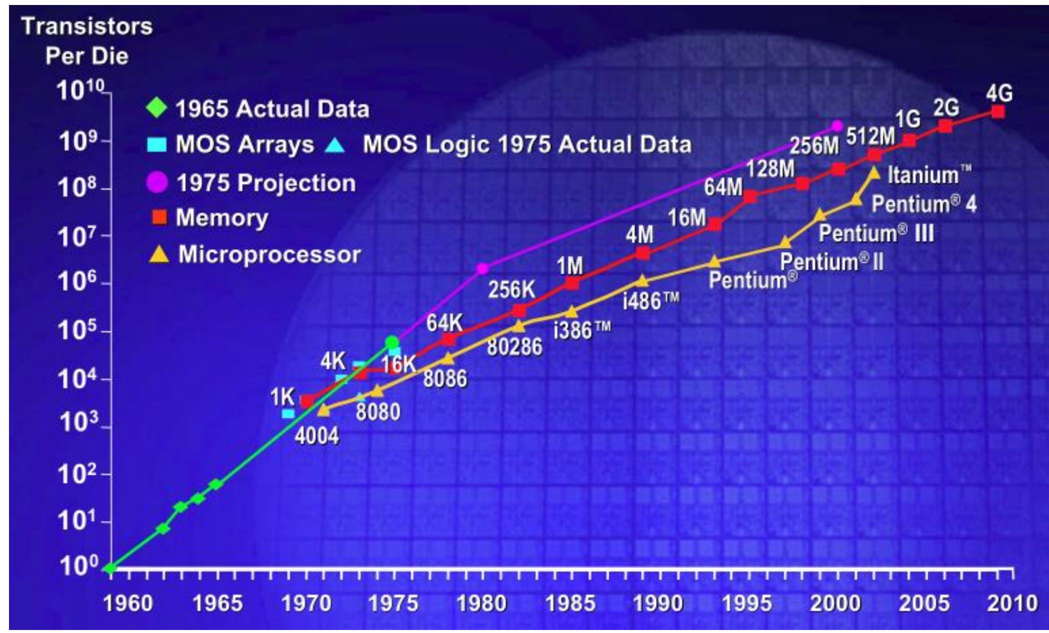

835
1NS4004D


3-state
Register C
ALU
Test
3-state
Register A
Register B
Instruction decoder
Clock
Reset
Instruction register
Program Counter
Address latch
3-state
3-state
3-state
3-state
Data out
Data in
Read
Write
Address bus
Data bus
©2000 How Stuff Works

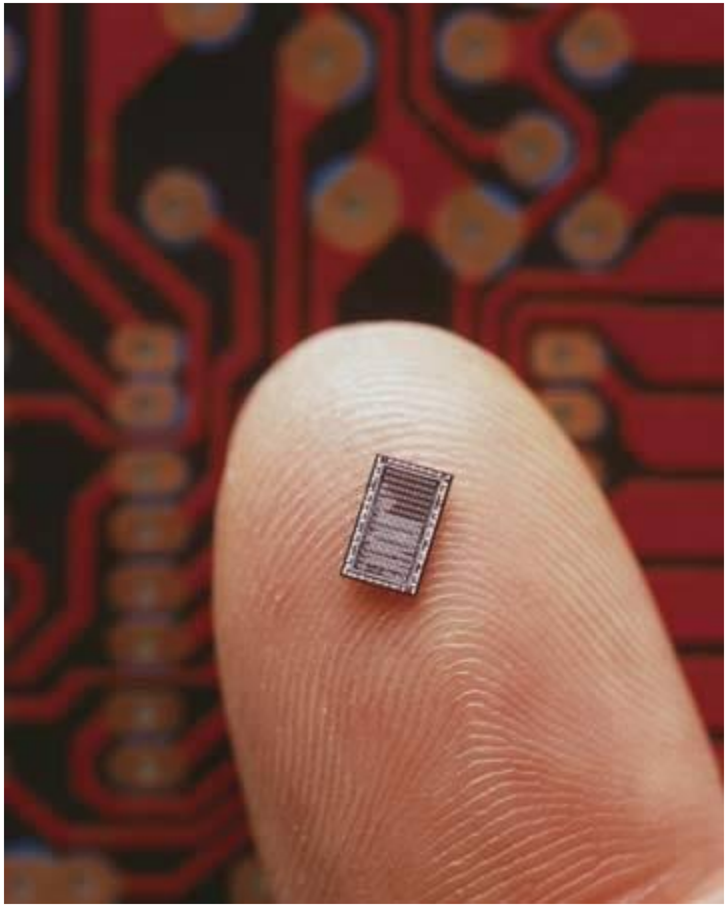




Trends in Semiconductors



Smaller Transistors **Higher Switching Speeds** **Declining Costs**



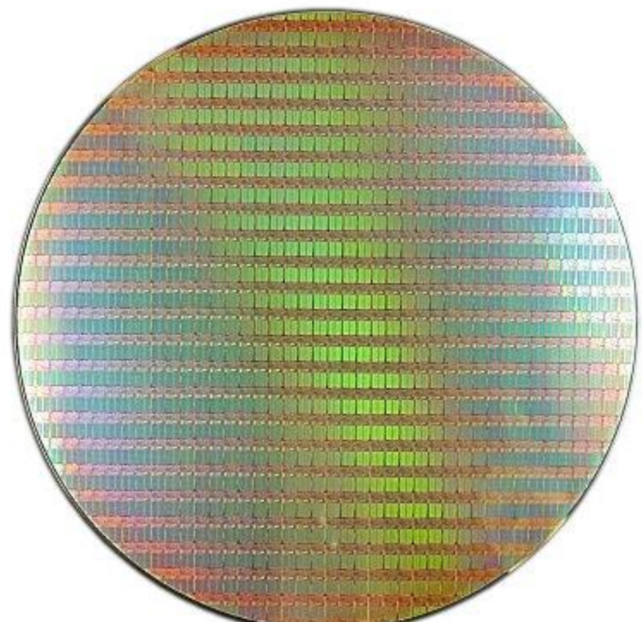
The semiconductor industry has been successful in its consistent efforts to reduce feature size on a chip.

55,000,000 transistors

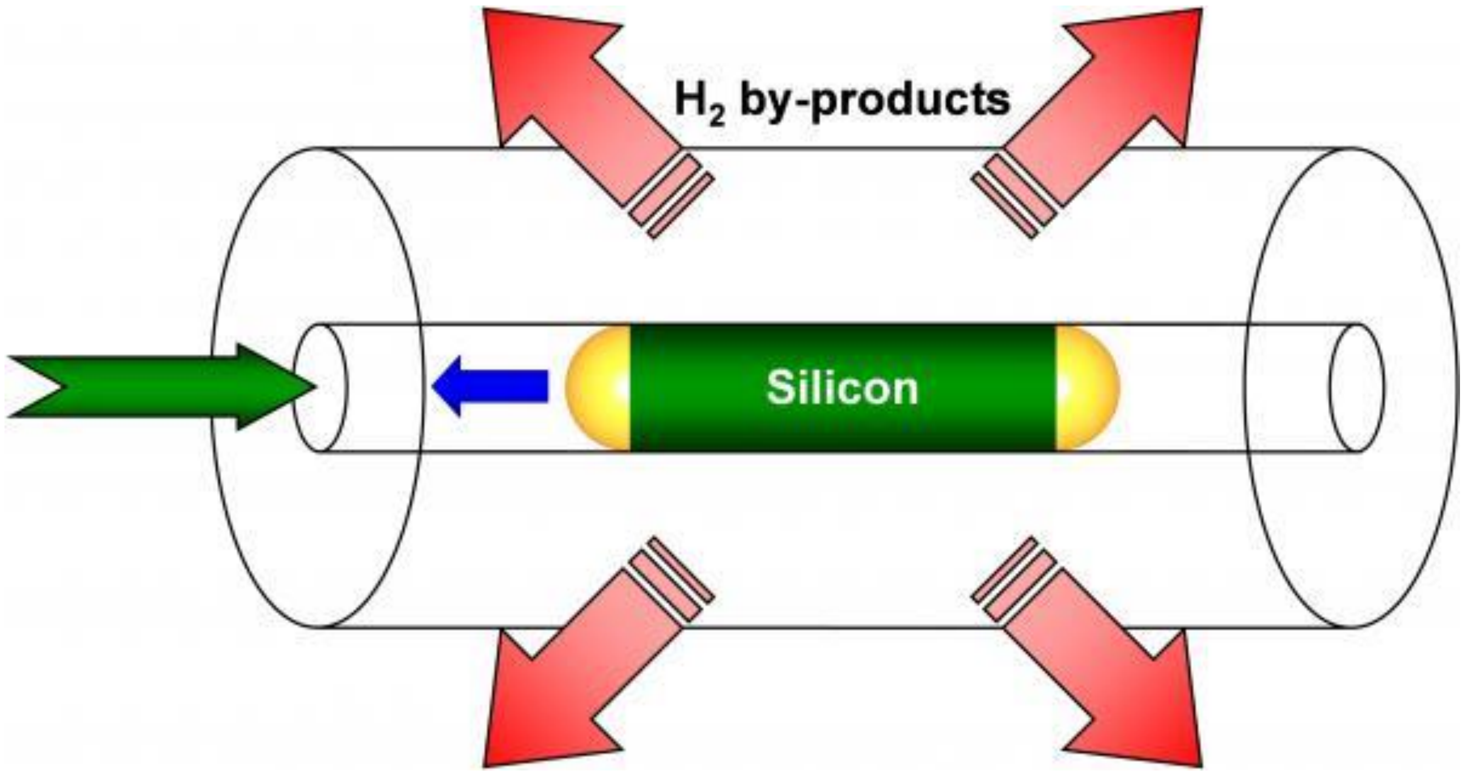
105,900,000 transistors

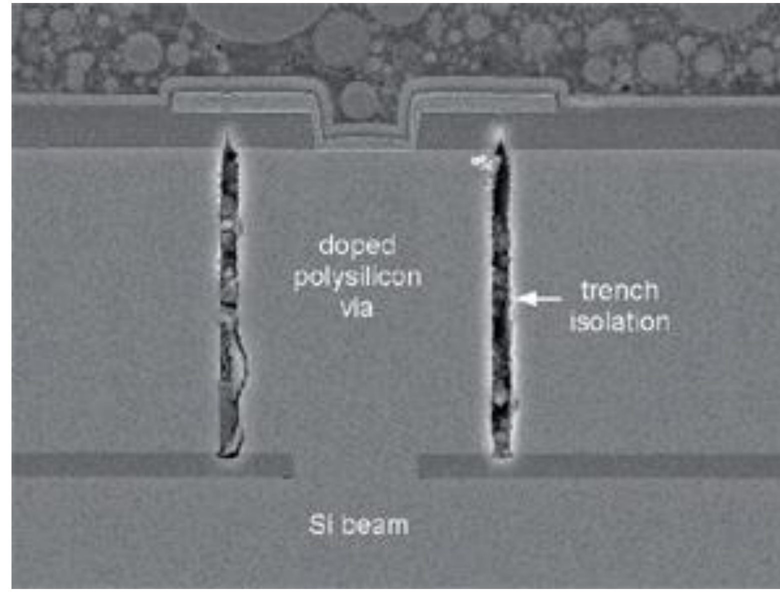
Smaller features mean denser packing of transistors, which leads to more powerful computers, more memory, and hopefully lower costs.

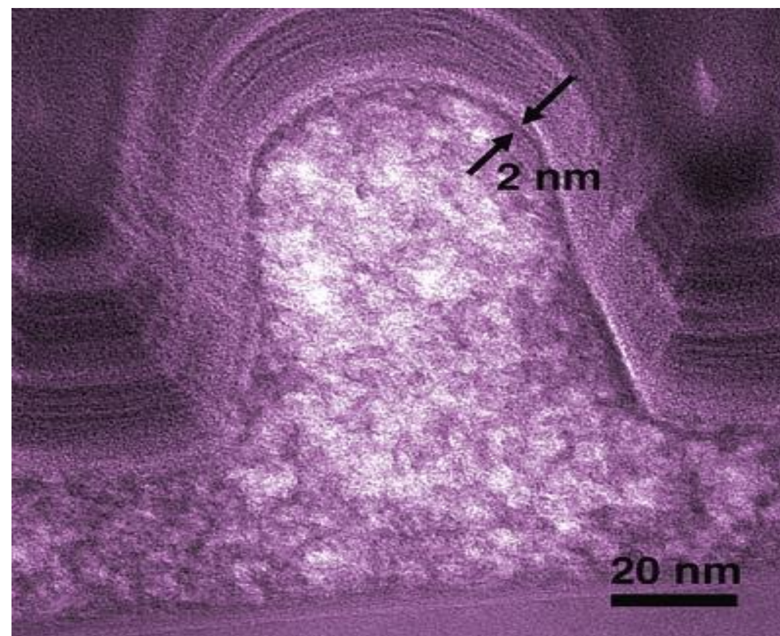


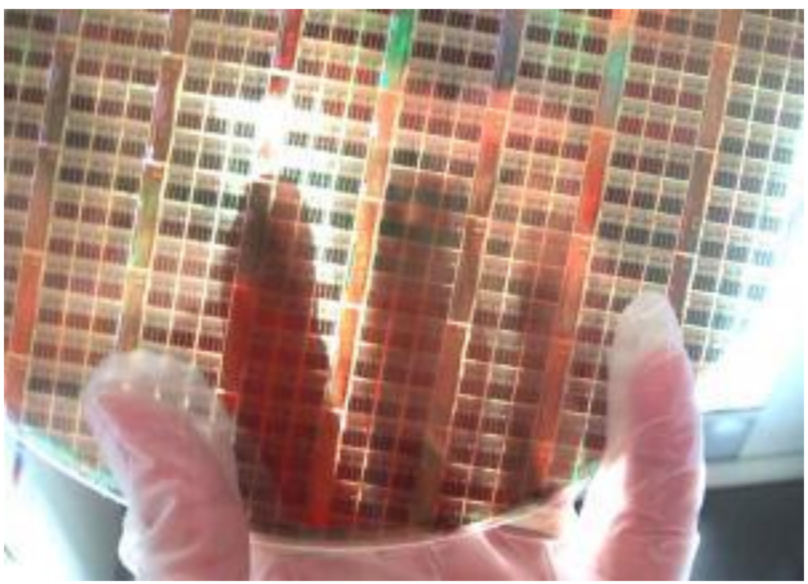


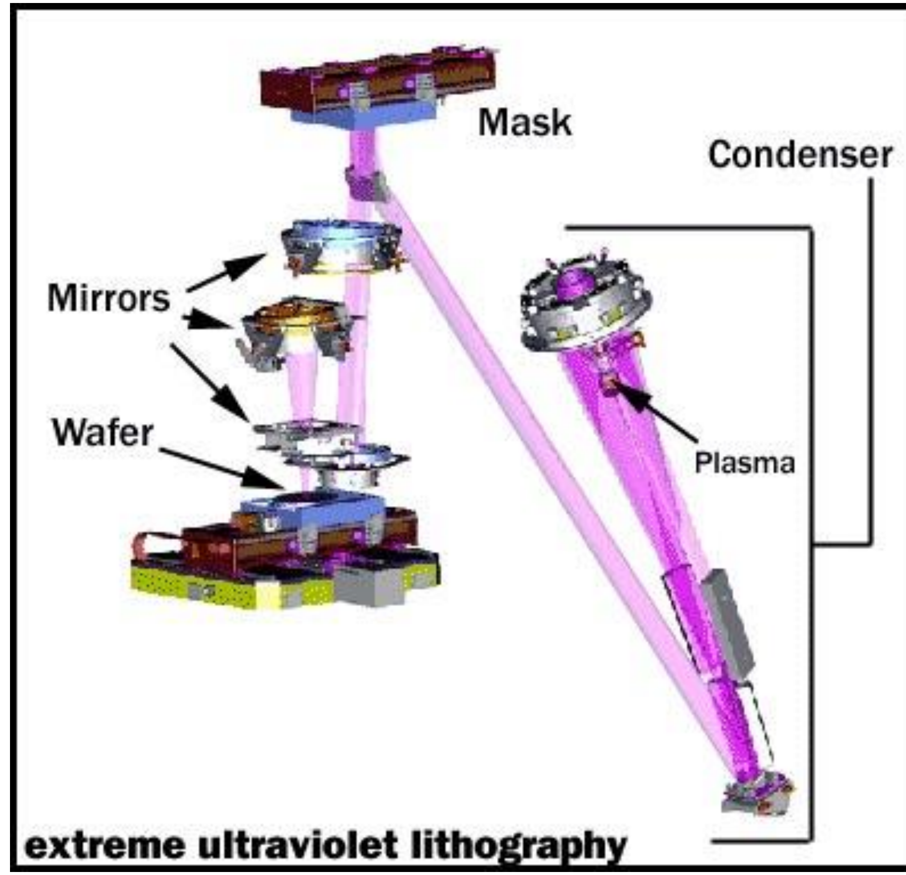
Single Crystal Semiconductor



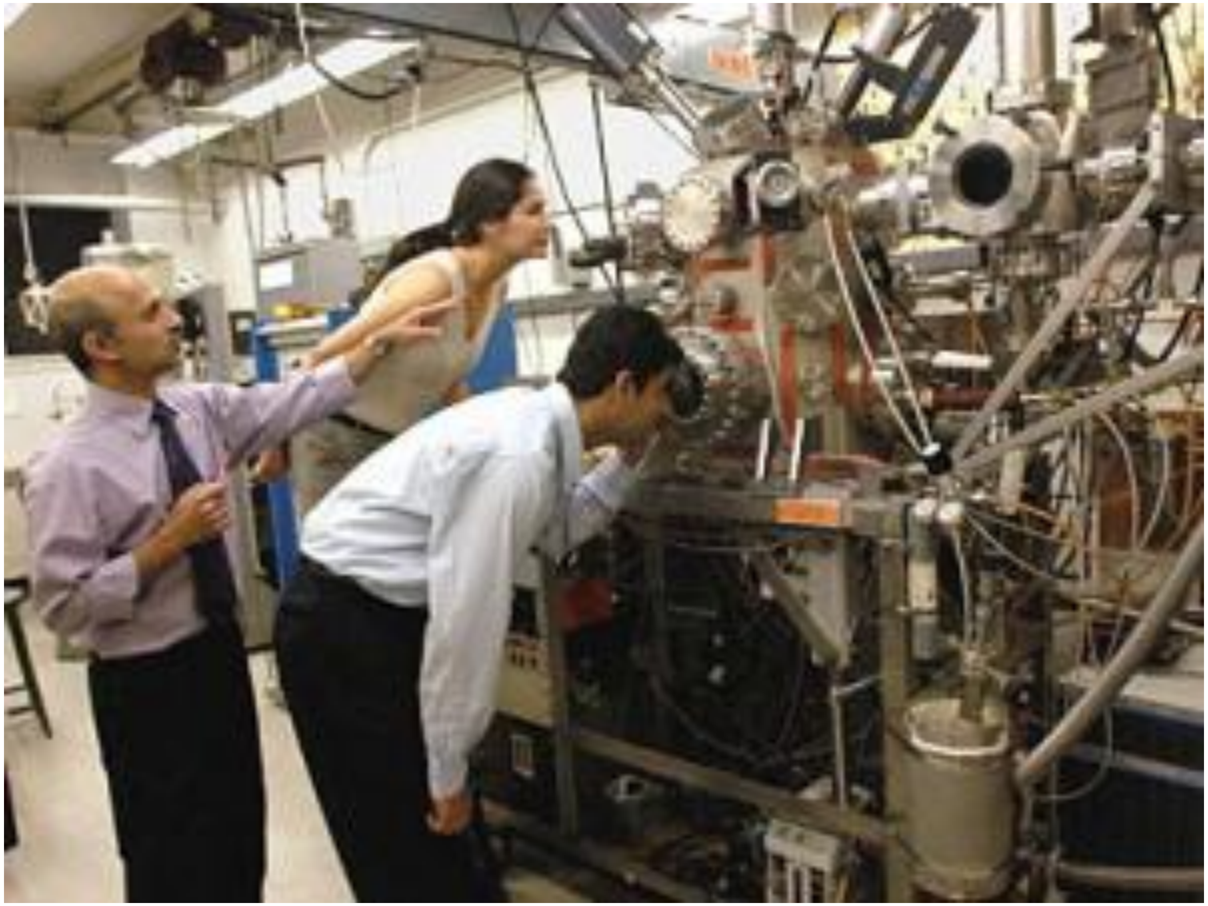

doped
polysilicon
via
trench
isolation
Si beam

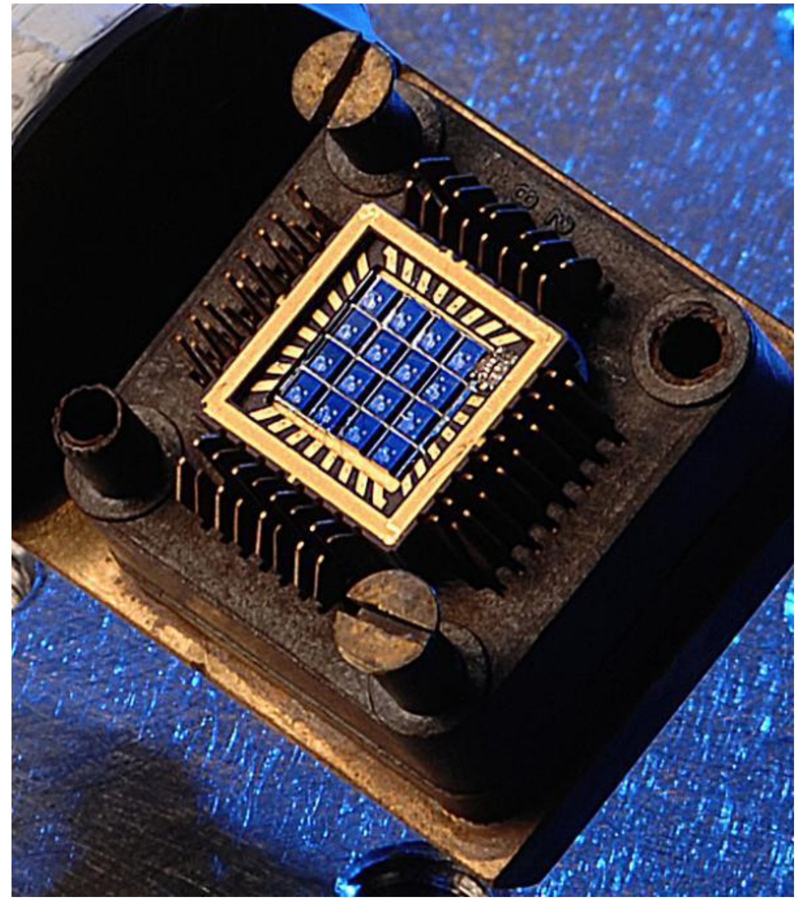

2 nm
20 nm

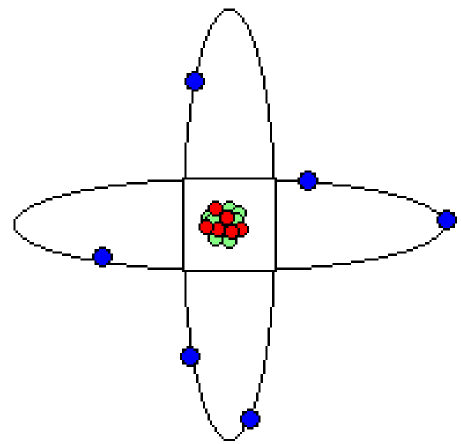


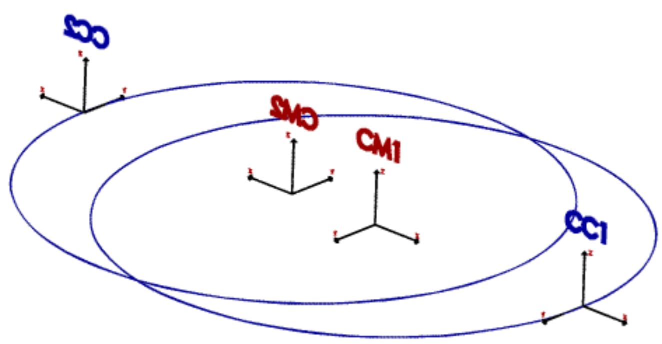

Mask
Condenser
Mirrors
Wafer
Plasma
extreme ultraviolet lithography

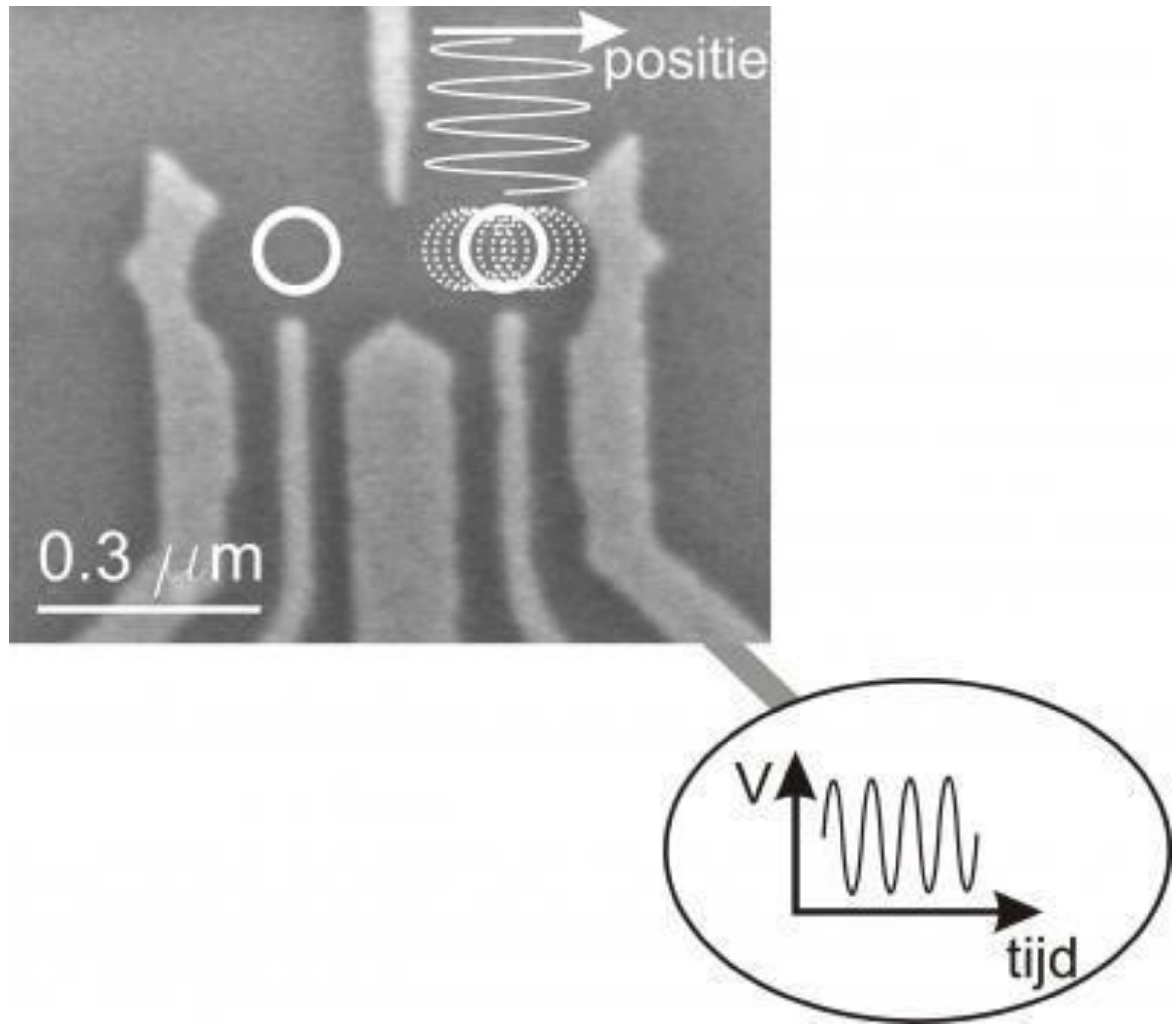
Semiconductor Spintronics



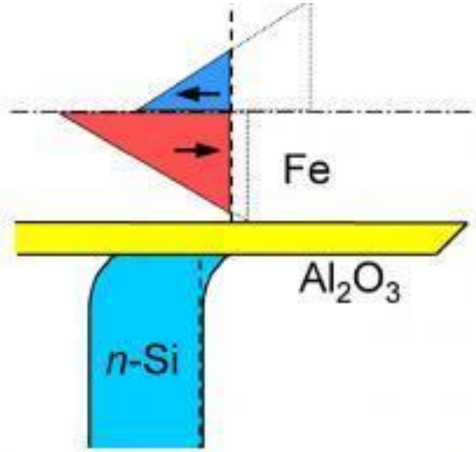


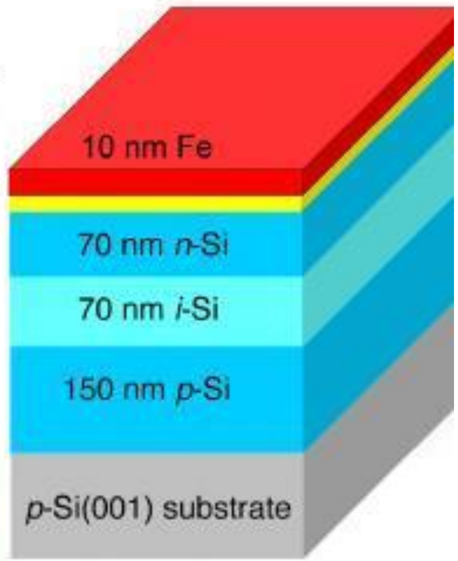


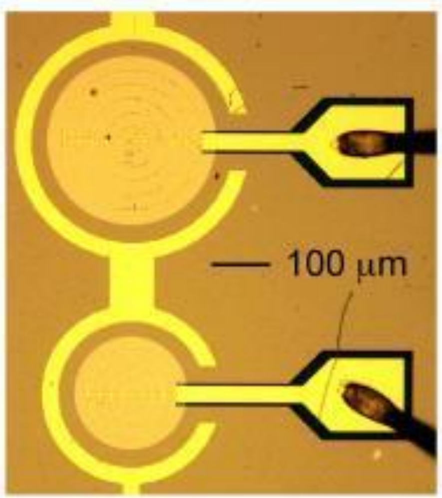

CC2
CM2
CM1
CC1

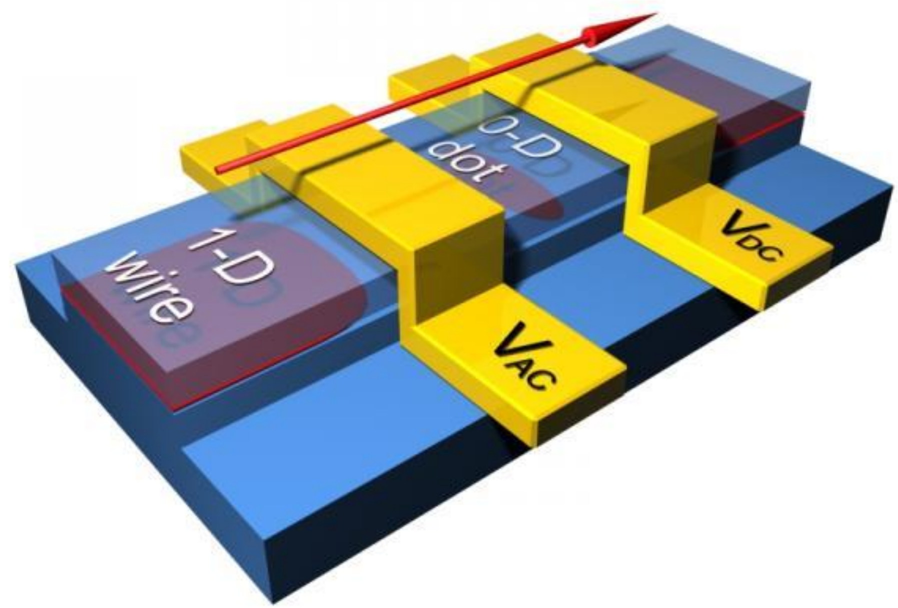


positie
0.3 μm
V
tijd

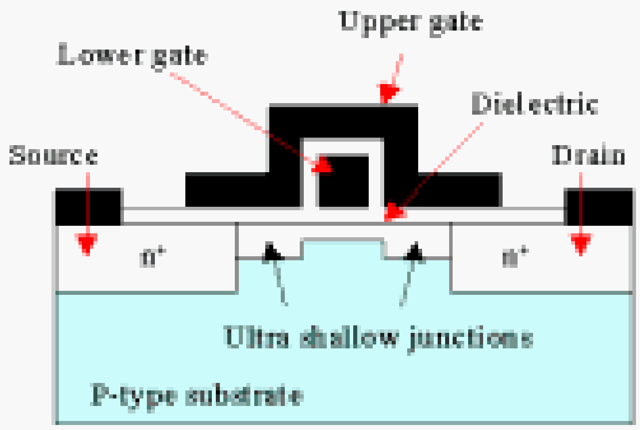

Fe
Al_2O_3
n-Si

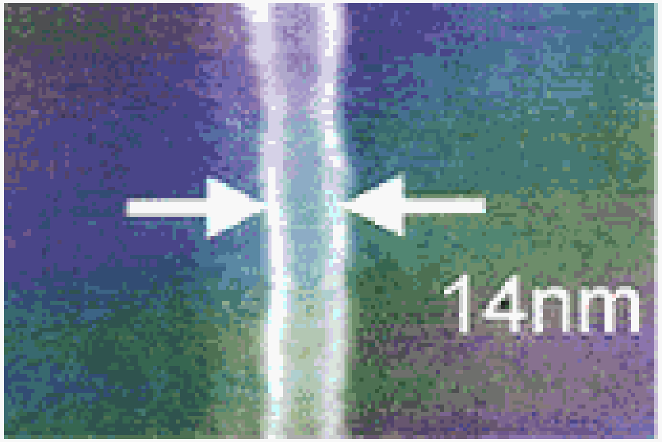

10 nm Fe
70 nm n-Si
70 nm i-Si
150 nm p-Si
p-Si(001) substrate

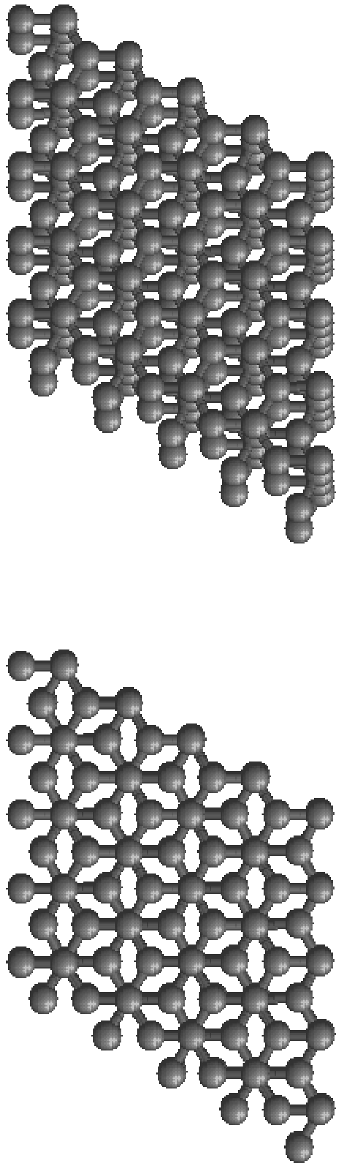

100 μm

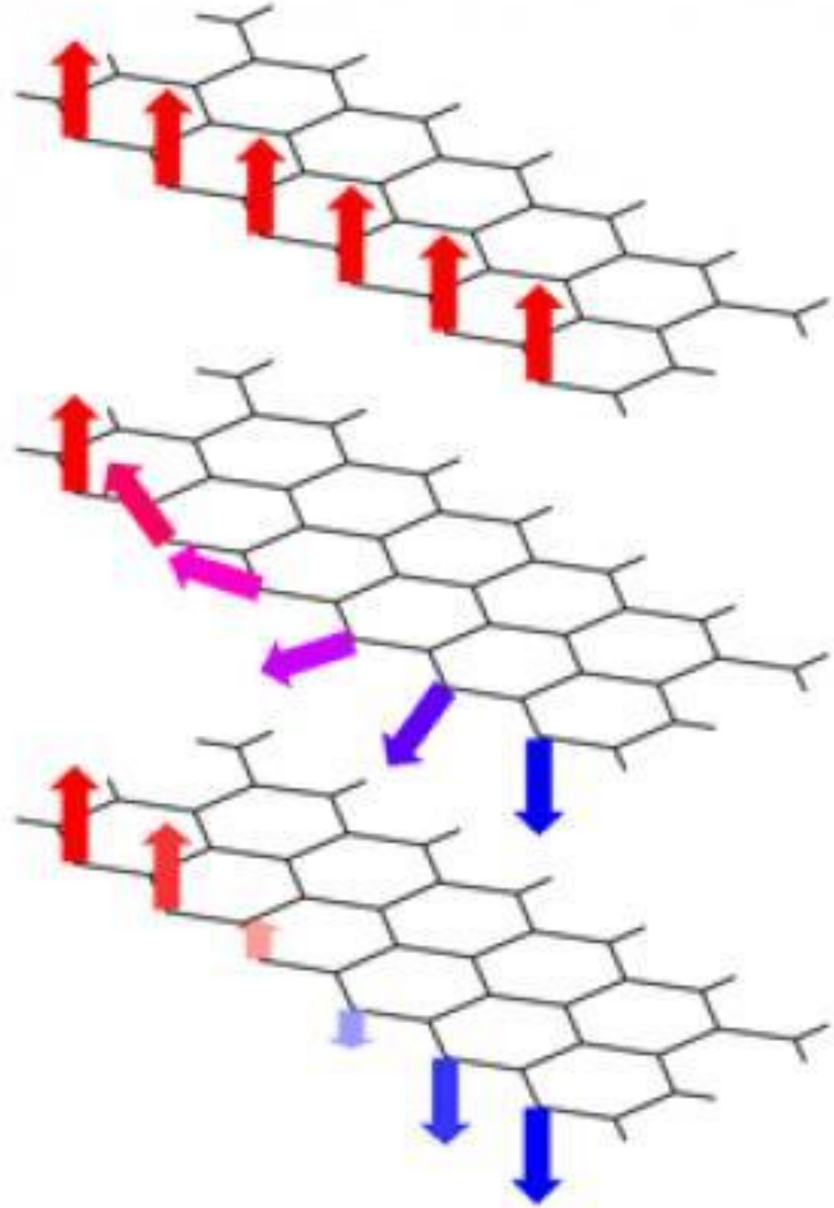

0-D dot
1-D wire
V_{DC}
V_{AC}

Smallest Transistor ?

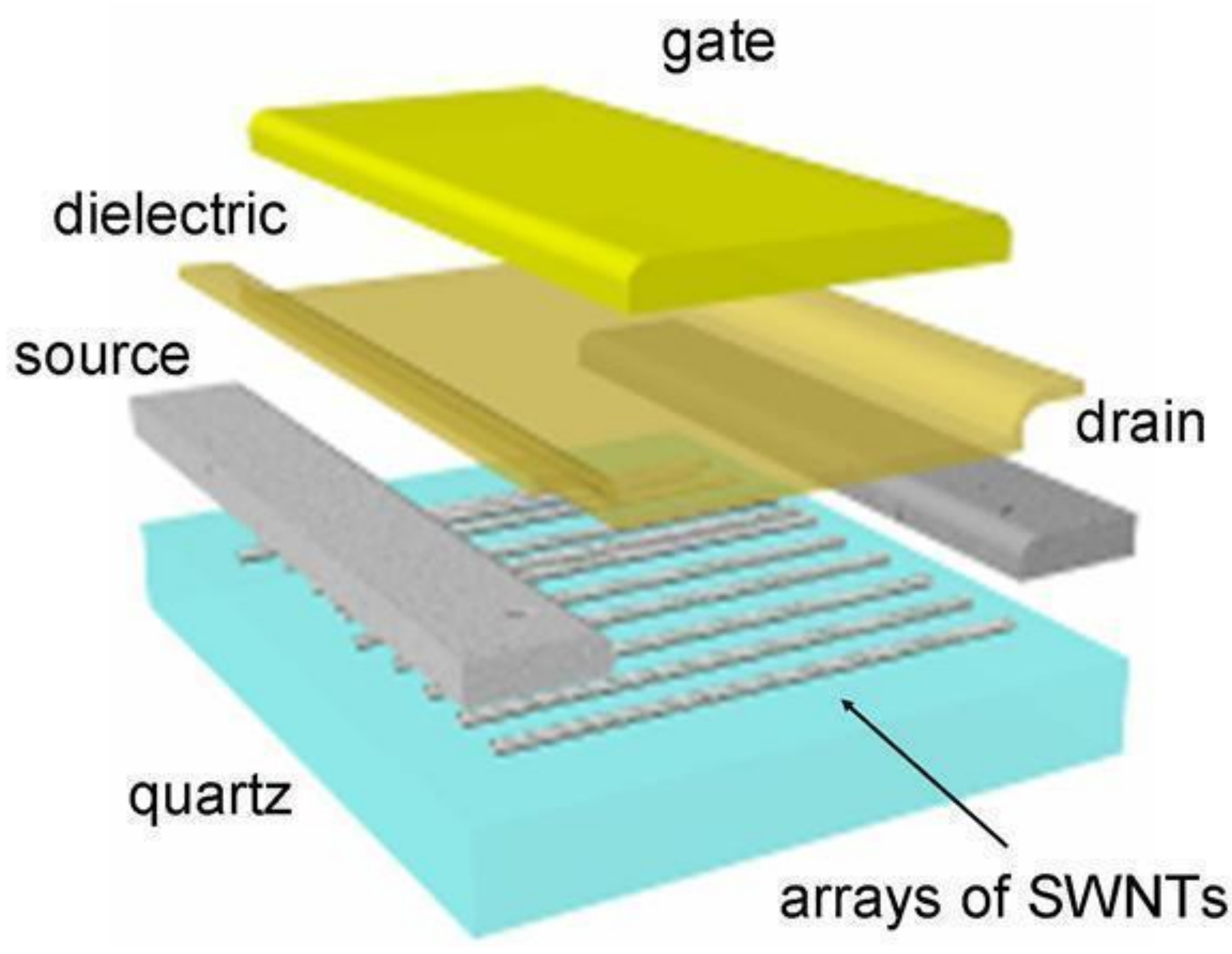




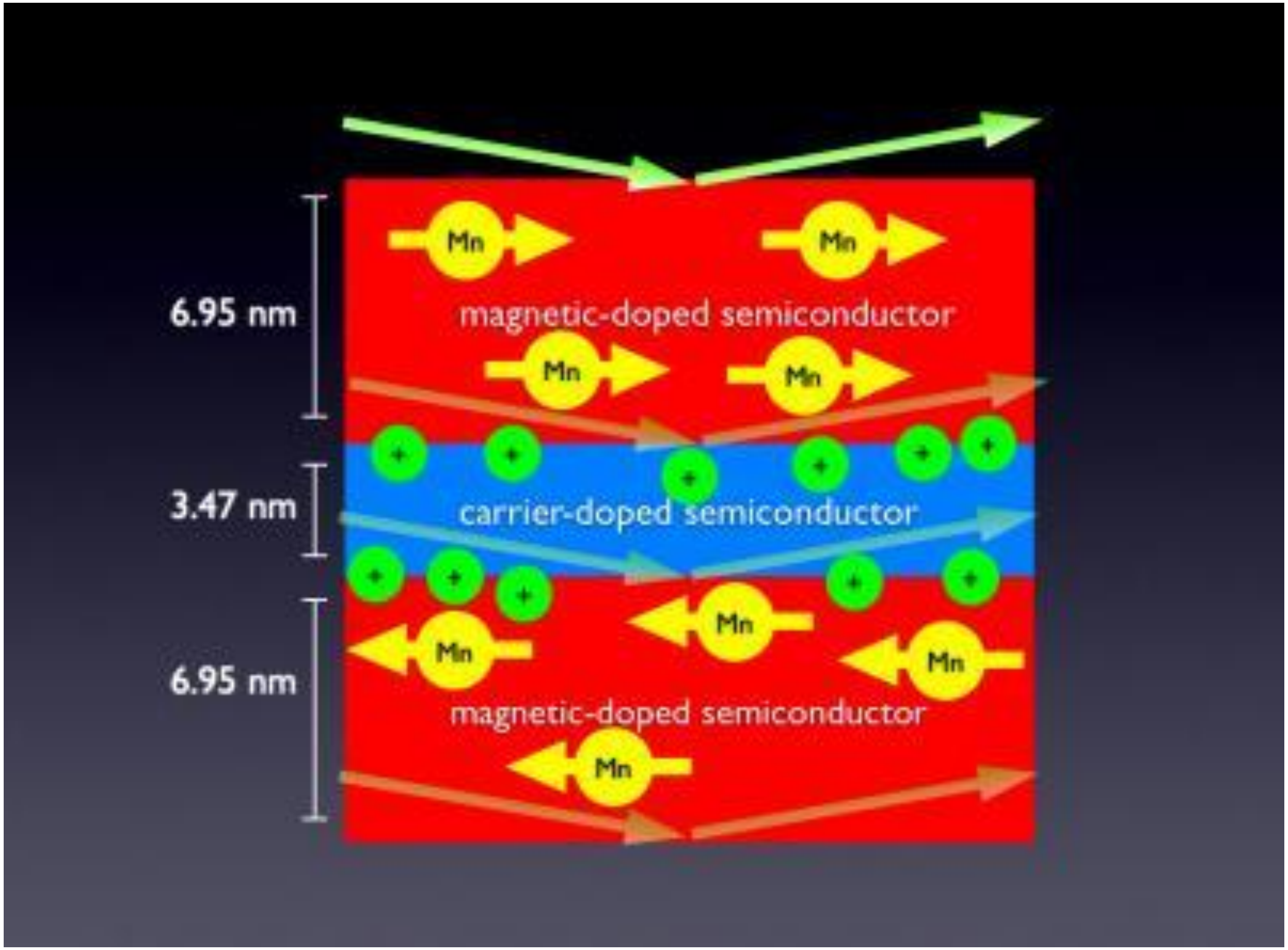




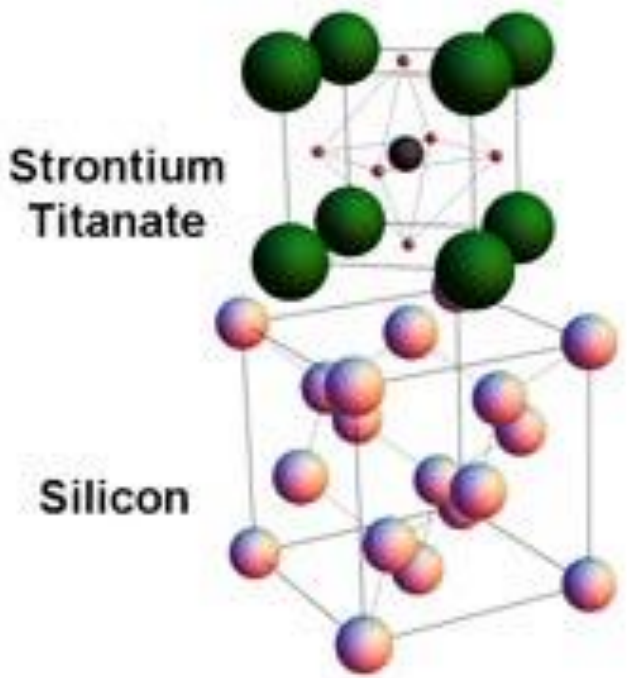
Smallest Radio?

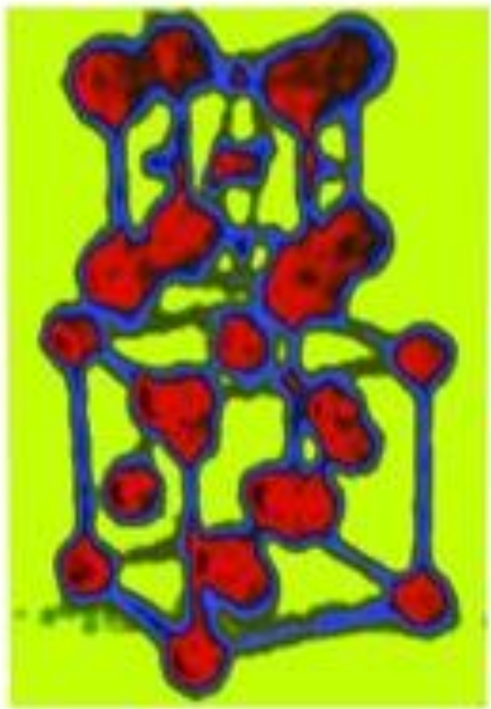


Antiferromagnetic Coupling

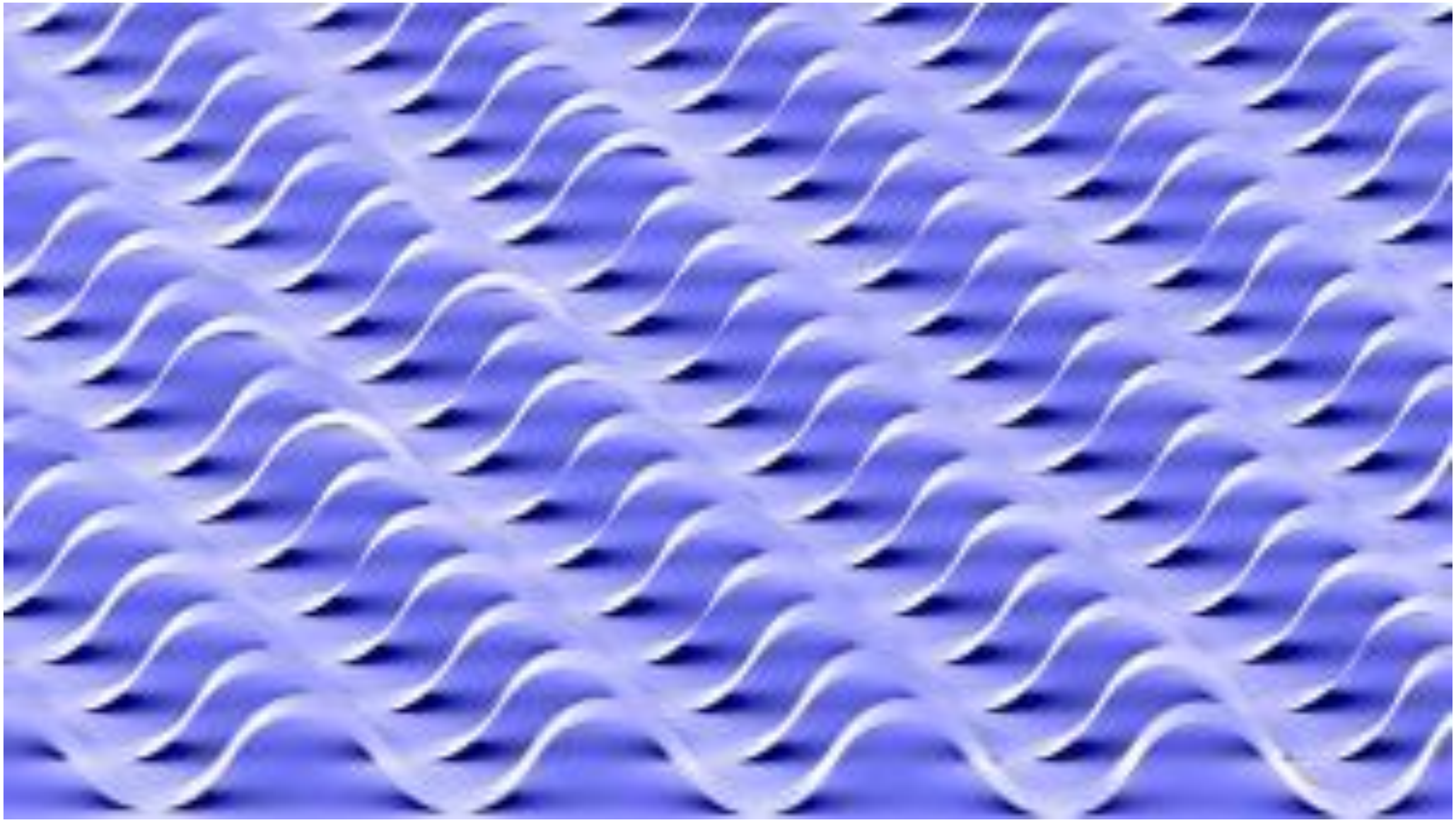


“Instant On” Computing!

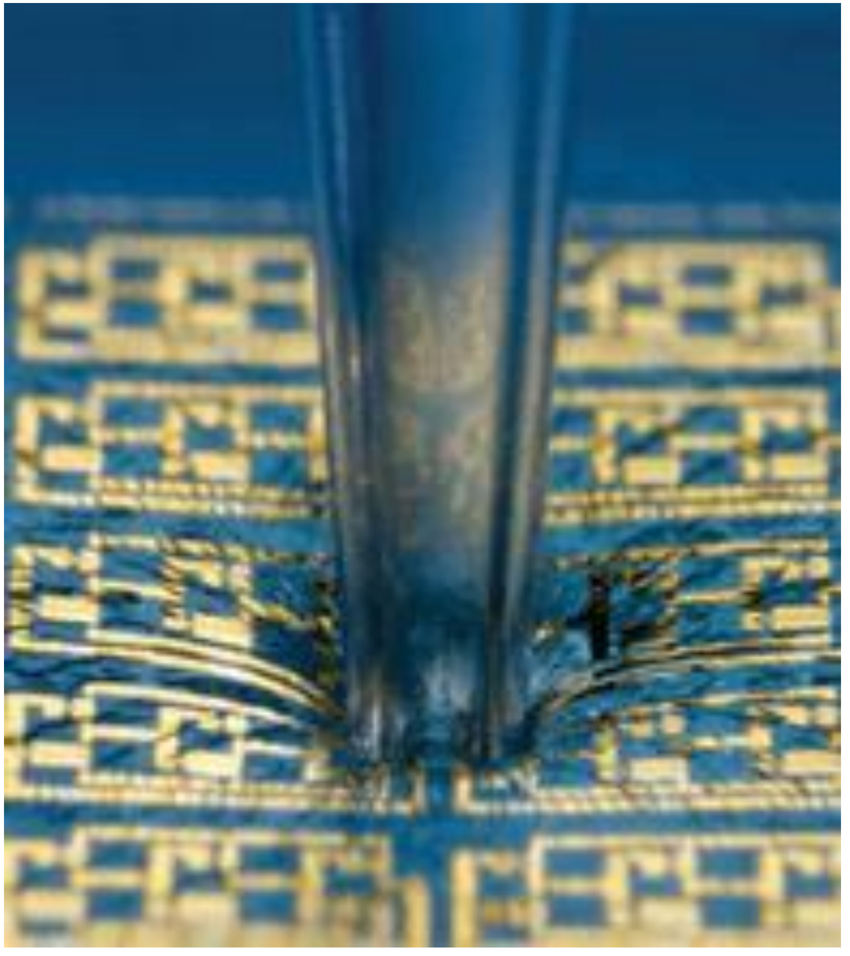




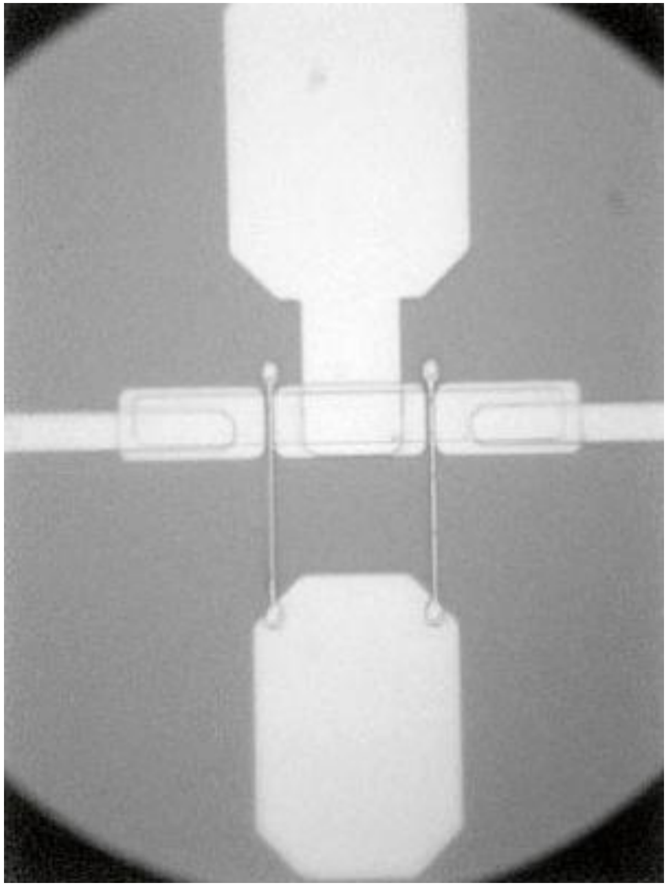
Stretchable and Foldable Silicon Integrated Circuits

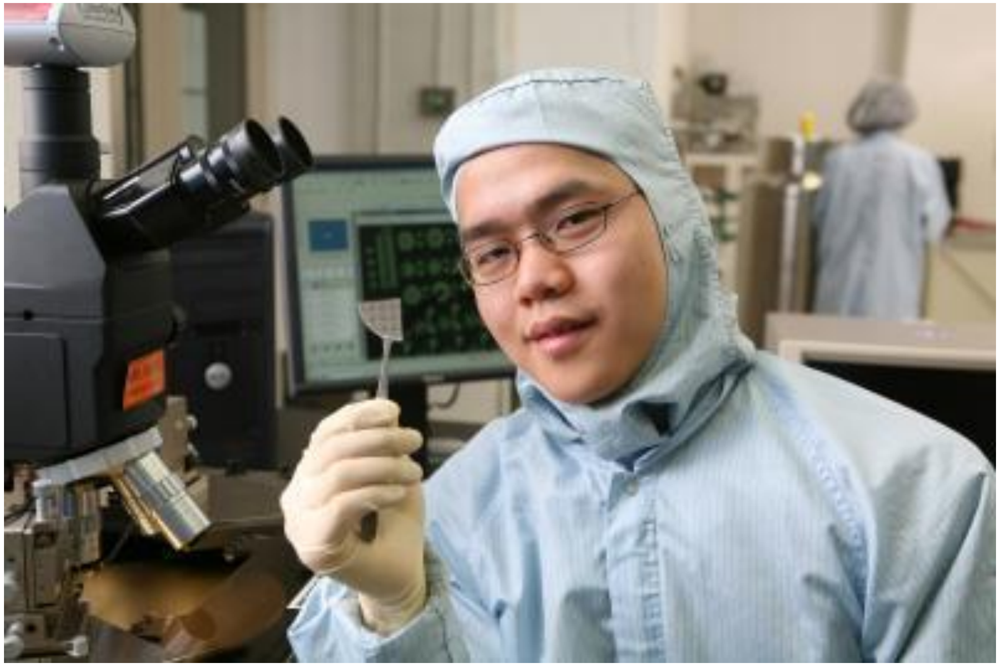


Stretchable and Foldable Silicon Integrated Circuits

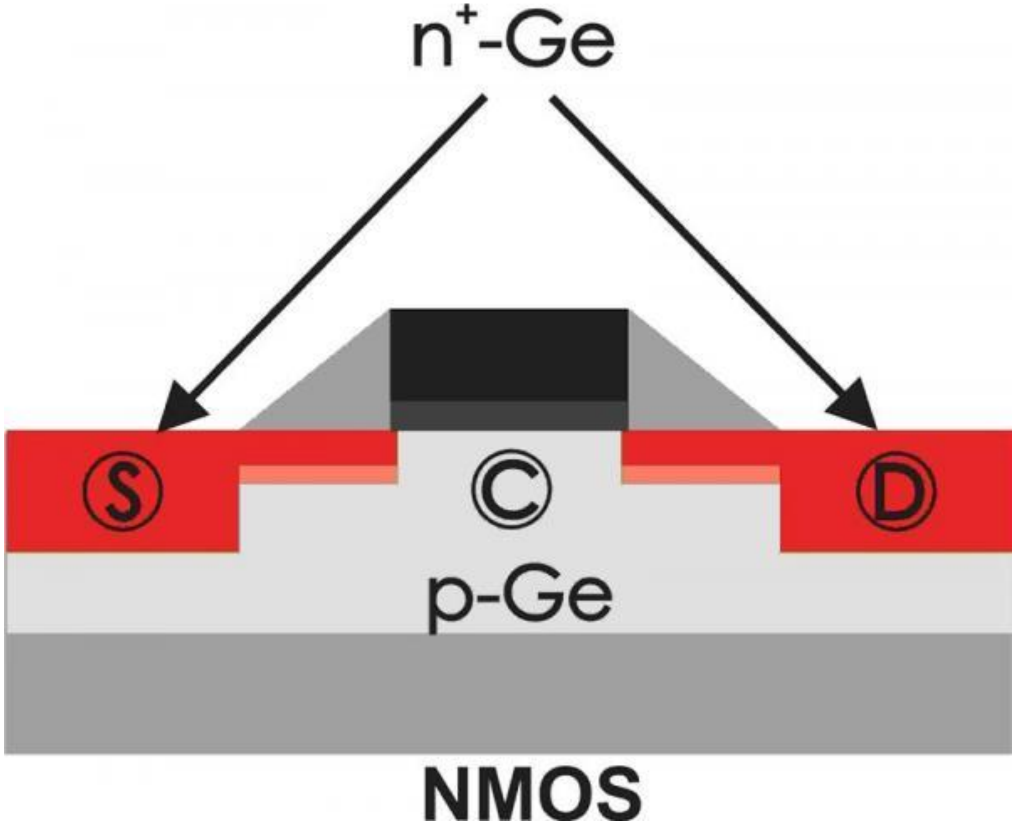


Beyond Silicon!





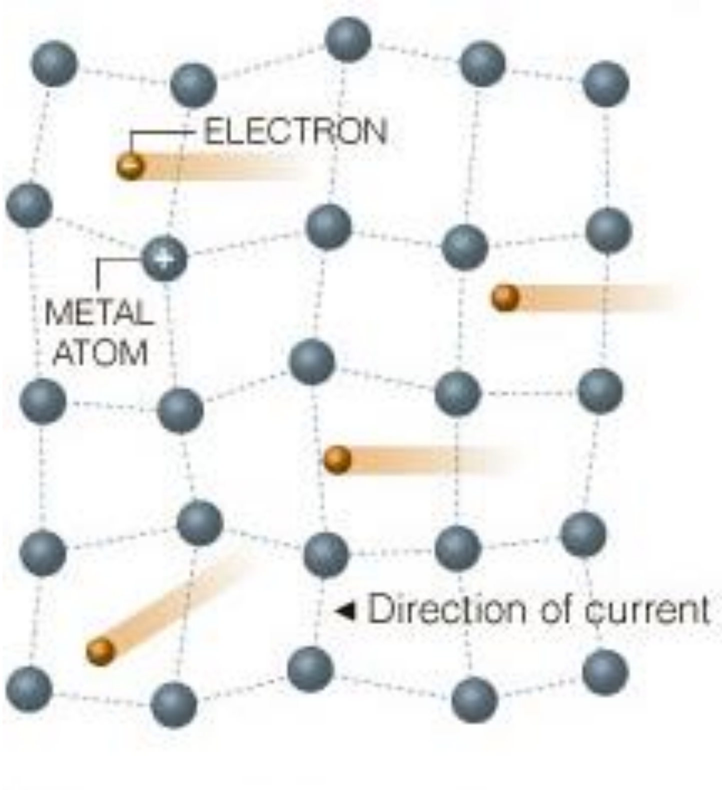
Germanium Nanoelectronics



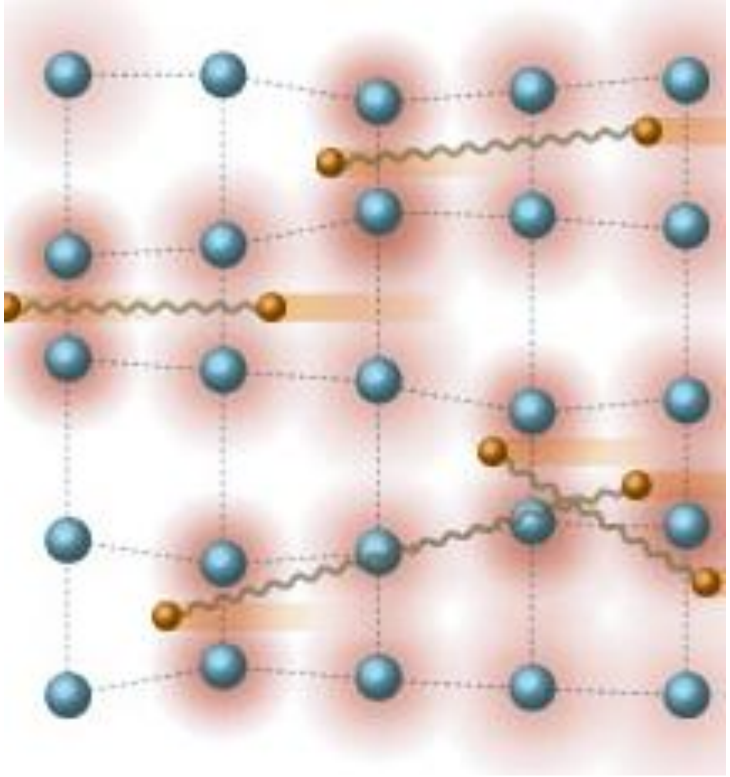
Will lead to even smaller, faster transistors!

Superconductors

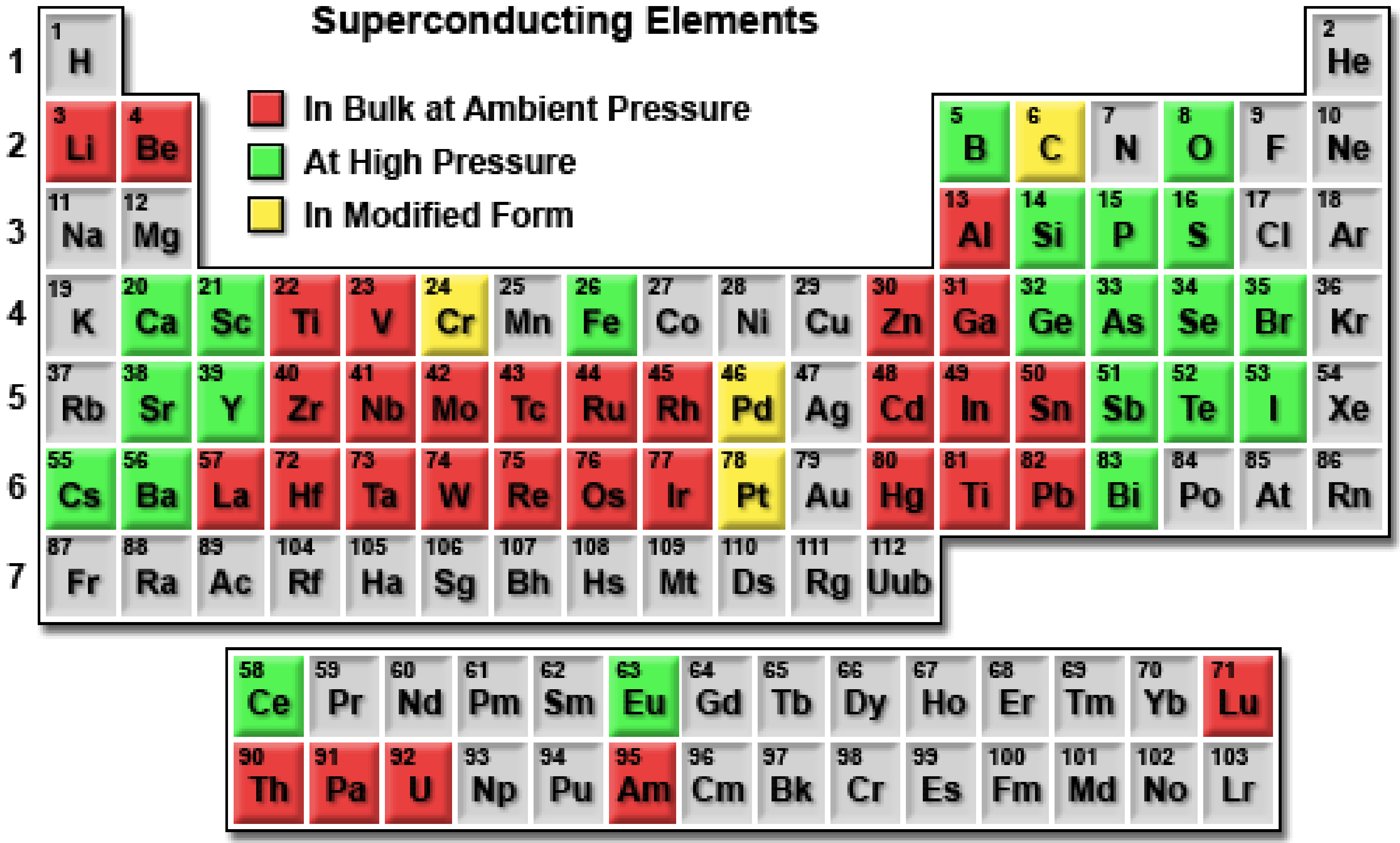
Superconductors



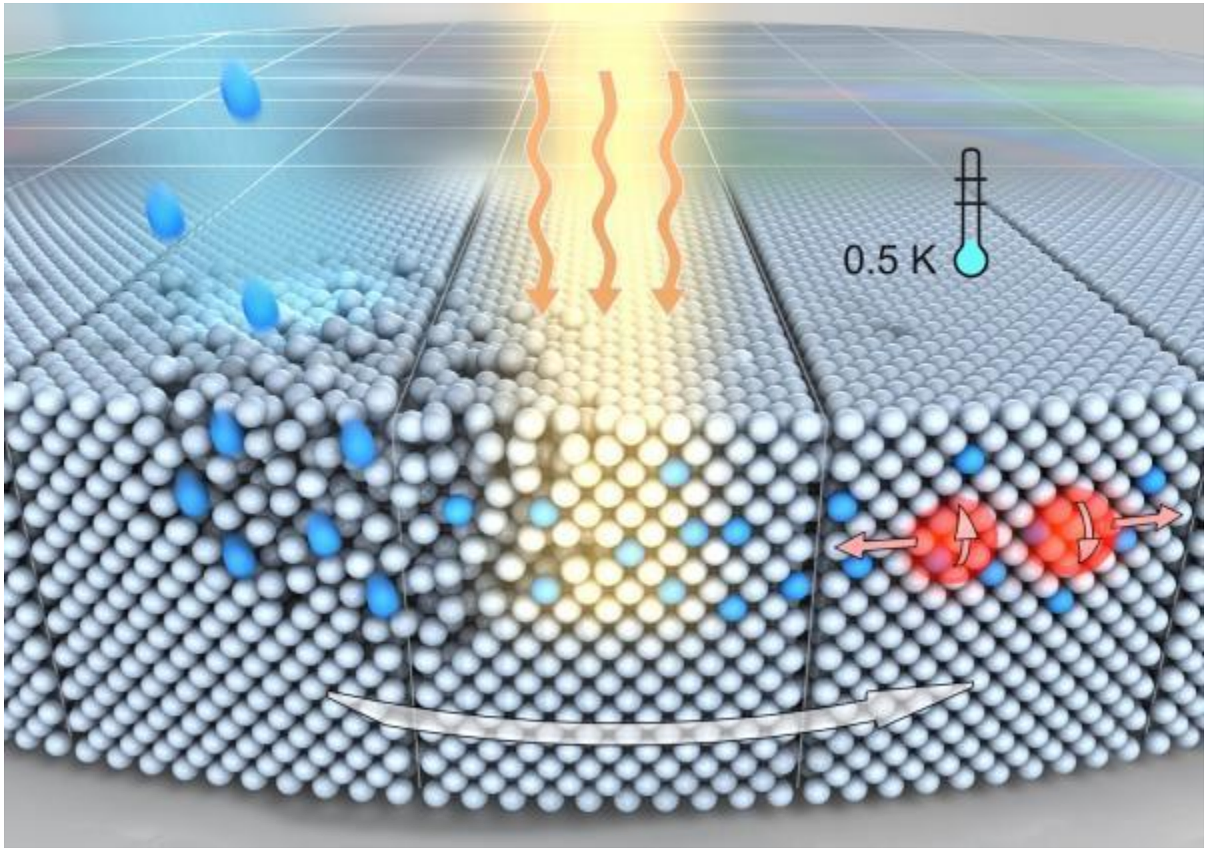
Normal State



Superconductor

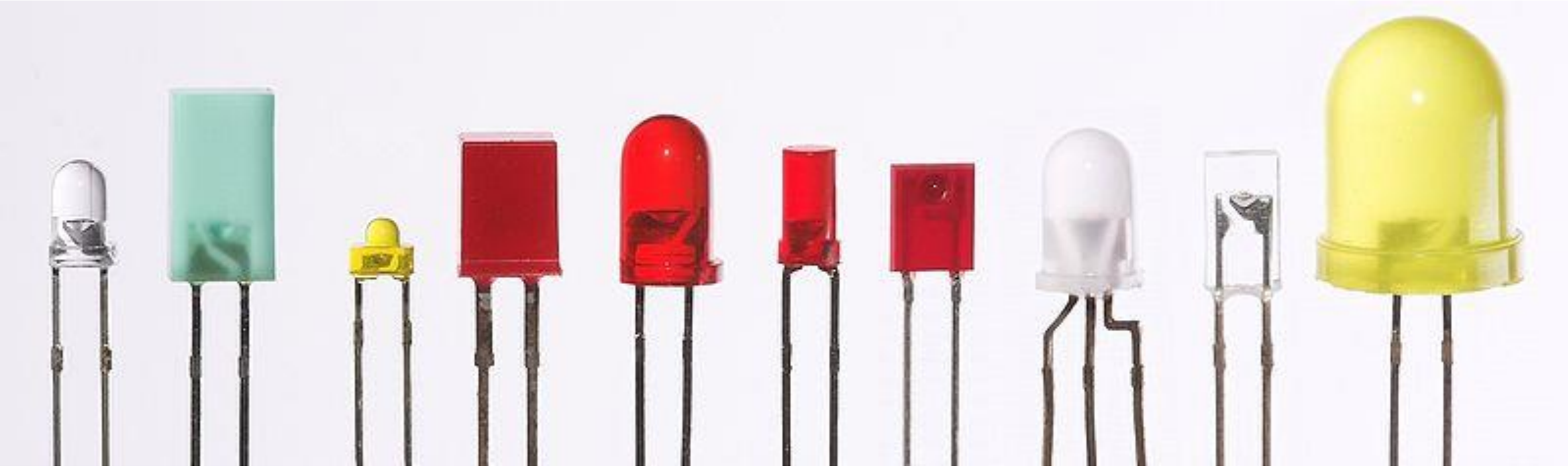

Superconducting Elements
In Bulk at Ambient Pressure
At High Pressure
In Modified Form
1
2
3
4
5
6
7
1 H
2 He
3 Li
4 Be
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
12 Mg
13 Al
14 Si
15 P
16 S
17 Cl
18 Ar
19 K
20 Ca
21 Sc
22 Ti
23 V
24 Cr
25 Mn
26 Fe
27 Co
28 Ni
29 Cu
30 Zn
31 Ga
32 Ge
33 As
34 Se
35 Br
36 Kr
37 Rb
38 Sr
39 Y
40 Zr
41 Nb
42 Mo
43 Tc
44 Ru
45 Rh
46 Pd
47 Ag
48 Cd
49 In
50 Sn
51 Sb
52 Te
53 I
54 Xe
55 Cs
56 Ba
57 La
72 Hf
73 Ta
74 W
75 Re
76 Os
77 Ir
78 Pt
79 Au
80 Hg
81 Ti
82 Pb
83 Bi
84 Po
85 At
86 Rn
87 Fr
88 Ra
89 Ac
104 Rf
105 Ha
106 Sg
107 Bh
108 Hs
109 Mt
110 Ds
111 Rg
112 Uub
58 Ce
59 Pr
60 Nd
61 Pm
62 Sm
63 Eu
64 Gd
65 Tb
66 Dy
67 Ho
68 Er
69 Tm
70 Yb
71 Lu
90 Th
91 Pa
92 U
93 Np
94 Pu
95 Am
96 Cm
97 Bk
98 Cr
99 Es
100 Fm
101 Md
102 No
103 Lr

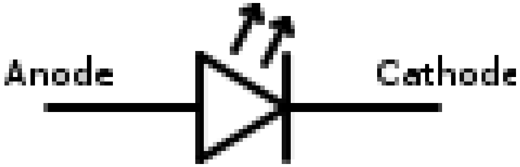
Semiconductor Superconductors

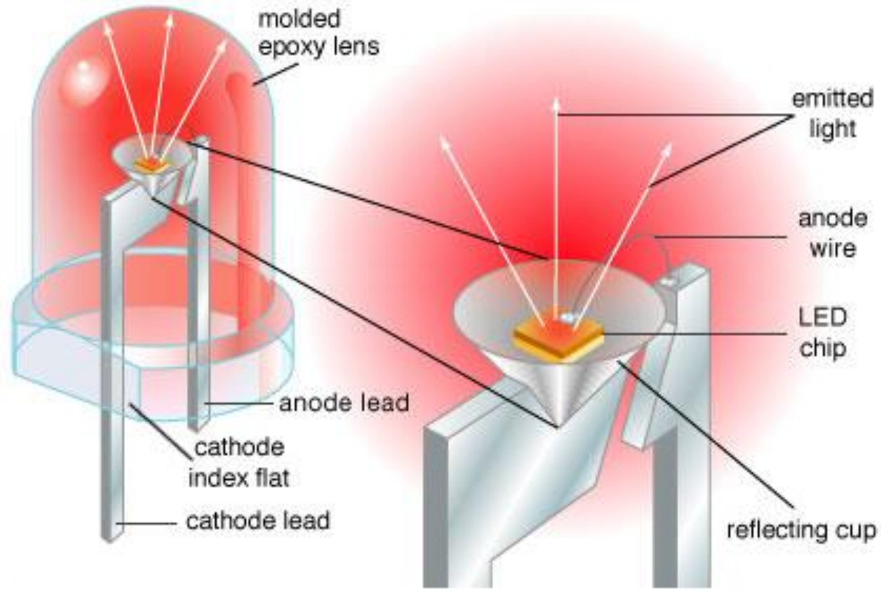


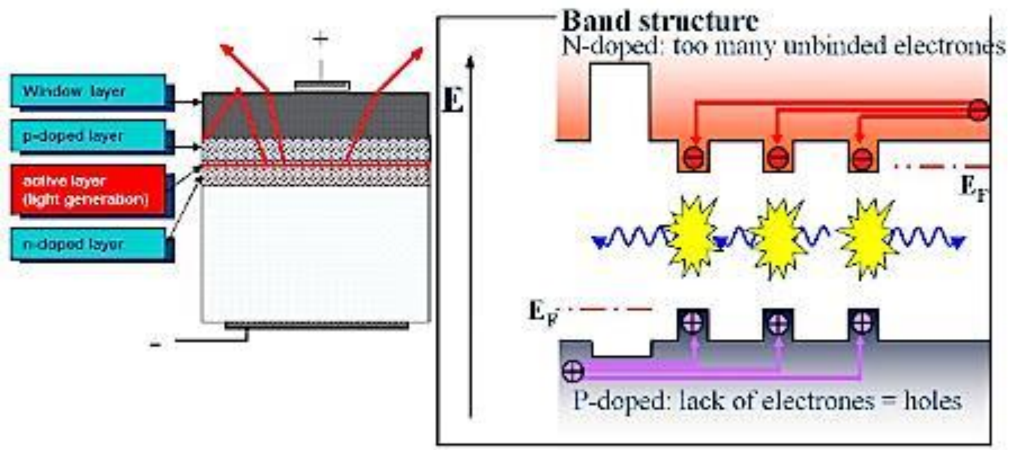
Doping germanium with charged gallium ions.

Light Emitting Diodes

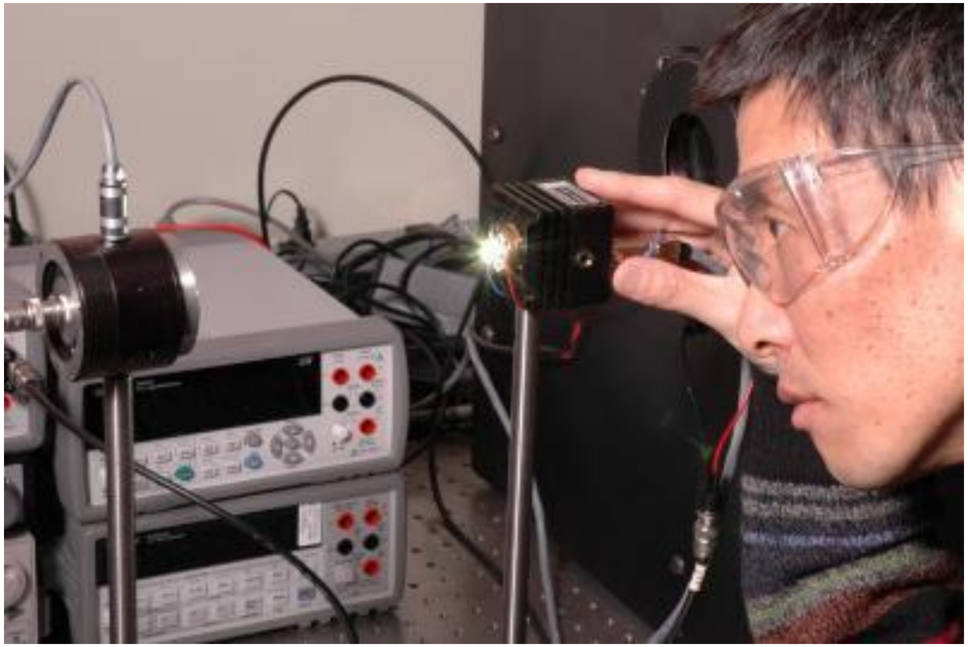


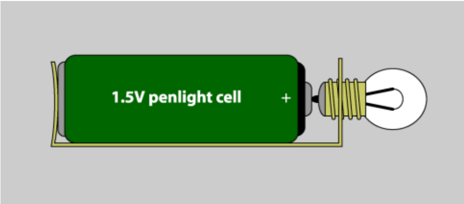


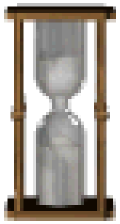

molded
epoxy lens
emitted
light
anode
wire
LED
chip
anode lead
cathode
index flat
cathode lead
reflecting cup

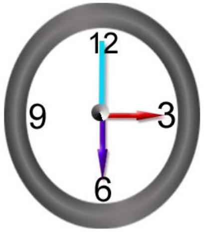

Window layer
p-doped layer
active layer
(light generation)
n-doped layer
+
-
E
Band structure
N-doped: too many unbinded electrones
E_F
E_F
P-doped: lack of electrones = holes

LED’s Advantages

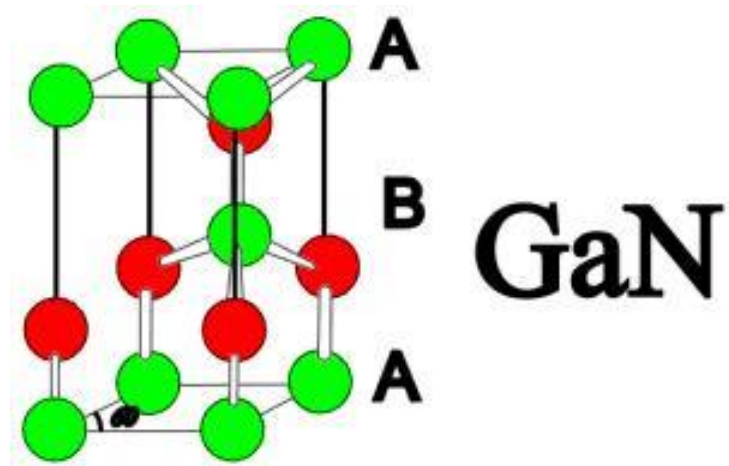


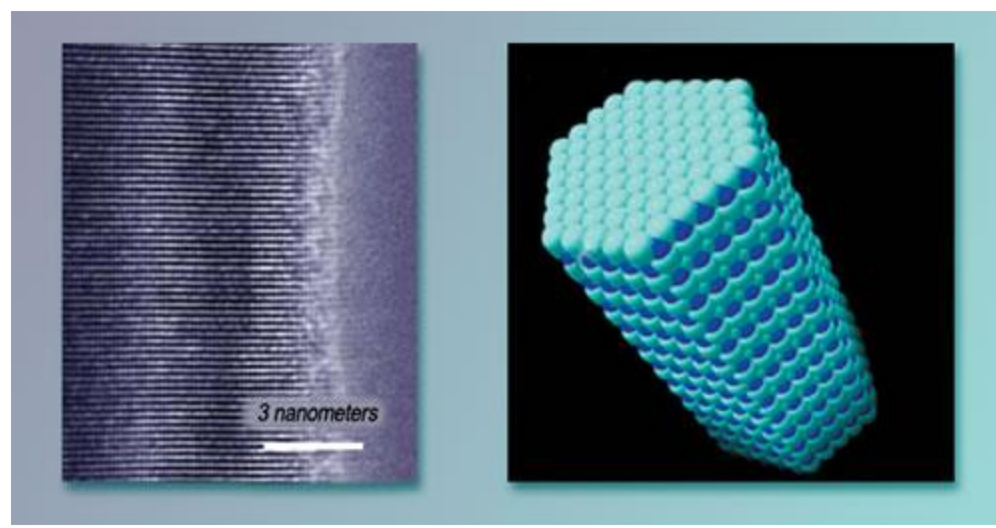




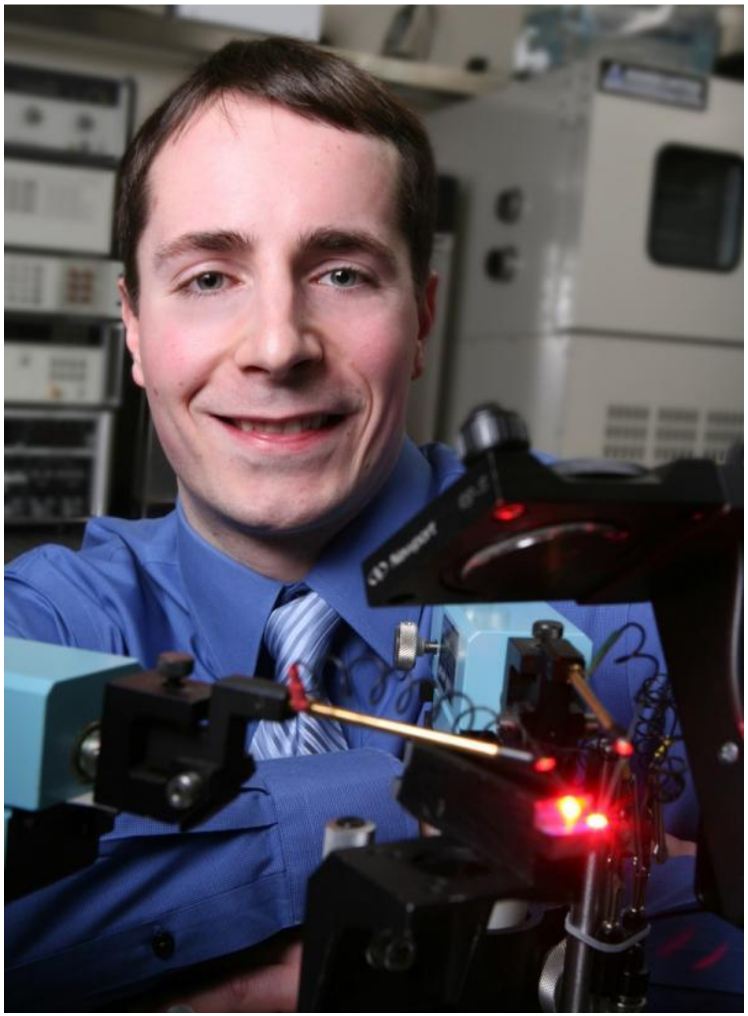


Gallium Nitride

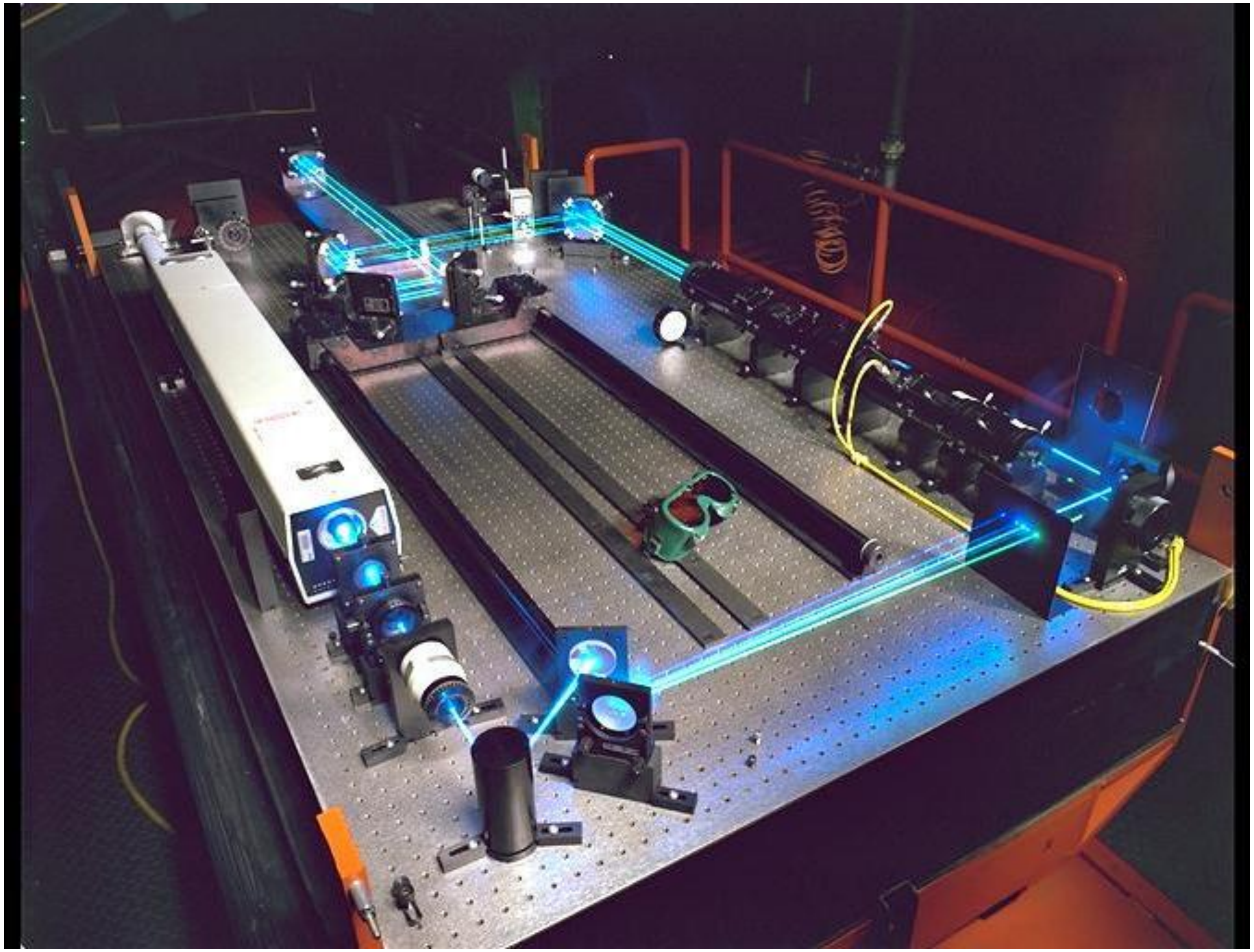




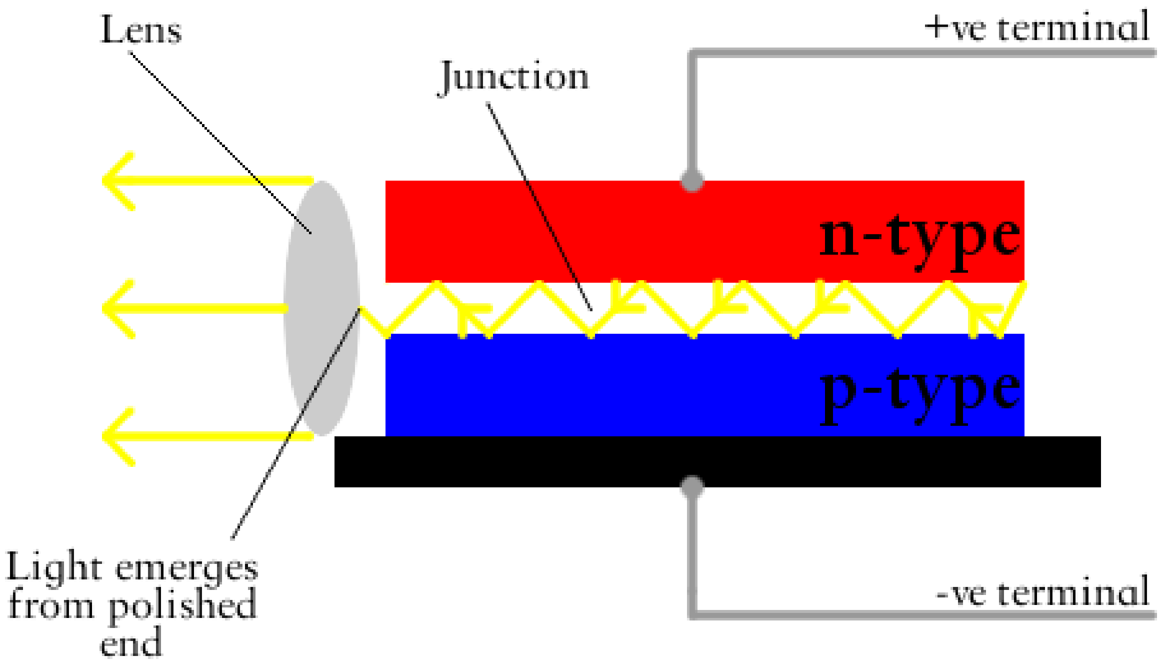
Polarized LED



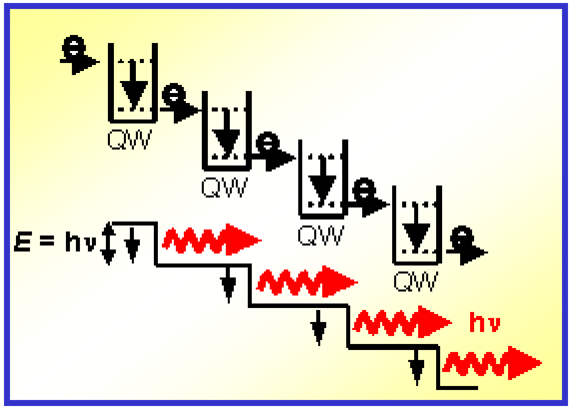
Semiconductor Lasers



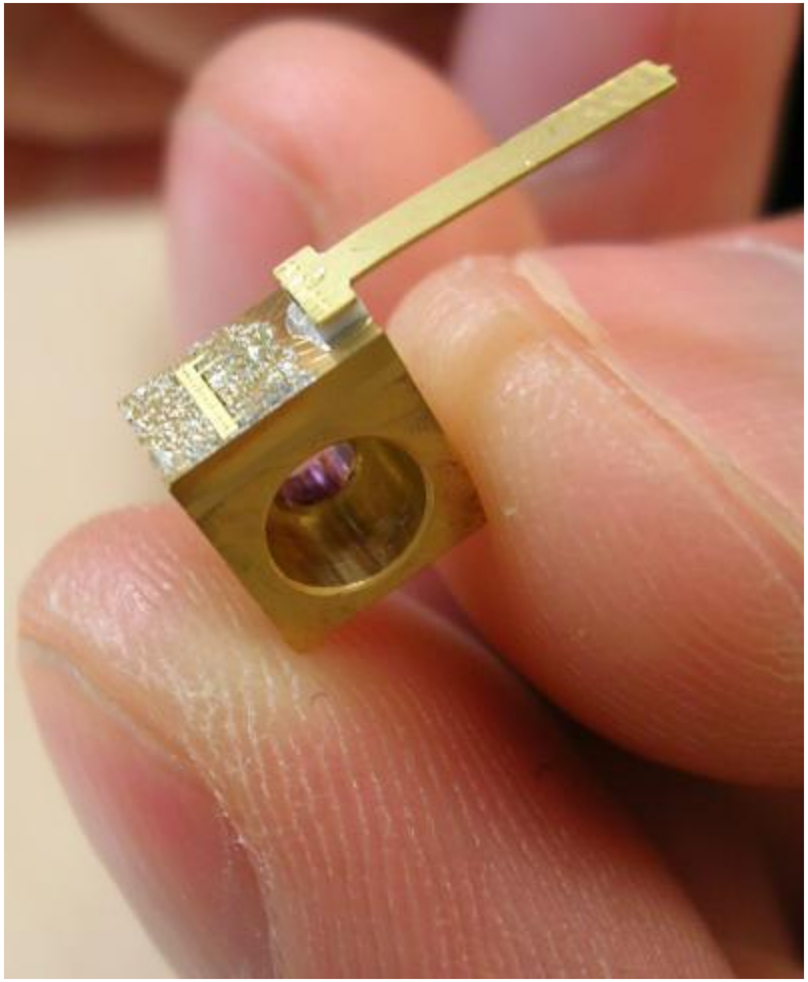
Semiconductor Lasers



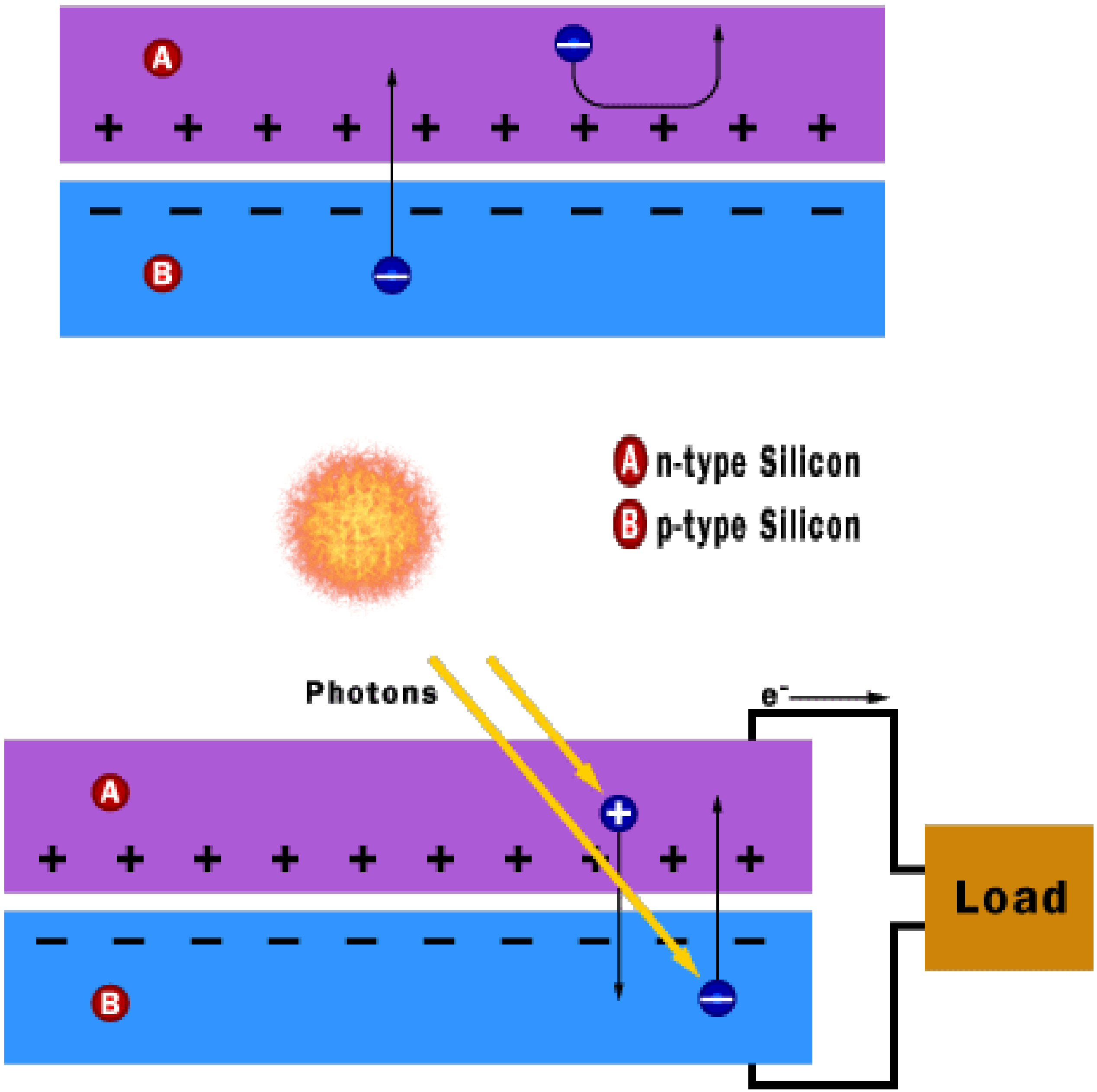
Cascade Lasers



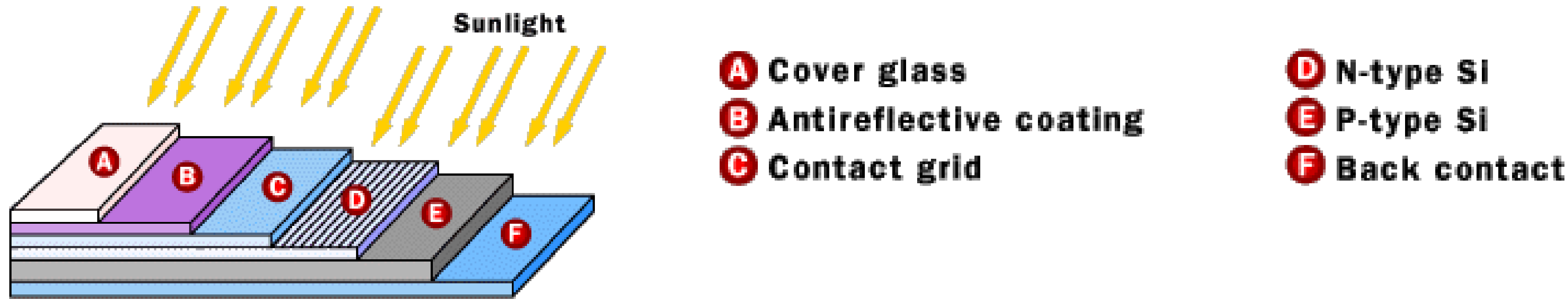
Quantum Cascade Laser

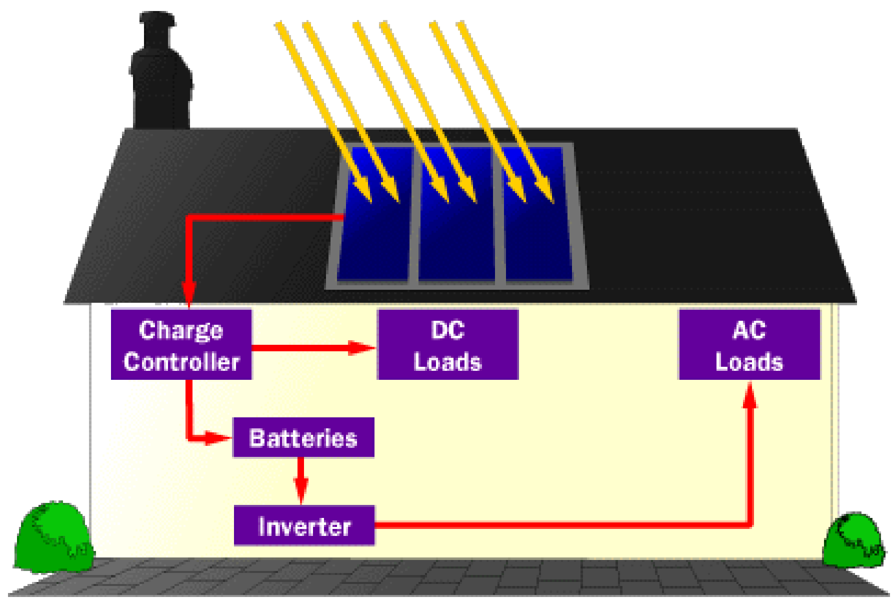


Solar Panels

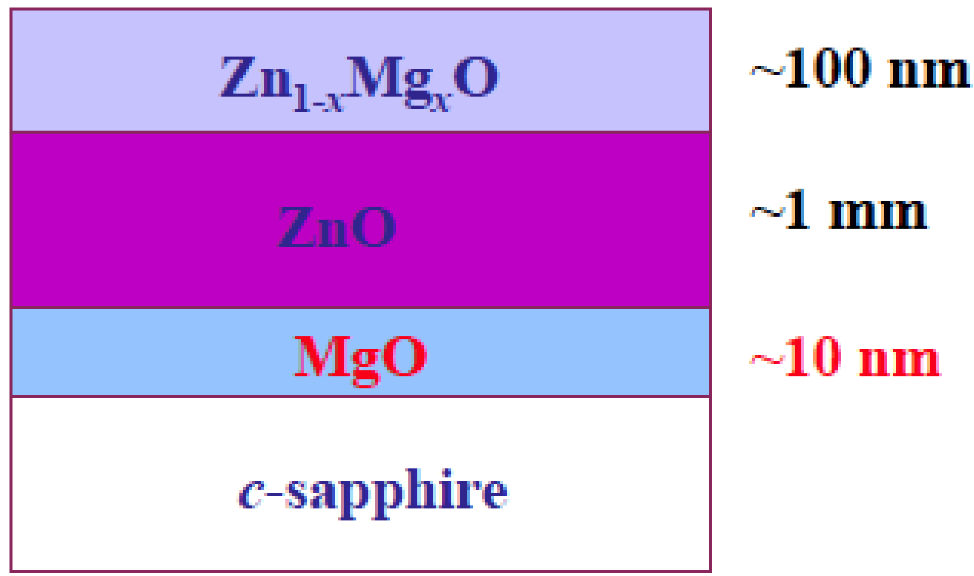


A
B
A n-type Silicon
B p-type Silicon
Photons
e⁻
Load


Sunlight
A
B
C
D
E
F
A Cover glass
B Antireflective coating
C Contact grid
D N-type Si
E P-type Si
F Back contact

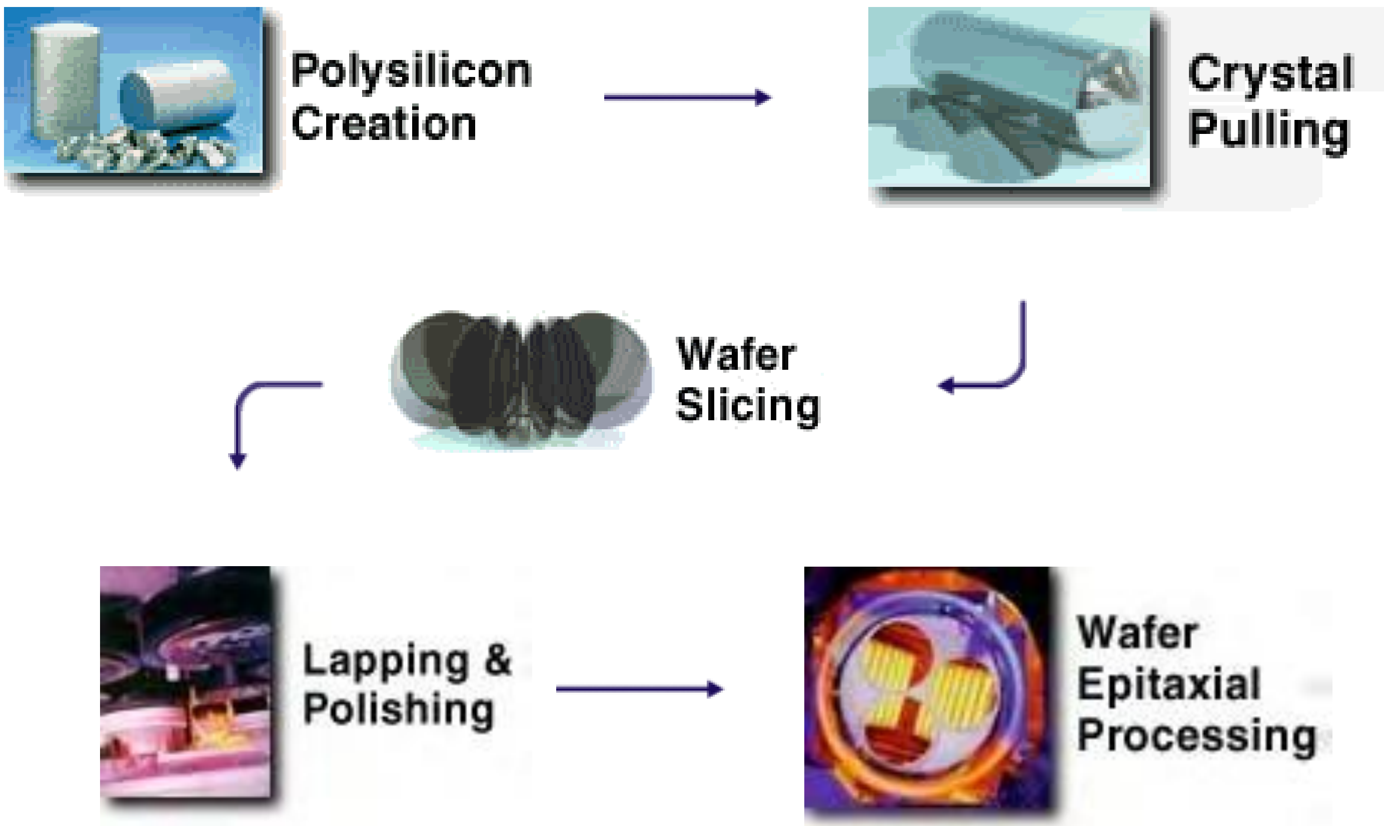

Charge Controller
DC Loads
AC Loads
Batteries
Inverter


PRIUS



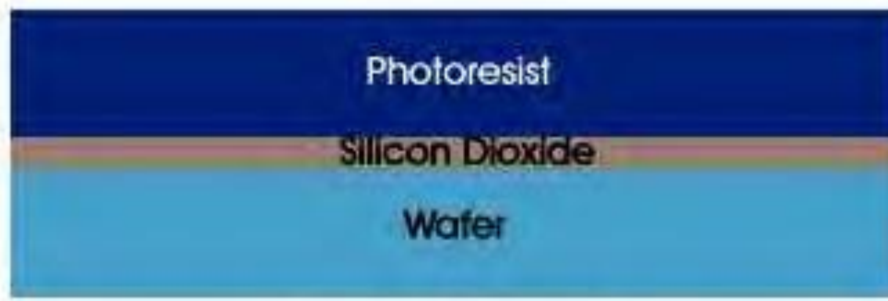
Zn1-xMgxO
~100 nm
ZnO
~1 mm
MgO
~10 nm
c-sapphire

Silicon Wafer Production



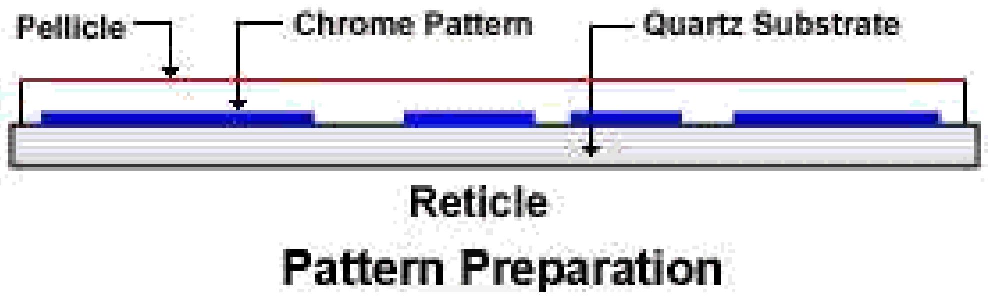
Semiconductor Manufacturing

Oxidation Layering

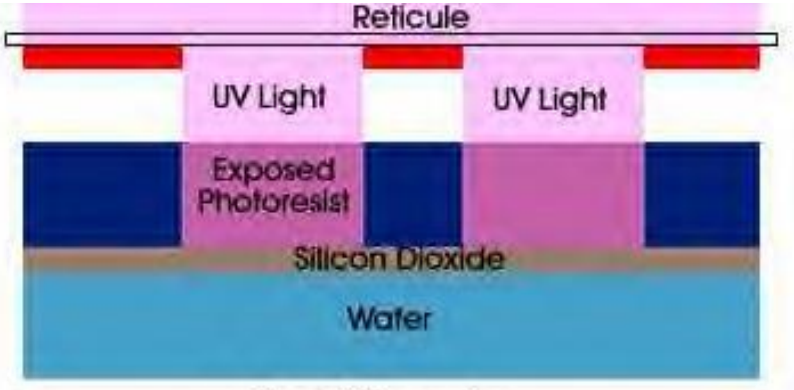


Photoresist Coating

Pattern Preparation



Photolithography

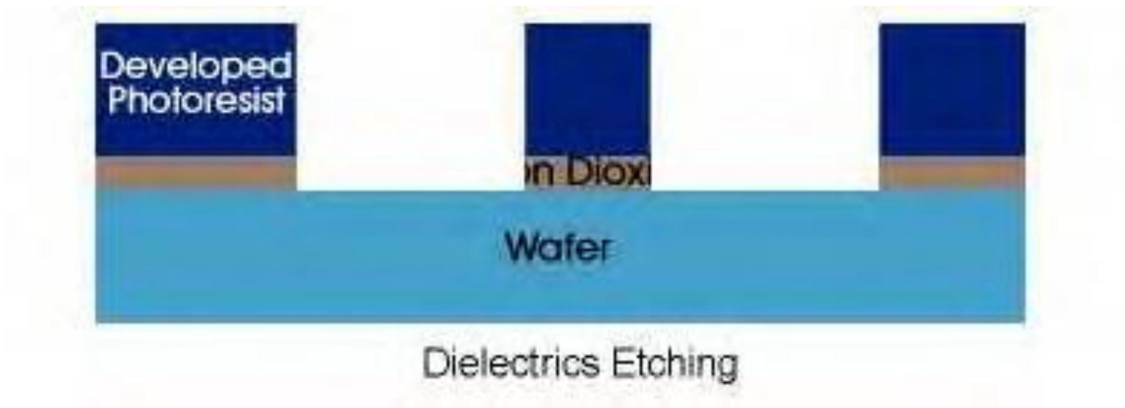


Photolithography

Photoresist Developing

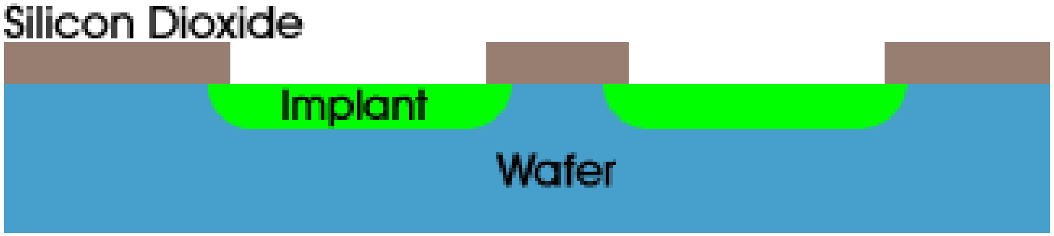
Photoresist Developing

Dielectrics Etching



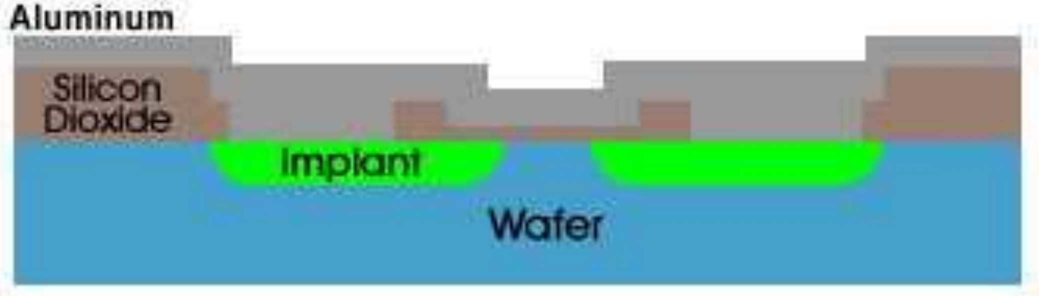
Photoresist Ashing

Ion Implant



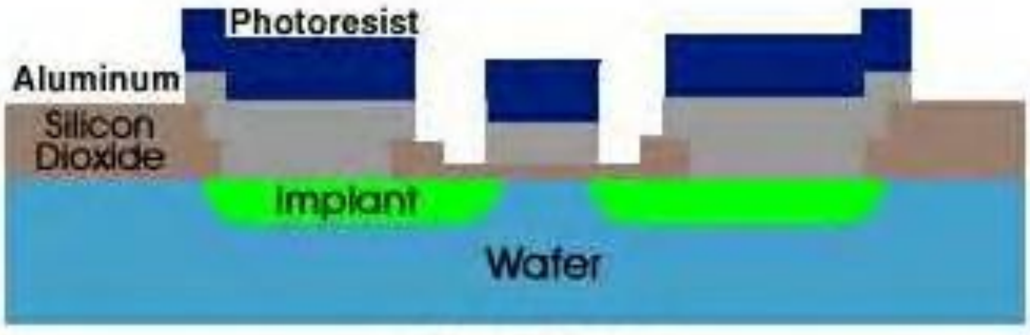
Ion Implant

Metal Deposition



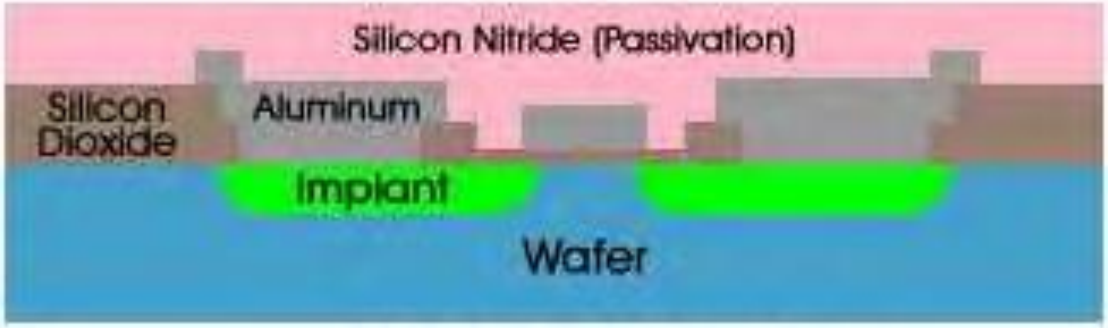
Metal Deposition

Metal Etching



Metal Etching

Dielectrics Layering



Dielectrics Layering