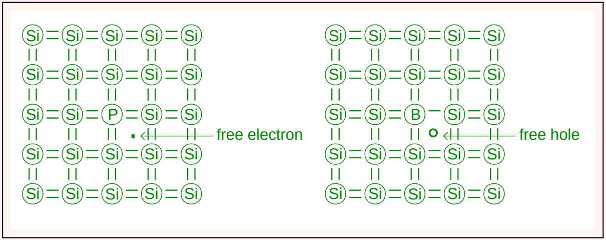
P-N Junctions

- Most semiconductor devices today are fabricated in silicon.
- Semiconductor materials behave as conductors in some cases, insulators in another.
- Silicon is non-conductive in its pure (intrinsic) form as there are no free charge carriers (either electrons or holes) available.
- If we introduce selected impurities (dopants) into the silicon crystal lattice structure we can produce semiconductors.
- By using dopants such as phosphorus (P) or boron (B) we can form n-type or p-type semiconductors respectively.

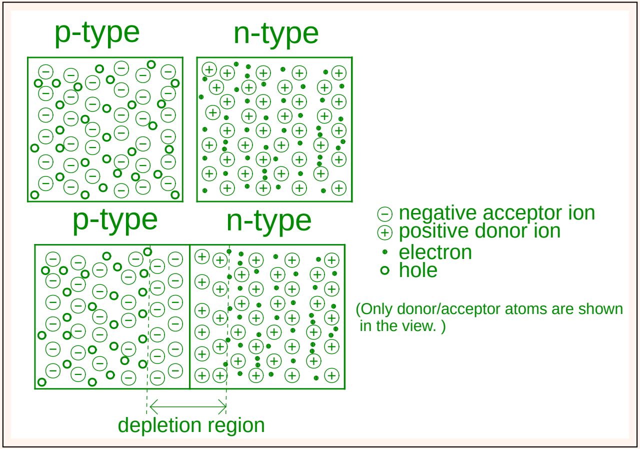
P-N Junctions

- Silicon atoms have 4 electrons in the valence shell. They share a covalent bond with adjacent silicon atoms to form a crystal lattice.
- Adding a pentavalent impurity into the lattice like phosphorus we produce an n-type semiconductor.
- Adding a trivalent impurity like boron we produce a p-type semiconductor.
- Phosphorus's 5th electron, and boron's "hole" are free to move about the silicon crystal and act as a charge carriers.
- Places where an electron is missing in the lattice is called a "hole".

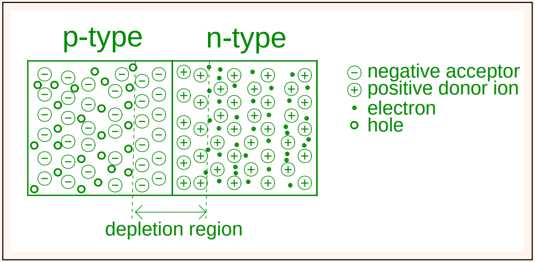


P-N Junctions

- When a n-type and p-type piece of silicon is brought together, we from a p-n junction.



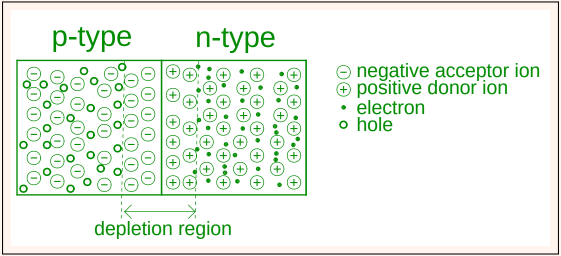
P-N Junctions



- Holes near the junction are attracted to the n-type silicon and electrons fill the holes in the p-type silicon forming a depletion region in a process called recombination.
- In the depletion region the dopant atoms become ions because the phosphorus atoms have given up an electron, and the boron atoms have given up a hole.

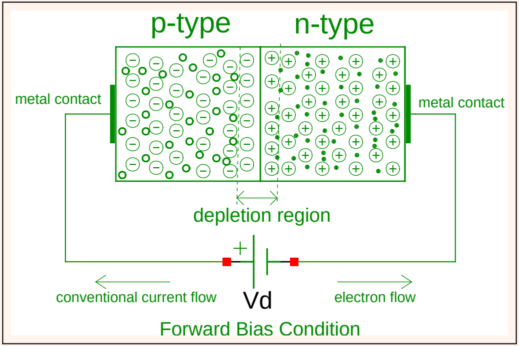
P-N Junctions

- The depletion region has no free charge carriers and the dopant atoms cannot move within the lattice.
- The ionized dopant atoms create an electric field across the junction.
- The width of the depletion region reaches equilibrium due to coulomb forces on both holes and electrons.
- For example, electrons not in the depletion region are repelled by negative ions in the depletion region of the p-type material.
- So, what happens when an external voltage is applied to the junction?



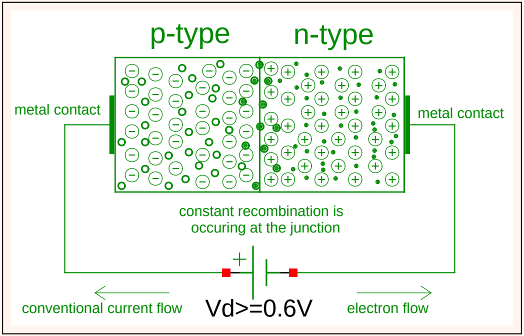
P-N Junctions

- Metal contacts are added to the silicon and a forward bias condition is applied to the diode.
- As V_d is increased, charge carriers are pushed towards the depletion region reducing its width.
- The positive charge from V_d repels the holes towards the n region and the negative charge from V_d pushes electrons towards the depletion region.



P-N Junctions

- As V_d is increased beyond 0.6V, the depletion region disappears and constant recombination occurs at the junction allowing current to flow from the p to n-type regions.
- The 0.6V potential is called the barrier potential. Silicon's barrier potential is 0.6V. Germanium has a barrier potential of about 0.3V.
- The barrier potential is the 0.6V we see across a forward biased diode.

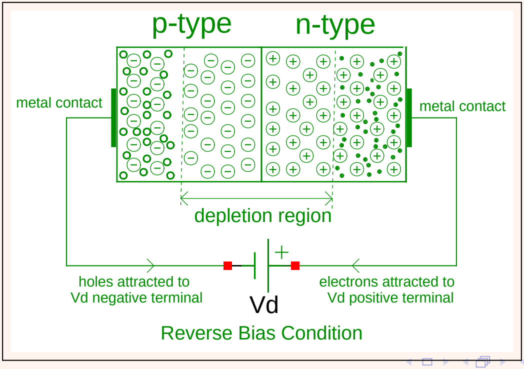


P-N Junctions

- The electrons flowing across the junction will recombine with holes in the p-type region. Likewise, holes will recombine with electrons in the n-type material. This is simply because its energetically favorable for them to do so.
- Although the charge carriers travel a short distance, current will continue to flow. The current flow continues uninterrupted as the holes continue to flow in replacing those who recombined with an electron and electrons flow into the junction to replace those who recombine with a hole. So at the junction under forward bias, charge carriers are constantly recombining. This is required by KCL.

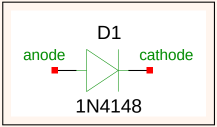
P-N Junctions

- In reverse bias holes in the p-type material are pulled away from the junction and electrons are drawn away from the junction by the positive potential on V_d. This action increases the width of the depletion region and no current flows.
- At some point with increasing V_d, the depletion region breaks down and current begins to flow. This is due to either avalanche or zener diode processes.



P-N Junctions

- The p-n junction forms a simple diode whose corresponding schematic symbol is below.



- As the symbol indicates, current flows typically through the diode in only one direction. The exceptions are reverse leakage current or zener breakdown.
- For current to flow through a silicon diode, a voltage potential of about 0.6V must be present across the junction. Thus, $I_d > 0$ when $Vd >= 0.6V$ (silicon).