Online laboratory assignment 8 – Semiconductors

Purpose: to investigate the basic characteristics of a semiconductor and doping properties. A simple diode will also be investigated.

Introduction

In order to understand how transistors work, we must examine the basic chemical properties of silicon-based semiconductors. Silicon is in group IVA of the periodic table and has 4 valence electrons with which it forms covalent bonds. In a pure silicon crystal as shown in Fig. 1, every silicon atom is covalently bound to four other silicon atoms. Pure silicon has no free electrons, and is therefore a very poor conductor. In a process called doping, impurities are purposely added to pure silicon to alter its characteristics. Typically, these impurities are in low concentration (1 part in 10^6 or 10^7). There are two types of doping elements used. Arsenic, comes from group VA, and has five valence electrons as illustrated in Fig. 1. Four of the valence electrons form covalent bonds with silicon, and the extra electron is "free," somewhat like electrons in a metallic conductor. When the fifth electron leaves the arsenic atom, the atom becomes a fixed positive ion. One fixed positive ion exists for every free electron in the doped silicon crystal. This type of silicon crystal is called an n-type semiconductor because negative charges (electrons) carry the current.

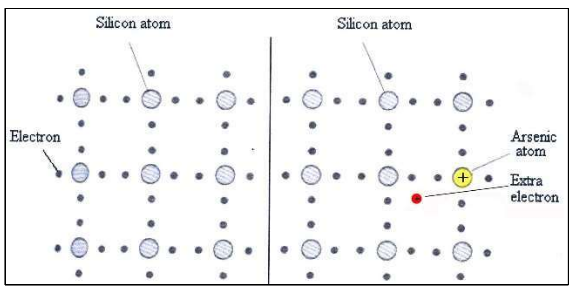


Fig. 1: covalent bonding in (left) pure silicon and in (right) arsenic doped silicon.

A second type of impurity comes from Group IIIA elements, such as gallium, which has only three valence electrons. Gallium forms three covalent bonds with silicon, and the fourth bond has only one electron rather than two. This missing electron can be obtained from a neighboring silicon atom, resulting in a negative gallium ion, and a positive neighboring silicon ion, which is called a positive hole. This positive hole can be filled by an electron from yet another silicon, etc. Although electrons are jumping from silicon to silicon, it appears as though the positive hole is the mobile charge carrier. This type of silicon crystal is called a p-type semiconductor because positive charges (holes) carry the current.

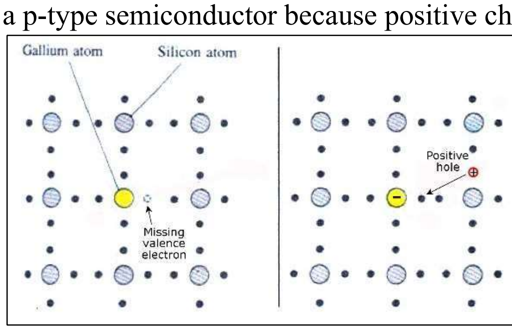


Fig. 2: (right) covalent bonding in gallium doped silicon and (left) the formation of positive holes.

In addition to the chemical nature of doped semiconductors, we must also understand how they behave when placed in physical contact, such as in a p-n junction diode. When an n-type semiconductor comes in contact with a p-type semiconductor, free electrons move from the n-type material into the p-type side, and positive holes move in the opposite direction as observed in Fig. 3.

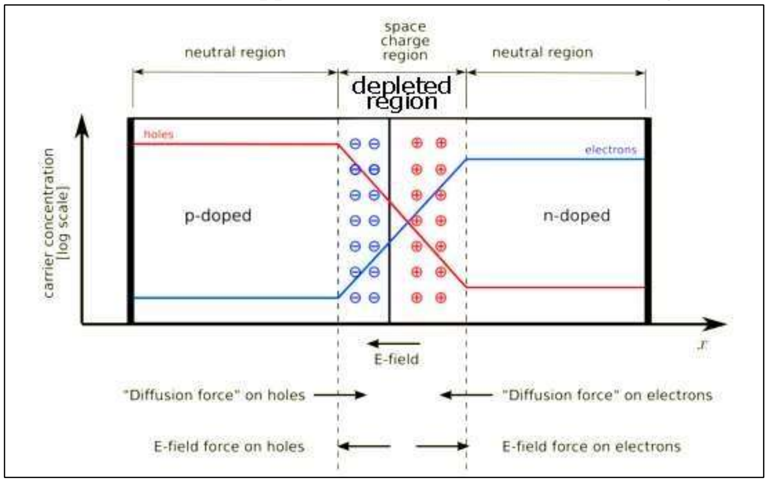


Fig. 3: pn junction with no external voltage applied

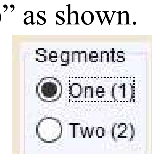
The electrons and holes neutralize each other, removing all charge carriers in a boundary layer called the depletion region. As the charge carriers move across the layer, a fixed positive charge develops on the n-side and a fixed negative charge develops on the p-side. This creates an intrinsic electric field that opposes the current from motion of the charges.

Eventually equilibrium is reached and charge advection is balanced by the electric field. Since the depleted region has no charge carriers, current cannot pass through it. There are two different ways in which a source of emf can be attached to a junction diode. If the positive terminal of a DC power supply is attached to the n-doped end and the negative terminal is attached to the p-doped end, the electric field generated by the source of emf will be in the same direction as the intrinsic field, and holes and electrons will move further away and widen the depleted region. This situation is called reversed biased, and no current will pass under these conditions. If the power supply terminals are reversed such that the positive terminal is attached to the p-doped side, the electric field due to the source of emf opposes the intrinsic field. As the power supply emf is increased, the depleted region gets thinner, and eventually, at what is called the bias potential, charge carriers reach the interface and a current passes through the diode. This situation is called forward biased.

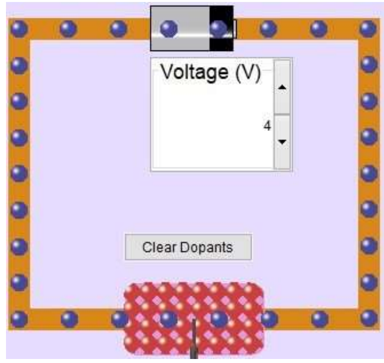
Laboratory assignment

I. Doping in a semiconductor material

1. Run the "Semiconductor" PhET simulation.
2. Set the "Segments" toggle to "One (1)" as shown.



3. Drag the p-type doped semiconducting material and set the voltage to 4 V as shown.



4. Explain what you observed in the energy bands and in the current.

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5. Reduce the voltage until it reaches a value -4 V.
6. Explain what you observed after you switched the battery polarity in step 5.

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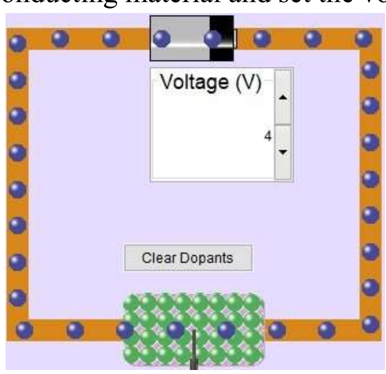
7. Clear the dopants by hitting the “Clear Dopants” button.
8. Drag the n-type doped semiconducting material and set the voltage to 4 V as shown.



9. Explain what you observed in the energy bands and in the current. Note differences with the p-type semiconductor.

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10. Reduce the voltage until it reaches a value -4 V.
11. Explain what you observed after you switched the battery polarity in step 10.

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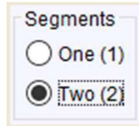
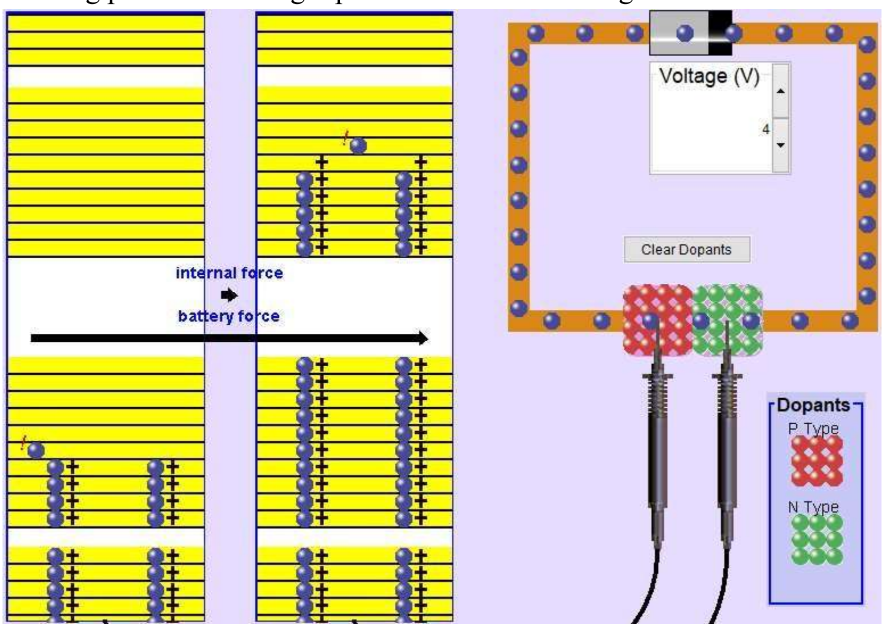
<u>II. Diodes with paired n-type and p-type semiconductors</u> 12.

Set the “Segments” toggle to “Two (2)” as shown.



13. Pause the simulation.
14. Drag the p-type doped semiconducting material to the left portion of the diode and the n-type semi-conducting portion to the right portion and set the voltage to 4 V as shown.



15. Play the simulation and wait a few seconds.
16. Explain what you observed (clear dopants and redo steps 13-15 if necessary)

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17. Pause the simulation.
18. Reduce the voltage to -4 V.
19. Play the simulation.
20. Explain what you observed.

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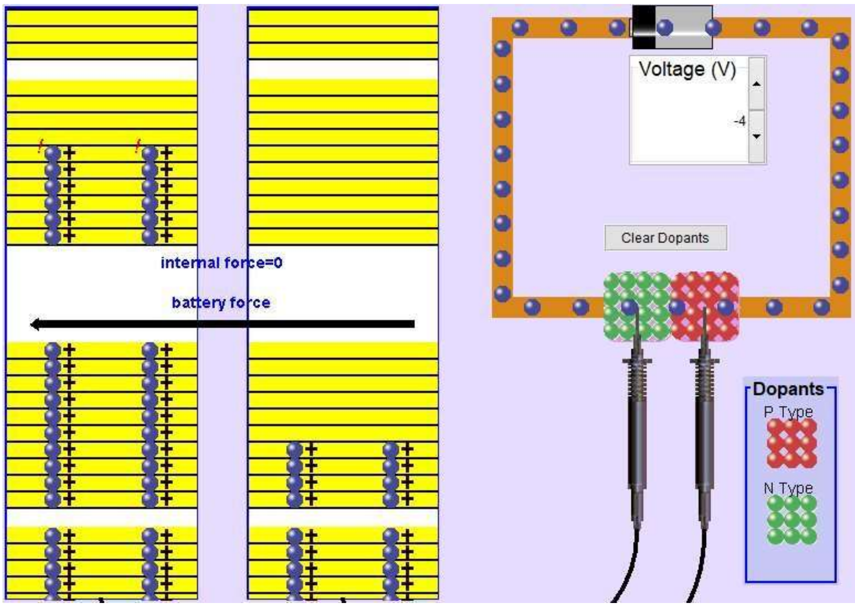
21. Clear the dopants.
22. Pause the simulation.
23. Drag the p-type doped semiconducting material to the right portion of the diode and the n-type semi-conducting portion to the left portion and set the voltage to -4 V as shown.



24. Play the simulation and wait a few seconds.
25. Explain what you observed (clear dopants and redo steps 22-24 if necessary)

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26. Pause the simulation.
27. Increase the voltage to 4 V.
28. Play the simulation.
29. Explain what you observed.

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30. For the placement of the n-type and p-type semiconductors, is the direction of the current important?

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31. Write a brief conclusion to the lab.

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