STUDY OF IONS' IMPACT ON METALLOIDS

Project Report

By

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CERTIFICATE

This is to certify that this project report entitled, **"Study of Ions' Impact on Metalloids"** is an authentic report of project done by AMAN PAL SINGH in the partial fulfillment of the requirement for the award of degree of **Master of Technology in Nuclear Science and Engineering** by Delhi Technological University in the year – July 2016.

The assistance and help received during the course of this investigation have been duly acknowledged.

Project Guide

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DECLARATION

I, hereby, declare that the work being presented in this dissertation, entitled **Study of Ions' Impact on Metalloids**, is an authentic record of my own work carried out under the guidance of **Dr. Nitin Kumar Puri**, Assistant Professor, Department of Applied Physics, Delhi Technological University (Formerly Delhi College of Engineering), Delhi. The work contained in this dissertation has not been submitted in part or full, to any other university or institution for award of any degree or diploma.

This dissertation is submitted to **Delhi Technological University** (Formerly Delhi College of Engineering) in partial fulfillment for the Master of Technology (M. Tech) in Nuclear Science and Engineering.

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(Signature and Name of Student)

AMAN PAL SINGH

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"*There is no happiness except in the realization that we have accomplished something"*

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"Change is inevitable, but something in life never change"

"Parents are God on earth"

Lastly, I express the utmost sense of gratitude to God and my Mummy Papa being the pillars of strength, inspiration and support in my life and career. Whom I am deeply indebted for their unconditional love, constant encouragement, affection and care, without which I would not be able to carry on in my academic endeavor.

Place: **(Aman Pal Singh)**

Date: **Author**

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ABSTRACT

Radiation has significant impact on the device materials. Devices go through different radiation environments when they are in operation. Radiation has its presence in space, high energy experiments, and nuclear power plants or in fabrication industry. The device material should be robust and must have high susceptibility to function flawlessly in different radiation conditions. In this study the interaction of ions into metalloids is being simulated using SRIM (Stopping and range of ions in matter) simulation. By using this simulation, the final distribution of ions in metalloids and kinetic phenomena related to energy loss of ions are calculated. Kinetic phenomenon includes target damage, ionization and phonons production. From the findings, it is observed that the interaction of ions with the metalloids produces lattice defects in the form of vacancies, displacement and interstitials. The simulation results also show that the damage in metalloids is depending on the electronic stopping, nuclear stopping and projected range of ions.

Chapter 1 *INTRODUCTION*

Great interests have always been shown by the researchers for irradiation of ions into a solid target material in the electron-volt to mega-electron-volt energy range. The physical properties of a particular solid substance are always affected by the presence of a trace amount of foreign atoms. Materials have potential applications in the semiconductor, mineral processing and metallurgy, corrosion and glass formation fields. Mechanical, electrical, magnetic, optical and conducting properties are all affected by the existence external atoms. Penetration of ions into metalloids leads to the deposition of energy which can induce temporary or permanent effect in the material.

A metalloid is an element with properties in between metals and nonmetals. It can also be the mixture of these.

The six commonly known metalloids are boron, silicon, germanium, arsenic, antimony, and tellurium. Out of the six commonly recognized metalloids boron, silicon and germanium are used as the target layer materials. Ions' ranges and loss of energy in elastic and inelastic collisions will be calculated. Irradiation of ions will be done on the Single, double and triple layers of B, Si, Ge. Vacancies created and the energy lost in ionization and phonons will be calculated and the results obtained will be discussed.

Usually metalloids have a metallic appearance and they are brittle. Metalloids are good conductors of electricity. The properties of metalloids are in between metals and nonmetals. They can form alloys. Metalloids can not be used as structural material. They are used in alloys, flame

retardants, glasses, biological agents, optoelectronics and semiconductor electronics.

Because of the electrical properties of silicon and germanium semiconductor industry could established in the 1950s and the development of solid-state electronics began from the early 1960s. Ionization energies of metalloids are around 200 kcal/mol and they have electro negativity values near to 2.0. Generally metalloids are considered as semiconductors. But antimony and arsenic have electrical conductivities approximately equal to those of metals.

Elements usually recognized as metalloids

Metalloids generally appear like metals but they behave mostly like nonmetals. In their physical appearance, they are shimmering, brittle solids. They have good electrical conductivity. Their electronic band structure is like that of semiconductor. Chemically, they are non-metals and have intermediate electro negativity and ionization energies values. They can form alloys with metals. Many other physical and chemical properties are intermediate in nature.

Boron:

Boron is a silver-grey shiny crystalline solid. Its density is less than aluminum. It is hard and brittle. Under normal conditions, it is not much reactive but when attacked by fluorine, it becomes reactive. It has

a melting point of 2076 °c. Boron has electrical conductivity value of 1.5 × 10^{-6} S•cm^{-1} at room temperature. It has a band gap of about 1.56 eV. The chemistry of boron is dominated by its small atomic size and high ionization energy. Boron has three valence electrons per atom, so octet rule can not be fulfilled by simple covalent bonding.

The bonding of boron describes the characteristic of behavior between metals and nonmetallic covalent solids like diamond 30 KJ/mol is the energy required for transforming boron from non metallic to metallic state. This energy indicates that boron is near to the metal-nonmetal borderline.

Silicon:

Silicon is a crystalline solid. It has blue-grey metallic shine. Its density is less than that of aluminum and its value is 2.33 g/cm^3. It is also hard and brittle. It is a relatively less active element. Its crystalline form is remarkably inert to all acids. Its melting point is 1414°C. The electrical conductivity of silicon is 10^{-4} S.cm^{-1} and its electronic band gap is about 1.11eV. After melting it converts into metal with an electrical conductivity of 1.0–1.3 × 10^4 S•cm^{-1}, This is similar to the conductivity of liquid mercury.

The chemistry of silicon is usually nonmetallic. Silicon can form cation. It can form alloys with metals like iron and copper. It has less

anionic behavior than ordinary nonmetals. The strength of oxyzen and silicon bond is high so it dominates the chemical behavior of silicon. The energy required to transform Si from non-metal to metallic states is 33 KJ/mol.

Germanium:

Germanium has a shiny grey white appearance. It has a density of 5.323 g/cm^3 .It is also hard and brittle. The melting point is 938 °C. It is a semiconductor and its electrical conductivity is around 2 × 10 $^{-2}$ S•cm^{-1}. It has electronic band gap of 0.67eV. Liquid germanium behaves like metallic conductor having electrical conductivity equal to that of liquid mercury.

Chemically germanium behaves like nonmetal. It is not clear that it forms a cation or not but Ge^{2+} ion exist in a few eccentric compounds. Germanium forms alloys with metals such as gold and aluminum. Germanium generally forms tetravalent compounds but it can also form less stable divalent compounds. Till 1930s it was considered as a poorly conducting metal but later writers sometimes classified it as a metal.

Properties of metals, metalloids and nonmetals

Physical property	Metals	Metalloids	Nonmetals
Electrical conductivity	good to high	intermediate to good	poor to good
Appearance	lustrous	lustrous	Several colorless others colored
Form	solid; some liquid at or near room temperature	solid	Mainly gases
Band structure	Metallic	are semiconductors or semi metallic	semiconductor or insulator
Elasticity	usually elastic, ductile, malleable	brittle	fragile, if solid
Chemical property	**Metals**	**Metalloids**	**Nonmetals**
Electronegativity	usually low	Have electro negativity values close to 2	high
Oxides	Lower oxides basic, higher oxides increasingly acidic	weakly acidic	acidic
Ionization energy	comparatively low	intermediate ionization energies	comparatively high
General chemical behaviour	Metallic	Nonmetallic	nonmetallic
When mixed with metals	give alloys	can form alloys	ionic or interstitial compounds formed

Applications of Metalloids:

Metalloids can not be used as structural material in their pure form. Their compounds are used in alloying components, catalysts, flame retardants, biological agents, glasses (oxide and metallic), and optical storage media. They are also used in optoelectronics, pyrotechnics, semiconductor and electronics.

Alloys

Copper-germanium alloy pellets having composition of 84% Cu and 16% Ge when combined with silver gives a tarnish resistant sterling silver.

"Some non- metallic elements can form compounds of distinctly metallic character with metals so these metals can go into the composition of alloys". Silicon, arsenic and tellurium are alloy-forming elements. Best classed alloys can be formed by combining silicon, germanium, arsenic and antimony with B metals such as lead, gold, palladium, platinum, mercury .

Lighter metalloids generally forms alloys with transition metals.

- Boron can form intermetallic compounds and alloys. The composition MnB is formed with the transition metals. Ferro boron is used to mix boron into steel. Nickel –boron alloys are also used in case hardening compositions for the engineering industry.
- In the automotive industry alloys of silicon with iron and with aluminium are used popularly.
- Germanium also forms many alloys, it forms alloys mainly with the coinage metals.

Biological agents

All six elements which are recognized as metalloids have medicinal, toxic or dietary properties. Arsenic and antimony compounds are mainly toxic. Boron, silicon, and arsenic are essential trace elements. In medical field applications boron, silicon, arsenic and antimony are used. Germanium and tellurium have potential to be used in medical application.

Boron has application as insecticide and herbicides. Boron is an essential trace element. It also has antiseptic, antifungal and antiviral properties in the boric acid form. Silicon is present in a highly toxic rodenticide namely silatrane. Inhalation of silica dust for a long time can

cause silicosis. It is a fatal disease of lungs. Silicon is a trace element. Silicon gel can be used on scars of badly burned patients.

If the salts of germanium are ingested for a long time, they can be very harmful to the humans. Germanium compounds can also be used for the pharmacological actions but till now there is no such medicine.

Catalysts

Boron compounds are used as catalysts in electronics and organic synthesis like boron trifluoride and trichloride. In the manufacturing of diborane, tribromide is used. Toxic phosphorus ligands can be replaced by non-toxic boron ligands in transition metal catalysts. Silica sulfuric acid has application in organic reactions. PET plastic for containers can be produced by keeping germanium dioxides as catalyst.

Flame retardants

Compounds of boron and silicon have application in the flame retardants. Borax, the compound of boron is used as flame retardant. It has this application since 18^{th} century. Silicones, silica and silicates, silanes, some of which were developed as alternative to the poisonous compounds. These can improve the flame retardancy of plastic materials. The use of phosphorus based flame retardants like organophosphates has exceeded the use of any other main retardant types.

Glass formation

Optical fibres are usually made of silicon dioxide glass. The additives such as boron trioxide or germanium dioxide are used for increasing sensitivity.

Some oxides B_2O_3, SiO_2 and GeO_2 can form glasses easily.

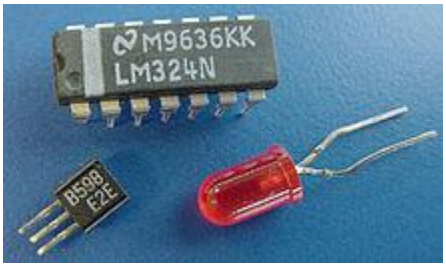
Boron trioxide is also a component of borosilicate glass besides used as a glass fibre additive. It is extensively used in laboratory glassware and domestic ovenware because of its low thermal expansion capacity. Majority of the ordinary glassware is made up of silicon dioxide. Germanium dioxide also found application in infrared optical systems.

To form amorphous metallic glasses readily, metalloids or near metalloid element such as boron, carbon, silicon, phosphorous or germanium should be used.

Pyrotechnics

Metalloids have pyrotechnic applications. They also have some associated properties to pyrotechnic. Boron and silicon are used as metal fuels. Boron is used in compositions of pyrotechnic initiators.It is used to ignite hard to start compositions. It is also used in delay compositions that burn at a constant rate. Boron carbide can be used as a replacement of toxic barium or hexachloroethane mixtures. It is used in smoke munitions, signal flares and fireworks. Silicon is also a part of delay mixture and initiator. Thermite fuel are made from the doped germanium.

Semiconductors and electronics



Semiconductor-based electronic components are shown in the above figure. There is a transistor, an IC and a Light Emitting Diode. In electronic devices, the metalloids are used widely. They are used as elemental or compound semiconductor constituents such as Si, Ge or GaAs or as doping agents such as B, Te, Sb.

Usually all recognized metalloids are used in the semiconductor or solid-state electronic industries.

Boron has properties which limited its use as a semiconductor. It has a high melting point, single crystal is comparatively hard to obtain, and it is difficult to introduce and retain controlled impurities.

Silicon is the main commercial semiconductor. It is the base of modern electronics which includes standard solar cells and information and communication technologies.

Silicon has more uses in semiconductor devices so it is replacing germanium at a large scale. Silicon is cheaper, more resilient at high temperature. It can be easily handled during the fabrication process. *Germanium is still a part of semiconducting silicon- germanium alloys. These alloys are growing in use in the field of wireless communication devices. Such alloys show higher carrier mobility.*

In 2013, the synthesis of gram scale quantities of semiconducting germanane was reported. This includes one atom thick sheet of hydrogen terminated germanium atoms which look like graphene. The conduction of electron is ten times faster than silicon and five times faster than germanium in this sheet. It can be used in optoelectronic and sensing applications.

The development of a germanium wire based anode was reported in 2014 which has double the capacity of lithium ion batteries. Defect free crystal of graphene which has electronic uses can be grown on and removed from a germanium substrate.

Out of the six commonly recognized metalloids boron, silicon and germanium will be used as the target layer materials. Ions' ranges and loss of energy in inelastic and elastic collisions will be calculated. Irradiation of ions will be done on the Single, double and triple layers of B, Si, Ge .Vacancies created and the energy lost in ionization and phonons will be calculated and the results obtained will be discussed.

In this chapter the mechanism of interaction of ions with the target atoms will be discussed.

The interaction of ions with the matter will be analyzed with the help of TRIM simulation .TRIM stands for "Transport of Ions in Matter". TRIM calculates the energy transferred to the target atoms. In TRIM software complex targets can be made .It can analyze data up to eight layers each of different materials but this study is only for three layers .It calculates the distribution of the ions in the matter as well as the phenomenon associated with the ion's energy loss ,i.e. target damage , sputtering ,ionization and phonon production.

Terms used in evaluating the damage process :

In this section some basic terms used in evaluating the damage process of a solid target are defined.

Some parts of target damage are defined below:

• **Displacement =** In this process an energetic ion knocks out a target atom from its site.

• **Vacancy =** It is a target site where no atom is present .initially all lattice sites are filled with the atoms but incident ions creates vacancy by knocking out the target atom.

• **Interstitial Atoms =** Some atoms are knocked out by the incident ions, if they come to rest within the target then they are called interstitial atoms. Also the incident ions, if they come to rest within the target are called interstitial atoms.

• **Replacement Collisions =** Replacement collision is the process in which an atom site is filled by new identical atom. A vacancy may be reoccupied in this mechanism only.

• $\mathbf{E_{disp}}$ **=** It stands for Displacement Energy. It is the minimum amount of energy which is required to displace an atom far enough away from its site so that it does not come back immediately. This energy creates a vacancy and an interstitial atom.

• $\mathbf{E_{latt}}$ **=** It stands for Lattice Binding Energy. It is the minimum energy required to break electronic bonds and displace an atom from lattice site. The lattice binding energy must be smaller than the Displacement Energy.

• $\mathbf{E_{surf}}$ **=** It stands for Surface Binding Energy. It is the energy required to remove a surface atom from its lattice site. A surface atom is not attached to the other atoms on one side whereas an inside atom is surrounded by the atoms. This energy is important for calculating sputtering which is the removal of surface atoms.

• **E_{final} =** It stands for Final Energy of a moving atom. The final energy of an atom is the energy possessed by an atom when it is about to come to rest. At this energy all kinetic phenomenon comes to an end. This energy is a very low in magnitude.

For germanium targets, the default values are:

E_{latt} = 2eV, E_{surf} = 3.88eV, E_{disp} = 15eV and $E_{final} \approx$ 1.9 eV.

The atoms which will be ejected from the lattice site by the impact of moving atoms,will have energy equal to $E_{recoil.}$

$E_{recoil} = E_{disp} - E_{latt}$, if the energy of the recoiled target atom is more than E_{disp} then it create further vacancies by hitting other target atoms.

There is special damage type that must be considered. If the incident atom is the same element as the atom that it hits, then the incident atom might transfer is energy to the target atom, knock it out of its lattice site, and the incident atom will then take its place in the lattice, while the hit atom moves on. This is called a Replacement Collision. Although this may sound complicated, this mechanism may reduce the total vacancies by up to 30%.

Three different coditions must be met for a Replacement Collision.

(1) The incident atom must end with less energy than E_{final} (it must come to rest).

(2) The struck atom must have enough energy to move on, i.e. its energy is greater than E_{disp}.

(3) The moving atom must be identical to the target atom.

There are certain assumptions to consider in the calculation of cascades, target displacements, replacement collisions, etc. These are defined below:

• Assume an incident atom has atomic number Z_1, it collides with another atom with atomic number Z_2 within the target .Suppose the energy of incident ion is E and after collision, the energy of incident ion is E_1 and the energy of struck atom is E_2.

• If the energy acquired by the struck atom (E_2) is greater than the displacement energy E_{disp} then atomic displacement occurs. A vacancy is created if E_1 and E_2 both are greater than $E_{disp.}$ It means both the atoms have enough energy to leave the site. In this way both the atoms become moving atoms of the cascade.

The energy of the atom Z_2 is reduced by E_{latt} before next collision. So if its energy after collision is less than E_{disp} then it will not be able to knock out another atom. In this case it will vibrate back to its original site releasing E_2 as phonons. It is the energy deposited into crystal lattice vibrations.

• If, after a collision,E_1 is less than E_{disp} and E_2 is greater than E_{disp} and the incident and struck atom has same atomic numbers ($Z_1 = Z_2$) then the incident atom will take place of the struck atom ,this collision is called replacement collision . The energy possessed by the atom Z_1 will be released as phonons . The atom in the lattice site remains the same atom by exchange. This type of collision is common in single elements targets with large recoil cascade. If E_1 is less than E_{disp} and E_2 is greater than E_{disp} and $Z_1 \neq Z_2$, then Z_1 comes to rest within the target as interstitial atom.

• If E_1 and E_2 both are less than E_{disp}, then Z_1 becomes an interstitial and E_1+E_2 energy will be released as phonons.

These damage types are related. We can relate these with the two equation given below.

Displacements = Vacancies + Replacement Collisions (Eq. 1)

Vacancies + Replacements = Interstitials + Atoms which leave the target volume (Eq. 2)

If the recoiled atom has enough energy than it may leave the target surface. The leaving atoms are discarded and not counted. The final resting place of these atoms will be out of the target. Vacancies will be created in this case and the number of vacancies will be more than the number of interstitial atoms because of the loss of atoms. If any replacement collision occurs, it reduces the number of vacancies and number of interstitial by one.

How does the TRIM software work is explained below. There is an icon SRIM2013 on the screen. The program runs by clicking it ,followed by the "TRIM calculation" button.

Steps followed:

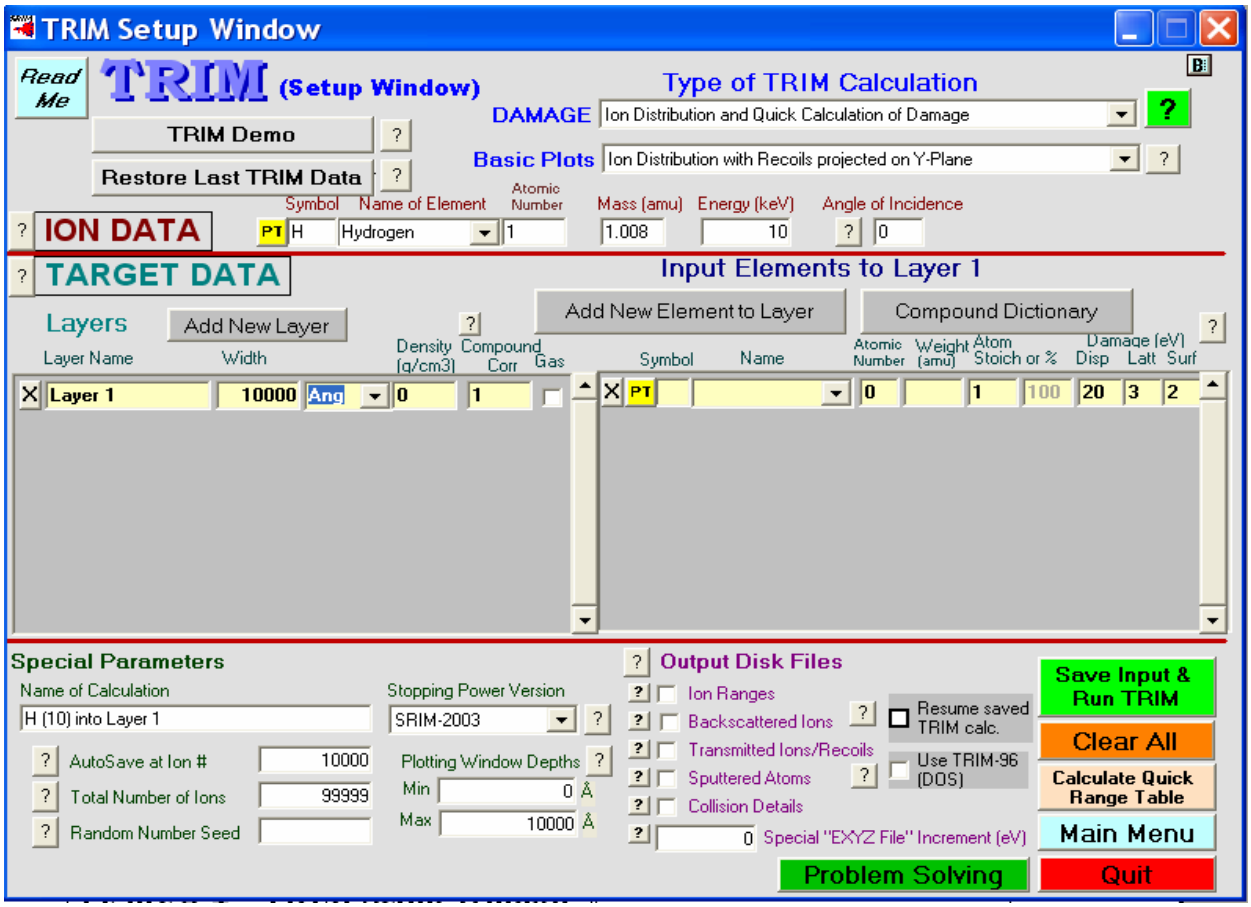
1. **Selecting Calculation type:** There are many types of calculation to choose in TRIM. It allows the user to omit certain aspects of collision kinetics in order to increase the speed of the calculation. In the "Full Damage Cascades" all normal kinetics of the ion collision are considered. In the "Quick" calculation only ion trajectories are calculated, target atom cascades is ignored
2. **Incident ion:** Incident ion data will be entered. Ion can be chosen by entering its atomic number or by typing its chemical abbreviation. A

button marked “PT” gives the periodic table to select ion. The other ion data box will automatically be updated.

3. **Target Data:** In the left box list of target layers can be seen. Target layer can be named by clicking on any target layer. The element present in this layer can be seen in the right box. We can add more than one element in a single layer. The target layer name is used by TRIM in graphs and output files. Name of the layer should be meaningful like boron or silicon. The width of the layer can be entered by keyboard. If the layer is gas than it will be displayed in the gas box otherwise solid will be displayed

4. **Saving data & Running:** After filling the requisite data, click on the button “*Save input and run TRIM*”. The calculation plot will be generated and it will be automatically updated after each ion. It will run until the all ions are passed through the target. When the calculation completes, the plot with the data generated can be printed

A view of TRIM setup window is shown below;



In the single layer analysis, we will calculate the ranges of ions in the target atom layer for different energies. In this study we will use proton, boron and phosphorous as the incident ions on the target layers of boron, silicon and germanium. We are selecting 6000 A° as the width of the layer in each case. By using SRIM, we will calculate the ion's energy sufficient to make it reach at end of the layer. Then using this energy we will do the TRIM calculation to see the impact of ion on the target atom.

The different results obtained will be analyzed with the results obtained from the impact of other ions on the same or the different target.

When an ion slows down and comes to rest in the target layer, a number of collisions are made with the lattice atoms. In these collisions, ion will loses its energy at a rate of dE/dx of a few electrons - volts per nanometer, depending on its impacted energy. The range R can be determined by the rate of energy loss along the path of the ion.

$$R = \int_{E_i}^{0} \frac{1}{dE/dx} \, dE$$

E_i = is the incident energy of the ion as it penetrates the solid. R is defined as the total distance that the projectile travels in coming to rest.

In the subsequent sections, we will see the impact of ions on the single, double and triple layers formed by boron, silicon and germanium arranged in different patterns.

This chapter has been devoted to presentation and description of empirical results and findings with regard to objectives of the study. Number of ions irradiated is 1000 for each layer study.

In the process of ionization energy is lost in the target electrons. The target electrons absorb energy from the fast moving ions and recoil atoms. This energy acquired by the electron will be released in two forms namely heat and phonons. In metals, it will be released as the heat energy and in case of insulators, it will be released as phonons.

Phonons are energy captured in atomic vibrations in a crystal. These vibrations are caused by the atoms which do not have enough energy to displace any target atom. So they release their energy in the form of crystal lattice vibrations. As all the atoms in the crystal are linked, if one atom vibrates then the other attached atoms also start vibrating. This mass vibration is called phonon.

In the process of *sputtering,* surface atoms are removed from the target by creating recoil cascades coming back. These back cascades give enough energy to the surface atoms to leave the target surface. Surface atoms are bound by a force called surface binding energy. If the energy given by the back cascade is greater than the E_{surf} , then electronic bonds will break and the surface atom will leave the target. Surface binding energy is always less than the displacement energy.

Interface Mixing is the process of mixing of atoms of one layer to the next layer. When the ion gives enough energy to the atoms of a layer then it moves long distance and enter into the next layer. In this way second layer is contaminated. It is an undesirable effect but in some

cases it is done intentionally. It is used to modify materials on purpose, this process is called “recoil implantation”. The materials which are dangerous or difficult to handle will be treated by this method.

An example is the fabrication of materials containing radioactive substances. For example, a thin layer of calcium may be deposited on a target of silicon, and then it is placed in a nuclear reactor to convert the calcium to a radioactive isotope.

If an energetic ion hits a target atom , it will transfer a significant portion of its energy. If the ion / target atom masses are very different, then there is much less energy transferred to the target atom. If the mass of ion is almost the same as the mass of target atom then the energy transfer will be higher. This is basic physics of the elastic collision of two particles. Every time there is a hard ion/atom hit, and a cascade is formed, there is a good chance that the ion changes direction.

When there is a collision of ion with a target atom, one vacancy created. The target atom then recoils and interact with the other atoms, subsequent collisions which cause vacancies are plotted with a different color.

In this study, five ions are chosen which will interact with the target atoms. Proton, boron, phosphorus, aluminum and copper ions will

interact with the layers of boron, silicon and germanium. In the first part interaction of each ion is analyzed on single layer of one element as target. In the second part ions interact with the double layer target and finally a triple layer target is chosen to get interacted with the ions.

The final distribution of the ions and also all kinetic phenomena associated with the ion's energy loss: target damage, ionization, and phonon production are discussed with the help of the plots.

Before the single layer analysis the ranges of ions in the target will be obtained, for this SRIM software simulation will be used. After entering the ion and the target details, the software gives the ranges of ions for different energies. Tables showing the energy and the corresponding ranges along with the inelastic and elastic energy loss are obtained. As there are three layers in study so for each ion there will be three tables. For these tables, projected range Vs ion energy plots are also shown below.

The energy loss, dE/dx of proton in boron can be divided into two parts: the energy transferred by the proton to the B electrons (called electronic stopping or inelastic energy loss) and to the B nuclei (called nuclear stopping or elastic energy loss). The nuclear stopping and electronic stopping energy loss of proton in B at different energy level are as shown in Table 3.1. *It is found that the electron energy loss is always higher than the nuclear energy loss.*

TABLE 3.1: THE ELECTRONIC STOPPING AND NUCLEAR STOPPING ENERGY LOSS OF PROTON ION IN BORON

Ion Energy (keV)	dE/dx Electron (keV/ µm)	dE/dx Nuclear (kev/ µm)	Projected Range (A)
10	4.246 E-01	5.456 E-03	1194
100	7.170 E-01	9.400 E-04	6601
200	5.565 E-01	5.297 E-04	13300
300	4.515 E-01	3.764 E-04	21800
400	3.827 E-01	2.947 E-04	32100
500	3.342 E-01	2.434 E-04	43900
600	2.981 E-01	2.080 E-04	57400
700	2.700 E-01	1.821 E-04	72400
800	2.475 E-01	1.822 E-04	88800
900	2.290 E-01	1.464 E-04	106600
1000	2.134 E-01	1.336 E-04	125800

The electron energy loss is due to the following processes:

1) Direct kinetic energy transfers to B electrons which is caused by the electron-electron collisions

2) Excitation, ionization of target atoms,

3) Excitation of band or conduction electrons,

4) Excitation, ionization or electron capture of the projectile itself.

The projected range of Proton in energy range from 10keV to 1000keV is as shown in the plotting of Fig. 3.1.

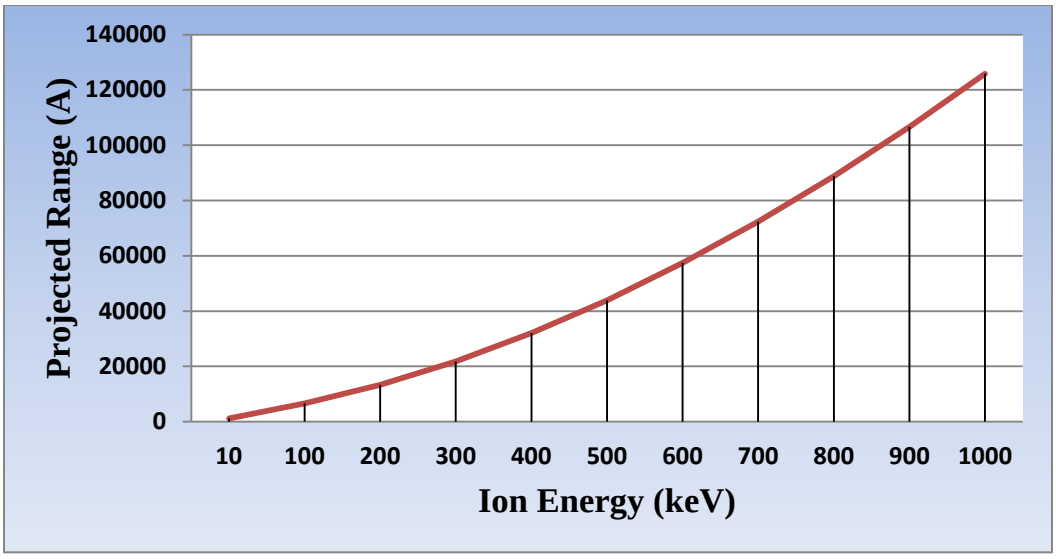


Fig. 3.1: Projected range, *Rp* of proton in Boron.

The energy loss, dE/dx of Boron, Phosphorous, Aluminum and copper ions can also be divided into two parts: the energy transferred by the ions to the B electrons (called electronic stopping or inelastic energy loss) and to the B nuclei (called nuclear stopping or elastic energy loss). The nuclear stopping and electronic stopping energy loss of ions in B at different energy level are as shown in Table 3.2, 3.3, 3.4 & 3.5 respectively.

TABLE 3.2: THE ELECTRONIC STOPPING AND NUCLEAR STOPPING ENERGY LOSS OF BORON ION IN BORON

Ion Energy (keV)	dE/dx Electron (keV/ µm)	dE/dx Nuclear (kev/ µm)	Projected Range (A)
10	6.488 E-01	5.124 E-02	319
100	2.215 E-01	1.449 E-02	2255
200	2.689 E-01	8.847 E-02	3860
300	3.069 E-01	6.530 E-02	5277
400	3.423 E-01	5.235 E-02	6551
500	3.748 E-01	4.398 E-02	7711
600	4.044 E-01	3.808 E-02	8784
700	4.310 E-01	3.368 E-02	9788
800	4.546 E-01	3.025 E-02	10700
900	4.755 E-01	2.751 E-02	11600
1000	4.937 E-01	2.525 E-02	12500
2000	5.801 E-01	1.426 E-02	20200
3000	5.868 E-01	1.014 E-02	27500

TABLE 3.3: THE ELECTRONIC STOPPING AND NUCLEAR STOPPING ENERGY LOSS OF PHOSPHORUS ION IN BORON

Ion Energy (keV)	dE/dx Electron (keV/ µm)	dE/dx Nuclear (kev/ µm)	Projected Range (A)
10	6.472 E-01	2.790 E+00	131
100	2.427 E+00	1.663 E+00	1063
200	3.311 E+00	1.174 E+00	2007
300	4.023 E+00	9.281 E-01	2872
400	4.554 E+00	7.759 E-01	3674
500	5.002 E+00	6.713 E-01	4427
600	5.414 E+00	5.942 E-01	5140
700	5.800 E+00	5.347 E-01	5817
800	6.164 E+00	4.873 E-01	6461
900	6.510 E+00	4.484 E-01	7077
1000	6.841 E+00	4.159 E-01	7667
2000	9.606 E+00	2.489 E-01	12600
3000	1.172 E+01	1.820 E-01	16500

The projected range of Boron, Phosphorous, Aluminum and copper ions in energy range from 10keV to 3000keV is as shown in the plotting of Fig. 3.2, 3.3, 3.4 &3.5 respectively.

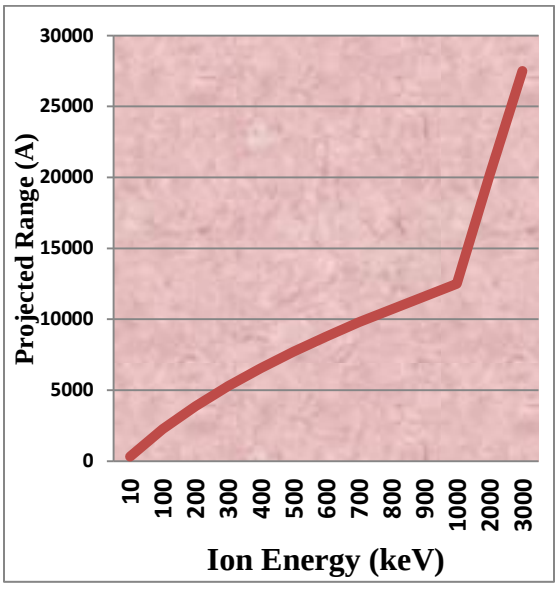


Fig. 3.2: Projected range, *Rp* of Boron ion in Boron.

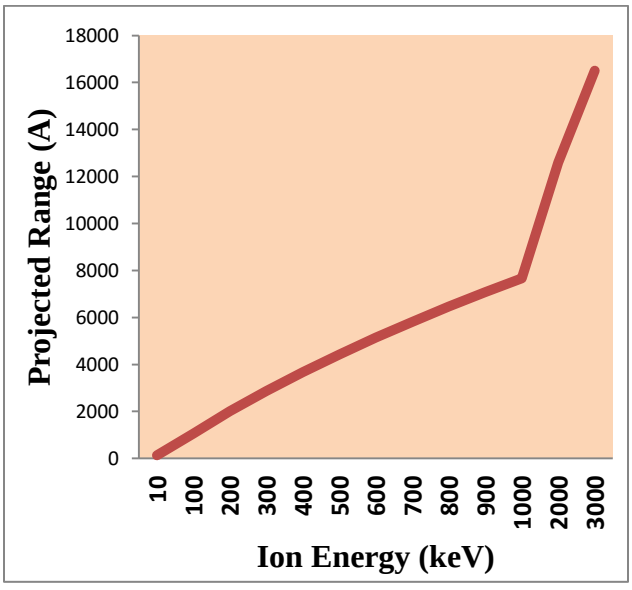


Fig. 3.3: Projected range, *Rp* of Phosphorous ion in Boron.

TABLE 3.4: THE ELECTRONIC STOPPING AND NUCLEAR STOPPING ENERGY LOSS OF ALUMINIUM ION IN BORON

Ion Energy (keV)	dE/dx Electron (keV/ µm)	dE/dx Nuclear (kev/ µm)	Projected Range (A)
10	4.870 E-01	2.355 E+00	148
100	1.766 E+00	1.251 E+00	1342
200	2.502 E+00	8.597 E-01	2612
300	3.145 E+00	6.706 E-01	3746
400	3.645 E+00	5.563 E-01	4771
500	4.097 E+00	4.786 E-01	5713
600	4.498 E+00	4.218 E-01	6589
700	4.869 E+00	3.784 E-01	7409
800	5.216 E+00	3.439 E-01	8183
900	5.545 E+00	3.157 E-01	8917
1000	5.860 E+00	2.923 E-01	9615

TABLE 3.5: THE ELECTRONIC STOPPING AND NUCLEAR STOPPING ENERGY LOSS OF COPPER ION IN BORON

Ion Energy (keV)	dE/dx Electron (keV/ µm)	dE/dx Nuclear (kev/ µm)	Projected Range (A)
10	3.178 E-01	5.037 E+00	105
100	1.005 E+00	5.175 E+00	674
200	2.069 E+00	4.319 E+00	1308
300	2.295 E+00	3.719 E+00	1963
400	2.668 E+00	3.283 E+00	2626
500	3.119 E+00	2.952 E+00	3327
600	3.567 E+00	2.690 E+00	3993
700	3.981 E+00	2.477 E+00	4641
800	4.357 E+00	2.300 E+00	5270
900	4.699 E+00	2.151 E+00	5882
1000	5.014 E+00	2.022 E+00	6479

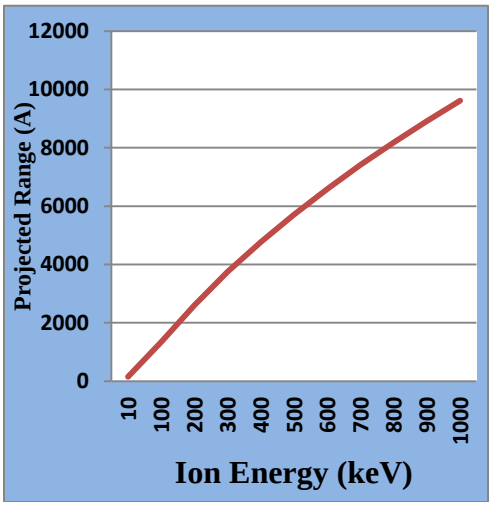


Fig. 3.4: Projected range, *Rp* of Aluminum ion in Boron

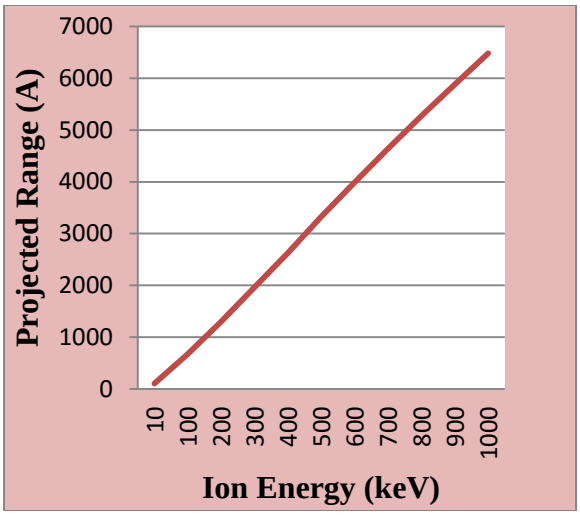


Fig. 3.5: Projected range, *Rp* of Copper ion in Boron

The energy loss, dE/dx of Proton, Boron, Phosphorous, Aluminum and copper ions in the Silicon and Germanium layer can also be seen in tables 3.6, 3.7, 3.8, 3.9, 3.10, 3.11, 3.12, 3.13, 3.14 and 3.15 respectively.

TABLE 3.6: THE ELECTRONIC STOPPING AND NUCLEAR STOPPING ENERGY LOSS OF PROTON IN SILICON

Ion Energy (keV)	dE/dx Electron (keV/ µm)	dE/dx Nuclear (kev/ µm)	Projected Range (A)
10	3.131 E-01	4.222 E-03	1342
100	4.957 E-01	8.673 E-04	8692
200	3.930 E-01	5.030 E-04	18300
300	3.288 E-01	3.624 E-04	30200
400	2.861 E-01	2.862 E-04	44100
500	2.554 E-01	2.379 E-04	59900
600	2.321 E-01	2.043 E-04	77500
700	2.137 E-01	1.795 E-04	96700
800	1.986 E-01	1.604 E-04	117400
900	1.861 E-01	1.452 E-04	139700
1000	1.755 E-01	1.328 E-04	163300
2000	1.124 E-01	7.331 E-04	476900
3000	8.486 E-01	5.156 E-04	920500

TABLE 3.7: THE ELECTRONIC STOPPING AND NUCLEAR STOPPING ENERGY LOSS OF BORON ION IN SILICON

Ion Energy (keV)	dE/dx Electron (keV/ µm)	dE/dx Nuclear (kev/ µm)	Projected Range (A)
10	3.912 E-01	3.418 E-01	400
100	1.249 E+00	1.278 E-01	3180
200	1.631 E+00	8.179 E-02	5749
300	2.043 E+00	6.172 E-02	7888
400	2.433 E+00	5.016 E-02	9690
500	2.774 E+00	4.255 E-02	11300
600	3.062 E+00	3.711 E-02	12700
700	3.299 E+00	3.301 E-02	14000
800	3.493 E+00	2.979 E-02	15200
900	3.649 E+00	2.719 E-02	16400
1000	3.775 E+00	2.505 E-02	17500
2000	4.188 E+00	1.442 E-02	28000
3000	4.135 E+00	1.035 E-02	38300

TABLE 3.8: THE ELECTRONIC STOPPING AND NUCLEAR STOPPING ENERGY LOSS OF PHOSPHORUS ION IN SILICON

Ion Energy (keV)	dE/dx Electron (keV/ µm)	dE/dx Nuclear (kev/ µm)	Projected Range (A)
10	3.902 E-01	1.868 E+00	169
100	1.376 E+00	1.403 E-01	1342
200	1.914 E+00	1.054 E-01	2612
300	2.267 E+00	8.589 E-01	3864
400	2.609 E+00	7.318 E-01	5069
500	2.964 E+00	6.416 E-01	6207
600	3.327 E+00	5.736 E-01	7272
700	3.692 E+00	5.203 E-01	8266
800	4.051 E+00	4.772 E-01	9194
900	4.401 E+00	4.415 E-01	10100
1000	4.740 E+00	4.414 E-01	10900
2000	7.358 E+00	2.526 E-01	17400
3000	8.927 E+00	1.870 E-01	22400

TABLE 3.9: THE ELECTRONIC STOPPING AND NUCLEAR STOPPING ENERGY LOSS OF ALUMINIUM ION IN SILICON

Ion Energy (keV)	dE/dx Electron (keV/ µm)	dE/dx Nuclear (kev/ µm)	Projected Range (A)
10	2.936 E-01	1.559 E+00	191
100	1.021 E+00	1.061 E+00	1673
200	1.429 E+00	7.751 E-01	3366
300	1.778 E+00	6.228 E-01	5006
400	2.134 E+00	5.261 E-01	6533
500	2.494 E+00	4.584 E-01	7933
600	2.853 E+00	4.080 E-01	9214
700	3.203 E+00	3.687 E-01	10400
800	3.543 E+00	3.372 E-01	11500
900	3.870 E+00	3.112 E-01	12500
1000	4.183 E+00	2.893 E-01	13400

TABLE 3.10: THE ELECTRONIC STOPPING AND NUCLEAR STOPPING ENERGY LOSS OF COPPER ION IN SILICON

Ion Energy (keV)	dE/dx Electron (keV/ µm)	dE/dx Nuclear (kev/ µm)	Projected Range (A)
10	1.916 E-01	3.676 E+00	128
100	6.059 E-01	4.330 E+00	791
200	1.170 E+00	3.814 E+00	1531
300	1.349 E+00	3.386 E+00	2308
400	1.545 E+00	3.052 E+00	3129
500	1.771 E+00	2.785 E+00	3974
600	2.010 E+00	2.568 E+00	4826
700	2.251 E+00	2.387 E+00	5675
800	2.492 E+00	2.233 E+00	6515
900	2.729 E+00	2.102 E+00	7343
1000	2.963 E+00	1.987 E+00	8155

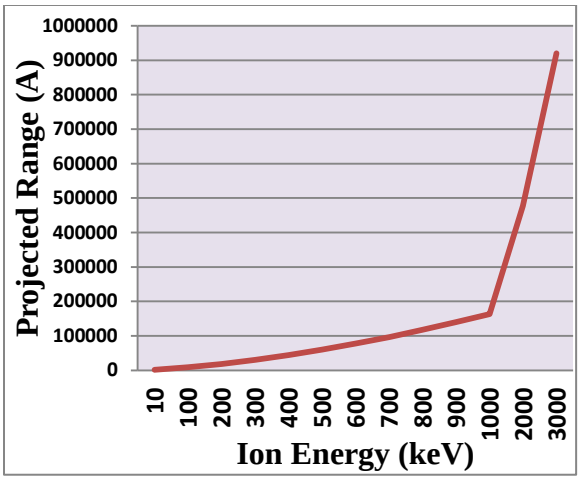


Fig. 3.6: Projected range, *Rp* of proton in Silicon.

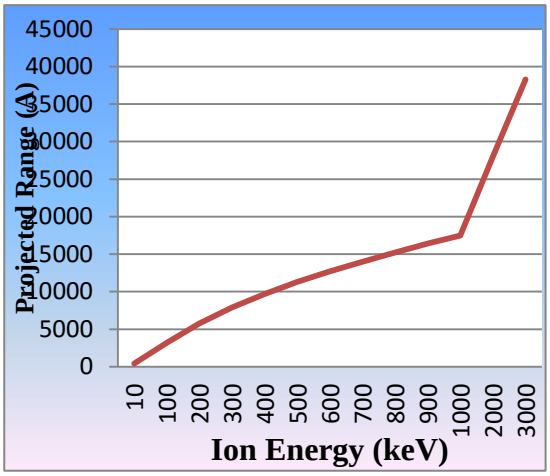


Fig. 3.7: Projected range, *Rp* of Boron ion in Silicon.

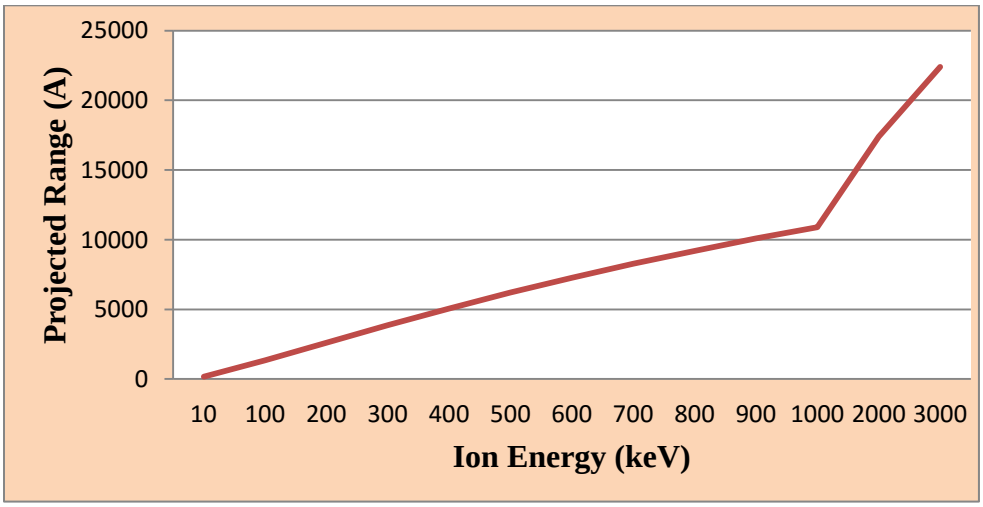


Fig. 3.8: Projected range, *Rp* of Phosphorous ion in Silicon.

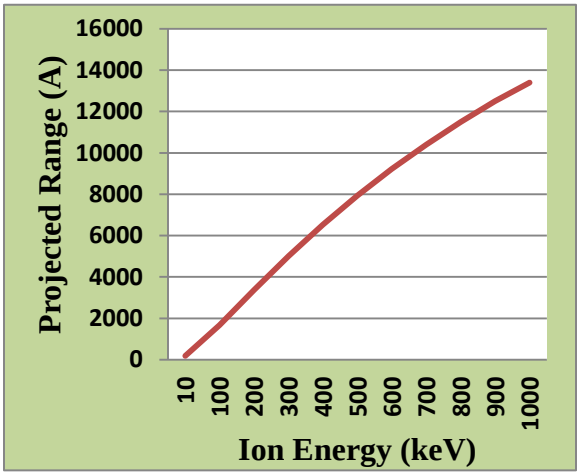


Fig. 3.9: Projected range, *Rp* of aluminum in Silicon.

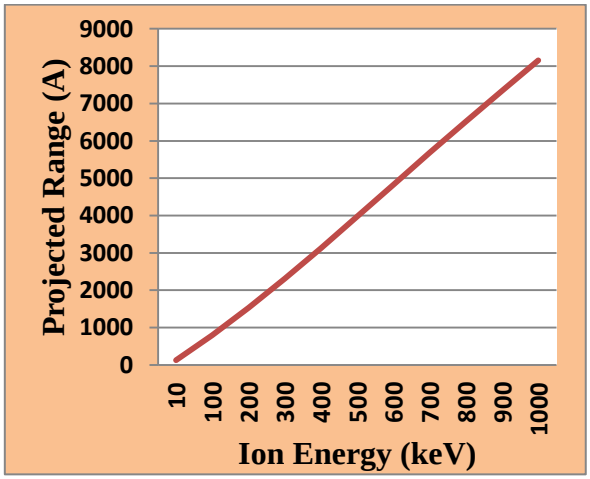


Fig. 3.10: Projected range, *Rp* of copper in Silicon.

TABLE 3.11: THE ELECTRONIC STOPPING AND NUCLEAR STOPPING ENERGY LOSS OF PROTON IN GERMANIUM

Ion Energy (keV)	dE/dx Electron (keV/ µm)	dE/dx Nuclear (kev/ µm)	Projected Range (A)
10	1.454 E-01	2.084 E-03	900
100	2.472 E-01	5.333 E-04	7066
200	2.152 E-01	3.203 E-04	14700
300	1.909 E-01	2.346 E-04	23600
400	1.723 E-01	1.872 E-04	33600
500	1.576 E-01	1.568 E-04	44600
600	1.456 E-01	1.354 E-04	56600
700	1.356 E-01	1.195 E-04	69600
800	1.271 E-01	1.072 E-04	83500
900	1.198 E-01	9.732 E-05	98300
1000	1.135 E-01	8.924 E-05	114100
2000	7.637 E-02	5.004 E-05	316300
3000	5.934 E-02	3.547 E-05	592600

TABLE 3.12: THE ELECTRONIC STOPPING AND NUCLEAR STOPPING ENERGY LOSS OF BORON ION IN GERMANIUM

Ion Energy (keV)	dE/dx Electron (keV/ µm)	dE/dx Nuclear (kev/ µm)	Projected Range (A)
10	1.689 E-01	1.404 E-01	261
100	6.125 E-01	7.172 E-02	2199
200	8.058 E-01	4.886 E-02	4109
300	9.704 E-01	3.796 E-02	5823
400	1.121 E+00	3.140 E-02	7359
500	1.255 E+00	2.697 E-02	8756
600	1.373 E+00	2.374 E-02	10000
700	1.477 E+00	2.127 E-02	11300
800	1.569 E+00	1.932 E-02	12400
900	1.651 E+00	1.772 E-02	13500
1000	1.723 E+00	1.640 E-02	14500
2000	2.152 E+00	9.674 E-03	23700
3000	2.336 E+00	7.027 E-03	31900

TABLE 3.13:THE ELECTRONIC STOPPING AND NUCLEAR STOPPING ENERGY LOSS OF PHOSPHOROUS ION IN GERMANIUM

Ion Energy (keV)	dE/dx Electron (keV/ µm)	dE/dx Nuclear (kev/ µm)	Projected Range (A)
10	1.685 E-01	8.025 E-01	116
100	5.998 E-01	7.508 E-01	899
200	8.977 E+00	6.056 E-01	1765
300	1.118 E+00	5.118 E-01	2630
400	1.305 E+00	4.464 E-01	3473
500	1.476 E+00	3.978 E-01	4289
600	1.636 E+00	3.602 E-01	5074
700	1.789 E+00	3.300 E-01	5829
800	1.935 E+00	3.051 E-01	6555
900	2.075 E+00	2.842 E-01	7252
1000	2.209 E+00	2.663 E-01	7924
2000	3.296 E+00	1.689 E-01	13600
3000	4.102 E+00	1.269 E-01	18200

TABLE 3.14: THE ELECTRONIC STOPPING AND NUCLEAR STOPPING ENERGY LOSS OF ALUMINIUM ION IN GERMANIUM

Ion Energy (keV)	dE/dx Electron (keV/ µm)	dE/dx Nuclear (kev/ µm)	Projected Range (A)
10	1.268 E-01	6.571 E-01	130
100	4.554 E-01	5.684 E-01	1095
200	6.825 E-01	4.463 E-01	2218
300	8.860 E+00	3.719 E-01	3325
400	1.066 E+00	3.215 E-01	4382
500	1.231 E+00	2.847 E-01	5388
600	1.385 E+00	2.565 E-01	6342
700	1.530 E+00	2.340 E-01	7249
800	1.667 E+00	2.157 E-01	8113
900	1.798 E+00	2.004 E-01	8938
1000	1.923 E+00	1.874 E-01	9728

TABLE 3.15: THE ELECTRONIC STOPPING AND NUCLEAR STOPPING ENERGY LOSS OF COPPER ION IN GERMANIUM

Ion Energy (keV)	dE/dx Electron (keV/ µm)	dE/dx Nuclear (kev/ µm)	Projected Range (A)
10	8.275 E-02	1.822 E+00	83
100	2.617 E-02	2.415 E+00	508
200	5.087 E-01	2.236 E+00	984
300	6.1.1 E-01	2.046 E+00	1484
400	7.231 E-01	1.882 E+00	2014
500	8.544 E-01	1.745 E+00	2561
600	9.901 E-01	1.628 E+00	3114
700	1.122 E+00	1.528 E+00	3669
800	1.246 E+00	1.442 E+00	4224
900	1.364 E+00	1.366 E+00	4776
1000	1.476 E+00	1.299 E+00	5325

The projected range of Proton, Boron, Phosphorous, Aluminum and copper ions in energy range from 10keV to 1000 keV or 3000keV is as shown in the plotting of Fig. 3.6, 3.7, 3.8, 3.9, 3.10, 3.11, 3.12, 3.13, 3.14 and 3.15 respectively.

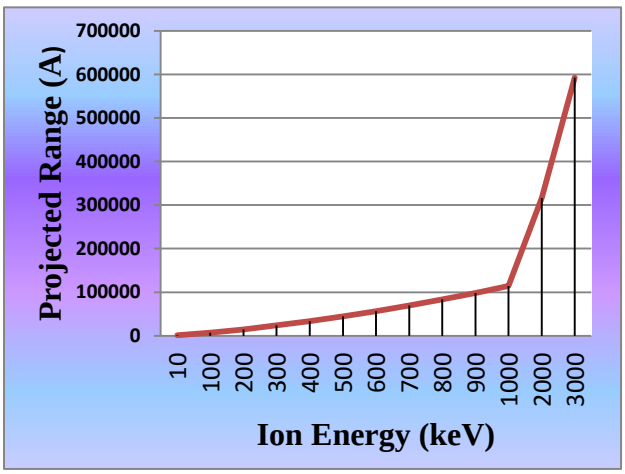


Fig. 3.11: Projected range, Rp of proton ion in Germanium.

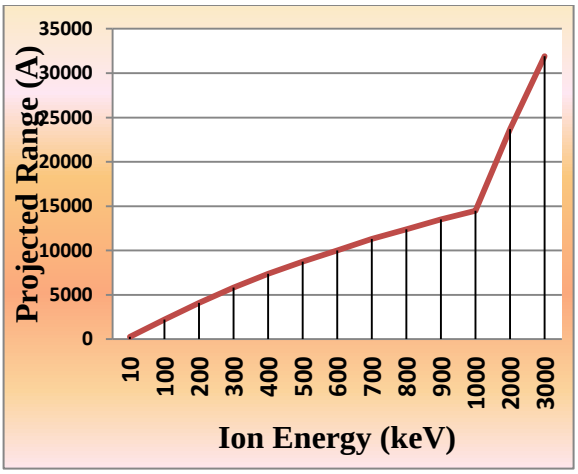


Fig. 3.12: Projected range, Rp of Boron ion in Germanium.

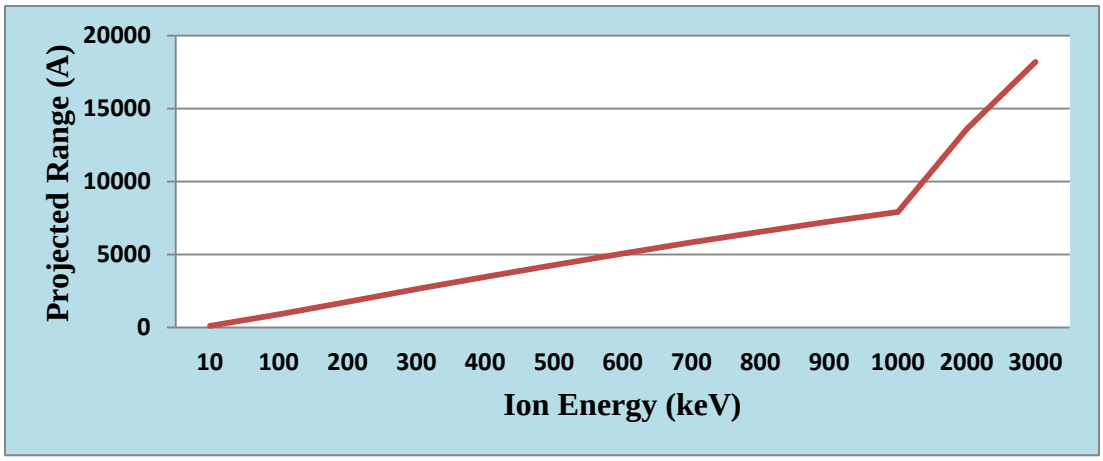


Fig. 3.13: Projected range, Rp of Phosphorous ion in Germanium.

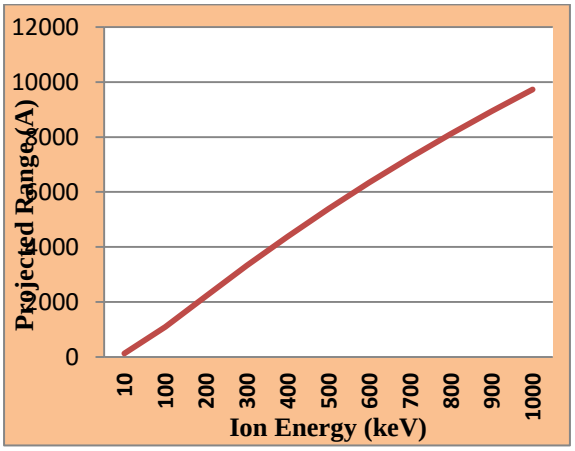


Fig. 3.14: Projected range, Rp of aluminum ion in Germanium.

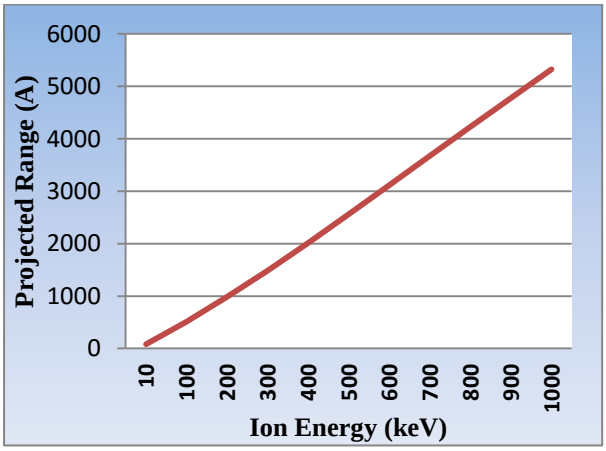


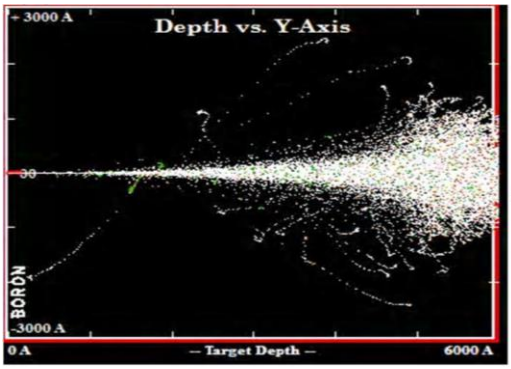
Fig. 3.15: Projected range, Rp of copper ion in Germanium.

There are some plots that show the calculation results for each ion. The red dots are the collisions between the ion and target atoms in which the target atoms are knocked from their lattice sites. The green dots are collisions between recoiling target atoms and other target atoms. The recoiling target atoms make collision cascades which dominate the damage process. The dot is only plotted if the transferred energy is large enough to displace the atom hit from its lattice site. Thus the plot shows the number of displacements which have occurred. There is a different color used to show where each ion stops.

Subsequent ion irradiations lead to the overlaps of the ion paths and then develop a uniform distribution of radiation damage.

Single layer Analysis:

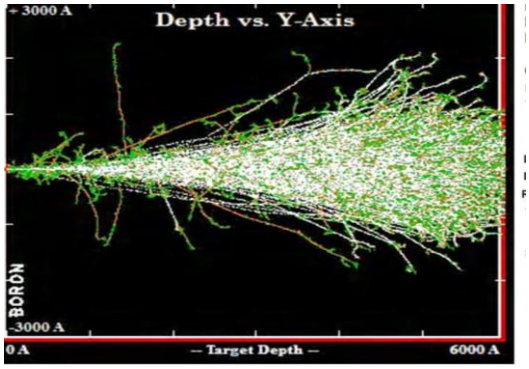
In this section proton ,boron, phosphorous, aluminum and copper ion with energies 85, 310,640,600,1000 in keV were irradiated on the single layers of boron , silicon and germanium respectively .The depth of each layer is 6000 A .



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	B (10.811)	Solid/Gas	Stop Corr.
1	BORON	6000	2.350	1.00000	Solid	1
	Lattice Binding Energy			3		
	Surface Binding Energy			5.73		
	Displacement Energy			25		

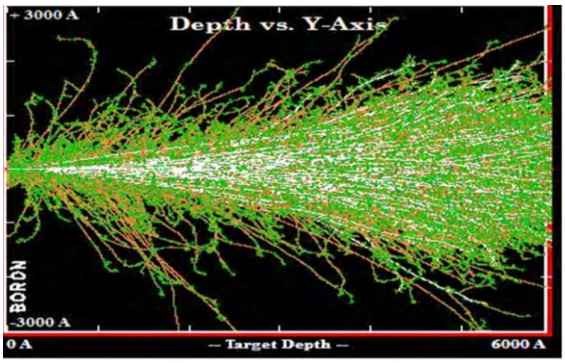
Fig.3.16: Proton into Boron



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	B (10.811)	Solid/Gas	Stop Corr.
1	BORON	6000	2.350	1.00000	Solid	1
	Lattice Binding Energy			3		
	Surface Binding Energy			5.73		
	Displacement Energy			25		

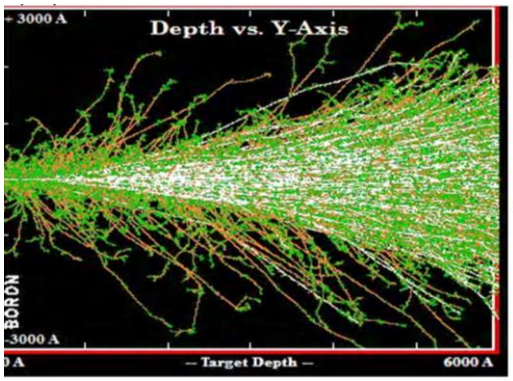
Fig. 3.17: Boron into Boron



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	B (10.811)	Solid/Gas	Stop Corr
1	BORON	6000	2.350	1.00000	Solid	
	Lattice Binding Energy			3		
	Surface Binding Energy			5.73		
	Displacement Energy			25		

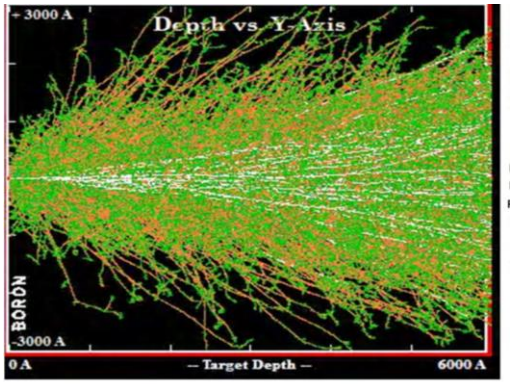
Fig. 3.18:Phosphorous into Boron



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	B (10.811)	Solid/Gas	Stop Corr
1	BORON	6000	2.350	1.00000	Solid	1
	Lattice Binding Energy			3		
	Surface Binding Energy			5.73		
	Displacement Energy			25		

Fig. 3.19: Aluminum into Boron



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	B (10.811)	Solid/Gas	Stop Corr
1	BORON	6000	2.350	1.00000	Solid	1
	Lattice Binding Energy			3		
	Surface Binding Energy			5.73		
	Displacement Energy			25		

Fig. 3.20: Copper into Boron

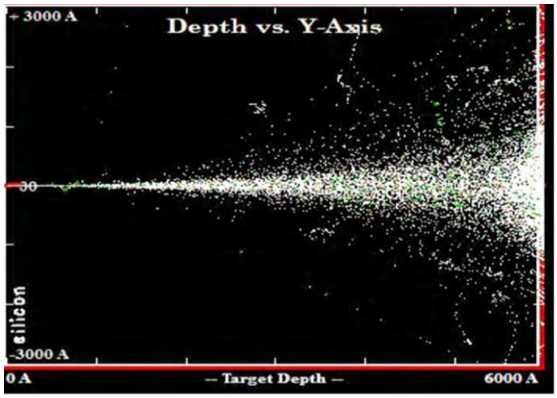
Table 3.16: Interaction and Energy loss of ions in Boron layer

Ion	Energy (keV)	Boron Layer (6000 A)						
		Damage events			% of Energy Loss in Ion		% of Energy Loss in Recoil	
		Total displacements /ion	Total vacancies /ion	Replacement collisions /Ion	Ionization	Phonons	Ionization	Phonons
Proton	85	9	8	0	99.12	0.26	0.15	0.45
Boron	310	321	307	13	91.53	0.51	3.35	4.32
Phosphorous	640	1536	1471	66	75.05	0.56	13.56	10.15
Aluminum	600	1069	1023	45	79.40	0.56	11.17	8.31
Copper	1000	3391	3246	144	51.74	0.55	30.24	16.37

The moving atoms are shown in the red color whereas stopped atoms are shown in green color .it is observed that when the lighter ion like proton is irradiated on the boron , the energy required to penetrate through the target is less but as we go for heavier ions energy required to penetrate through keep on increasing .the lattice binding energy ,surface binding energy and displacement energy for boron layer are 3 eV, 5.73eV and 25 eV respectively .

For boron layer ions' energy loss in ionization is found to be higher than energy loss in phonons .

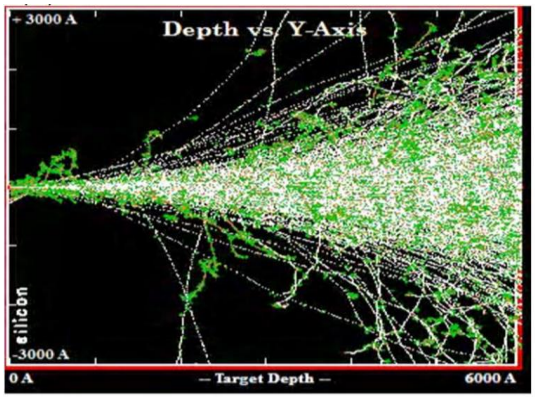
For recoil atoms energy loss is higher in phonons for proton and boron but lower in phonons for P ,Al and Cu ions .



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Si (28.086	Solid/Gas	Stop Corr
1	silicon	6000	2.321	1.00000	Solid	
	Lattice Binding Energy			2		
	Surface Binding Energy			4.7		
	Displacement Energy			15		

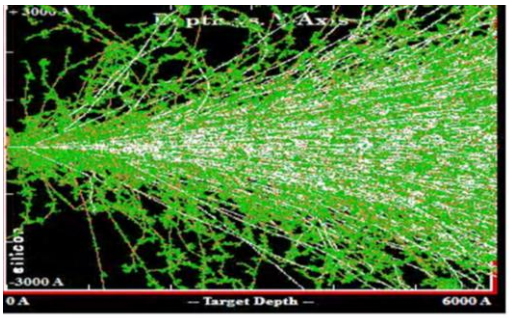
Fig. 3.21: Proton into Silicon



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Si (28.086	Solid/Gas	Stop Corr.
1	silicon	6000	2.321	1.00000	Solid	1
	Lattice Binding Energy			2		
	Surface Binding Energy			4.7		
	Displacement Energy			15		

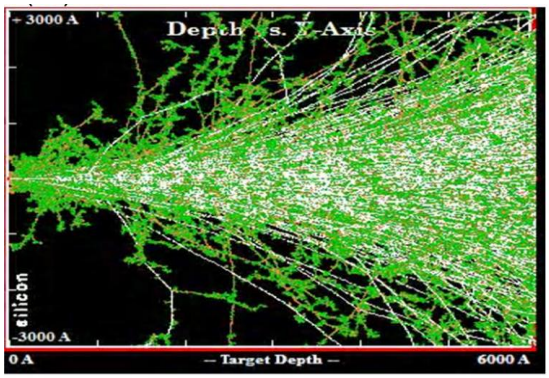
Fig.3.22: Boron into Silicon



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Si (28.086	Solid/Gas	Stop Corr
1	silicon	6000	2.321	1.00000	Solid	
	Lattice Binding Energy			2		
	Surface Binding Energy			4.7		
	Displacement Energy			15		

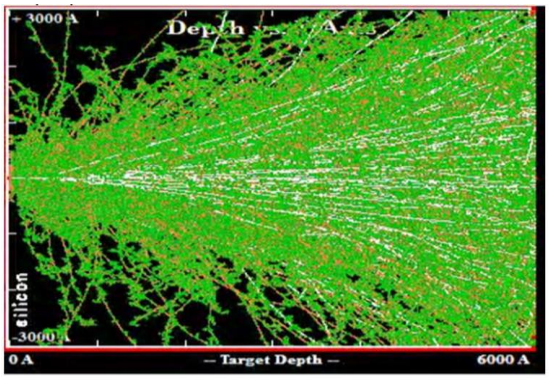
Fig.3.23: Phosphorous into Silicon



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Si (28.086	Solid/Gas	Stop Cor
1	silicon	6000	2.321	1.00000	Solid	
	Lattice Binding Energy			2		
	Surface Binding Energy			4.7		
	Displacement Energy			15		

Fig.3.24: Aluminum into Silicon



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Si (28.086	Solid/Gas	Stop Cor
1	silicon	6000	2.321	1.00000	Solid	
	Lattice Binding Energy			2		
	Surface Binding Energy			4.7		
	Displacement Energy			15		

Fig.3.25: Copper into Silicon

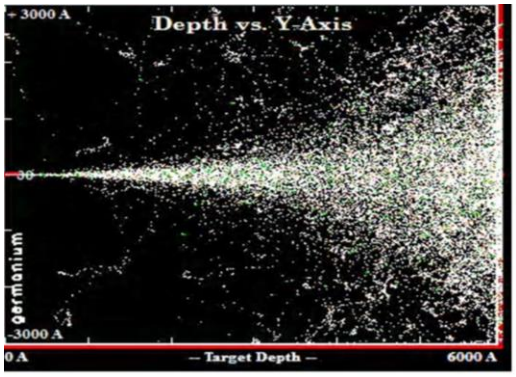
Table 3.17: Interaction and Energy loss of ions in Silicon layer

Ion	Energy (keV)	silicon Layer (6000 A)						
		Damage events			% of Energy Loss in Ion		% of Energy Loss in Recoil	
		Total displacements /ion	Total vacancies /ion	Replacement collisions/Ion	Ionization	Phonons	Ionization	Phonons
Proton	85	7	7	1	99.62	0.06	0.08	0.22
Boron	310	419	386	33	93.45	0.19	2.52	3.53
Phosphorous	640	2733	2518	215	75.31	0.21	12.11	11.34
Aluminum	600	1932	1780	152	78.59	0.23	10.24	10.03
Copper	1000	7168	6606	562	46.89	0.21	28.76	22.12

The lattice binding energy ,surface binding energy and displacement energy for silicon layer are 2eV, 4.7eV and15eV respectively .

For silicon layer ions' energy loss in ionization is found to be higher than energy loss in phonons .

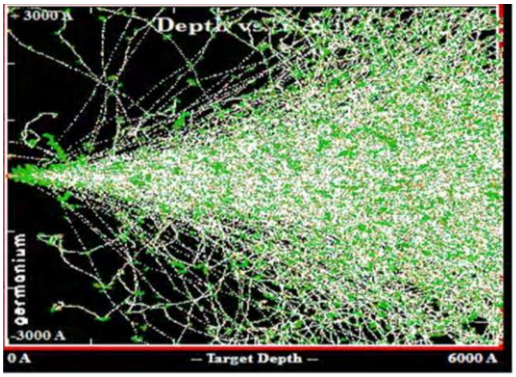
For recoil atoms energy loss is higher in phonons for proton and boron but lower in phonons for P ,Al and Cu ions .



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Ge (72.61	Solid/Gas	Stop Cor
1	germanium	6000	5.350	1.00000	Solid	
	Lattice Binding Energy			2		
	Surface Binding Energy			3.88		
	Displacement Energy			15		

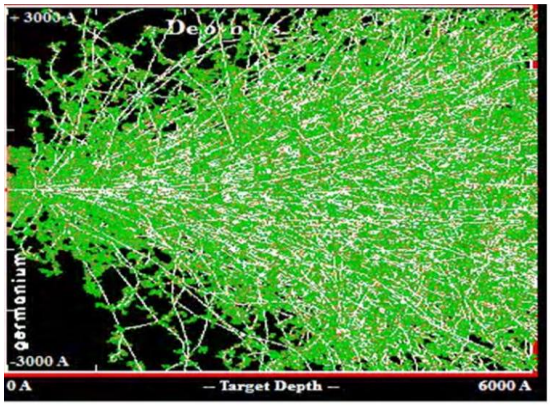
Fig. 3.26: Proton into Germanium



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Ge (72.61	Solid/Gas	Stop Corr.
1	germanium	6000	5.350	1.00000	Solid	1
	Lattice Binding Energy			2		
	Surface Binding Energy			3.88		
	Displacement Energy			15		

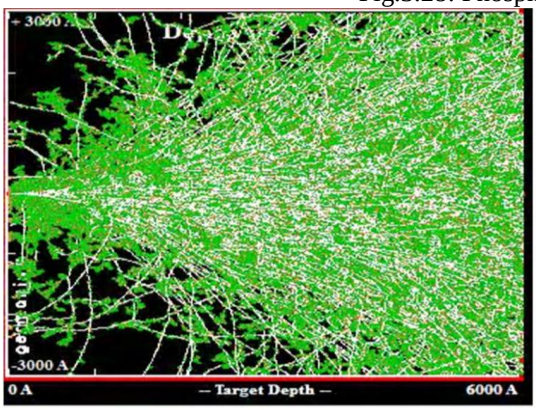
Fig. 3.27: Boron into Germanium



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Ge (72.61	Solid/Gas	Stop Corr.
1	germanium	6000	5.350	1.00000	Solid	1
	Lattice Binding Energy			2		
	Surface Binding Energy			3.88		
	Displacement Energy			15		

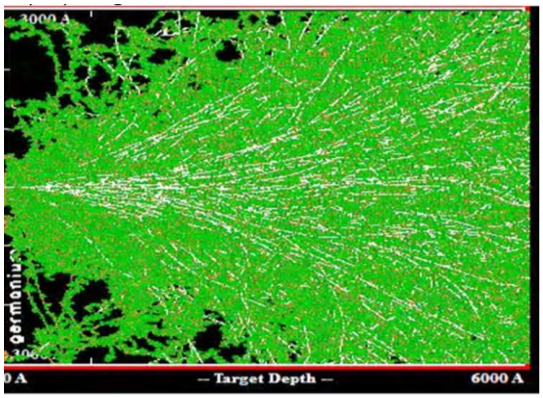
Fig.3.28: Phosphorous in Germanium



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Ge (72.61	Solid/Gas	Stop Cor
1	germanium	6000	5.350	1.00000	Solid	
	Lattice Binding Energy			2		
	Surface Binding Energy			3.88		
	Displacement Energy			15		

Fig.3.29: Aluminum in Germanium



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Ge (72.61	Solid/Gas	Stop Cor
1	germanium	6000	5.350	1.00000	Solid	
	Lattice Binding Energy			2		
	Surface Binding Energy			3.88		
	Displacement Energy			15		

Fig.3.30: Copper in Germanium

Table 3.18: Interaction and Energy loss of ions in Germanium layer

Ion	Energy (keV)	germanium Layer (6000 A)						
		Damage events			% of Energy Loss in Ion		% of Energy Loss in Recoil	
		Total displacements /ion	Total vacancies /ion	Replacement collisions/Ion	Ionization	Phonons	Ionization	Phonons
Proton	85	16	15	1	99.34	0.13	0.06	0.44
Boron	310	1177	1090	87	89.88	0.24	1.66	7.44
Phosphorous	640	8215	7607	608	65.86	0.20	7.10	24.30
Aluminum	600	6383	5911	472	68.41	0.22	6.53	22.49
Copper	1000	22259	20613	1646	34.97	0.17	15.85	44.37

The lattice binding energy, surface binding energy and displacement energy for silicon layer are 2eV, 3.88eV and15eV respectively.

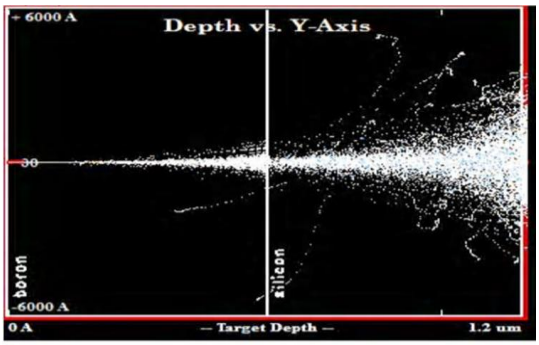
For germanium layer ions' energy loss in ionization is found to be higher than energy loss in phonons.

For recoil atoms energy loss is higher in phonons for all five ions, it shows that much of recoil atoms' energy is lost in lattice vibrations in case of germanium layer. Ionization caused by recoil atoms is low.

It was also found that the vacancies created by ions in germanium are higher as compared to the vacancies created by ions in boron and silicon layers.

Double layer Analysis:

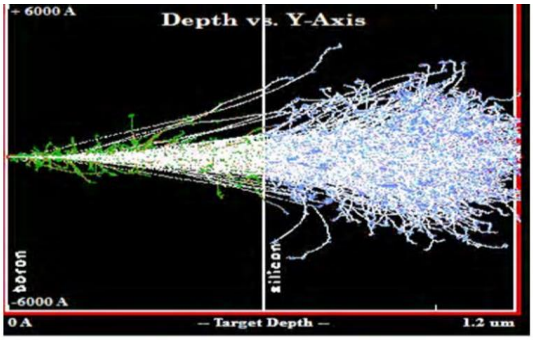
In the double layer analysis , ions will be irradiated with the double energy into the boron + silicon , silicon + germanium ,germanium + boron layers respectively . The width of the composite layer is 12000 A .



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	B (10.811)	Si (28.086)	Solid/Gas
1	boron	6000	2.350	1.00000	0.00000	Solid
2	silicon	6000	2.321	0.00000	1.00000	Solid
	Lattice Binding Energy			3	2	
	Surface Binding Energy			5.73	4.7	
	Displacement Energy			25	15	

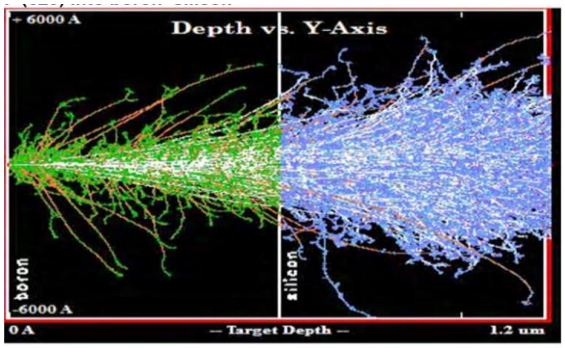
Fig.3.31: Proton into Boron+Silicon



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	B (10.811)	Si (28.086)	Solid/Gas
1	boron	6000	2.350	1.00000	0.00000	Solid
2	silicon	6000	2.321	0.00000	1.00000	Solid
	Lattice Binding Energy			3	2	
	Surface Binding Energy			5.73	4.7	
	Displacement Energy			25	15	

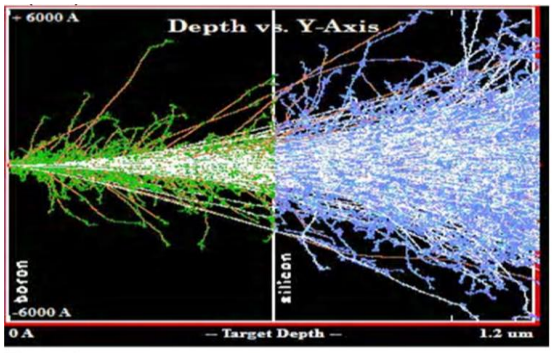
Fig.3.32: Boron into Boron+Silicon



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	B (10.811)	Si (28.086)	Solid/Gas
1	boron	6000	2.350	1.00000	0.00000	Solid
2	silicon	6000	2.321	0.00000	1.00000	Solid
	Lattice Binding Energy			3	2	
	Surface Binding Energy			5.73	4.7	
	Displacement Energy			25	15	

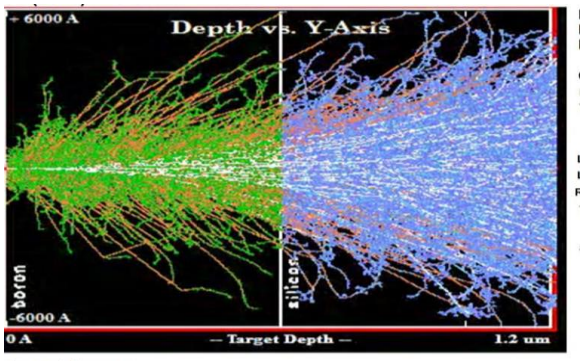
Fig 3..33: Phosphorous into Boron+Silicon



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	B (10.811)	Si (28.086)	Solid/Gas
1	boron	6000	2.350	1.00000	0.00000	Solid
2	silicon	6000	2.321	0.00000	1.00000	Solid
	Lattice Binding Energy			3	2	
	Surface Binding Energy			5.73	4.7	
	Displacement Energy			25	15	

Fig 3..34: Aluminum into Boron+Silicon



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	B (10.811)	Si (28.086)	Solid/Gas
1	boron	6000	2.350	1.00000	0.00000	Solid
2	silicon	6000	2.321	0.00000	1.00000	Solid
	Lattice Binding Energy			3	2	
	Surface Binding Energy			5.73	4.7	
	Displacement Energy			25	15	

Fig 3..35: Copper into Boron+Silico

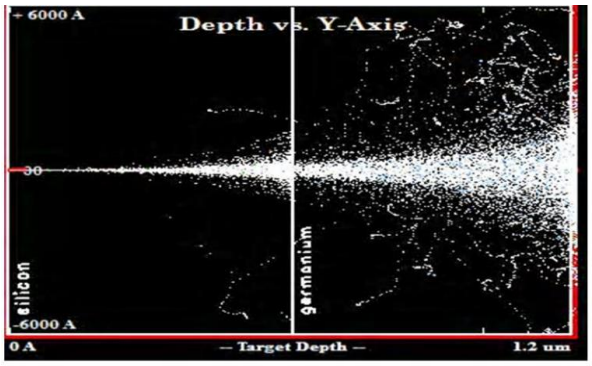
Table 3.19: Interaction and Energy loss of ions in Boron+ Silicon layer

Ion	Energy (keV)	Boron + silicon Layer (12000 A)						
		Damage events			% of Energy Loss in Ion		% of Energy Loss in Recoil	
		Total displacements /ion	Total vacancies /ion	Replacement collisions/Ion	Ionization	Phonons	Ionization	Phonons
Proton	170	12	11	1	99.70	0.06	0.06	0.17
Boron	620	863	798	65	94.21	0.23	2.12	3.13
Phosphorous	1280	4329	4012	317	82.24	0.27	8.81	7.89
Aluminum	1200	3209	2973	236	85.06	0.26	7.38	6.63
Copper	2000	9484	8798	685	64.92	0.30	20.53	12.99

The moving atoms are shown in the red color whereas stopped atoms are shown in green color for boron layer and in sky blue and blue color for silicon layer.

For boron + silicon layer ions' energy loss in ionization is found to be higher than energy loss in phonons .

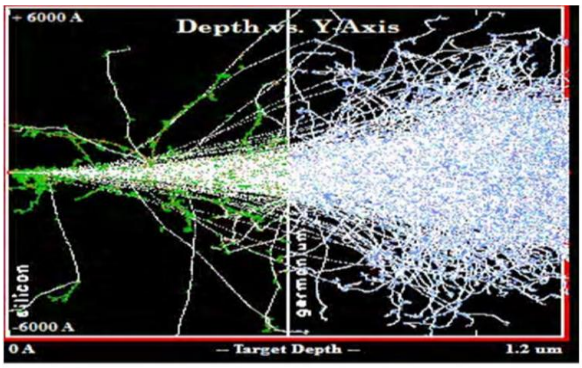
For recoil atoms energy loss is higher in phonons for proton and boron but lower in phonons for P ,Al and Cu ions .



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Si (28.086	Ge (72.61	Solid/Gas
1	silicon	6000	2.321	1.00000	0.00000	Solid
2	germanium	6000	5.350	0.00000	1.00000	Solid
	Lattice Binding Energy			2	2	
	Surface Binding Energy			4.7	3.88	
	Displacement Energy			15	15	

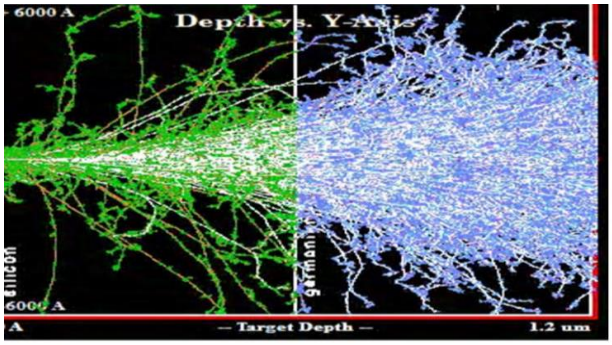
Fig 3.36: Proton into Silicon+Germanium



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Si (28.086	Ge (72.61	Solid/Gas
1	silicon	6000	2.321	1.00000	0.00000	Solid
2	germanium	6000	5.350	0.00000	1.00000	Solid
	Lattice Binding Energy			2	2	
	Surface Binding Energy			4.7	3.88	
	Displacement Energy			15	15	

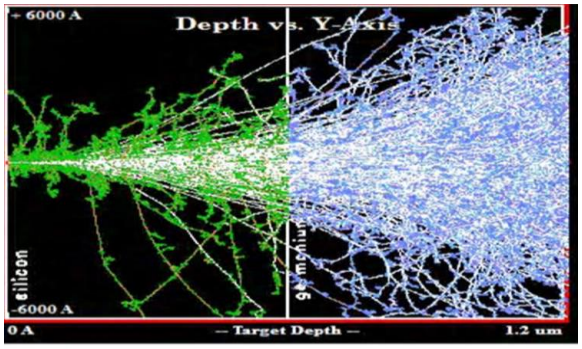
Fig.3.37: Boron into Silicon+Germanium



arget layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Si (28.086	Ge (72.61	Solid/Gas
1	silicon	6000	2.321	1.00000	0.00000	Solid
2	germanium	6000	5.350	0.00000	1.00000	Solid
	Lattice Binding Energy			2	2	
	Surface Binding Energy			4.7	3.88	
	Displacement Energy			15	15	

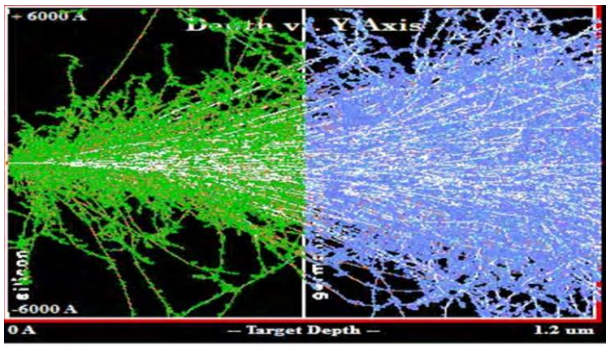
Fig.3.38: Phosphorous into Silicon+Germanium



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Si (28.086	Ge (72.61	Solid/Ga
1	silicon	6000	2.321	1.00000	0.00000	Solid
2	germanium	6000	5.350	0.00000	1.00000	Solid
	Lattice Binding Energy			2	2	
	Surface Binding Energy			4.7	3.88	
	Displacement Energy			15	15	

Fig.3.39: Aluminum into Silicon+Germanium



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Si (28.086	Ge (72.61	Solid/Ga
1	silicon	6000	2.321	1.00000	0.00000	Solid
2	germanium	6000	5.350	0.00000	1.00000	Solid
	Lattice Binding Energy			2	2	
	Surface Binding Energy			4.7	3.88	
	Displacement Energy			15	15	

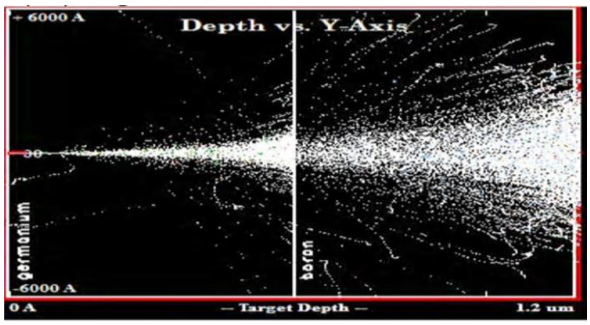
Fig.3.40: Copper into Silicon+Germanium

Table 3.20: Interaction and Energy loss of ions in Silicon+Germanium layer

Ion	Energy (keV)	Silicon + germanium Layer (12000 A)						
		Damage events			% of Energy Loss in Ion		% of Energy Loss in Recoil	
		Total displacements /ion	Total vacancies /ion	Replacement collisions/Ion	Ionization	Phonons	Ionization	Phonons
Proton	170	13	12	1	99.72	0.05	0.03	0.18
Boron	620	1524	1411	113	93.34	0.18	1.46	4.56
Phosphorous	1280	9639	8920	719	78.08	0.16	6.45	13.89
Aluminum	1200	7079	6552	527	81.90	0.16	5.00	11.74
Copper	2000	24945	23082	1863	56.32	0.15	15.08	25.81

For silicon + germanium layer ions' energy loss in ionization is found to be higher than energy loss in phonons .

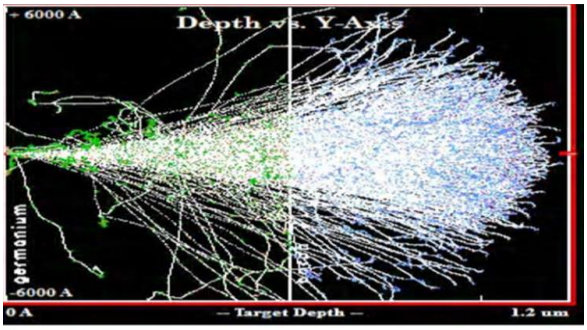
For recoil atoms, energy loss is higher in phonons for all five ions. it shows that much of recoil atoms' energy is lost in lattice vibrations in case of silicon + germanium layer.



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Ge (72.61	B (10.811)	Solid/Ga
1	germanium	6000	5.350	1.00000	0.00000	Solid
2	boron	6000	2.350	0.00000	1.00000	Solid
	Lattice Binding Energy			2	3	
	Surface Binding Energy			3.88	5.73	
	Displacement Energy			15	25	

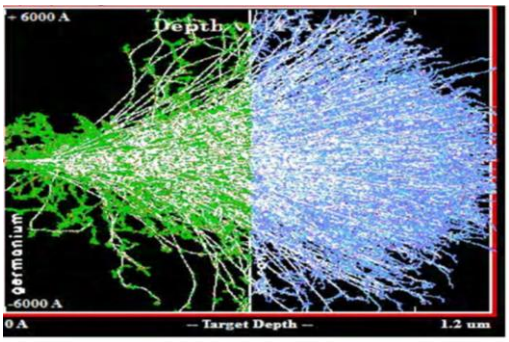
Fig.3.41: Proton into Germanium + Boron



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Ge (72.61	B (10.811)	Solid/Ga
1	germanium	6000	5.350	1.00000	0.00000	Solid
2	boron	6000	2.350	0.00000	1.00000	Solid
	Lattice Binding Energy			2	3	
	Surface Binding Energy			3.88	5.73	
	Displacement Energy			15	25	

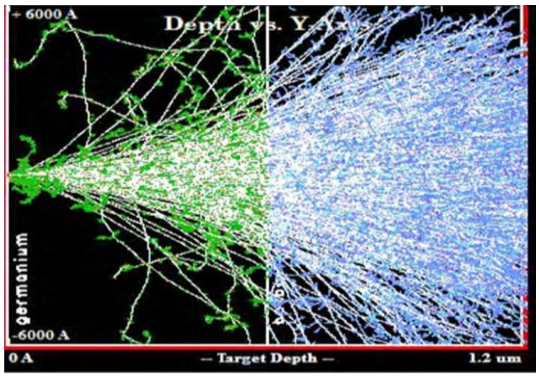
Fig.3.42: Boron into Germanium + Boron



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Ge (72.61	B (10.811)	Solid/Gas
1	germanium	6000	5.350	1.00000	0.00000	Solid
2	boron	6000	2.350	0.00000	1.00000	Solid
	Lattice Binding Energy			2	3	
	Surface Binding Energy			3.88	5.73	
	Displacement Energy			15	25	

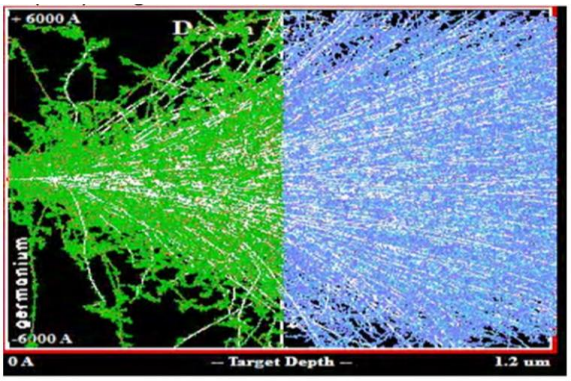
Fig.3.43: Phosphorous into Germanium + Boron



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Ge (72.61	B (10.811)	Solid/Ga
1	germanium	6000	5.350	1.00000	0.00000	Solid
2	boron	6000	2.350	0.00000	1.00000	Solid
	Lattice Binding Energy			2	3	
	Surface Binding Energy			3.88	5.73	
	Displacement Energy			15	25	

Fig.3.44: Aluminum into Germanium + Boron



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Ge (72.61	B (10.811)	Solid/Gas
1	germanium	6000	5.350	1.00000	0.00000	Solid
2	boron	6000	2.350	0.00000	1.00000	Solid
	Lattice Binding Energy			2	3	
	Surface Binding Energy			3.88	5.73	
	Displacement Energy			15	25	

Fig.3.45: Copper into Germanium + Boron

Table 3.21: Interaction and Energy loss of ions in Germanium+ Boron layer

Ion	Energy (keV)	Germanium+ boron Layer (12000 A)						
		Damage events			% of Energy Loss in Ion		% of Energy Loss in Recoil	
		Total displacements /ion	Total vacancies /ion	Replacement collisions/Ion	Ionization	Phonons	Ionization	Phonons
Proton	170	12	11	1	99.56	0.11	0.07	0.24
Boron	620	803	753	50	94.03	0.29	1.89	3.49
Phosphorous	1280	5906	5514	392	79.72	0.30	8.05	10.85
Aluminum	1200	4058	3798	260	83.00	0.34	7.12	8.73
Copper	2000	17362	16185	1177	57.60	0.30	19.21	20.75

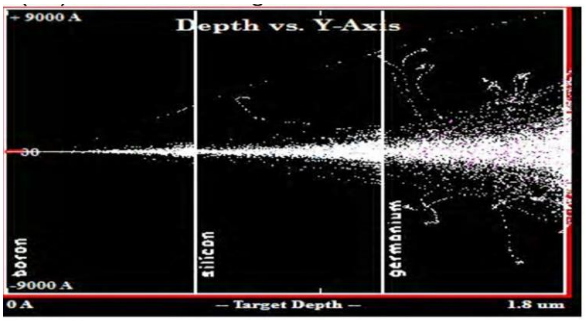
For germanium+boron layer ions' energy loss in ionization is found to be higher than energy loss in phonons.

For recoil atoms energy loss is higher in phonons for all five ions, it shows that much of recoil atoms' energy is lost in lattice vibrations in case of germanium layer. Ionization caused by recoil atoms is low.

It was also found that the vacancies created by ions in silicon+germanium layer are higher as compared to the vacancies created by ions in boron+silicon , germanium+boron layers for same ions' energies .

Triple layer Analysis:

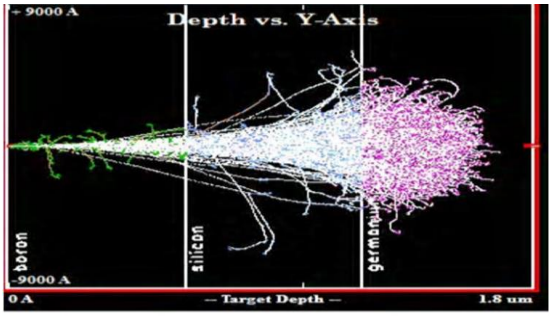
In the triple layer analysis , ions will be irradiated with the triple energy into the boron + silicon + germanium , silicon + germanium + boron ,germanium + boron + silicon layers respectively . The width of the composite layer is 18000 A .



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	B (10.811)	Si (28.086)	Ge (72.61)
1	boron	6000	2.350	1.00000	0.00000	0.00000
2	silicon	6000	2.321	0.00000	1.00000	0.00000
3	germanium	6000	5.350	0.00000	0.00000	1.00000
	Lattice Binding Energy			3	2	2
	Surface Binding Energy			5.73	4.7	3.88
	Displacement Energy			25	15	15

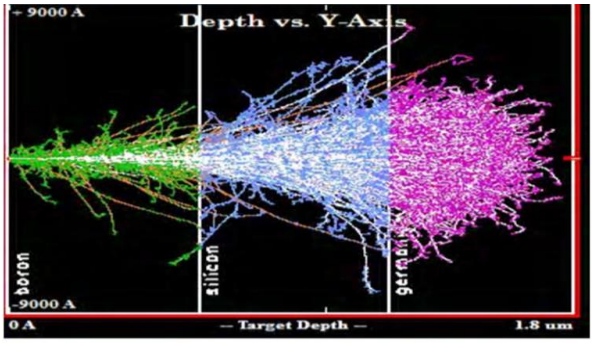
Fig.3.46: Proton into Boron + Silicon + Germanium



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	B (10.811)	Si (28.086)	Ge (72.61)
1	boron	6000	2.350	1.00000	0.00000	0.00000
2	silicon	6000	2.321	0.00000	1.00000	0.00000
3	germanium	6000	5.350	0.00000	0.00000	1.00000
	Lattice Binding Energy			3	2	2
	Surface Binding Energy			5.73	4.7	3.88
	Displacement Energy			25	15	15

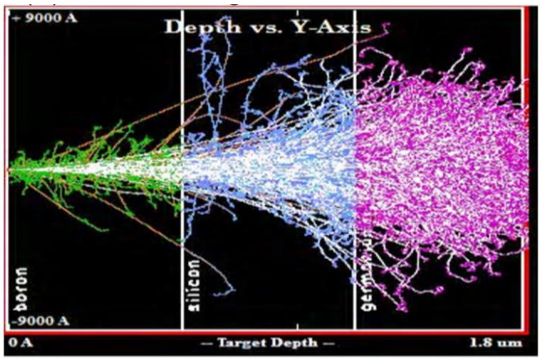
Fig.3.47: Boron into Boron + Silicon + Germanium



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	B (10.811)	Si (28.086)	Ge (72.61)
1	boron	6000	2.350	1.00000	0.00000	0.00000
2	silicon	6000	2.321	0.00000	1.00000	0.00000
3	germanium	6000	5.350	0.00000	0.00000	1.00000
	Lattice Binding Energy			3	2	2
	Surface Binding Energy			5.73	4.7	3.88
	Displacement Energy			25	15	15

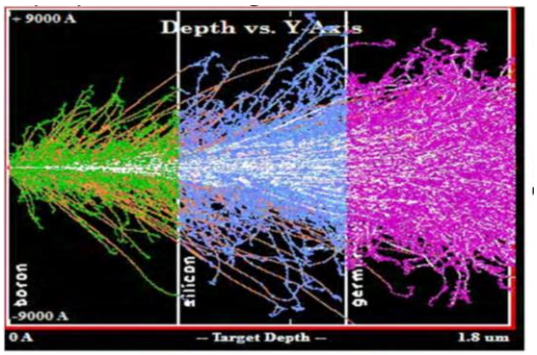
Fig.3.48: Phosphorous into Boron + Silicon + Germanium



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	B (10.811)	Si (28.086)	Ge (72.61)
1	boron	6000	2.350	1.00000	0.00000	0.00000
2	silicon	6000	2.321	0.00000	1.00000	0.00000
3	germanium	6000	5.350	0.00000	0.00000	1.00000
	Lattice Binding Energy			3	2	2
	Surface Binding Energy			5.73	4.7	3.88
	Displacement Energy			25	15	15

Fig.3.49: Aluminum into Boron + Silicon + Germanium



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	B (10.811)	Si (28.086)	Ge (72.61)
1	boron	6000	2.350	1.00000	0.00000	0.00000
2	silicon	6000	2.321	0.00000	1.00000	0.00000
3	germanium	6000	5.350	0.00000	0.00000	1.00000
	Lattice Binding Energy			3	2	2
	Surface Binding Energy			5.73	4.7	3.88
	Displacement Energy			25	15	15

Fig.3.50: Copper into Boron + Silicon + Germanium

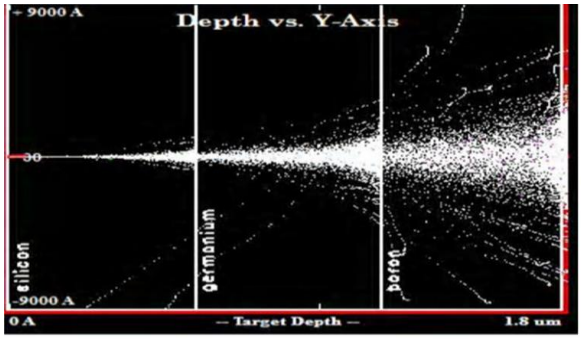
Table 3.22: Interaction and Energy loss of ions in Boron+ Silicon +Germanium layer

Ion	Energy (keV)	Boron + silicon + germanium Layer (18000 A)						
		Damage events			% of Energy Loss in Ion		% of Energy Loss in Recoil	
		Total displacements /ion	Total vacancies /ion	Replacement collisions/Ion	Ionization	Phonons	Ionization	Phonons
Proton	255	11	11	1	99.81	0.03	0.03	0.12
Boron	930	1354	1254	99	95.45	0.16	1.22	2.85
Phosphorous	1920	8006	7417	589	85.25	0.18	5.51	8.16
Aluminum	1800	8266	7659	607	85.23	0.19	4.84	8.75
Copper	3000	27028	25046	1982	65.98	0.20	14.06	17.76

The moving atoms are shown in the red color whereas stopped atoms are shown in green color for boron layer, in sky blue and blue color for silicon layer, in pink and purple color for germanium layer .

For boron+ silicon+ germanium layer ions' energy loss in ionization is found to be higher than energy loss in phonons .

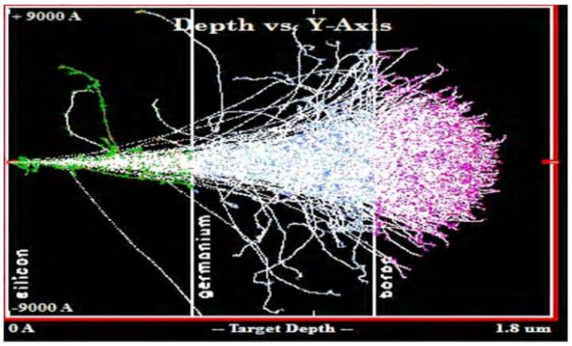
For recoil atoms, energy loss is higher in phonons for all five ions. it shows that much of recoil atoms' energy is lost in lattice vibrations in case of boron +silicon + germanium layer.



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Si (28.086	Ge (72.61	B (10.811)
1	silicon	6000	2.321	1.00000	0.00000	0.00000
2	germanium	6000	5.350	0.00000	1.00000	0.00000
3	boron	6000	2.350	0.00000	0.00000	1.00000
	Lattice Binding Energy			2	2	3
	Surface Binding Energy			4.7	3.88	5.73
	Displacement Energy			15	15	25

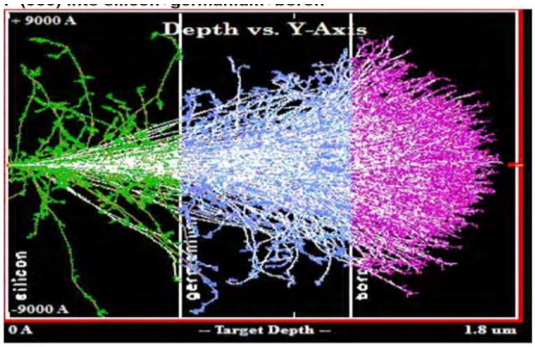
Fig.3.51: Proton into Silicon + germanium + boron



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Si (28.086	Ge (72.61	B (10.811)
1	silicon	6000	2.321	1.00000	0.00000	0.00000
2	germanium	6000	5.350	0.00000	1.00000	0.00000
3	boron	6000	2.350	0.00000	0.00000	1.00000
	Lattice Binding Energy			2	2	3
	Surface Binding Energy			4.7	3.88	5.73
	Displacement Energy			15	15	25

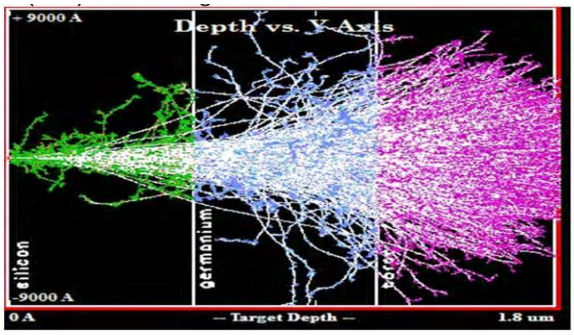
Fig.3.52: Boron into Silicon + germanium + boron



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Si (28.086	Ge (72.61	B (10.811)
1	silicon	6000	2.321	1.00000	0.00000	0.00000
2	germanium	6000	5.350	0.00000	1.00000	0.00000
3	boron	6000	2.350	0.00000	0.00000	1.00000
	Lattice Binding Energy			2	2	3
	Surface Binding Energy			4.7	3.88	5.73
	Displacement Energy			15	15	25

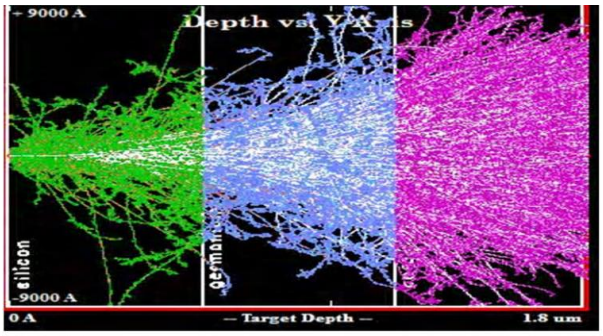
Fig.3.53: Phosphorous into Silicon + germanium + boron



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Si (28.086	Ge (72.61	B (10.811)
1	silicon	6000	2.321	1.00000	0.00000	0.00000
2	germanium	6000	5.350	0.00000	1.00000	0.00000
3	boron	6000	2.350	0.00000	0.00000	1.00000
	Lattice Binding Energy			2	2	3
	Surface Binding Energy			4.7	3.88	5.73
	Displacement Energy			15	15	25

Fig.3.54: Aluminum into Silicon + germanium + boron



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Si (28.086	Ge (72.61	B (10.811)
1	silicon	6000	2.321	1.00000	0.00000	0.00000
2	germanium	6000	5.350	0.00000	1.00000	0.00000
3	boron	6000	2.350	0.00000	0.00000	1.00000
	Lattice Binding Energy			2	2	3
	Surface Binding Energy			4.7	3.88	5.73
	Displacement Energy			15	15	25

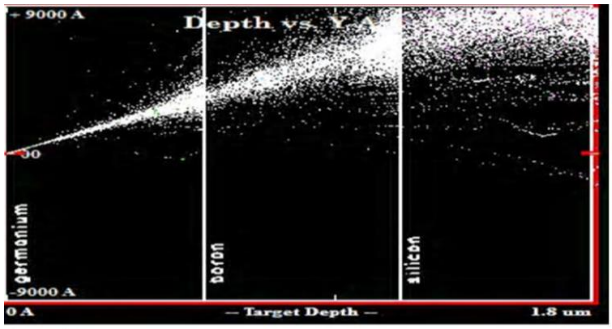
Fig.3.55: Copper into Silicon + germanium + boron

Table 3.23: Interaction and Energy loss of ions in Silicon + germanium + boron layer

Ion	Energy (keV)	Silicon + germanium + boron Layer (18000 A)						
		Damage events			% of Energy Loss in Ion		% of Energy Loss in Recoil	
		Total displacements /ion	Total vacancies /ion	Replacement collisions/Ion	Ionization	Phonons	Ionization	Phonons
Proton	255	8	7	0	99.83	0.03	0.03	0.10
Boron	930	1050	980	70	95.51	0.19	1.36	2.69
Phosphorous	1920	7567	7038	529	84.44	0.20	6.01	8.50
Aluminum	1800	5889	5491	398	85.70	0.24	5.73	7.61
Copper	3000	20949	19488	1461	66.48	0.23	15.85	15.87

For silicon + germanium +boron layer ions' energy loss in ionization is found to be higher than energy loss in phonons.

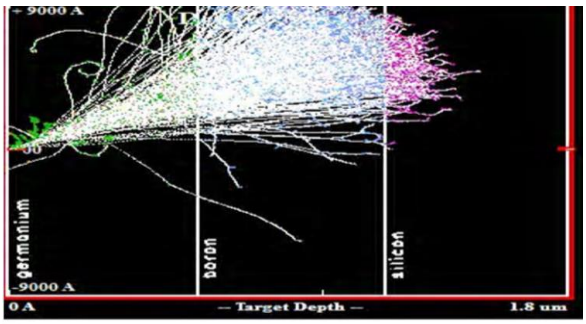
For recoil atoms, energy loss is higher in phonons for all five ions. it shows that much of recoil atoms' energy is lost in lattice vibrations in case of silicon + germanium +boron layer.



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Ge (72.61	B (10.811)	Si (28.086
1	germanium	6000	5.350	1.00000	0.00000	0.00000
2	boron	6000	2.350	0.00000	1.00000	0.00000
3	silicon	6000	2.321	0.00000	0.00000	1.00000
	Lattice Binding Energy			2	3	2
	Surface Binding Energy			3.88	5.73	4.7
	Displacement Energy			15	25	15

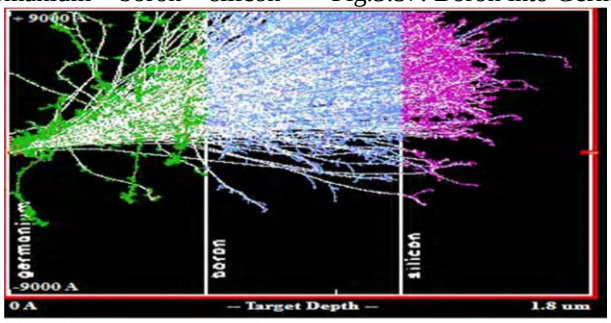
Fig.3.56: Proton into Germanium + boron + silicon



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Ge (72.61	B (10.811)	Si (28.086
1	germanium	6000	5.350	1.00000	0.00000	0.00000
2	boron	6000	2.350	0.00000	1.00000	0.00000
3	silicon	6000	2.321	0.00000	0.00000	1.00000
	Lattice Binding Energy			2	3	2
	Surface Binding Energy			3.88	5.73	4.7
	Displacement Energy			15	25	15

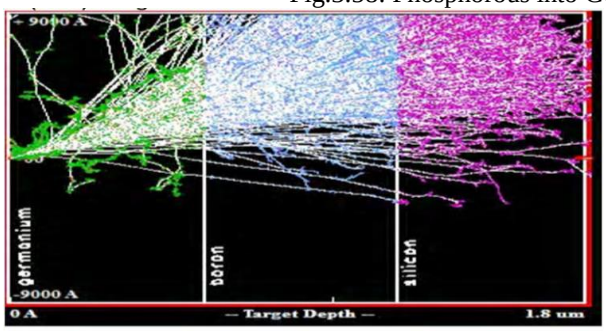
Fig.3.57: Boron into Germanium + boron + silicon



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Ge (72.61	B (10.811)	Si (28.086
1	germanium	6000	5.350	1.00000	0.00000	0.00000
2	boron	6000	2.350	0.00000	1.00000	0.00000
3	silicon	6000	2.321	0.00000	0.00000	1.00000
	Lattice Binding Energy			2	3	2
	Surface Binding Energy			3.88	5.73	4.7
	Displacement Energy			15	25	15

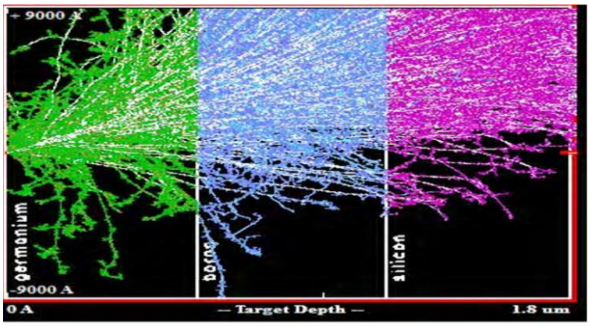
Fig.3.58: Phosphorous into Germanium + boron + silicon



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Ge (72.61	B (10.811)	Si (28.086
1	germanium	6000	5.350	1.00000	0.00000	0.00000
2	boron	6000	2.350	0.00000	1.00000	0.00000
3	silicon	6000	2.321	0.00000	0.00000	1.00000
	Lattice Binding Energy			2	3	2
	Surface Binding Energy			3.88	5.73	4.7
	Displacement Energy			15	25	15

Fig.3.59: Aluminum into Germanium + boron + silicon



Target layers:

		Moving atom colors ->				
		Stopped atom colors ->				
	Layer Name	Width (A)	Density	Ge (72.61	B (10.811)	Si (28.086
1	germanium	6000	5.350	1.00000	0.00000	0.00000
2	boron	6000	2.350	0.00000	1.00000	0.00000
3	silicon	6000	2.321	0.00000	0.00000	1.00000
	Lattice Binding Energy			2	3	2
	Surface Binding Energy			3.88	5.73	4.7
	Displacement Energy			15	25	15

Fig.3.60: Copper into Germanium + boron + silicon

Table 3.24: Interaction and Energy loss of ions in Germanium + boron + silicon layer

Ion	Energy (keV) at incident angle 30°	Germanium + boron + silicon Layer (18000 A)						
		Damage events			% of Energy Loss in Ion		% of Energy Loss in Recoil	
		Total displacements /ion	Total vacancies /ion	Replacement collisions/Ion	Ionization	Phonons	Ionization	Phonons
Proton	255	20	18	1	99.67	0.07	0.06	0.19
Boron	930	771	724	48	95.94	0.21	1.39	2.29
Phosphorous	1920	5680	5302	377	85.75	0.24	6.22	7.15
Aluminum	1800	5415	5036	379	86.41	0.25	5.80	6.89
Copper	3000	21237	19731	1506	65.29	0.24	17.29	15.63

For germanium+boron+silicon layer ions' energy loss in ionization is found to be higher than energy loss in phonons.

For recoil atoms energy loss is higher in phonons for all five ions, it shows that much of recoil atoms' energy is lost in lattice vibrations in case of germanium layer .

Ions were irradiated at incident angle 30° in this case and it was found that there was not much effect on vacancies created and energy loss in ionization and phonons .

It was also found that the vacancies created by ions in boron +silicon+germanium are higher as compared to the vacancies created by ions in Si + Ge + B , Ge+ B +Si layers for same ions' energies .

Chapter 4 *DISCUSSION AND SUMMARY*

The results obtain in this study have shown excellent agreement with a wide range of experimental data for ions with energies below 3 MeV. In this project, the damage induced by ions on metalloids target layers was simulated.

Out of the six commonly recognized metalloids boron, silicon and germanium were used as the target layer materials. Ions' ranges and loss of energy in inelastic and elastic collisions were calculated. Irradiation of ions was done on the Single, double and triple layers of B, Si, Ge. Vacancies created and the energy lost in ionization and phonons calculated and the results obtained were discussed.

The SRIM-TRIM simulation is useful in the transporting energetic ions into metalloids as it describes the slowing down and scattering of energetic ion in solid target layers. From the simulation, ions were shown to impose dislocations and other types of electrical active defects in the layers. The deposition of energy by the irradiated ions in target layer is not much effected by its incident angle. It was also found that electronic energy loss is always higher than the nuclear energy loss.

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