

A Preliminary Study of Radiation Damage to Electronic Components

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Abstract

This research work is the study of effect of radiation exposure on the different active electronic components such as transistor 9016 1C-H & diode IN 400-MIC. The measurements were taken using circuit operating with dc values only. The commercially available transistor (9016- 1C-H) and diode (IN 400 MIC) are exposed to gamma radiation for different doses such as .5 K Rad, 1.0 K Rad and 1.5 K Rad. The output characteristic curves of the voltage amplifier with the increase of voltage gain, frequency response & decrease in bandwidth. The output characteristics curves of the diode characteristics circuit show that decrease in diode's biasing is due to increase in the values of the diode resistance (static and dynamic) by increasing dose rate. In this study we have seen the effect of the gamma radiations (cobalt 60 source) on the efficiency of diodes, transistors. The samples of transistor (9016- 1C-H) and diode (IN 400 MIC) are mounted on digital trainers would be used to see the effect of radiations on these active electronics components.

Key Words: *Active electronic components, radiation exposure, variations in characteristics, need of collaborative efforts.*

I. Introduction

The radiation effects on electronic components is indeed a broad area to review, not only due to lack of data available but also due to the specificity of available data for specific devices. There are many reasons for this; the obsolescence of device, change in their characteristics, the use of device in new combinations, the change in manufacturing, technology, the change in environmental conditions during device use and probably of least importance, ignorance of existence of test data at the first place.

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In nature everyone and everything has some degree of tolerance to radiation. Many electronic components can still function properly. Without a glitch after mild exposure to radiation. Circuit response to irradiation varies from circuit to circuit, and from circumstance to circumstance and is often unpredictable. There are four basic categories of radiation effects that an integrated circuit is vulnerable to. These fore effects are Neutron, total ionizing dose, single event effect (SEE) and transient dose effect. The SEE is further subdivided as SE upsets, SE Latch up, SE Snapback, and SE Gate Rupture.

Ionizing radiations of threshold energy to produce ionization when interact with matter are natural and artificial. Natural radiations are high-speed particles while artificial radiations are photons examples are neutrons, α -, and β - for natural and gamma, x-ray for artificial. Non-ionizing radiations are natural and artificial radiations are low energy electrons low energy photons are UV, visible, IR, micro and radio low energy electrons are cathode rays. Interaction of radiation with matter depends upon three factors i.e., mass of the incident particle, energy of the incidentparticle and the charge of the particle due to the double electronic charge. The α -particle interacts strongly with matter than the β -particle or electron dose. This is why the α -particle has more ionizing power than β -particle of the same energy. Different radiations and their types can be detected by the amount of ionization produced in a target material.

The ionization is the main interaction with matter to detect the particle or to measure its energy. The range depends on the charge, mass, energy of the particle, density of the medium and ionization potentials of the atoms of the medium. Since α -particle is about 7000 times more massive than an electron, so it does not suffer any appreciable deflection from its straight path, provided it is not approached too closely to the nucleus of the atom. β -particles are more easily deflected by collisions than heavy α -particles. Thus the path of β -particles in matter is not straight but shows much straggling or scattering behavior. The range of β -particles is measured by the effective depth of penetration into the medium not by the length of erratic path.

The more dense the material through which the particle moves, the shorter its range will be. Photons of gamma rays being uncharged very little ionization photons are removed from the beam by either scattering or absorptions in the medium. They interact with matter in three distinct ways depending mainly on their energy. At low energies (less than about 0.5MeV) the dominant process that removes photons from beam of photoelectric effect.At intermediate energies the dominant process is Compton effect and at higher energies (more than 1.02 MeV), the dominant process is pair production. Gammairradiation intensity falls off as the inverse square of the distance from the source in air whereas in solids the intensity decreases

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exponentially with increasing depth of penetration into the material. The intensity I_0 of a beam after passing through a distance X in the medium is reduced to intensity I given by the relation:

$$I = I_0 e^{-uv}$$

Where u is the linear absorption coefficient of the medium. There are four basic categories of radiation effects that an integrated circuit is vulnerable to. These four effects are *neutron, total ionizing dose, transient dose, and single event effect (SEE)* neutron effects. When neutrons strike a semiconductor chip, they display atoms within the crystal lattice structure.

The minority carrier lifetime is reduced because of the increased recombination centers created. In bipolar integrated circuit, the base transit time and width are the main physical parameters affected. Therefore, neutron radiation significantly reduces gain in bipolar devices. Total ionizing dose effects includes the accumulation of ionizing radiation over time typically measured in rads. Slow, steady accumulation on the ionizing over the life of an integrated circuit causes performance parameters to degrade. Transient dose can also cause junction breakdown or trigger latch up destroying the device single event effect (SEE). TheSEEs have been studied only recently. They typically affect digital devices significantly but they are of primary concern in today's digital age. A SEE occurs when a single high energy particle strikes a device, leaving behind an ionized track.

The ionization along the path of the impinging particle collects at a circuit node. If the charge is high enough it can create a soft error single event upset (SEU) such as a bit flip. A change in states that causes a momentary glitch in the device output, or corruption of the data in a storage element.

There are two different radiation effects on semiconductors. These are accumulated dose effects and single event effects. Accumulative dose effects are primarily due to electrons and photons passing through silicon devices. The dosage is measured in rads (Si) with the Si indicating the material in which the dosage is measured.

Transistor (9016- 1C-H) and diode (IN 400 MIC) (active components) are the components, which can amplify, modify or changing energy from one form to another but they cannot control energy. These are very important for estimating the effect of radiation on these components. if given dose of radiation is of above the controlled limit then these Active components would be damaged.

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There are the displacements in the atoms of transistor and diode after radiation effect. Atomic displacements is determined the degradation of the bulk and long-term ionization is responsible for surface damage.

Producing displacement is four step process.

The primary particle hits an atom in the lattice transferring enough energy to displace it. Thus interstitials and vacancies appeared and their pairing the so-called Frankle defects. The fragments of the target atom migrate through the lattice causing further displacement. The mean free path between two successive collision decreases toward the end of the range, so that defect produced or closed enough and can interact.

Thermally activated proton causes rearrangement of the lattice defects at room temperature (annealing). Part of these arrangements is influenced by the presence of impurities in the initial material. Thermally stabled defects influence the transistor and diode properties. Effects of displacement are seen in the increase of capture generation and recombination rates of the non-equilibrium charge carriers. Long-term ionization effects also comprised several steps. Ionization is produced along the track of the primary ionizing particle or some time in restricted regions around a nuclear reaction. Electrons and holes are created with certain distribution. Many of the electrons, holes pairs produced recombine before they could move due to diffusion or the electric drift. Recombination's take place between particles produced in the same or in different events. The electrons which did not recombine in the initial phase diffuse or drift away. Some electrons end up on traps, other may escape from the insulator. The carriers trapped on levels with low ionization energies are thermally re-excited and get into the conduction or the valence band [1-6].

II. Materials and methods

This study was conducted at Department of Physics GC University Faisalabad and NIAB to check the effects of atomic radiation on different active electronic components such as Transistor 9016 – 1c H & Diode IN 400 MIC.

2.1 Median Lethal Dose (LD5, LD10, LD15)

When comparing the effects of various types or circumstances, then dose, which is lethal, did cause the death of 50% of given population is a very useful parameter. The term is usually defined for a specific time, being limited, generally, to studies of acute lethality. The common time periods used are 30-60 days or less for most of the active electronics components. It should be understand that the LD5, LD10, LD15 Assumes that the individuals did not receive

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other damages in active electronics components such as Transistor (9016- 1C-H) and diode (IN 400 MIC).

2.2 Mark IV Irradiator

Mark IV irradiator will be used for gamma ray exposure to different active electronic components such as Transistor 9016 – 1c H & Diode IN 400 MIC.

Its initial activity when it was imported from U.S.A was 25 KCurie, which was decreased after 6 half-lives. Now a day its activity level is 270 curie. Basically it consists on cobalt-60 source which is placed on the base of mark IV assembly shielded by dematerialized water. Its present dose rate is 1.25gy/hrs.

2.3 Designing of the Experiment

The equipment used includes Mark IV irradiator (gamma source), Integrated circuits (ICs) such as Voltage amplifiers, Diode characteristic circuits, DC power supply, multi-meter (for ammeter and voltmeter), rheostat, Transistor 9016 – 1c H, Diode IN 400 MIC, digital trainers, Vero board, audio generators and oscilloscope.

We have active electronics components such as Transistor 9016 – 1c H & Diode IN 400 MIC and then mounted them on the digital trainers and Vero boards. We labeled them as sample VA-0, VA-1, VA-2&VA-3 for voltage amplifier and sample D-0, D-1, D-2&D-3 for diode characteristic circuits. The samples VA-0&D-0 are the samples without gamma radiation exposure. The samples are labeled in such a way that the dose of 0.5K rad is being given to samples VA-1&D-1, the dose of 1.0 K rad is given to samples VA-2&D-2 and the dose of 1.5 K rad to samples VA-3&D-3 respectably. We put these samples in Mark IV irradiator Chamber to give them the respective doses to each sample of 0.5 K Rad, 1.0 K Rad and 1.5 K Rad. The present dose rate of irradiator chamber is 12gy/h. The samples are kept in chamber from 25 mints to 75minutes for different doses (5gy to 15gy) where 1gy = 100 Rad = 1joule/kg, 1 rad = 10^{-2} gy.

Transistor and diode are capable of rectifying, amplifying and changing energy from one form to another. Both passive and active electronic components are generally used together to form complete circuits in all types of electronics components e.g., diodes, transistors capacitors and resistors [7-14].

III. Results

3.1 Pre-Irradiation Results of Transistor

The transistor is biased with dc power supply as shown in the figure. First the measurements were taken at fixed collector to emitter voltage of 12 volt. Voltage amplification of the samples was obtained by plotting the linear part of the A_v - f curves. It is seen that the bandwidth of the amplifier circuit of sample VA-0 before radiation exposure is 273.5 KHz corresponding to the fixed collector to emitter to voltage of 12 volt. The $A_v - f$ characteristic curves showing the voltage amplification and bandwidth of amplifier of sample VA-0 is shown in figure 1.

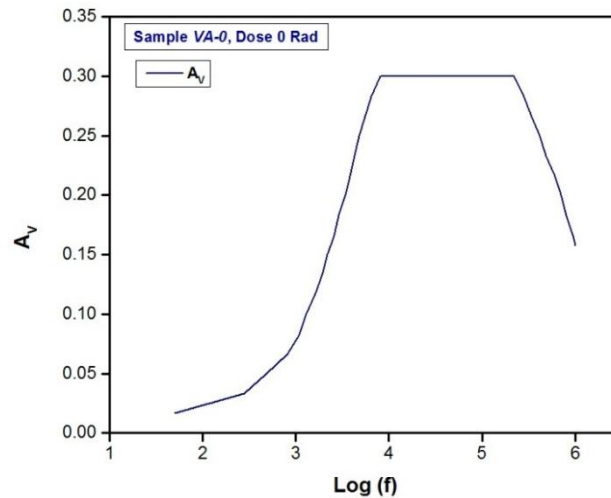


Figure 1: Voltage gain vs frequency response of sample VA-0 before irradiation

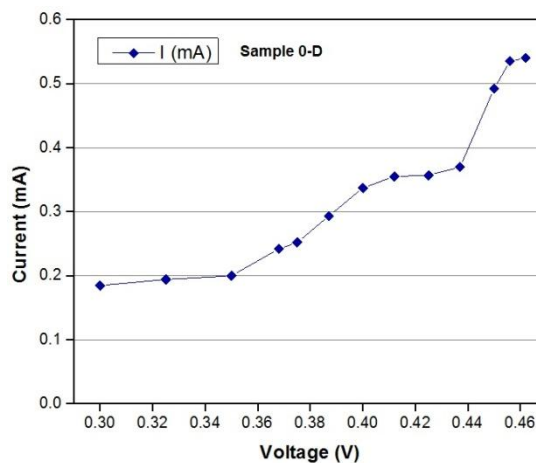


Figure 2: I-V Characteristics of sample D-0 before Irradiation

Table 1: Measurements of diode static and dynamic forward resistance

Sample	Radiation Exposure (K Rad)	Static Resistance "R" (Ω)	Dynamic Resistance "r" (Ω)
D-0	0	0.00109	.00495
D-1	0.5	0.00131	0.00548
D-2	1.0	0.00135	0.00553
D-3	1.5	0.00158	0.00924

3.2 Pre-Irradiation Results of Diode:

The diode *IN 400 –MIC* is used in forward biased configuration to find out the values of current, voltage and resistance of diode.

In this study we use a diode characteristic circuit as shown in figure above. The diode *IN 400 MIC* is connected in series with the *Ammeter* and *resistance of 300 Ω* and *voltmeter is connected* in perpendicular circuit to the diode. The *I-V* characteristics curve for sample *D-0* is shown in figure 2.

3.2.1 Measurement of diode resistance:

To measure the diode resistance following formulas are used the formula for Static resistance at point p before maximum I-V value

$$\text{Static resistance} = OE/OF = V/I (\Omega)$$

Where O = initial voltage, E = a value of the voltage before the maximum, F = the value of the current before the maximum value, P = the point before the maximum values at (V–I).

The formula for the Dynamic resistance in neighborhood of P is given as

$$\text{Dynamic resistance} = CD/BA = \Delta V/ \Delta I (\Omega)$$

C is a value of voltage before point P, D is value of voltage at maxima, B is the value of frequency before point P and A is a value of frequency.

The value of static resistance is 0.000109 Ω and of dynamic resistance is 0.00495 Ω of sample *D-0* before radiation exposure. The value of static resistance and of dynamic resistance of samples *D-0, D-1, D-2, D-3* before and after radiation exposure is given in table 1 and static & dynamic forward resistance curves are shown in figure 3.

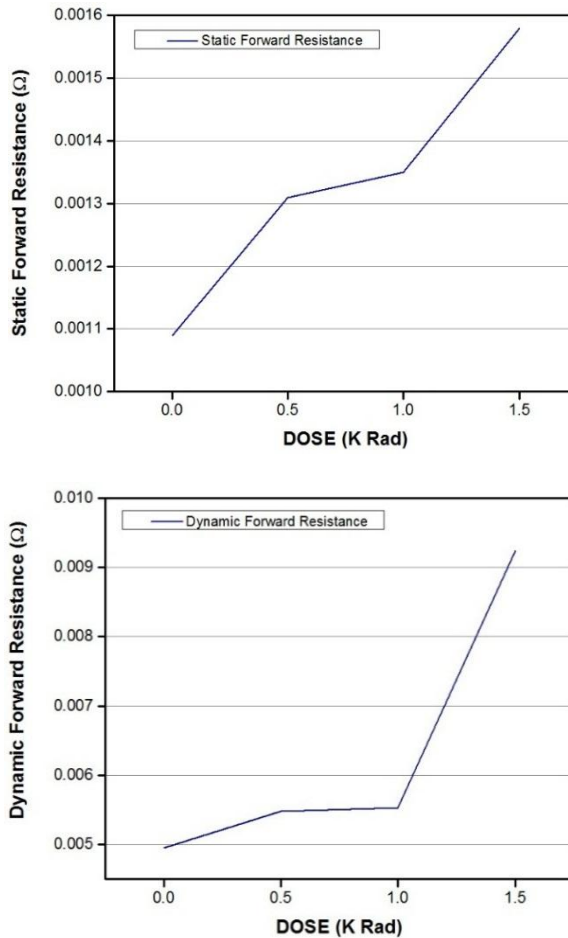


Figure 3: Static Forward Resistance curve (up) and dynamic forward resistance curve (down) of diodes with and without irradiation

3.3-Post-Irradiation Measurements:

The samples after taking measurements before irradiation were made to expose to gamma radiations for different doses like 0.5 KRad, 1KRad and 1.5 KRad. In this way samples VA-1&D-1 were delivered 0.5 KRad, VA-2&D-2 were delivered a dose of 1 KRad and VA-3&D-3 were delivered a dose of 1.5 KRad.

3.3.1 Post-Irradiation Measurements for Transistor:

The pre and post irradiation measurements are taken by using the same sample circuit with dc measurement only. The post irradiation measurements reveal the decrease of voltage gain, frequency of the amplifier of the devices. It is also noticed that for the lower dose rates, effects on the voltage gain and frequency of the amplifier are very low and for the large dose

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rates, the voltage gain, frequency effects readings of the samples of the after exposure for different doses are shown below.

The values of the voltage gain and frequency response of the amplifier are measured after the doses of gamma radiations for samples VA-1, VA-2, VA-3. The measurements are made for the parameters like voltage gain, frequency response and bandwidth. The characteristic curves between voltage gain (A_v) and $\log(f)$ for the samples VA-1, VA-2, VA-3 after irradiation are shown in the figure 4(a), 4(b), and 4(c) respectively.

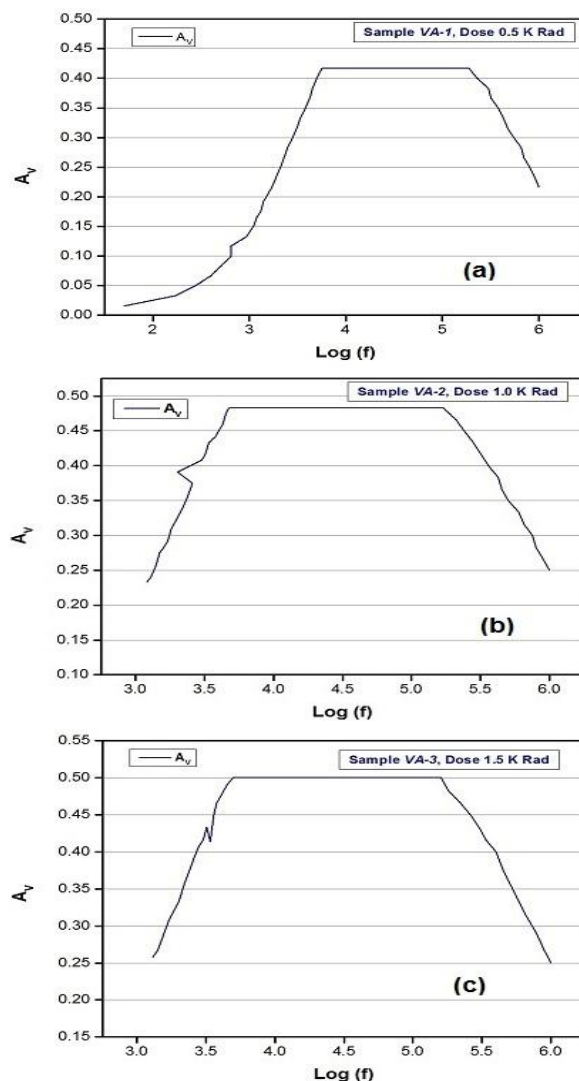
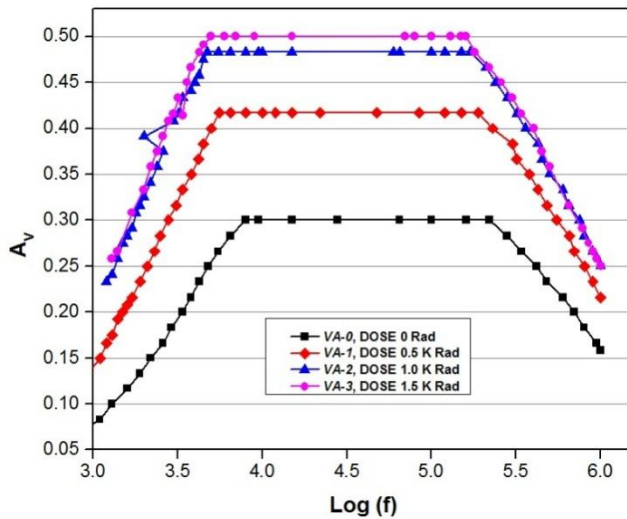


Figure 4: Voltage gain vs frequency response of samples after irradiation (a) VA-1 after 0.5 K Rad dose, (b) VA-2 after 1.0 K Rad dose and (c) VA-3 after 1.5 K Rad dose

A comparison between characteristic curves of $A_v - \log(f)$ for different samples is shown in figure 5 for the comparison of Voltage gain, bandwidth and frequency response.

Figure 5: Comparison of voltage gain and frequency response for different samples



3.3.2-Post-Irradiation Measurements for Diode:

The pre and post irradiation measurements are taken by using the same sample circuit with dc measurement only. The post irradiation measurements reveal the decrease in the current at the same values of voltage of the diode with respect to increase in the dose rate. It is also noticed that for the lower dose rates, the decrease in the radiation effect is very low and for the large dose rates the voltage readings of the samples after exposure are shown below.

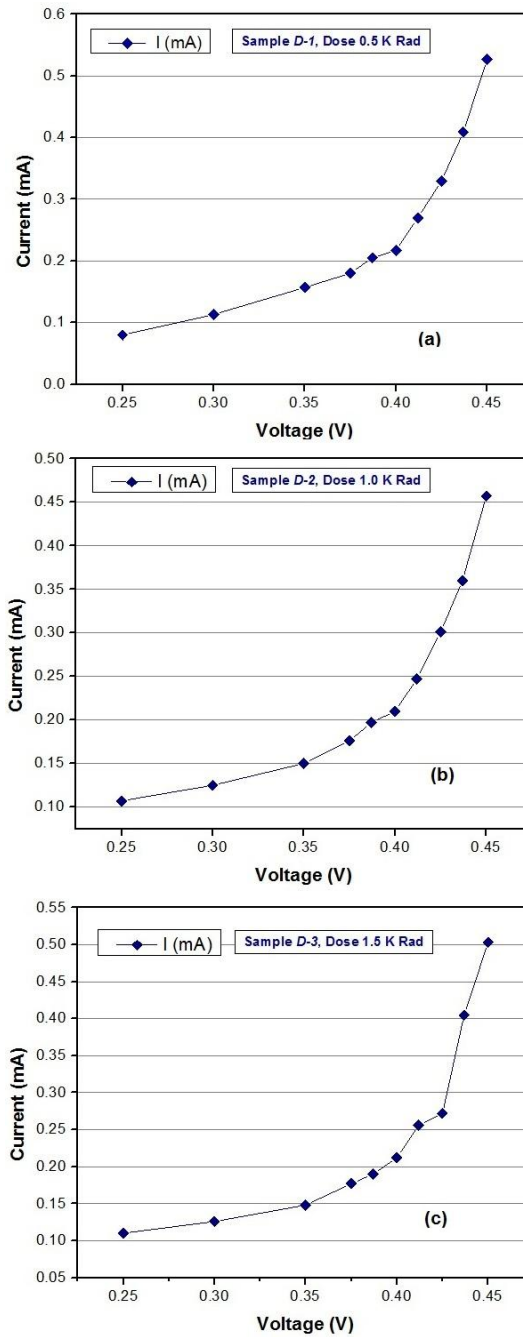
The measurements are made for the parameters like voltage and current after the doses of gamma radiations on samples D-1, D-2, D-3. The I-V characteristic curves of the samples D-1, D-2, D-3 after the effects of the radiations are shown in the figure 6 (a), (b) and (c) respectively.

The comparison of I-V characteristics of diodes due to different radiation doses is given in figure 7 [15-20].

IV. Discussion

In the present study, the gamma radiation exposure on the parameters of the commercially available transistors 9016-1c-H and diode IN 400 MIC has been observed. The parameters to be studied were voltage gain, frequency response and bandwidth of the amplifier for transistor and parameters like static and dynamic resistance is also observed in this way in diode characteristic circuit.

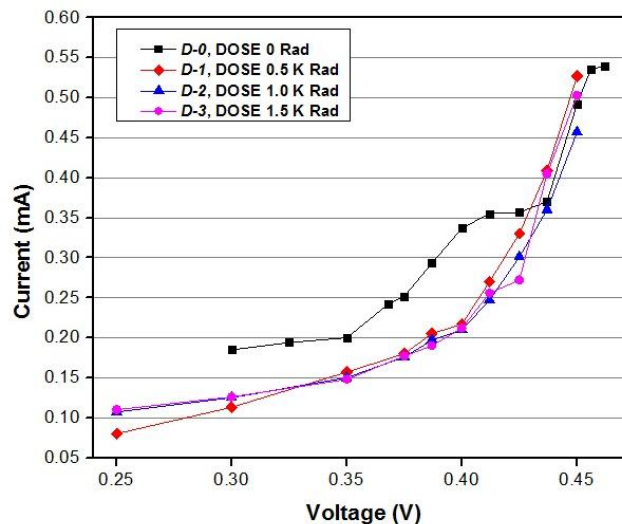
Figure 6: Effect of gamma irradiation on I-V Characteristics on sample (a) D-1 after 0.5 K Rad, (b) D-2 after 1.0 K Rad and (c) D-3 after 1.5 K Rad



The parameters were studied by using dc methods only. The shifts in the parameters were observed. The voltage gain of the devices seen to be decreased with respect to the dose rate. The static and dynamic resistance is also seen to be decreased with respect to the dose rate. The

gamma radiation Co-60 source present at NIAB was used to study the effect. The average energy coming from this source is about 1.2 MeV. The energy required to create the electron hole pairs in the device is 1.02 MeV. It means that 1.2 MeV energy coming from Co-60 source is sufficient to produce ion pairs in the transistors (9016-1C-H) and diode (in 400-MIC).

Figure 7: Comparison of *I-V* characteristics of diodes for different magnitude of radiations.



When the dose is 1 K Rad, there is significant change in the parameters of samples VA-2&D-2. When the dose rate is 1.5 K Rad, the change in sample VA-3&D-3 is more significant. It means that with the increasing dose of irradiation, there is significant change in the parameters voltage gain, frequency response & band width of the transistor and static & dynamic resistance of the diode.

When the transistor is used as a switch, the sharp voltage level is not needed for the transistor to be ON and OFF because there is a range in the input and output switching devices for ON and Off, hence even the sufficient changes in the voltage gain do not affect the ON/Off time of the transistor, therefore the transistors are not very sensitive to the minor drift in voltage gain.

In this present study the diode resistance characteristic showing that the forward resistance is not constant quality and it varies from point to point on the characteristic curves. It has a high value in the non-linear region and a low values in the linear region of the characteristic curve. The repeated observation and measurements shows that the change is of permanent nature. It cannot be explained on the supposition that due to ionizing radiation, the more electron hole

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pair are created. They are of course created during exposure to ionizing radiation but they cannot permanently contribute to the drift in the turn on voltage.

The values of voltage gain, frequency response and bandwidth of the amplifier circuit for transistor and static & dynamic resistance of the diode are also measured after the exposure of radiation. The shift in the parameters just after exposure of radiation is noticed. It has been observed that the values of the Bandwidth are 227.5 K Hz, 225 K Hz, 205.75 K Hz & 175.5 K Hz for sample VA-0 (without radiation exposure), VA-1 (at dose of 0.5 K Rad), VA-2(at dose of 1.0 K Rad) &VA-3 (at dose of 1.5 K Rad) respectively of transistor. This shows that the values of bandwidth decreased with respect to increase in values of the dose rate from 5 gy/h – 15 gy/h.

It has also been observed that the values of static resistance are 0.00109 Ω , 0.00131 Ω , 0.00135 Ω & 0.00158 Ω for sampleD-0 (without radiation exposure), D-1 (at dose of 0.5 K Rad), D-2 (at dose of 1.0 K Rad) &D-3(at dose of 1.5 K Rad) respectively. Similarly it has also been observed that the values of Dynamic resistance are 0.00109 Ω , 0.00131 Ω , 0.00135 Ω & 0.00158 Ω for sampleD-0 (without radiation exposure), D-1 (at dose of 0.5 K Rad), D-2 (at dose of 1.0 K Rad) &D-3(at dose of 1.5 K Rad) respectively. This shows that the value of the diode resistance (static and dynamic) increase with respect to increase in the dose rate.

Many of the electrons-hole pairs produced recombine before they could move due to diffusion or the electric drift. Recombination take place between the particles produced in the same or in different events. The electrons which did not recombine in the initial phase diffuse or drift away. The carriers trapped on levels with low ionization energies are thermally re-excited and get into the conduction or the valence band. The results related to my research nearly resemble to the previous research work [21-34].

V. Conclusions

No doubt the need of the next decade are difficult to predict, but in view of such type of limited studies, electronic components of all types (active and passive both) need to possess all of the attributes of the most highly developed present day equipment, reliability, power consumption, compactness, as well as the new modified equipment of radiation protection keeping in view the current knowledge of radiation protection and measurement techniques. These in turn will project from planned programmes of research and testing coordination by physicists, chemists, engineers and military strategists. Moreover a combination of material's knowledge, circuit design and shielding design can be parlayed into the circuitry which will meet requirements not only of function in an atomic radiation fields but also in Van Allen belt type radiation or in proton flares and the other related radiation fields which may be

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encountered. Even with the relatively simple types of radiation environments which we now know exist there are considerable complications.

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