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# EFFECT OF PROTON RADIATION ON THE PERFORMANCE OF GaAs-BASED SOLAR CELL

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For the purpose of understanding the effect of the space radiation, we exposed our solar cell that based on AlGaAS/GaAs to proton ions radiation with different energies and different incidence angles using SRIM simulation software, and investigate the effect of proton energy on the I-V characteristics, this lead us to understand the effect of the radiation on the proprieties of the solar cell more deeply, and how can we restrict this effects in order to enhance the performance. We used other simulation software on this work, to simulate and investigate the performance of desired solar cell. The software called SCAPS-1D (Solar Cell Capacitance Simulator in one dimension).

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*Keywords:* Proton, Irradiation, Solar cell, AlGaAS/GaAs, SRIM, SCAPS-1D

## 1. Introduction

AlGaAs/GaAs based solar cells have been widely used as power sources by space satellites because of their excellent properties such as high quantum efficiency and good irradiation tolerance. While working in space solar cells are inevitably impaired by variety of irradiations, like electrons, protons and heavy ions, resulting in the degradation of their electrical properties [1,2,3]. In particular solar protons (hydrogen ions) cause heavy damage, which is represented in the occurrence of large vacancies in crystalline structure. After a period of time and under space radiation, we can easily achieve a degradation of the solar cell performance because of the presence of vacancies that act as recombination centers and can create compensating defects that reduce the acceptor concentration in semiconductors. This in turn, can reduce the output power generated by photovoltaic devices.

In this work we report results obtained using both SRIM and SCAPS-1D computer simulator for the goal of investigating the effect of proton radiation on the performance of GaAs based solar cells for space applications.

## 2. Simulations

In the past few years much effort was devoted to studying the effects of energy and fluence of high-energy particles on GaAs solar cells, so because of this an evaluation specification for space-based GaAs solar cells was established [4, 5]. We choosed spaced energy values and multiple incidence angles for the goad of making comparative study under those various parameters.

This work based on tow simulation softwares, to simulate proton irradiation, we use SRIM [6] (Stopping and range of ions in matter) which can represent the radioactive environment of space (protons radiation) then we use SCAPS (Solar Cell Capacitance Simulator) to investigate the performance of the solar cell under the effect of proton irradiation, this lead to review how the charged particles (protons) irradiation will influence on solar cell proprieties, and how can we reduce this influence that can we abbreviate it as crystalline structure damage.

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The sample studied were AlGaAs/GaAs solar cells as shown in Fig. 1. The cell input parameters are those of a solar cell grown by metalorganic chemical vapor deposition technique (MOCVD). The emitter layer of the diode structures was doped to $2.7*10^{18}$ cm$^{-3}$., the base layer was intentionally doped to about $5*10^{17}$ cm$^{-3}$. Additional details of the structure can be found in references [6, 7]. The input set used in our simulation is reported in Table 1.

In this paper, we exposed this sample to protons irradiation with different energies, i.e., 10, 100 and 500 keV and with different incidence angles 30, 45, 60 and 75 degrees. For each different incidence angle we choosed 500 keV as the reference of irradiation energy exposing, the proton flux was set as $10^{12}$ cm$^{-2}$ and the sample has area of 50 μm$^2$ with AM0.

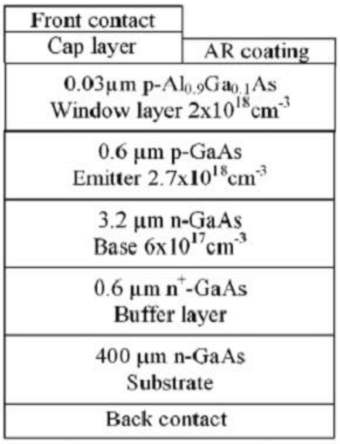

*Fig. 1. Structure of AlGaAs/GaAs solar cell sample [7, 8].*

*Table 1. Physical parameters for AlGaAs/GaAs solar cell sample.[9]*

| *Characteristics* | *$Al_{0.9}Ga_{0.1}As$* | *GaAs* |
|---|---|---|
| Bandgap (eV) | 2.12833 | 1.424 |
| Electron Affinity (eV) | 3.514 | 4.07 |
| Dielectric Permittivity (relative) | 10.344 | 12.9 |
| CB Effective Density of States (1/cm$^3$) | $1.54*10^{19}$ | $4.7*10^{17}$ |
| VB Effective Density of States (1/cm$^3$) | $1.5753*10^{19}$ | $9.0*10^{18}$ |
| Electron Mobility (cm²/Vs) | 205.8 | ≤8500 |
| Hole Mobility (cm²/Vs) | 96.4 | ≤400 |
| Effective Mass of Electrons | $0.1377m_o$ | $0.063m_o$ |
| Effective Mass of Holes | $0.735m_o$ | $0.51m_o$ |

## 3. Results and observations

### 3.1. The simulation software SRIM

Stopping and Range of Ions in Matter (SRIM) is a group of computer programs that calculate interaction of ions with matter; the core of SRIM is a program Transport of ions in matter (TRIM), SRIM is popular in the ion implantation research and technology community and used widely in other branches of radiation material science.

SRIM is based on a method; as the input parameters, it needs the ion type and energy (in the range 10 eV – 2 GeV) and the material of one or several target layers [6].

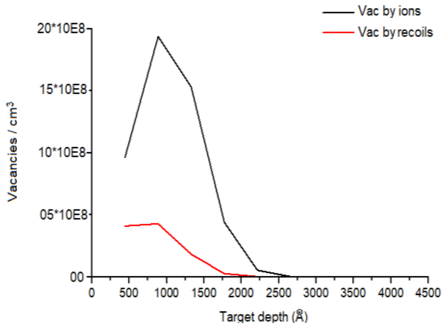

*Fig. 2. Distribution of vacancy concentration in the GaAs/AlGaAs solar cells for 10 KeV proton irradiation.*

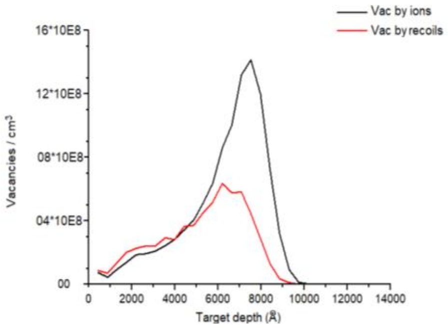

*Fig. 3. Distribution of vacancy concentration in the GaAs/AlGaAs solar cells for 100 KeV proton irradiation.*

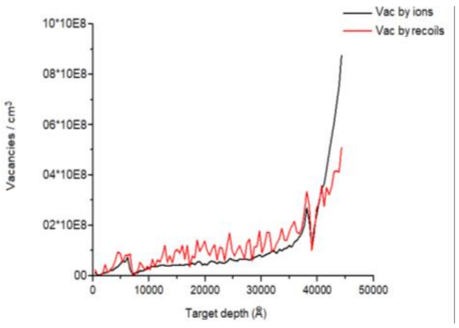

*Fig. 4. Distribution of vacancy concentration in the GaAs/AlGaAs solar cells for 500 KeV proton irradiation.*

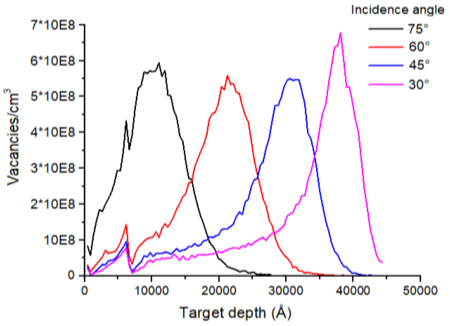

*Fig. 5. Distribution of vacancy concentration by ions in the GaAs/AlGaAs solar cells for 500 KeV proton irradiation with different incidence angles.*

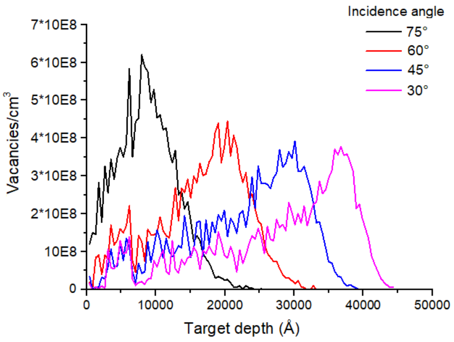

*Fig. 6. Distribution of vacancy concentration by recoils in the GaAs/AlGaAs solar cells for 500 V proton irradiation with different incidence angles.*

### 3.2. I-V Characteristics

After exposing this sample to certain proton irradiation with defined energies and incidence angles, we extracted the defects profile and integrated all the data on next simulation step to investigate the effect of proton irradiation on the I-V characteristic of our sample as Fig. 7 and Fig. 8 shows.

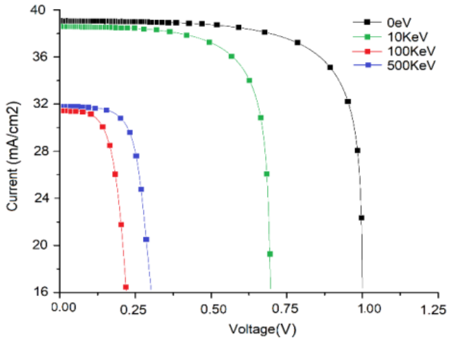

*Fig. 7. I–V curves for GaAs p+n solar cells irradiated by protons with different energy.*

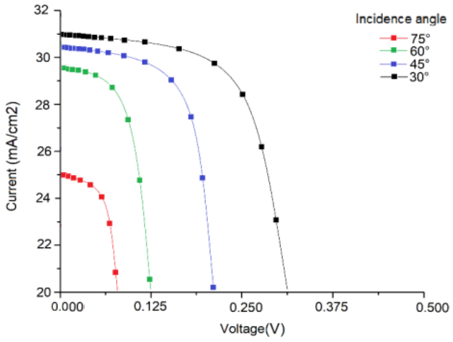

*Fig. 8. I–V curves for GaAs p+n solar cells irradiated by protons with energy of 500 KeV and different incidence angles.*

We fixed proton irradiation energy to 500 KeV and we changed the angle of incidence as the schema explains in Fig. 9.

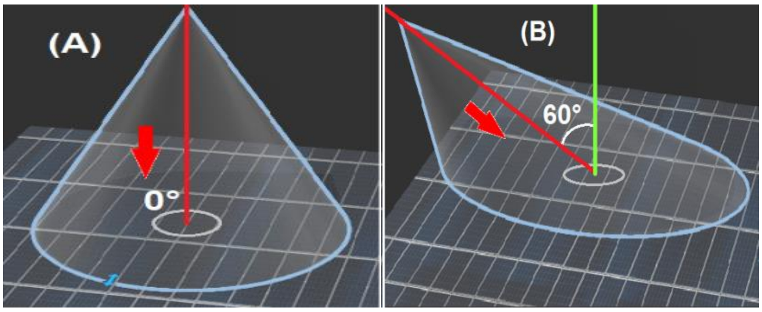

*Fig. 9. Schema explains how the irradiation exposed from different angle, (A) exposing with 0° and (B) with 60°.*

## 4. Discussion

The SRIM has been widely used to simulate the profile of damages caused by ion implantation [10], figure 2 shows the simulated vacancy profile in the GaAs solar cells irradiated by protons with energy of 10 KeV as we see damage is less intense than other cases, and is located in region between window and emitter layer from 0 to 0.25 µm. Figure 3 shows vacancy profile by protons irradiation with energy of 100 KeV and as we see that damage is located exactly between emitter and base layer with 0.2 to 1 µm, in this case we experienced the highest degradation of the cell performance as shown in Fig. 7.

Fig. 4 represents vacancy profile by protons irradiation with energy of 500 KeV, as we see that damage is located approximately from the middle of emitter layer to the limit of substrate layer, this caused noticeable damage at the level of the entire structure and of course affected I-V measurement as shown in Fig. 7.

From Fig. 5 and Fig. 6 it can be seen that the changing on the incidence angle is directly affecting the defects profile and of course this will be translated on the I-V characteristics as Fig. 8 shows, the increase of incidence angle value (Fig. 9) with fixed energy of 500 KeV shifted the damage cascade to more shallower levels in the crystalline structure, 60, 45, 30 degrees have caused almost similar effects in I-V characteristics as figure 8 shows and much intense degradation for 75 degrees.

For each proton radiation with different energy and different angle of incidence we have experienced a creation of vacancies by ions and recoils in the crystalline structure and of course different behaviors of degradation in I-V characteristics, but as we can see in Fig. 2 the degradation was much intense for proton irradiation with 100 KeV, and as Fig. 3 shows the distribution of vacancy for proton energy with 100 Kev, because the stopped region for both ions and recoils was fit the depletion region between emitter and base layers, in 100 KeV we have experienced the most intense degradation over all cases, and that should refer recombination centers that are created by irradiation damage.

75 degrees with 500 KeV proton irradiation showed much intense degradation in I-V characteristics too (Fig. 8) and because of the damage showed approximately between emitter and base layer, this confirm our derivation about the region that is more sensitive to proton radiation effect and how much its affecting the I-V characteristics too.

## 5. Conclusions

The I–V characteristics of the GaAs-based solar cell simulated under $AM_0$ before and after proton irradiation with testing the effect of changing in proton energy and its incidence angle, as we found 100 keV proton irradiated has experienced the most severe damage, 500 KeV has experienced a damage too but with less severe and for10 KeV it was the least influential on the performance of our solar cell, this lead us to understand that the relationship between protons radiation energy and the resulting damage is not always positive, we can define a energies interval that should be presented as the most influential on the performance of certain solar cells.

Changing in incidence angle explained to us how the damage profile will behave and also led us to understand how proton radiation affects each layer independently and saw how this translated to I-V characteristics or in generally the performance of our solar cell.

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