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Effect of Neon Ion Implantation on the Electrical Propertie of CIGS Photovoltaic Cells

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Abstract: The global energy demand is huge. Conventional fossil fuels such as oil, natural gas and coal are running out fast. These fossil fuels produce a huge amount of carbon dioxide, which is one of the greenhouse gases identified as the main cause of the global warming of the planet. More and more alternative sources of energy are being used: renewable and environmentally friendly. Solar energy is one of them. The photovoltaic sector converts solar radiation into electricity. This is done using photovoltaic cells. The highest conversion yields are obtained from mono-crystalline silicon cells. mono-crystalline silicon becomes relatively expensive, the ternary and quaternary chalcopyrite semiconductors are a viable economic alternative. Thin films chalcopyrite (CuInGaSe2) semiconductors have gained their place in solar energy harvesting. CIGS solar cells are increasingly efficient every year. It has been shown that the ion implantation affects the structure by changing or introducing defects. This in turn affects the electric properties of the material and may increase the efficiency of the solar cells. Thin films of Cu(InGa)Se2 deposited by low cost process were studied by simulating the ion implantation using SRIM software. Different energies and different doses of implantation were simulated in order to analyze the electrical properties of photovoltaic cells.

Keywords: Ion implantation, CIGS, Thin films, Solar cells, SRIM

Introduction

In a modern society, energy is vital for social and economic development. In today's world the comfort of modern computers, internet, and mobile phones lead to an increase in the energy demand. Providing the necessary energy without polluting our environment needs some sort of renewable energy resources. Green power represents those renewable energy resources and technologies that provide the greatest environmental benefit. It is defined as electricity produced from solar, wind, geothermal, biogas and hydroelectric sources. Solar energy is one of the most important sources among these renewable energy sources. Solar energy is sufficient enough to meet all of the Earth's energy demands. Generating electricity from solar energy is done using solar cells. Photovoltaic cells convert sunlight directly into electricity.

The the oldest cells called first generation solar cells are made of silicon and involve single and multicrystalline solar cells. Power conversion efficiencies of cells made from silicon exceeds 25%. Second generation solar cells are made from materials like copper indium diselenide (CIS), and copper indium gallium selenide , amorphus silicon (A-Si) thin films, and cadmium telluride (CdTe). Conversion efficiencies are a bit smaller than that of first generation solar cells, but the cells use small quantities of material and are compatible with flexible substrates. Perovskite solar cells, dye sensitized solar cells (DSSCs) and nanocrystal solar cells counte as third generation solar cells. Conversion efficiencies are even lower that that of second generation solar cells, but these cells are flexible, low-cost and easily fabricated (Dincer, 2018).

Manufacturers look for stability and efficiency when producing solar cells. Researchers take these two factors into account for improving solar cells. Some researchers are looking for new materials to achieve those goals,

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others are trying to improve existing materials by tuning the fabrication process or by adding dopents or impurities to affect the crystalline structure of the material. Ion implantation is one of these techniques.

Ion Implantation

During the ion implantation process, the strongly accelerated ions will collide with the substrate (target material). By entering the substrate, these ions will lose their energy following the collisions with the atoms of the substrate until the complete stop of these ions.

Certain atoms of the crystalline network of the material will be moved from their site (primary collisions) and can in turn move other atoms (secondary collisions). This phenomenon depends on their masses as well as the temperature and energy of the implanted ions. These relocations induce an appearance and an accumulation of vacant sites and interstitials (Frenkel effect) which can be dissociated or agglomerated, as well as more complex defects along the course of the implanted ion (Nastasi, 1969).

Ionic implantation is not without effects on the crystalline network of the substrate. Each incident ion has kinetic energy which decreases during its interactions with the atoms of the target material. This energy is thus transferred to the crystalline network in the forms of electronic stopping and nuclear shocks until the ion is immobilized. If by meeting the target atom, the ion has an energy greater than E_L (threshold energy which depends on the substrate), it will eject it from its substitutional site and give it energy between 0 and $E\text{-}E_L$ (Rouha, 2014). If this energy is sufficiently high, the atom thus moved will generate a cascade of collisions within the substrate. With each movement of an atom of the crystalline network, an interstitial-lacune pair called the pair of Frenkel, will be created called elementary defect. Part of these pairs can recombine during the very implantation process or during the receipt phase. The concentration of these defects depends on the conditions of implantation (dose, temperature, energy, etc.) (Ziegler, 2008).

Radiation damage has a large impact on the electrical properties of semiconductors. Often, low doses are enough to reduce the lifespan of minority carriers. The mobility of the carriers is considerably affected. There are two types of implantations according to the degree of damage to the crystalline network. When the density of punctual defects is greater than a critical density, an amorphous area is created to a depth determined by the conditions of implantation and the implantation is said to be amorphizing. The thickness of this amorphous layer is generally greater than the free RP route of the implanted ions and depends on their mass, their energy and the implanted dose. For lower concentrations of punctual defects, the substrate, while being damaged, retains its crystalline character and the implantation is said to be non-amorphizing. (Ryssel, 1986)

Some researchers chose sodium ions for implantation on polycrystalline $CuIn_{1-x}Ga_xSe2$ films. Energy and dose for the simulation were 100KeV and 10^{+15} cm^{-2} respectively. The mean range and straggling of implanted Na were 1469 Å and 895 Å. Na-implantation on CIGS films induced lattice displacement and lead to an enhancement in electrical properties of devices made with these films (Wu, 2012). Other researchers chose xenon implantation for their material. (Satour, 2012) showed a mean projected range Rp of 170 Å and a mean straggling range ΔRp of 78 Å. The implantation energy used was 40 keV. Atom displacement is limited to a small region very close to the surface.

Oxygen ion implantation into CuInSe2 crystals revealed some concentration changes of already existing defects and the creation of new defects. These defects influence the photoelectric properties of the material (Zegadi, 2015). The energy was 40 keV, ion doses were 10^{+15} cm^{-2} and 10^{+16} cm^{-2} the obtained mean projected range Rp was 744 Å, the mean straggling range ΔRp was 364 Å.

Neon ion implantation in silicon was used by Wegierek (2021) for generating intermediate levels in the band gap of the material in order to change the electrical properties of the silicon implanted with neon ions and thus improving the efficiency of photovoltaic cells. From our side we intend to study the neon ion implantation of CIGS photovoltaic cells. We primarily look at the effect of ion damage on the structure of the material and try to relate this to the electrical properties of the cells.

Simulations

In the present work we used the SRIM tools to simulate the effects of the irradiation of the ternary (or quaternary) semiconductor CuInGaSe2 by Neon ions. The simulations were carried out for a 40KeV implantation energy and an angle of incidence perpendicular to the substrate. We choose a number of ions N=10000, in a crystalline structure of CuInSe2 with a mass density of 5.8g/cm3. The SRIM simulator, designed on the basis of the Ion-Matter interaction, makes it possible to predict the distribution of these defects (distribution of displaced atoms, interstitial sites, etc.). Figure 1 shows the neon accelerated ions inside CIS material. Ions diffuse inside the material in all direction due to cascade elastic collisions with angular deflexions. The maximum depth penetration is about 2000 Å.

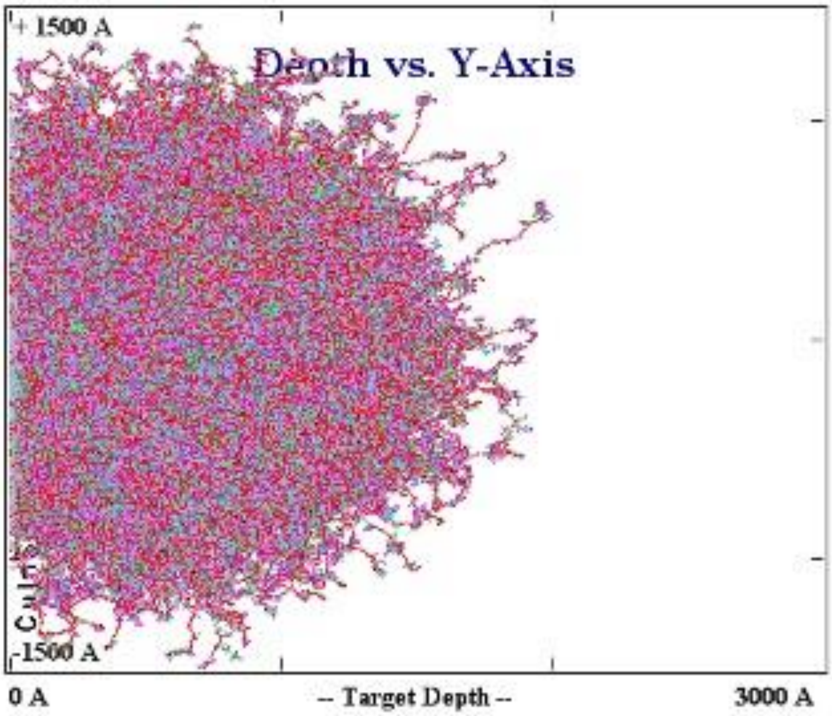

Figure 1. Neon diffusion inside CIS

The penetration profile is showed in Figure 2. The mean projected range Rp was 642 Å with a mean straggling range ΔRp of 340 Å.

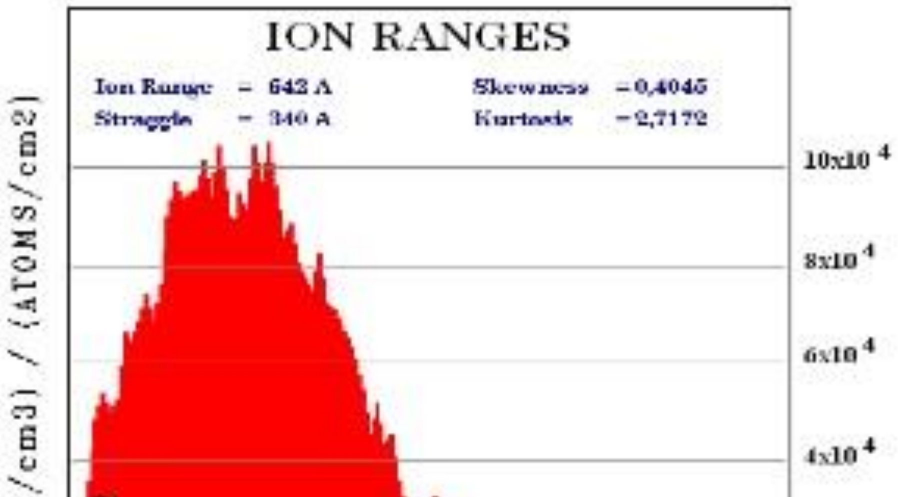

Figure 2. Ion range profile

A lot of other parameters can be extracted from SRIM simulation tools: energy losses due to the ionization process and phonons, the energy given to target electrons, energies absorbed by target atoms and so on, all of which tell us about the damage created in the target. There are some more simulations that need to be calculated in order to determine the defects introduced by ion implantation in the quaternary semiconductor films of CIGS. Electrical behavior of devices made from these films depend on those defect changes.

Conclusion

In this paper, we presented the need for efficient electrical solar energy converter devices, we reviewed few generations of these solar cells. In the way of improving electrical and physical properties of these cells, we recalled the physical phenomena of the implantation of ions in solids. We reviewed the works that have been conducted by other researchers with various ion sources. We mentioned the impact of accelerated ions on the crystalline structure of the photovoltaic material. Knowledge of the distribution and evolution of defects thus created in the structure is essential as to the use of this semiconductor. SRIM tools were used to simulate the neon ion implantation in the $CuInSe_2$ compound, various parameters were examined like the course of neon ions and their distribution in the semiconductor. There has been a modification of chemical defects close to the surface of the crystal. These changes include a variation in the concentration of existing defects and the creation of new faults. Those defects are supposed to influence the electric properties of the photovoltaic material.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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