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Aging of solar cells under working conditions

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Rapid development and wide application of photovoltaic (PV) solar systems are primarily based on thorough investigations of the characteristics of solar cells. Though proved to be relatively stable (except perhaps amorphous silicon solar cells) under ordinary working conditions, solar systems are (like any other electronic devices) prone to the effects of aging, which could deteriorate their characteristics. The aim of this paper is to investigate the influence of aging on the main characteristics of solar cells such as efficiency, fill factor, short circuit current etc. To simulate and accelerate the effects of aging, solar cells were exposed to the radiation fields of different doses. Investigations were directed to the effects of defects and impurities that influence the minority carrier lifetime, better understanding of transport properties, electron-hole pair creation etc., that would ultimately lead to larger scale application of solar energy in the near future.

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1. Introduction

Regardless of the very high standards in the production of electronic devices, all of them are more or less, prone to the effects of aging even if they're not exposed to extreme (hostile) working conditions. This process of aging is more pronounced when the devices are in some kind of radiation fields or exposed to the large variations of temperature. Solar cells, the basic elements for photovoltaic conversion of solar energy, are also in certain degree sensitive to the effects of aging.

The wider substitution of conventional energies by solar energy lies in the rate of developing solar cell technology. Silicon is still the mostly used element for solar cell production, so efforts are directed to the improvement of physical properties of silicon structures [1]. Investigations are directed to the effects of defects and impurities that influence lifetime of charge carriers, better understanding of transport processes, optical absorption properties that determine electron-hole pair creation ability, etc [2]. Output characteristic of all semiconductor devices are primarily defined by fundamental parameters (resistance, lifetime and mobility of charge carriers, diffusion length etc.), and processes in them. Analytical connections between fundamental and output characteristics of solar cells are matter of theoretical analysis, but experimentally obtained results are more complex than theoretical suppositions. Both in production process of solar cells, and during their performance, the distribution of dopants, impurities and especially defects is usually not uniform and unpredictable, and could directly influence the processes in the cells [1-4]. Empirically obtained influence of fundamental parameters is usually mathematically defined by formal introduction of the ideality factor, n, in the exponent of current – voltage characteristics of solar cells. Ideality factor combines all variations of current flow from the ideal case, induced by various internal and external influences of physical parameters during the manufacturing process or as a consequence of aging. Main characteristics of solar cell: efficiency, η, open circuit voltage, V_{oc}, short circuit current, J_{sc}, maximum power, P_m and fill factor, ff, strongly depend on the fundamental parameters of real solar cell (and p-n junction generally), such as series and parallel resistance, ideality factor and saturation current density - R_s, R_{sh}, n, J_0, respectively. It has been established [5] that an increase of the ideality factor has great and negative influence on the output characteristics of the solar cells, primarily on the fill factor and the efficiency. Lower quality of the devices with large ideality factor are connected to the quality of the semiconductor material, which could influence the charge carrier generation, their transport across the junction and collection at the terminal contacts, leading to the decrease in the output current and voltage. Therefore, in this paper possible degradation of the main characteristics of solar cells through aging process was investigated. For that reason, solar cells were exposed to the radiation fields of different doses, since radiation and aging produces similar effects in semiconducting devices.

2. Theoretical analysis

Dependency of the output characteristics on the fundamental physical parameters, although very complex, presents the final step towards the better understanding of the electrical transport processes in the solar cells. Though the current transport mechanism is (theoretically) similar for most solar cells based on p-n junction, the choice of the material and its structure (monocrystalline, polycrystalline or amorphous) has some influence on the transport processes. Amorphous silicon, a-Si, for example, is a direct-gap material with very high density of states within the energy gap, that could behave like recombination centers for the charge carriers. Though a-Si has high absorption coefficient and is easy to manufacture, the main difficulty in a-Si solar cell technology lies in constant decrease of efficiency during time. This effect is called Staebler – Wronski effect, and is dependent on total number of the absorbed photons, i.e., on the intensity of the light to which the cell is exposed, and the duration of the exposure.

Polycrystalline and monocrystalline solar cells are more reliable than amorphous, but inherent presence of defects and impurities in the basic material could, during time, produce some negative effects. This is specially emphasized if those states are located within the energy gap and are activated during work. In such a case they become traps for optically produced electron-hole pairs, and thus decrease the number of collected charge carriers. Macroscopically, this effect could be observed as a decrease of the output current and voltage, and ultimately could lead to the decrease of the efficiency of solar cell. Lower values of short-circuit current indicate the existence of the recombination centers that decrease the mobility and diffusion length of the charge carriers, making the recombination in the depletion region dominant transport in such solar cells [5]. Also, voltage decrease in the maximum power point (P_m) has great influence on the efficiency. One of the main reasons for this decrease is the increase of the ideality factor, so it could be said that the influence of the ideality factor on the solar cell efficiency is through the voltage. Set of the experimentally obtained $\eta = f(n)$ dependencies for different solar cells is shown in Fig. 1 [5].

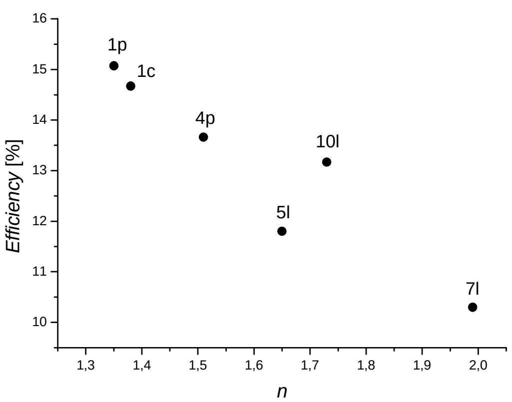

Fig. 1. Efficiency dependence on the ideality factor [5].

Direct connection of the saturation current density J_0 and ideality factor n, Fig. 2 [5], has as a consequence the decrease of the efficiency with the increase of either of these parameters. Series resistance R_s, has the similar effect on the output characteristics, i.e. an increase of the R_s would directly lead to the decrease of efficiency. The series resistance includes the surface resistance from the p-n junction to collection grid and the base region resistance.

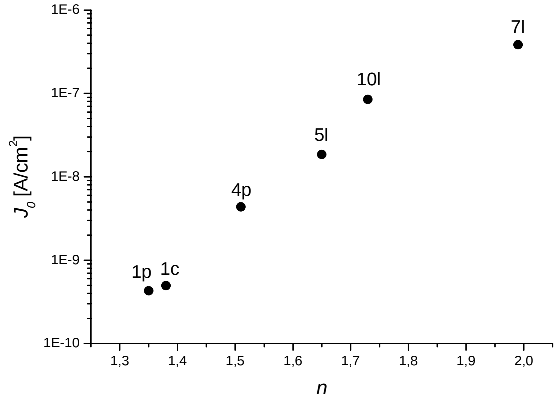

Fig. 2. Saturation current dencity dependence on ideality factor [5].

All of these effects could be induced in many ways during the lifetime of solar cells (optically, by the changes of the environment temperature, etc.), and are consistent with the effects that radiation produces in the semiconductor devices. The main effect of the radiation is an increase of the saturation current generated within or at the surface of the depletion region. The permanent damage in the solar cells materials is caused by collisions of the incident radiation particles with the atoms in the crystalline lattice, which are displaced from their positions. These defects degrade the transport properties of the material and particularly the minority carrier lifetime [6]. This lifetime decrease produces degradation of the parameters of the cell. Many experiments have shown that the short-circuit current and output power decrease gradually with the increase of the radiation dose [6,7], while the open circuit voltage could be degraded severely even for low doses [7]. The change in short-circuit current was mainly related to the lifetime of the minority carriers, and the change in open circuit voltage to the damage of p-n junctions. So, heavy particles (protons, neutrons) produce physical damage of the lattice structure of the cell, and permanently degrade electrical performances of the solar cell.

On the other hand, γ radiation damage is induced by the ionization and excitation of silicon atoms within the junction space charge region of a solar cell. The presence of impurity atoms that are either added to the base material as donors, or during the manufacturing process, has indicated the possibility that some of the produced electrons might be trapped by those atoms between the valence and conduction band [8]. Therefore, the power output of the solar cells exposed to γ radiation is also reduced.

3. Experimental procedure

Experimental measurements in this paper were carried out on the commercially available solar cells based on encapsulated polycrystalline silicon manufactured by Leybold. Current-voltage data were used for the characterization of the properties of solar cells. Standard measurement equipment was used to measure *I*-*V* curve under different illumination levels (between 40 and 350 W/m^2). Reflective lamp was used as a solar simulator. From the obtained curves, all relevant parameters were obtained.

Solar cells were irradiated with Co^{60} gamma source with different doses. Irradiation was performed through glass in controlled environment. Before and after every step of the irradiation, current-voltage characteristics of the diodes were measured in highly controlled conditions at room temperature.

4. Results and discussion

Although effects of gamma irradiation on the solar cells are known to be primarily through ionization effects, for all measured samples an increase of series resistance was observed, Fig. 3. Almost linear dependence of series resistance on the absorbed irradiation dose indicates that some changes in the collection of the charge carriers have occurred. This behaviour of R_s is reflected mostly on the short-circuit current density J_{sc}, since radiation induced activation of defects and impurities mainly affects the transport mechanisms in the device. Dependence of the J_{sc} on the absorbed dose for different illumination levels was shown in Fig. 4. Steeper decrease of the J_{sc} for higher illumination levels indicates that recombination centers could be both optically activated and activated by irradiation. Therefore, solar cells exposed to the higher values of solar irradiation during their performance could exhibit greater decrease in the initial J_{sc}. Similar behaviour was observed for the open circuit voltage, Fig. 5.

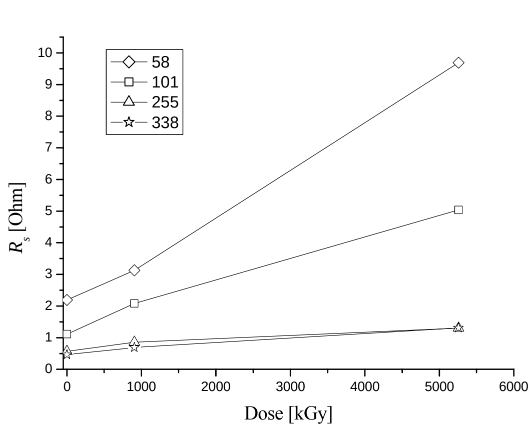

Fig. 3. Dependence of the series resistance on doses.

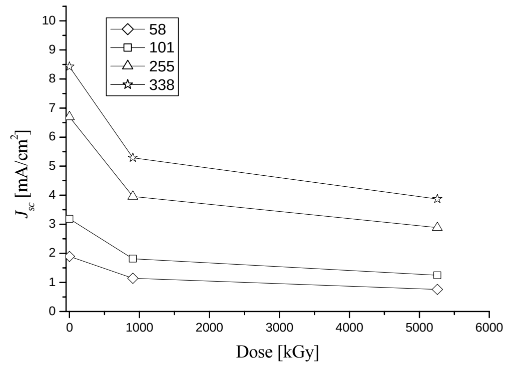

Fig. 4. Dependence of the J_{sc} on doses.

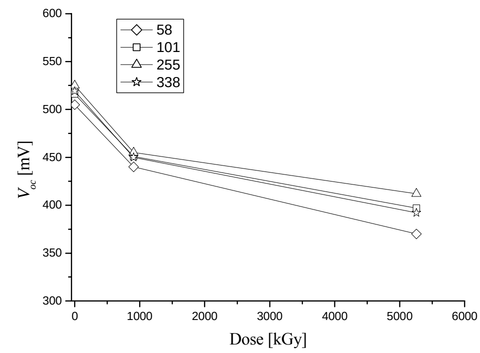

Fig. 5. Dependence of the V_{oc} on doses.

Also, all samples were polycrystalline, so presence of grain boundaries, characteristic for the polycrystalline material, has great influence on the collection of the photogenerated carriers. Presence of the recombination centers, small diffusion length and minority carrier lifetime, as a result of either irradiation or aging, finally leads to the decrease of the efficiency of solar cells. As could be seen in Fig. 6, this decrease is very pronounced, regardless of the illumination level. Although initial efficiencies were slightly different for different illumination levels, after irradiation they became almost equal. Comparing Fig. 4 and Fig. 6, it could be concluded that for higher irradiation doses factors that influence the output voltage (both V_{oc} and V_m) dominate the processes in the solar cells, and have greater influence on the efficiency.

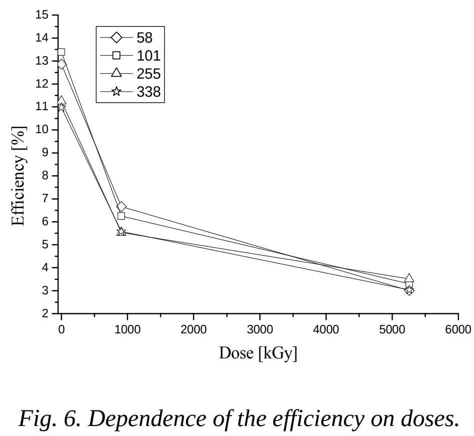

Fig. 6. Dependence of the efficiency on doses.

5. Conclusion

Degradation of the main solar cells parameters, as a consequence of irradiation, was observed for all used samples. Whether artificially induced (by irradiation, for example), or as a result of the exposure of the devices to the various meteorological conditions, these effects of degradation of the electrical performance indicate that strict conditions for the application of solar cells must be predetermined. Although proven to be reliable in terrestrial applications, solar systems are (like other semiconductor devices) sensitive to variety of radiation environments in which they are used. Performance failure could have negative impact both on the financial and environmental aspects of the device application. Therefore, form the technological point of view, it is important to study the variations induced by aging of semiconductor junction parameters that affect the performance of the solar cells.

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