INFLUENCE OF RADIATION ON THE PROPERTIES OF SOLAR CELLS

by

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The wide substitution of conventional types of energy 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. There are several trends in the development of solar cells, but mainly two directions are indicated: the improvement of the conventional solar cell characteristics based on semiconductor materials, and exploring the possibilities of using some new materials. The aim of this paper is to present some different approaches of improvement of solar cell properties through the investigation of radiation effects on the main solar cell characteristics.

Key words: solar cell, noise, silicides, radiation

INTRODUCTION

Faced with an alarming increase of energy consumption on one side and very limiting amounts of available conventional energy sources on the other, scientists have turned to the most promising, renewable energy sources. Possibilities for the application of solar systems based on photovoltaic (PV) conversion of solar energy are very wide, primarily because of their relatively low cost and very important fact that solar energy is the most acceptable source of electrical energy from the environmental point of view. Recently, increased investments in the development of PV technology have been observed worldwide. However, as every other energy source, PV technology has some limitations and disadvantages, primarily connected to their low efficiency.

Silicon solar cells belong to a wide group of semiconductor detector devices, though somewhat specific in its design (larger than most of the detectors). Regardless of 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 are not exposed to extreme (hostile) working conditions. One of the most limiting factors for all kinds of detectors is their noise, such as frequency dependent generation-recombination noise, burst noise and $1/f$ noise. That is why lowering noise is important for obtaining good quality detectors. It is known that low frequency noise ($1/f$ and burst noise) manifests as random fluctuation of the output current or voltage, leading to lowering of the efficiency of the device. Various experiments suggest [1, 2] that the origin of this noise is the fluctuation of the number of free charge carriers connected to the existence of the traps located in the vicinity or directly in the junction area, or the fluctuation of the mobility of charge carriers. In both cases these fluctuations arise from the interactions of carriers with defects, surface states, and impurities that are either introduced during manufacturing of the device or as a consequence of the hostile working conditions (radiation, high temperature, humidity). Because of the large surface to volume ratio, surface effects are expected to be a major cause of $1/f$ noise, so good quality contacts are of great importance. Silicides belong to a very promising group of materials with low resistivity and good temperature stability and are used for fabrication of reliable and reproducible contacts. Even so, surface effects such as surface recombination fluctuations in carrier mobility, the concentration of surface states, *etc*., have great influence on frequency dependent noise in silicides too. It has been found [3-5] that the ion implantation of As^+ ions in the formation of silicides could improve the electrical characteristics of silicides regarding their noise level.

The common source of noise that is connected to the hostile working conditions is radiation. Solar cells,

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the basic elements for PV conversion of solar energy, are especially susceptible to radiation damage, primarily due to their large surface. The lifetime of the solar cell is restricted by the degree of radiation damage that the cell receives. This is an important factor that affects the performance of the solar cell in practical applications. The permanent damage in solar cell materials is caused by the collisions of incident radiation particles with 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 [6-9]. This lifetime decrease produces the degradation of the parameters of the cell ultimately leading to an increase of the noise level. The interaction between vacancies, self-interstitials, impurities, and dopants in Si leads to the formation of undesirable point defects such as recombination and compensator centers which affect performance of solar cells, especially in space. The introduction of radiation-induced recombination centers reduces the minority carrier lifetime in the base layer of the p-n junction increasing series resistance. After very high doses of radiation series the resistance of the base layer could be so high that most of the power generated by the device is dissipated by its own internal resistance [10-13]. However, small doses of radiation carefully introduced and monitored could have some beneficial effects on the device performance due to the possible relaxation of crystal lattice, leading to the lowering of series resistance.

Factors that influence the internal parameters of solar cells such as series and parallel resistance lead to changes in efficiency and maximum generated power in a solar cell. The capability of a solar cell to convert solar energy into electrical depends on various fundamental and technological parameters. Variations from the ideal case of current transport could be represented by the ideality factor [14] that could be easily obtained from current-voltage (I-V) characteristics of solar cells. The non-ideal behaviour of the device is reflected in the values of n greater than 1, and that is the result of the presence of different transport mechanisms that can contribute to the diode current. The determination of the dominant current mechanism is very difficult because the relative magnitude of these components depends on various parameters such as density of the interface states, the concentration of the impurities and defects, the height of the potential barrier, device voltage, and device temperature. The dependence of the maximum power on the ideality factor can be observed in fig. 1. Considering that the maximum power point depends on the resistance (and ideality factor as well), series and parallel resistance should be maintained at such values to obtain the maximum efficiency.

Since the relatively low efficiency of solar cells based on the conventional semiconducting materials such as Si, GaAs, and InP is the main limitation to PV applications, the investigations are now directed to the

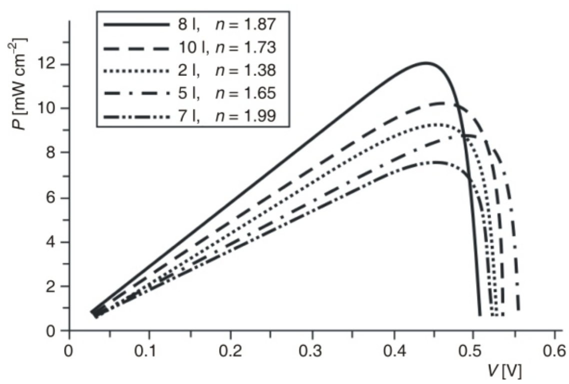

Figure 1. Simulation of the dependence of P-V characteristics on the ideality factor

development of new materials, primarily organic molecules and polymers. PV technology based on silicon semiconductors and similar materials has shown certain limitations and disadvantages so a novel approach in the investigations of materials for PV conversion is needed. Namely, at the beginning of the 21st century a new type of organic PV low cost cells was developed. Solar cells based on organic materials use the process of photosynthesis in plants that leads to photochemical processes. It is estimated that the production cost of this cells will be between 10% and 20% of the cost of solar cells produced in conventional way.

Also, conducting and semiconducting polymers are considered as possible materials for solar cell production. New technologies in this field have given great contribution in the development of nanophotovoltaic cells with increased efficiency.

EXPERIMENTAL PROCEDURE

The investigations of frequency dependent $1/f$ noise in silicides included the studies of arsenic ion implantation effects on the frequency noise level characteristics of TiN/Ti contacts on p-type Si. Ion implantation with As^+ ions, annealing and electrical characterization were performed on 45 samples. The implantation of arsenic was performed at 350 keV with the dose range between 10^{15} ions/cm^2 to 10^{16} ions/cm^2. Thermal treatment was performed at temperature with the mean value of 800 C for 20 minutes. The structural analysis of TiN/Ti/Si samples was performed by Rutherford backscattering spectrometry (RBS), with a 1.5 MeV He^+ ion beam at normal incidence and the detector position at 160 °C. Noise level measurements were performed with the measurement equipment consisting of the multichannel analyzer ND-100, low noise pre-amplifier, and amplifier (standard ORTEC equipment). MAESTRO II code was used for automatic energy calibration. Frequency noise measurements were performed at room temperature.

Experimental measurements concerning solar cells were carried out on the commercially available solar cells based on encapsulated monocrystalline silicon from different manufacturers. The solar cells were irradiated with a Pu-Be point neutron source. A mixture of ^{238}Pu with beryllium is a good source of neutrons, through a nuclear reaction in which ^{9}Be absorbs an alpha particle from ^{238}Pu and forms ^{12}C with the emission of a neutron. This neutron source provides a broad beam of emitted neutrons up to about 11 MeV with an intensity maximum of about 5 MeV. The samples were in direct contact with the source, and the maximum dose rate was d*D*/d*t* = 0.36 mGy/h. Current-voltage data were used for the characterization of the properties of solar cells. Standard measurement equipment was used to measure I-V curve for two illumination levels of 32 W/m^2 and 58 W/m^2 after every irradiation step.

Combined measurement uncertainty was less than 5% for all measurements performed within the experiment [15, 16].

RESULTS AND DISCUSSION

Noise measurements

The measurements of 1/*f* noise in this type of silicides have shown that As ion implantation of different doses could have an impact on quality of silicides as contacts. Structural RBS analysis has shown that ion implantation did not induce redistribution of components for lower implantation doses (fig. 2). The spectra indicate that the entire titanium layer has interdiffused with the silicon substrate. The presence of the $TiSi_2$ and $TiSi_2$ phase in the implanted samples has been observed. In all cases the top TiN layer remains unaffected, but for higher doses of implantation (10^{16} ions/cm^2) a disordered structure has been registered. This corresponds to the amorphization of the silicon substrate, which is moving deeper with the ion dose, showing that the physical properties of TiN/Ti/Si are influenced by the implantation.

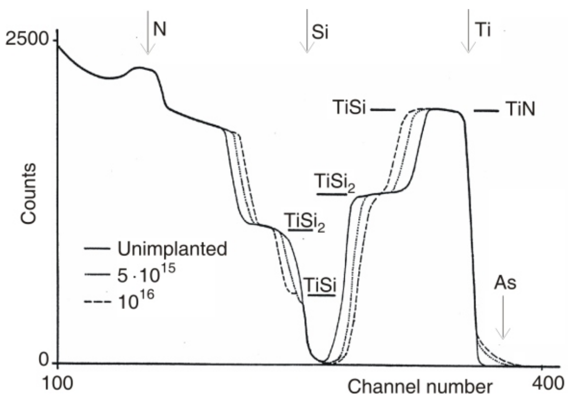

Figure 2. RBS spectra of TiN/Ti/Si samples

This influence has been confirmed by noise level measurements (all of the samples exhibit similar behaviour). Noise spectra have been measured for different time constants τ (frequency range $\tau \sim 1/f$) of the low noise amplifier. The implantation doses have different effects for different frequency ranges. In the frequency range of 15-26 kHz (time constant of 6-10 μs) the ion dose of 10^{16} ions/cm^2 gives better results than an unimplanted sample, but in the range beyond 80 kHz (time constant lower than 2 μs), it produces greater noise compared to an unimplanted sample (fig. 3). However, the ion dose of 5 10^{15} ions/cm^2 shows the best results for the entire measuring range, suggesting that this dose of implantation induces a more homogeneous silicidation and the formation of Ti-Si phase with a lower concentration of crystal defects (after annealing). The lower concentration of point defects and dislocations and a more homogeneous silicide/silicon interface results in a lower frequency noise level of the analyzed structures. Also, previous results have shown [4] that the noise level was lower for the samples implanted after annealing. This suggests that thermal treatment induces the relaxation of the crystal lattice and the improvement of the crystal structure of the silicides.

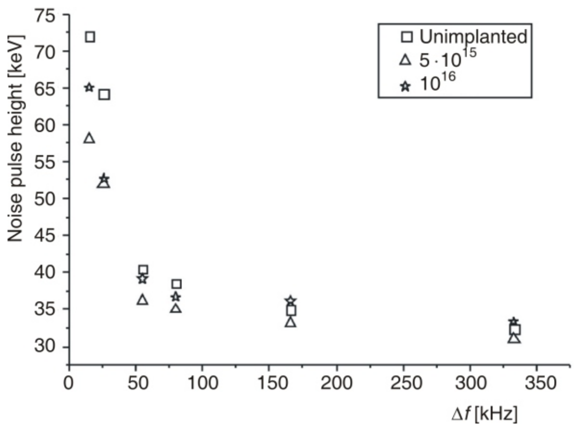

Figure 3. Frequency noise level for TiN/Ti/Si samples

Effects of irradiation

Surprisingly, effects similar to the annealing have been observed in some solar cells after irradiation. Although the negative influence of radiation on electrical characteristics of the semiconducting devices is a well known and thoroughly investigated fact, especially when working in hostile conditions, in some cases irradiation could improve cell characteristics.

Radiation damage due to neutrons is, as mentioned before, primarily connected to the displacement of silicon atoms from their lattice sites in the crystalline silicon solar cells, leading to the destruction and distortion of local lattice structure and formation of defects. If, under the influence of neutrons, stable defects are made, they could, together with impurity atoms, donors and for example implanted atoms, form complex defects acting as recombination sites or traps, significantly decreasing minority carrier lifetime. This lifetime decrease produces the degradation of the electrical parameters of the cell, such as series resistance (R_s), output current and finally efficiency (μ). The high level of series resistance usually indicates the presence of impurity atoms and defects localized in the depletion region acting as traps for recombination or tunneling effects, increasing dark current of the cell. Moreover, shallow recombination centers in the vicinity of conducting zone enhance tunneling effect, further degrading output characteristics of the cell by increasing noise level (especially burst noise that is connected to the presence of excess current).

Such negative impact of neutron radiation has been observed in this experiment, as could be seen in fig. 4.

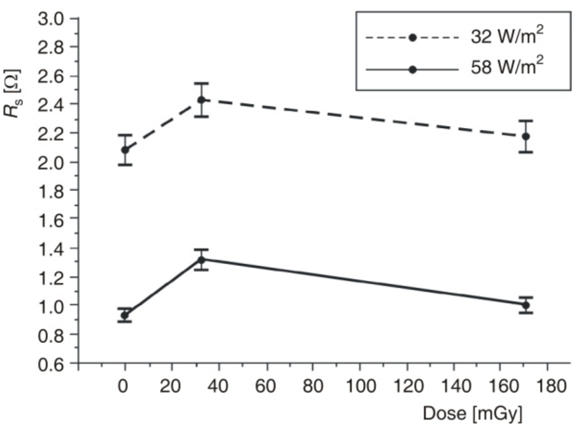

Figure 4. Dependence of the series resistance on doses for two illumination levels

However, after the initial increase of series resistance, for both illumination levels and for higher irradiation doses the decrease of R_s has been observed. This decrease is very significant from the solar cell design standpoint because it indicates the possible beneficient influence of low doses of irradiation, even with neutrons. It could be explained by the fact that during the fabrication process of any semiconducting device structural defects and impurities that have been unavoidably made produce tension in the crystal lattice. The low doses of radiation could act similarly to annealing, relaxing the lattice structure and decreasing series resistance.

This is especially important because the other parameters of solar cells (voltage in the maximum power point V_m and fill factor *ff*) have shown the similar tendencies (figs. 5 and 6). Namely, after the first deterioration due to the exposure to radiation an increase was observed with an increase of the irradiation dose

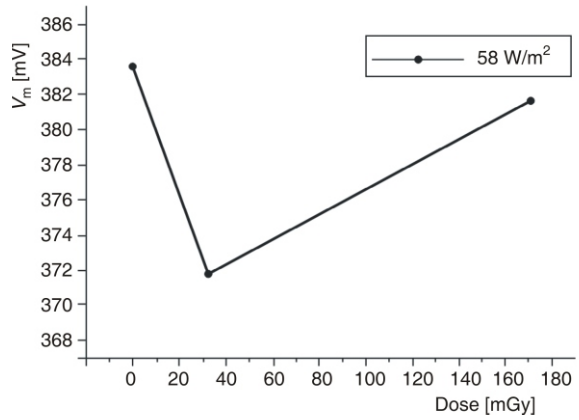

Figure 5. Dependence of the voltage in the maximum power point on doses

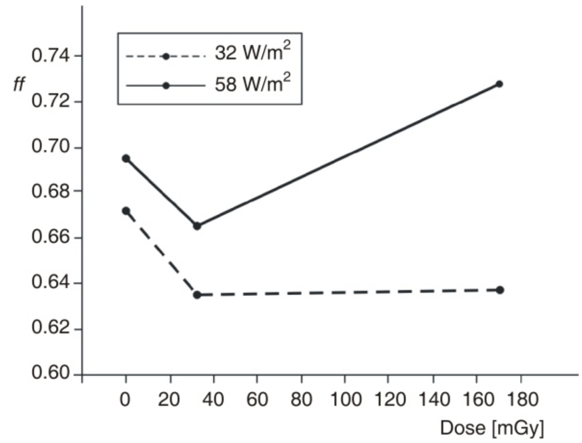

Figure 6. Dependence of the fill factor on doses for two illumination levels

for both parameters. Since some other influences (except radiation) that could affect voltage in the maximum power point were present at the low level of illumination, measurements at 32 W/m^2 for V_m were omitted.

Although somewhat unexpected, this behavior could be explained by the fact that impurities and defects in the crystal structure which are unavoidable in the production process create certain tension of the crystal lattice. Some irradiation doses could lead, similar to the annealing, to the relaxation of the crystal structure and the decease of series resistance. Considering the fact that maximum power and fill factor directly influence efficiency of the solar cells, their increase leads to an increase in efficiency.

CONCLUSIONS

The concept of the sustained development as well as the economic crisis has promoted the investigations of the renewable energy sources, especially solar energy. Considered environmentally clean (non-polluting) and available in unlimited amounts, solar energy is the most promising energy source of the future (from the current standpoint). As has been shown in this paper, lowering noise level in solar cells based on silicon could be one way of improvement of solar cell characteristics. It has been established that both physical and electrical properties of used silicides are influenced by the implantation doses. As could be expected, higher doses result in the degradation of electrical characteristics (via increasing noise level). But the results of frequency noise measurements indicate that ion implantation could successfully be applied in order to achieve a more homogeneous silicidation, if carefully optimized dose (in our case 5 10^{15} ions/cm^2) is used. This dose of As^+ ions has been proved to be optimal for the fabrication of low-resistivity and low-noise contacts. Another way of obtaining solar cells with better output characteristics is exposure to relatively low doses of radiation (neutron, in this case). The observed improvement of the characteristics indicates that there is a possibility of using irradiation for enhancement of the solar cells quality.

Finally, a new category of materials based on the organic and polymer materials has recently emerged, and it is expected that they could successfully compete (in characteristics and low cost) with conventional inorganic semiconducting materials.

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УТИЦАЈ ЗРАЧЕЊА НА ОСОБИНЕ СОЛАРНИХ ЋЕЛИЈА

Распострањена замена конвенционалне енергије соларном енергијом лежи у стопи развоја технологије соларних ћелија. Силицијум је и даље најчешће коришћени елемент за израду соларних ћелија, па се напори улажу у побољшање физичких карактеристика силицијумских структура. Постоји неколико различитих трендова у развоју соларних ћелија, али углавном се могу разликовати два правца: побољшање карактеристика конвенционалних соларних ћелија базираних на полупроводничким материјалима и истраживање могућности примене нових материјала. Циљ овог рада је да представи различите приступе у побољшању особина соларних ћелија кроз истраживање ефеката зрачења на главне карактеристике соларних ћелија.

Кључне речи: соларна ћелија, шум, силициди, зрачење