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Possibilities of improvement of silicon solar cell characteristics by lowering noise

A. VASIĆ, P. OSMOKROVIĆ*, M. VUJISIĆ, Ć. DOLIĆANIN[a], K. STANKOVIĆ[b]
University of Belgrade, 11000 Belgrade, Serbia
[a]*University of Novi Pazar, Novi Pazar, Serbia*
[b]*Institute of Nuclear Sciences "Vinča", P.O. Box 522, 11001 Belgrade, Serbia*

Possibilities for the application of solar systems based on photovoltaic conversion of solar energy are very wide, primarily because of their relatively low cost and very important fact that solar energy is most acceptable source of electrical energy from the environmental point of view. However, as every other energy source, PV technology also has some limitations and disadvantages. In the first place, compared to some other sources, the efficiency of PV modules (i.e. solar cells) is relatively small. One of the most limiting factors for all kinds of detectors is their noise, especially frequency dependent generation-recombination noise, burst noise and 1/*f* noise. It has been suggested that the cause of the 1/*f* noise is the trapping of electrons at the surface states as well as in the bulk. That is why the improvement of electrical characteristics of contact layers is very important. Silicides are widely investigated as promising reliable and reproducible contacts. The aim of this paper is to present the possibilities of lowering noise in silicides (that could be used as contacts) and in solar cells as a whole.

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1. Introduction

Photovoltaic (PV) conversion of solar energy is one of the most up-to-date semiconductor technologies that enables application of PV systems for various purposes. 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. Silicon solar cells belong to a wide group of semiconductor detector devises, though somewhat specific in its design (larger than most of the detectors). One of the most important characteristic of detectors is their energy resolution that primarily depends on 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) is manifested as random fluctuation of the output current or voltage, leading to lowering of the efficiency of the device. Various experiments suggests [1,2] that the origin of this noise is fluctuation of the number free charge carriers connected to existence of the traps located in the vicinity or directly in the junction area, or 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 ration, 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 that are used for fabrication of reliable and reproducible contacts. Even so, surface effects such as surface recombination fluctuations in carrier mobility, concentration of surface states, etc., have great influence on frequency dependent noise in silicides also. It has been found [3,4] that ion implantation of As^+ ions in the formation of the silicides could improve electrical characteristics of silicides regarding their noise level.

Other most common source of noise that is connected to the hostile working conditions is radiation. For example, spent nuclear fuels emit simultaneously, in addition to γ-rays, several neutrons also, so semiconducting device (e.g. solar cell) placed in the vicinity of these fuels sustains different kind of radiation damage both from γ-rays and from neutrons. 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 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 [5-9]. This lifetime decrease produces 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 affects performance of the solar cells, especially in space. Introduction of radiation-induced recombination centers reduce the minority carrier lifetime in the base layer of the p-n junction increasing series resistance. After very high doses of radiation series 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 [10,11]. However, small doses of radiation carefully introduced and monitored, could have some beneficial effects on device performance due to possible relaxation of crystal lattice, leading to lowering of series resistance.

In the previous paper we studied the aging of solar cells due to radiation fields of different doses [12].

In this paper, two aspects of improvement of solar cell characteristics via lowering noise level were presented. First one is related to methods of lowering 1/*f* noise in silicides that could be used as reliable contacts, and the other to the application of small dose radiation.

2. Experimental Procedure

Experimental measurements in this paper concerning 1/*f* noise in silicides included 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 the samples. Thin films were deposited by ion sputtering in a Balzers Sputtron II system, at the background pressure in the chamber of $1\text{x}10^{-6}$ mbar, and the argon pressure during sputtering of $1\text{x}10^{-3}$ mbar. Implantation of arsenic was performed at 350 keV with the dose range between $1\text{x}10^{15}$ ions/cm^2 to $1\text{x}10^{16}$ ions/cm^2. Thermal treatment was performed at different temperatures for 20 min. 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°. 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 polycrystalline silicon manufactured by Leybold. Solar cells were irradiated with Pu-Be point neutron source. Samples were in direct contact with the source, and maximum dose was $dD/dt = 0.36$ 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.

3. Results and discussion

3.1. Noise Level in Silicides

The results of structural (RBS) analysis have shown that ion implantation did not induce redistribution of components for lower implantation doses. 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 was observed. In all cases top TiN layer remains unaffected, but for higher doses of implantation ($1\text{x}10^{16}$ ions/cm^2) a disordered structure was registered. This corresponds to the amorphization of silicon substrate, which is moving deeper with the ion dose, showing that the physical properties of TiN/Ti/Si are influenced by the implantation.

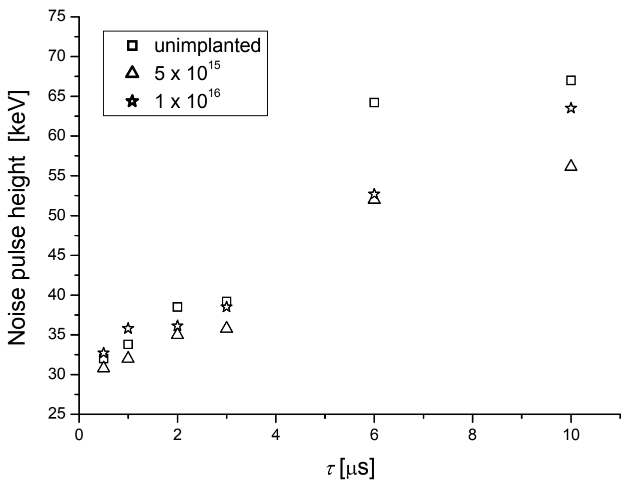

Fig.1. Frequency noise level for three TiN/Ti/Si samples.

This observation was confirmed by noise level measurements. Spectra of the frequency noise (1/*f*) level for unimplanted sample and two different doses of implantation ($5\text{x}10^{15}$ ions/cm^2 and $1\text{x}10^{16}$ ions/cm^2) were presented in Fig 1.

These spectra were taken at different time constant τ (frequency ranges $\tau \sim 1/f$) of the low noise amplifier. From Fig. 1 it could be seen that implantation doses have different effects for different frequency ranges. In the frequency range of 15-26 kHz (time constant of 6-10 μs) ion dose of $1x10^{16}$ ions/cm^2 gives better results than unimplanted sample, but in the range beyond 80 kHz (time constant lower than 2 μs), it produces greater noise compared to unimplanted sample. However, ion dose of $5x10^{15}$ ions/cm^2 shows the best results for the entire measuring range, suggesting that this dose of implantation induce 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 result in a lower frequency noise level of the analyzed structures. Also, previous results have shown [4] that the noise level was lowest for the samples implanted after annealing. This suggests that thermal treatment induce relaxation of crystal lattice and improvement of the crystal structure of the silicides. All of these methods lead to an improvement of electrical characteristics of silicides and devices based on silicides as contacts.

3.2. Irradiation of Solar Cells

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. Solar cells used in space are exposed to all kinds of radiation, both wave and particle. Their special design (surface to volume ratio) makes them susceptible to radiation damage, and improvement of electrical performance of such damaged calls is the aim of many experiments [8]. Radiation damage due to neutrons (heavy particles) is, as mentioned before, primarily connected to the displacement of silicon atoms from their lattice sites in the crystalline silicon solar cells, leading to 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 degradation of electrical parameters of the cell, such as series resistance (R_s), output current and finally efficiency (η). High level of series resistance usually indicate 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).

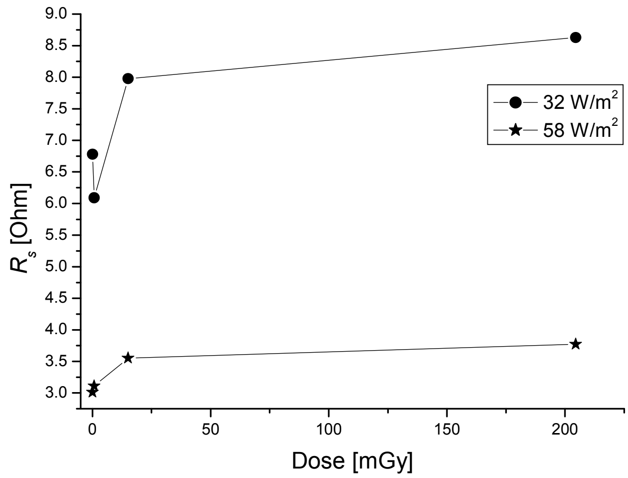

Fig.2. Dependence of the series resistance on doses for two illumination levels.

Such negative impact of neutron radiation was observed in this experiment for higher illumination level also, as could be seen in Fig. 2. But interesting phenomena - the decrease of series resistance, was observed for lower values of illumination. (Different behavior for different illumination level is due to the presence of finite series and parallel resistance in the cell.)

This decrease is very significant from the solar cell design standpoint because it indicates possible beneficent influence of low doses of irradiation, even with neutrons. It could be explained by the fact that during fabrication process of any semiconducting device, structural defects and impurities that were unavoidably made, produce tension in the crystal lattice. Low doses of radiation could act similarly to annealing, relaxing lattice structure and decreasing series resistance. Subsequently, this leads to lowering of noise level and an increase of the output current as shown in Fig.3 (J_m - current in the maximum power point).

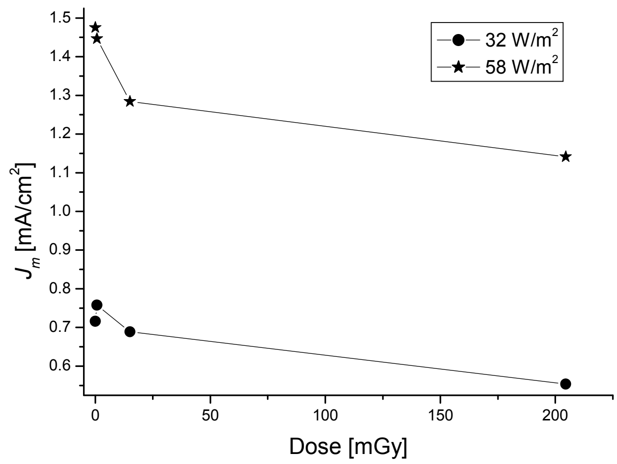

Fig.3. Dependence of J_m on the doses.

Finally, improvement of output characteristics after the first irradiation step for low illumination level is registered for the efficiency also, Fig. 4.

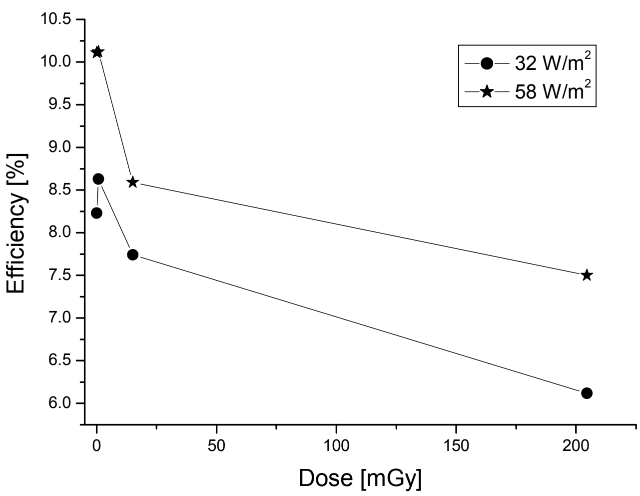

Fig .4. Dependence of the efficiency on doses.

Although higher doses of neutron radiation undoubtedly have negative impact on the performance of solar cells, observed phenomena give possibilities for using radiation as a method for the improvement of solar cell characteristics.

4. Conclusions

Noise, as one of the most important limiting factor for energy resolution of detectors (in this case, solar cells) was investigated in this paper. Two different approaches for lowering noise in silicon solar cells were presented. First part of the paper was oriented to the frequency dependent 1/*f* noise in contacts, since recombination, trapping-detrapping of carriers and other interactions are more pronounced in the surface area. For that reason, silicides were proposed to be used as contacts, because of their good electrical characteristics and stability. Arsenic ion implantation of TiN-Ti-Si structure was used to further improve the performance of silicides as contacts, and to reduce their noise. It was established that both physical and electrical properties of used silicides are influenced by the implantation doses. As could be expected, higher doses result in 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 $5x10^{15}$ ions/cm^2) was used. This dose of As^+ ions was proved to be optimal for fabrication of low-resistivity and low-noise contacts.

Second approach investigated in this paper was lowering noise in the bulk of solar cells. It was shown that, though commonly referred to as a source of noise in semiconducting devices, radiation induced effects (interaction of neutrons with Si solar cells, in particular) could have in some cases positive effect on main electrical characteristics (R_s, J_m, η). Initial improvement of the characteristics observed for small doses of neutron radiation and low illumination level, indicates that there is a possibility of using irradiation for enhancement of the solar cells quality.

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[*]Corresponding author: opredrag@verat.net