Influence of Electron Irradiation on Photoelectric Properties of Solar Cells with Porous Silicon

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Abstract – Influence of electron irradiation on spectral and luminescent properties of solar cells (SC) with porous silicon (PS) has been studied. Degradation of the main parameters of SC with PS has been calculated as a function of density of integral 2-MeV electron flux. Porous silicon was formed on the n^+-layer of the solar cell using the modified electrolyte. The photoluminescence spectrum of newly-prepared SC samples with PS shows increase in the PL intensity with the increase in irradiation dose. The authors calculated the lifetime, diffusion length of minority carriers and damage coefficient for SC with PS.

1. Introduction

Developers of solar cells have recently shown an increasing interest in antireflection coatings made from porous silicon, which also serves as a passivating and heterogeneous layer.

Many authors point out advantages of PS as an antireflection layer as compared with other coatings. It is shown in [1] that effective reflection obtained with PS is much less than that obtained with the usage of classical TiO_2 coating. In the other paper [2] smaller values of reflection coefficient as compared with antireflective ZnS layer were obtained.

At the present time due to large-scale usage of solar cells in the outer space their developers carry on works aimed at increasing of SC radiation resistance. For example, the authors [8] subjected highly efficient (20.8% for AMO) solar cells by 1-MeV electron irradiation with doses from 10^{14} to $5*10^{15}$ cm^{-2} and showed that irradiation sharply reduced photosensitivity in the shortwave range by destruction of the double antireflection coating.

The present work purpose is to study influence of 2-MeV electron irradiation on photoelectric and luminescent properties of SC with PS.

2. Experimental technique

Solar cells were made from the monocrystalline p-type silicon wafers with resistivity of 10.0 Ohm/cm and orientation (100), one of its sides was textured under creating n^+-layer by phosphorus diffusion. PS in the n^+-layer was formed by electrolytic anodizing in the follow mixture HF:oxidized alcohol:H_2O in ratio 1:2:1 during 10–15 s at current density 20 mA/cm^2. Anodizing was carried out in a specially constructed teflon cell.

Initial efficiency of solar cells was measured at daylight for AM = 1.5 and intensity of incident radiation 86 mW/cm^2. Efficiency (η) of solar cells under the above conditions was 12–13%.

Voltage-current characteristics before and after irradiation were measured at the equipment using computer control with the National Instruments data acquisition card NI-6251.

Spectral characteristics before and after irradiation were registered in the wave range from 400 to 1100 nm.

Electron irradiation of SC samples was carried out with 2-MeV electrons at dose rates 10^{14}, 10^{15} and 10^{16} cm^{-2} and current density 1 μA/cm^2 at room temperature on linear accelerator "Electronik" ELU-4.

Photoluminescence of SC samples was measured at room temperature at KSBU-23 device using as a source of radiation impulse laser ILGI-503 operating on molecular nitrogen in a quasi-continuous mode at wavelength 337 nm.

Photoelectric properties of PS SC samples before and after irradiation were studied for both newly-prepared and long-stored (for 6 months) samples.

3. Experimental results

The experimental data show that solar cells with PS increase the short-circuit current from 25 to 28 mA/cm^2 and open current voltage running from 0.54 to 0.57. In all photosensitivity range solar cells with PS have high gathering coefficient: from 0.74 (for 450 nm) to 0.96 (for wavelengths from 600 to 1000 nm).

Porous Si – 0.2 μm
n^+ Si – 0.2 μm
p – Si – 350 μm
Al

Fig. 1. Scheme of a solar cell with porous silicon coating

Some samples of solar cells with PS have gathering coefficients in the shortwave region as high as 0.76 (for 450 nm), which is higher than the gathering coefficient for a standard sample with antireflection ZnS coating equal to ~ 0.56.

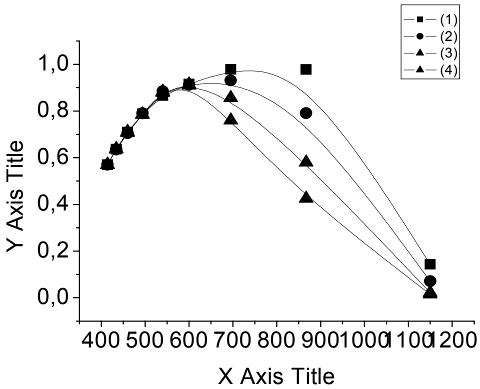

Fig. 2. Spectral characteristics of SC with PS before and after irradiation

Fig. 2 shows spectral characteristics of SC with PS i.e. dependence of the SC collection efficiency on the wavelength before and after electron irradiation. It is seen that in the shortwave region from 400 to 610 nm the photosensitivity spectrum does not change for all irradiated samples independent of the irradiation dose. However, in the long-wave region the collection efficiency for SC with PS coating decreases, which is caused by the decrease in the diffusion length of minority charge carriers and, as an inevitable consequence, decrease in the efficiency, e.m.f of idle running (Voc) and short-circuit current.

Table 1 shows tendencies in the main photoelectric parameters degradation of SCs with PS before and after irradiation for 4 samples.

Table 2 shows changes in the same parameters with respect to their initial values; in order to present the results more explicitly they are shown in Fig. 3.

Analysis of dependence of normalized parameters on the integral density of the electron flux showed that the degradation character of studied PS SC is the same: Jsc decreases by 25% for flux $F=9*10^{14}$ cm^{-2}, Voc decreases by 25% for $F=10^{16}$ cm^{-2} and efficiency – for $F=5*10^{14}$ cm^{-2}.

Table 1. Tendencies in the degradation of the main photoelectric parameters of SCs with PS before and after irradiation for 4 samples

No	Before irradiation			Dose rate 10^{14} cm^{-2}			Dose rate 10^{15} cm^{-2}			Dose rate 10^{16} cm^{-2}		
	J_{SC}, mA/cm^2	V_{OC}, B	ξ_0	J_{SC}, mA/cm^2	V_{OC}, B	ξ_1	J_{SC}, mA/cm^2	V_{OC}, B	ξ_2	J_{SC}, mA/cm^2	V_{OC}, B	ξ_3
1	26.0	0.548	0.646	22.45	0.5	0.66	18.39	0.468	0.66	14.6	0.413	0.64
2	28.1	0.543	0.526	24.84	0.497	0.53	19.8	0.454	0.55	16.5	0.4	0.52
3	27.85	0.563	0.494	22.16	0.532	0.51	18.17	0.495	0.54	13.35	0.46	0.55
4	27.4	0.567	0.577	23.16	0.533	0.55	17.79	0.495	0.61	13.35	0.45	0.575

Table 2. Changes in the same parameters with respect to their initial values

J_{SC1}/J_{SC0}	V_{oc1}/V_{oc0}	ξ_1/ξ_0	η_1/η_0	J_{SC2}/J_{SC0}	V_{oc2}/V_{oc0}	ξ_2/ξ_0	η_2/η_0	J_{SC3}/J_{SC0}	V_{oc3}/V_{oc0}	ξ_3/ξ_0	η_3/η_0
0.856	0.924	0.99	0.78	0.68	0.85	1.05	0.62	0.53	0.77	1.02	0.42

In the degradation of the main SC parameters a slight increase of filling coefficient was observed, it was caused by approaching of reverse voltage-current branch to the X axis, where the product I*V increased.

Fig. 4a shows PL spectra of newly-prepared samples before and after irradiation. An unusual process is observed: the intensity of PL spectrum increases as irradiation dose increases. We suppose that this effect is explained as follows: after short etching numerous broken bonds formed by admixture luminescent centers are created on the PS surface. The electron flux, on the one hand, reconstructs broken admixture bonds by the influence of ozone medium; on the other hand, electrons break Si-O bonds. Thus, alternative processes occur in the PS. However, the effect of "curing" of luminescent centers prevails over the effect of Si-Si bonds destruction. On the opposite, for long-stored solar cells samples with PS, shown in Fig. 4b, the intensity of PL spectra gradually decreases. Therefore one may conclude that electron irradiation causes distortion of "cured" centers on the boundaries of PS and SiO_2 by creating non-radiating recombination centers. Therefore in the PL spectra we observe 25–30% peak decrease as compared with initial samples.

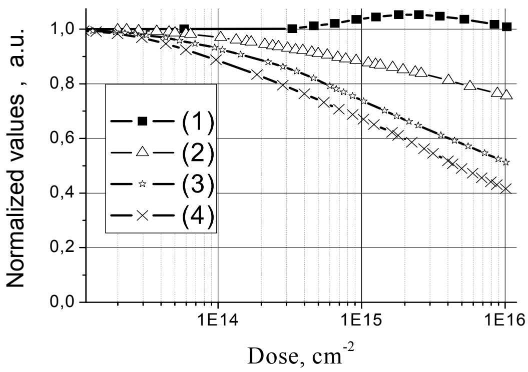

Fig. 3. Dependence of normalized values of PS SC parameters on the electron flux. 1 – ξ, 2 – Voc, 3 – Jsc, 4 – η

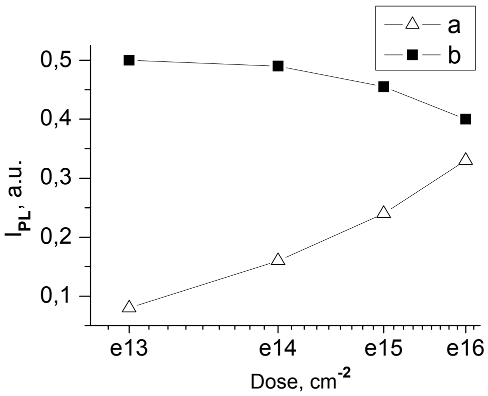

Fig. 4. Photoluminescence peak amplitude of solar cells with PS coating: newly-prepared and long-stored samples

We determined the lifetime and diffusion lengths for minority charge carries in the SC samples with PS before and after irradiation. Measurements were made in the long-wave region of spectral characteristics in the range 800–900 nm. The lifetime and diffusion lengths of minority charge carries were determined using known parameters – absorption and collection efficiency.

Diffusion length in SC samples with PS and defect formation coefficient after irradiation were calculating using the formulae:

$$L = \frac{Q}{\alpha(1-Q)} \quad \frac{1}{L^2} = \frac{1}{L_0{}^2} + KF$$

where L is the diffusion length of minority charge carries after irradiation,
L_0 is the diffusion length of minority charge carries before irradiation,
K – damage coefficient,
F – electron flux,
α – absorption coefficient.

The diffusion length in our SC samples with PS was ~ 170 μm before irradiation, 54 μm after first irradiation, 20 μm after the second irradiation and 10 μm after the third irradiation. We also determined the damage coefficient, it was equal to ~ $2*10^{-10}$; the above data coincide with many literature data [4].

4. Conclusion

Comparison of spectral characteristics of SC with PS in the range 400 – 1100 nm before and after irradiation showed radiation stability of photosensitivity in the shortwave region in the 400–610 nm range. The PS layer is this wavelength range seems to have protection to electron radiation due to its passivating and heterogeneous properties. In the long-wave range (λ > 610 nm) spectral sensitivity decreases with the increase of irradiation dose, which is caused by the decrease of the minority charge carries diffusion length in the silicon bulk.

The decrease of the main parameters degradation of solar elements with PS coating was determined. Dependences of Jsc, Voc and efficiency on the density of integral electron flux were calculated and plotted.

It was established from PL spectra that for newly-prepared samples intensity of PL peak with maximum at 660 nm increases with the increase of irradiation dose from 10^{14} to 10^{16} cm^{-2}. For long-stored SC samples with PS the intensity of PL peak slightly decreases as irradiation dose increases.

The damaging coefficient for SC samples after irradiation was determined, it shows decrease in the diffusion length of minority charge carries, which was also calculated from the experimental data.

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