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STUDY OF ELECTRICAL PROPERTIES OF SCHOTTKY DIODES IN DIFFERENT TREATMENTS

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Abstract- This paper assesses the electrical properties of Schottky Diodes (SD) in different treatments and γ-radiation-damaged quanta performance technology with SD using amorphous metal alloy (αNiTi-nSi) sample of solar cells. It is shown that annealing kind of "cures wounds" is introduced by the mechanical load and improves the parameters of the damaged SD. At the same time it studies the experimental results demonstrating of the ability to recover and control the parameters of silicon solar elements (SE) with ultrasonic impact treatment (UIT), which is probably due to rearrangement and athermal annealing of radiation defects, formed by γ-rays.

Keywords: Barrier Height, Amorphous Metals, Schottky Diodes, Ultrasonic Impact Treatment, Annealing, Silicon Solar Cells, Degradation, γ-Quantum.

I. INTRODUCTION

Increased reliability and quality of electronic devices, including devices based on Schottky barrier remains a hot topic for modern semiconductor technology. The role of the metal in most cases is neglected. The role of metals and its crystal structure in the process was either not reviewed or poorly understood. To identify the role of metal processes in recovery of degradation properties have been studied, depending on the structure and the contact metal [1-10]. It is known that the irradiation of semiconductor devices of high-energy charged particles accumulate in the bulk of radiation defects, which leads to a significant deterioration of electrophysical and photoelectric characteristics of the devices [6, 8, 11-13].

Controlled impact on the defect structure of a semiconductor device in the pn junction and the base region can specifically adjust its characteristics. Traditionally, to restore damaged properties of irradiated materials heat treatment is used, which leads to some negative consequences [14]. Therefore, as an alternative, more and more attention is paid to ways of athermal treatments, one of which is ultrasonic treatment (UIT). Based on the results of numerous works on Acousto-stimulated improve the properties of semiconductor materials [12, 15, 16], the use for this purpose, the ultrasonic waves can also be an effective way for the semiconductor devices.

In recent years, non-diminished interest in the issue of purposeful changes in the physical properties of semiconductor materials and devices is controlled by external influences. Therefore, the solutions are developed and used the various methods of gettering, which are based on the effects of high temperatures on the semiconductor crystal, while creating the conditions for it to diffusion processes, e.g. thermal or non-homogeneous elastic fields [16]. Last often formed by the introduction of structural defects or crystal volume (internal getter), or surface layer, usually are broken hand, and free of active regions fabricated devices.

In this case, however, along with the positive effect of gettering impurities and nonequilibrium intrinsic point defects potentially lays conditions for activation and the development of processes for the transformation which defect structures getter during manufacturing operations or the operation of the finished device (one of the causes of degradation) [7, 15]. Therefore, the interest in the search for low-temperature has been increased gettering methods that do not require the creation of artificial damage layers, which use the real surface of the crystal, including the stages of abrasive chemical substrate preparation. In connection with this challenging the attempt is to use as a stimulating factor gettering various external factors including treatment in an alternating magnetic field, pulsed or continuous hydrostatic pressure, pulsed or scanning laser processing flash incoherent light, and pulse duration of the impact of ultra narrow-band microwave radiation. The temperature of the semiconductor structure is not greater than $0.5T_m$ (melting temperature).

Following the problem decision, a lot of attention has been given to the effects of ultrasound waves, which pass through the semiconductor accompanied by a change in its properties, including photosensitivity, electrical conductivity, and the intensity of radiation recombination noises [11, 14]. It should be noted that the previously used ultrasound frequency in the range of kilohertz is developed to megahertz range now.

Despite a general agreement virtually all publications in this subject, which affects the RCD defective subsystem Si, are not clear about the specific mechanisms of these effects.

The introduction to periodical literature on patent and licensing data shows that there are many works devoted on the influence of ultrasound treatment on the electrical properties of semiconductor diodes and devices of this type. In this paper we study the properties of the restoration of degradation of αNiTi-nSi in the SD by means of annealing and ultrasonic treatment, broken by γ-ray irradiation characteristics of solar cells fabricated using amorphous materials. The effect of various treatments including mechanical, thermal and ultrasonic (UIT) on the properties of Schottky Diodes (SD) and γ-radiation-damaged quanta characteristics, made by SD technology (αNiTi-nSi) as a sample of solar cells are also studied.

II. EXPERIMENTAL PROCESS

For the manufacturing of an SD an n-type silicon wafer with (III) orientation and a resistivity of 0.7 ohm.cm was used. The matrix contained 14 LEDs, which ranged from 100 to 1400 μm^2 in size. In this case, the contact area was equal to 500 μm^2. The metal alloy was deposited by aNiTi electron-beam evaporation from two sources. The Ni-Ti alloy was chosen from the consideration that both components are widely used in microelectronics, and the alloy is technologically good. For manufacturing of αNiTi-nSi SD sample, the Schottky diodes technology was used [1, 10]. The possibility of obtaining films of this alloy with amorphous structure was reported in [15]. Evaporation rate of the components were chosen so as to match the composition of the $Ni_{35}Ti_{65}$ alloy film as in [8, 15], it was reported that this alloy is prone to amorphization.

SE were irradiated by ^{60}Co γ-rays with a dose of $\sim 10^6$ Rad at room temperature. Then these samples were consequently, in two stages, subjected to UIT, with the the longitudinal wave injected from the rear side of the sample perpendicular to its surface. In the first phase UIT-1 (frequency $f_{us} = 95$ MHz, intensity $W_{us} = 0.55$ W/cm^2, duration $t = 120$ min) and UIT-2 ($f_{us} = 30$ MHz, $W_{us} = 15$ W/cm^2 and $t = 200$ min). After each stage of the UIT, the electrical and photovoltaic parameters of solar cells were measured. It is shown that γ-irradiation affects both the inverse and the direct current-voltage characteristics, worsening the latter as opposed to original (increase of reverse current I_{rev}).

Study of SD's current-voltage characteristics degradation shows that under normal conditions it is uncommon, therefore, for a detailed study of these issues a CVC of an artificially degraded SD was studied. The inhomogeneity of the metal-semiconductor contact was artificially created using a «PMT-3» microhardness tester. The structure of the alloy films before and after annealing was controlled by X-ray analysis and electron microscopic study of the film surface [11].

III. RESULTS AND DISCUSSIONS

Figure 1 represents the VAC of αNiTi-nSi SD before and after annealing at 560 ºC. As it can be seen from the graph of forward and reverse voltage excessive current appears. It is known that amorphous metal film at certain temperatures alter their structure and turn into polycrystalline state [15]. Consequently, we can assume that the appearance of excess current in the VAC of αNiTi-nSi SD after annealing at a temperature of 560 ºC and above is due to changes in the structure of metal alloy films [15]. Diodes annealing was performed at 100-600 ºC temperatures for the same duration of time $t = 20$ min.

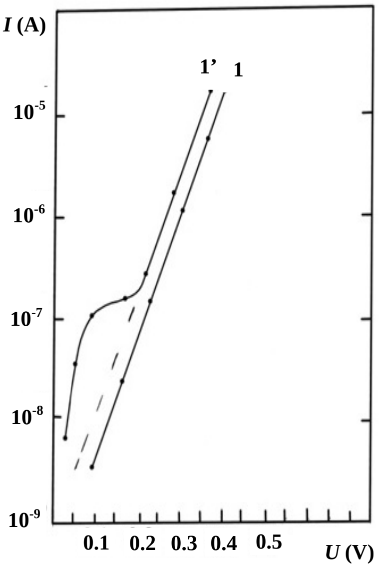

Figure 1. The current-voltage characteristics for αNiTi-nSi SD before (1) and after (1') annealing at 560 ºC and $S = 500$ μm^2

Figure 2 represents the restoration of CVC for αNiTi-nSi SD degraded artificially by means of diamond identera at the load $F(100G)$, the number of violations ($N = 1$) before and after annealing at 400 ºC during the time (1-17, 2-65, 3-148, 4-260, 5-410, 6-580 sec) ($U = 0.2$ V). Recovery of degradation properties of αNiTi-nSi SD was monitored by measuring the both forward and reverse CVCs.

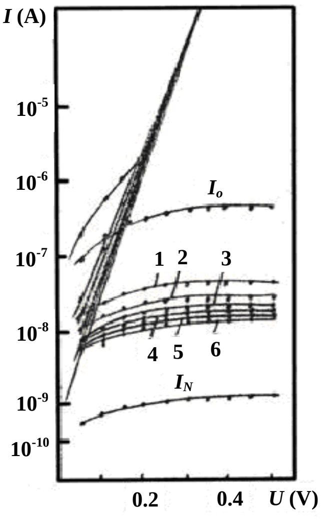

Figure 2. Recovery of degradation properties of αNiTi-nSi SD in normal, artificially degraded and annealed (400ºC) states with the load $F(100G)$ and the number of defects

For the quantitative characterization of rehabilitation of the excess current under the influence of annealing taking time into account this formula was used:

$$\alpha_T = \frac{I_t - I_N}{I_o - I_N} \tag{1}$$

where I_N is the current normal (intact), Schottky diode, I_o is the current of the diode immediately after exposure of identer $(t = 0)$, I_t is the fault current of the diode annealed for *t* seconds, and α_T is the characterizes the relative recovery of the excess current under the influence of annealing during period *t*.

As shown in Table 1, changing the parameters of annealing varies its value in the interval $0 \le \alpha_T \le 1$. From these results it is evident that, first, the main stage of the annealing process occurs over a short initial period of time, and secondly, the annealing process "cure" restores damaged diodes over time, even at room temperature, the level of excess current decreases, the recovery process occurs more rapidly, the higher of the temperature of annealing time.

Table 1. The results of the restoration of degradation properties of αNiTi-nSi SD in normal, artificially degraded and annealed (200 ºC - 400 ºC) conditions, load *F* = 100 *G* and the number of defects (*N* = 1) over period 17, 65, 148, 260, 410, 580 sec and *U* = 0.20 V

t (sec)	17	65	148	260	410	580
α_T (200 ºC)	0.260	0.160	0.110	0.089	0.082	0.06
α_T (300 ºC)	0.060	0.038	0.031	0.022	0.021	0.018
α_T (400 ºC)	0.031	0.020	0.015	0.012	0.009	0.007

Direct effects of γ-irradiation and UIT on the electrical characteristics of studied photovoltaic solar cells can be seen in Table 2 and Table 3, which show photovoltaic and electrical parameters of the sample solar cell, resulting in a decrease in short-circuit current I_{sc} and open-circuit voltage U_{xx}, and as a consequence, in reduction of the maximum output power $P_{\max}$ following UIT-1 and, especially, UIT-2 SD restore options of SD, bringing the them to the source, where I_{sc} is short-circuit current, U_{xx} is open circuit voltage, I_{rev} is reverse current, *A* is a dimensionless coefficient, $P_{\max}$ is the maximum output power, ξ is fill factor, τ_n is diffusion coefficient and lifetime of minority carriers, L_n is diffusion length of minority carriers, I_0 is the reverse saturation current, N_{ef} iseffective concentration of ionized centers, and E_a is the activation energy.

Table 2. Photovoltaic parameters of αNiTi /Si solar cell samples before and after γ-irradiation and after UIT at *P* = 120 mW/sm^2 and *T* = 25ºC

	A	U_{xx} (V)	I_{sc} (mA)	*P* (mW)	ξ
Before irradiation	2.32	0.542	26.82	12.54	0.7232
after γ-irradiation	2.66	0.498	21.14	9.53	0.7214
after UIT-1	2.56	0.528	22.61	10.52	0.7235
after UIT-2	2.42	0.536	26.65	12.41	0.7263

Table 3. Electrophysical parameters of αNiTi /Si solar cell samples before and after γ-irradiation and after UIT at *P* = 120 mW/sm^2 and *T* = 25ºC

	N_{ef} (cm^{-3})	E_a	I_o (mA)	L_n (mm)	τ_n (msec)
Before irradation	2.34×10^{16}	0.83	90.235	72.0	0.883
after γ-irradiation	3.25×10^{16}	0.67	306.4	65.4	0.752
After UIT-1	3.916×10^{16}	0.73	286.9	69.7	0.801
After UIT-2	2.62×10^{16}	0.83	128.6	70.4	0.838

Let us analyze the possible mechanisms for the observed changes. It is known that the magnitude of the photocurrent is determined from the expression [16]:

$$I_f = q.SNf.Q \tag{2}$$

where, *q* is electron charge, *SNf* is total number of photogenerated electron-hole pairs at the site *S*, and *Q* is collection coefficient of charge carriers. Since the value of *SNf* remains practically constant in this experiment, it is happening as a result of γ-irradiation drop in photocurrent SD is obviously due to a decrease in *Q*. When the diffusion length of minority carriers in the base $L_n \ll dp$, the value of *Q* is defined in [13]:

$$Q = \frac{\alpha L_n}{\alpha L_n + 1} \tag{3}$$

where α is light absorption coefficient. It is known that $L_n = \sqrt{D_n \tau_n}$, where D_n and τ_n are the factors of diffusion and time of life of non-basic carriers in base accordingly.

Considering (2) for a photocurrent the following expression is obtained:

$$I_\Phi = qSN_\Phi \frac{\alpha\sqrt{D_n \tau_n}}{\alpha\sqrt{D_n \tau_n} + 1} \tag{4}$$

Open-circuit voltage U_{xx} is determined as (5)

$$U_{xx} = \frac{AKT}{q} \ln\left(\frac{I_{kz}}{I_o}\right) \tag{5}$$

where *K* is Boltzmann constant, *T* is temperature, *k* is dimensionless coefficient characterizing the rate of recombination in the space-charge layer, I_o is the reverse saturation current flowing through the p-n junction, and I_{sc} is short-circuit current. According to our estimates, the irradiation of γ-rays does not lead to significant change and the effect of γ-irradiation and RCD directly on the photoelectric characteristics of the investigated solar cells can be seen from Tables 2 and 3.

The irradiation of ^{60}Co γ-rays with an energy of 1.35 MeV, which is equivalent to the internal irradiation of SD by fast electrons occuring from Compton scattering and photoabsorption, leads mainly to the formation of point-type defects. In this case the interaction of radiation defects with the existing defects in the crystal.

Conducted in two phases, UIT-1 and UIT-2 of studied silicon solar cells, have led to a decrease in N_{ef} (Table 3), which indicates the athermal annealing of radiation defects. As it is known the annealing of radiation defects may correspond to several mechanisms: migration of defects to sinks [12], the formation of more complex defect, the dissociation of the complex, etc.

Thus, the impact of UIT is an effective way to increase the internal energy of solids. In contrast to the thermal energy absorbed uniformly throughout the bulk of the semiconductor, the damping of the UIT waves mainly occures on the crystal lattice defects, contributing to their redistribution to the equilibrium state [5, 9, 11].

Because exposure to γ-rays creates a radiation-induced defects in solar cells, which are more mobile, the UIT in the subsequent acoustic wave interacts primarily with the latter contributing to their redistribution and athermal annealing [11, 12, 14, 16].

IV. CONCLUSIONS

Thus, it is concluded that the recovery of the excess current is due to the change in the parameters of annealing, in this work its value varies in the interval $0 \leq \alpha_T \leq 1$. From obtained results it is evident that, first, the main stage of the annealing process occurs over a short initial period of time, and secondly, the main stage of the annealing process "heals" damaged diodes.

Based on the electrophysical and photoelectric measurements was proved that the recovery of the electrophysical and photoelectric properties of silicon αNiTi/Si solar cell sample using ultrasonic treatment, broken by γ-irradiation, is due to rearrangement and athermal annealing of radiation defects formed by gamma rays. Results show that the UIT partially restores the perfection of crystalline of structure αNiTi/Si solar cell sample, broken in the process of γ-ray irradiation.

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BIOGRAPHY

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