Investigation of HIT solar cells low frequency noise characteristics

A V Ermachikhin1,*, Y V Vorobyov1, E P Trusov1 and V G Litvinov1

1 Ryazan State Radio Engineering University named after V.F. Utkin, Ryazan 390005, Russia

* al.erm@mail.ru

Abstract. The effect of solar cell fragment annealing on its noise characteristics is shown. The calculated difference in relaxation times arising from the change in noise after annealing was 30%. Measurements of noise characteristics in the dark and under illumination with a red laser with different radiation power were carried out. Close to linear dependences of noise power reduction with increasing radiation power were obtained.

1. Introduction
Solar cell (SC) based on amorphous/crystalline silicon heterojunction (heterojunction with intrinsic thin layer – HIT) [1] have become widespread over the past few years. HIT have good energy conversion characteristics [2]. Usually solar panels consist of several cells connected in series and/or in parallel [3]. For example, HIT element N330/N325 has four bypass diodes (1 bypass diode per 24 cell). Each such cell has a small spread in characteristics which gives a certain average value for large numbers. Also, each cell introduces fluctuations in the total value of the solar panel current and voltage creating a general noise component.

Measurement of noise arising in the SC can be used as a technique for studying the solar cells parameters. Semiempirical models for the correlation of low-frequency (LF) noise with fluctuations in the mobility [4,5], with fluctuations in the number of free charge carriers (CCs) in the space charge region [6] or with the semiconductor surface [7] were formulated. However, Hsu [8] and Van der Ziel [9] were the first to associate LF noise of the 1/f type in the metal – oxide – semiconductor system and in p-n junctions with fluctuations in the population of deep energy levels (DL) or defect states. Fluctuations in solar cells with p-n junction strongly depend on the diode geometry [4], photogeneration processes and bias voltage [6]. The mechanism of CCs capture and recombination in the presence of defect states causes current fluctuations which can be the main source of noise [10].

2. Methods and Samples

2.1. Research methods
The samples were annealed on a measuring complex based on a Janis CCS-400/204N closed-cycle cryostat controlled by a LakeShore 335 temperature controller. The current-voltage (I-V) characteristics were measured using a Keithley 6517B electrometer. Noise characteristics were measured by LF noise spectrometer [11]. The surface of the structure was irradiated by the 805 nm laser. The laser diode was powered using a constant current source; the value of current was used to
control the power of light beam. The average light power on the sample surface was varied from 10.2 to 27.5 mW.

2.2. Sample description
As a sample of the study we used a ready-made SC fragment based on the a-Si:H(n)/a-Si:H(i)/c-Si(p)/a-Si:H(i)/a-Si:H(p+) structure [12]. The HIT-structure was manufactured at the Research and Development Center "Thin-Film Technologies in Energetics" of the Ioffe Institute (St. Petersburg, Russia). The spectral dispersion of the quantum efficiency for the front and rear sides, as well as the temperature dependences of the open circuit voltage and the diffusion potential were measured [13].

3. Results and Discussion
The degree of the laser power influence on the processes occurring in the structure was tested by measuring the I-V characteristics under different laser radiation. The laser power was chosen to cover the entire possible radiation range. The obtained I-V characteristics of the SC’s fragment are shown in Figure 1.

![I-V characteristics of the HIT structure under the laser radiation.](image)

The power spectral density (PSD) of noise at the same values of the laser radiation power is shown in Figure 2. The noise PSD under radiation is clearly higher than the noise component in the dark condition. In the dark and under radiation the noise value depends on the volumetric emission and capture rate coefficients per unit time for electron and hole traps [14]. Under the radiation these capture coefficients and emission rates change and the density of filled traps also changes [15]. As a consequence the carrier photogeneration process increases traps filling until saturation occurs. It means that all traps have been activated in terms of noise. In this situation the contribution of the photoinduced noise is dominant as a result it is larger than the dark background noise. According to [16] the clear differences between dark and photoinduced noise were interpreted in terms of Shockley-Read-Hall theory. In particular the explanation of current fluctuations mechanisms is considered by a combination of processes associated with the capture and emission of CCs and the phenomena of CCs recombination. The recombination rate in the depletion region and at the interfaces is dominant in conventional HIT solar cells [17].
Figure 2. Noise PSD characteristics of the HIT structure fragment when illuminated by a laser with different power.

Figure 2 also shows that with an increase in the laser power the structure noise decreases. The noise reduction is shown more clearly in Figure 3. It can be seen that at all selected frequencies the noise PSD gradually decreases with increasing laser power. These dependences are close to straight lines which indicates the linear influence of illumination on the processes of noise generation.

Figure 3. Noise PSD value at a fixed frequency at different laser power.
The frequencies shown in Figure 3 were chosen so because of the impossibility to get rid of the mains component of 50 Hz and their harmonics. The influence of the electrical network can be clearly seen in Figure 4. The dark PSD (lower curve) has only one peak at a frequency of 50 Hz. Under the radiation the PSD has a second sharp peak at a frequency close to 55 Hz. A “domed” component still appears from about 40 to 55 Hz. This may be due to laser noise. This behavior of the noise is characteristic only of the sample under the radiation. In the above fragments of the noise PSD the values of the dark measurement practically fall on a straight line. If we remove the overshoot associated with the network interference and subtract the slope line then the standard deviation will be equal to 3.56·10^{-9}. If we do the same manipulations with the PSD under the radiation then the standard deviation is 2.66·10^{-6}. Thus, a laser radiation not only increases the noise PSD but also makes serious changes in the very appearance of these curves.

![Figure 4. Noise PSD in dark and under light.](image)

All measurements of the sample’s characteristics were first carried out at room temperature in the dark and under illumination of the sample. Then there was heating to the temperature of 100 °C and holding for 3 hours. Then slow cooling to room temperature was carried out. Measurements were taken again after returning to the initial temperature. The dark I-V characteristics show a slight electrical current increase after annealing on the forward branch of the I-V characteristic and a very insignificant current decrease on the reverse branch of the I-V characteristic. The current everywhere became slightly higher under the radiation conditions (i.e., the negative values of the currents became slightly lower in absolute value). On average the current increased by 3.8% but it should be borne in mind that this growth is taken over the entire measured voltage range from -0.7 to 0.7 V.

Noise spectra under the radiation showed no differences between the studies before and after annealing which may be associated with a general increase in noise upon irradiation of the sample surface with a laser.

The absolute LF noise PSD values without radiation after annealing became smaller. There was also a shift of the kink frequency (Figure 5). The noise reduction can be directly related to the change in the contact properties of the conductive tracks. A change of the kink frequency is associated with a change of the CCs’s lifetime. The kink frequency was 147.8 Hz before annealing and after it was became 112.9 Hz. The kink frequency was determined by the method of finding the kink on the graph
of multiplying PSD by the frequency. With this approach, the bends in the spectrum stand out more noticeably [18,19].

![Figure 5. Noise PSD before and after thermal annealing.](image)

Figure 5. Noise PSD before and after thermal annealing.

Considering that the multiplication of the kink frequency and time is constant [20]:

$$\omega \tau = 1$$

where $\omega = 2\pi f$, it turns out that the relaxation time changed from 1.08 ms to 1.41 ms. A relaxation time increase was about 30%. The generation-recombination noise is characterized by a Lorentzian spectrum with a time constant $\tau$ given by [21]

$$\tau = \tau_0 \exp \left( \frac{E_a}{k_B T} \right),$$

where $\tau_0$ is the atoms thermal vibration period [22], $k_B$ is the Boltzmann constant, $T$ the temperature, and $E_a$ is the thermal activation energy of the trap [23]. Thermal activation energy values are deduced from Arrhenius plots of $\tau$ versus $1/T$ or $e_n(e_p)$ versus $1/T$, where $e_n(e_p)$ is an emission rate of CCs (electrons or holes) which is determined from the equilibrium Shockley-Read-Hall statistics [24]. Energy change can be estimated. If we consider that the time $\tau$ has changed by 30% and other things being equal, then the $E_a$ has changed by almost 4%.

4. Conclusions

Noise generation phenomena in HIT structure is considered as a combination of CCs capture and recombination processes. According to measurements carried out in [13] the external quantum efficiency at a wavelength of about 800 nm is approximately 0.904. That is for 10 incident photons there are 9 generated and brought to the contacts CCs pairs. It was shown in [17] that the main CCs recombination occurs at the interfaces. The capture of CCs is mainly due to the DL the energy of which is 455 meV [13]. This DL is associated with the dopant for the p-type region.

The conductive tracks are printed using a screen printing process. The annealing itself does not occur at the same high temperatures as in the case of a SC without a heterojunction. The layers are deposited at low process temperatures of less than 250 °C. And in some cases the passivation layers electrically conductive adhesives are used instead of soldering to avoid damage [3]. For these reasons it is not possible to use a high temperature for annealing.
LF noise spectroscopy is an effective method for assessing the effect of annealing on SC. Even insignificant changes in the processes occurring in the structure are visible in the research results. The measured CCs relaxation time before and after annealing showed a difference of almost 30% that indicates a proportional increase in mobility after heat treatment. At the same time, the thermal activation energy of the trap changed by almost 4%.

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