Acoustically driven degradation in single crystalline Si solar cell

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Abstract. Abstract

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1. Introduction

The silicon solar cells (SSC) are still dominant in the photovoltaic (PV) field due to their high efficiency, low selling price and process maturity. Therefore, understanding the way of material properties modification is a top priority for most of PV device manufacturers. It is known, for example, the loss in the SSC efficiency is observed in consequence of excess carrier injection by above-bandgap illumination or forward biasing [1, 2, 3] (so-called light-induced degradation or LID), high voltage stress [4, 5] (potential-induced degradation or PID), or radiation treatment [6, 7] (irradiation-induced degradation or IID). Degradation reasons are processes in crystal defect sub-system under external influence. It is may be a transformation of the boron-oxygen or copper-contained complex (for the LID case), a decoration of stacking faults by sodium (PID case) or a creation of radiation-induced recombination centers (IID case). The partial or full SSC efficiency recovery is observed quite often during of subsequent annealing at an elevated temperature.

On the other hand, it has been shown experimentally that ultrasonic waves (USWs) can be the effective instrument for defect engineering in silicon. In particular, ultrasound is used to affect a carrier diffusion length [8, 9], to vary a current in p–n structures and

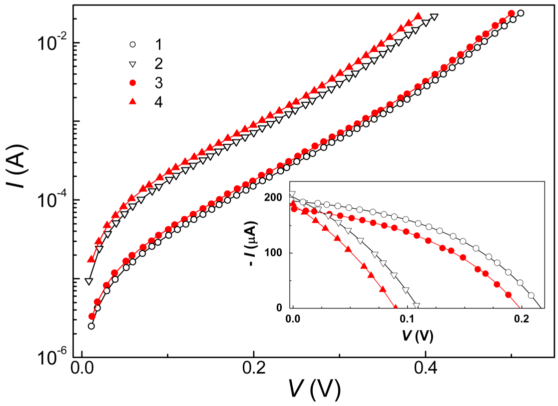

Figure 1. Reverse (left side) and forward (right side) I–V characteristics of Mo/n–Si Schottky structures measured at 10 K intervals without USL. The lines are added to guide the eye.

Schottky diodes [10, 11, 12, 13, 14, 15], to transform an impurity defect [16, 17, 18], to change a spectrum [19] and density [20] of surface states. Frequently the crystal and device properties recover after stopping of ultrasound action at room temperature even [8, 9, 10, 16].

This article presents the result of experimentally investigation of the acoustic strain field influence on the electrical characteristic of the n^+–p SSC. Ultrasound has been found to result the decrease of carriers lifetime and, accordingly, solar cell efficiency. The USWs intensity did not exceed 0.5 W/cm^2 and the full recovery of cell characteristics was observed. Dependencies of such sound induced degradation on USW type and intensity are presented. The findings are discussed by using model of coupled defect level recombination [21, 22].

2. Experimental and calculation details

The investigated solar cell was created on 2 inch p-type CZ-Si:B wafers with doping level of 1.4×10^{15} cm^{-3} and thickness of 300 μm. The n^+–layer with carrier concentration of about 10^{19} cm^{-3} and thickness of 0.5 μm was created by phosphorus implantation. Then wafer surface were passivated by Al_2O_3 film and further capped by TiO_x as antireflective coating. Finally the aluminium solid contact and metal grid was fabricated on p– and n–surface respectively. The samples with area of 1.5 to 2.1 cm^2 used in our experiments were cut from the central part of the wafer.

The dark and illuminated forward current-voltage (I–V) characteristics of the samples were measured over a temperature range 290–340 K. The sample temperature was controlled by differential copper-constantan thermocouple.

The revers current-voltage (I–V) characteristics of the samples both with and without US loading were measured in the temperature range from 130 to 330 K. In case of US loading, the longitudinal waves excited in the samples were 4.1 and 8.4 MHz in frequency f_{US} and had the intensity of $W_{US} < 0.8$ W/cm^2. It was reported previously [17, 15, 11, 9] that a characteristic time of change in the silicon structure parameters under the ultrasound action did not exceed $2 \cdot 10^3$ s. In order to wait till the acoustically induced transitional period the following experimental procedure was used. After USL start the sample was kept at room temperature during 30 min. Then the sample was cooled to 130 K. The cooling time was about a half of hour. After cooling the I–V measurements and the sample heating were started. The sample temperature was controlled by differential copper-constantan thermocouple.

In order to avoid the effect of piezoelectric field on I–V characteristics, the piezoelectric cell was shielded and aluminium acoustic line was used. The more details about the experimental setup are presented elsewhere [10].

The data non-linear fitting were done by using the differential evolution method [23].

3. Results and Discussion

3.1. Ultrasound influence on reverse current

Figure 1 shows the complete I-V-T characteristics that were measured without US loading. To avoid a busy looking graph, the selection of measured I–V characteristics is shown in this figure. Below the reverse branches only are under consideration . It is a universal observation that the current from any SD never truly saturates at large reverse bias. Such "soft" reverse characteristics are observed for structures under investigation too. One can see that the reverse current change with the bias increase is larger at the low temperature.

Therefore I_1 can be described as follows

$$I_1 = I_0 T^2 \exp(-q\Phi_b/kT)[1 - \exp(-V_R/kT)]\,, \tag{1}$$

where Φ_b is zero bias Schottky barrier height (SBH), I_0 is the constant. It is predicted theoretically [24] and observed experimentally [25, 26], that the SBH decreases with temperature increase in the way similar to semiconductor band gap.

4. Conclusion

The experimental investigation of ultrasound influence on the reverse leakage current of Mo/n-n^+-Si Schottky barrier structure has been carried out in the temperature range from 130 to 330 K. The investigation has revealed the acoustically induced reversible increase of reverse current. The efficiency of ultrasound influence decreases with the bias and the temperature rising and increases with the acoustic waves frequency growth. The analysis has shown that the thermionic emission and the phonon-assisted tunneling make a major contribution to the leakage current and both mechanisms are affected by ultrasound. It has been found that the ultrasonic loading leads to the decrease of barrier height, trap depth, occupied interface state density, Poole–Frenkel factor.

Thus, ultrasound can be an effective tool for controlling metal-semiconductor structure characteristics.

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