ELECTRICALLY ACTIVE DEFECTS IN THE AMORPHOUS SILICON/CRYSTALLINE SILICON HETEROJUNCTION SOLAR CELL AFTER HEAVY Xe IONS IRRADIATION

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1. Introduction

Solar cells based on silicon heterostructures belong to highly prospective photovoltaic devices. A significant advance in the development of heterostructures with hydrogenated amorphous silicon, a-Si:H, and crystalline silicon, c-Si, has been achieved by the heterojunction with a thin intrinsic layer technology (HIT) [1]. The reason is in its simplicity, low costs and a higher efficiency at higher temperatures in comparison with the conventional cells [2]. The charge flow through the HIT structure is strongly affected by the traps at the interface between amorphous and crystalline silicon [3]. In spite of the achieved results, the mechanism of charge carrier transport through such an interface and mutual relationships between technological and physical parameters and their impact upon the short-circuit current and open-circuit voltage of the final solar cell still have not been explained satisfactorily [4].

Intentional implementation of the electrically active defects into HIT structures by the heavy ions irradiation gives possibility to analyze the generation - recombination processes regarding to the photovoltaic phenomenon. Generally, the semiconductor devices exposed to extremely harsh type of radiation, show incorrect functionality [5]. Formation of the radiation-induced defects in the a-Si:H/cSi heterostructures irradiated by high energy heavy ions has particular influence on their electrical parameters.

The contribution introduce the results of electrically active defects investigation on the Al/a-Si:H(n)/a-Si:H(i)/c-Si(p)/Al structures irradiated with the high doses of 167 MeV Xe ions by capacitance DLTS method.

2. Experimental

The a-Si:H(n) 50nm/a-Si:H(i) 5nm/c-Si(p) 525μm structures were fabricated on high-quality <111>-oriented p-type silicon doped by boron at the concentration of 1.6×10^{21} m^{-3}. The thickness of Si wafers was 525 μm. Prior to deposition, the surface of the silicon wafer was cleaned in a solution of HF. In the next step, a-Si:H(i) at thickness 5 nm was deposited. Subsequently, samples were finalized by the deposition of 50 nm thick a-Si:H(n) to form the heterojunction emitter. The layers of amorphous silicon doped by phosphorus as well as of the intrinsic silicon were deposited by plasma enhanced chemical vapor deposition (PECVD) in the Laboratory of Photovoltaic Materials and Devices, TU Delft in Netherlands.

Subsequently, these structures were irradiated with heavy Xe ions of the energy of 167 MeV in the Joint Institute for Nuclear Research, Dubna, Russia. The samples with irradiation fluences, **AB1** 5×10^{8} cm^{-2} , **AB2** 5×10^{9} cm^{-2}, **AB3** 5×10^{10} cm^{-2} and non-irradiated control sample **AB** were investigated.

For the DLTS study, the top emitter contact was prepared by evaporation of 100 nm thick aluminium layer with the various photolithographically patterned areas of the gates. The bottom contact was created by evaporating full area aluminium contact onto the back side of silicon.

Deep levels and electrically active traps were identified by the capacitance DLTS method. Measurements were carried out in the temperature range from 85 to 375 K using the BIORAD DL8000 measuring system equipped with the Fourier transform analysis of the measured capacitance transients, Deep Level Transient Fourier Spectroscopy (DLTFS). The DLTFS is a digital system that records the whole capacitance transients. It has significant advantages over both the rate window and lock-in amplifier types of measuring systems in terms of a higher sensitivity and better deep level energy resolution. During measurements, the reverse bias was set at different voltages and periodically pulsed to the fill voltage for trap filling. The obtained DLTS spectra were evaluated using the Fourier transform analysis by “Direct auto Arrhenius single evaluation”.

3. Results and discussion

The measured DLTS spectra were obtained by applying identical measurement parameters: pulse width $t_p = 5.12$ ms, period width T_W = 5 ms, reverse bias voltage U_R = -0.5 V and pulse voltage $U_p = 0.05$ V, at the temperatures of 85-350 K and then the traps were evaluated by simulation of the particular parameters. The correlation curves together with the Arrhenius graphs with particular parameters are introduced in Fig.1. The calculated activation energy parameters ΔE_T, cross section $\sigma_{T,}$ and defects concentration N_T are introduced in Tab.1.

The analysis of the non irradiated sample AB showed high value of volume defects of Si substrate (T3, T4) which correspond to the metallic impurities Fe, Cu and Pt. The traps (T1, T2) are located in the interface between amorphous and crystalline silicon thereby was confirmed the results of original DLTS measurements [6]. On the samples irradiated with the various types of Xe heavy ions fluences were detected the deep levels, which represent the electrically active defects due to destruction from the implanted Xe heavy ions in both, the amorphous and crystalline region of heterostructure. Theoretically, the deep levels can be characterized as the radiation induced defects of different types of divacancies, eventually as the vacancy-impurity bonds.

The exposed samples with lower fluences (AB1, AB2) showed typical A-center defect [7], vacancy-oxygen (T5) in the vicinity of a-Si:H(n)/cSi(p) interface. A radiation defect vacancy-boron E_v+0.3-0.45 eV stated by [8] was with high probability also present (T6) in the investigated samples with lower fluences (AB1). The high fluence of Xe ions (AB3) suppressed the existence of T5 trap, however, with the strong conservation of the original trap T3 with deep level in cSi(p) volume. The traps T7, T8 a T9 with the high activation energy value were indicated at the high fluences (AB2, AB3), unfortunately, without exact determination of their type. The measured correlation curves were obtained at the higher temperatures. It is supposed that those are deep levels localized in the forbidden band of a-Si:H(n) and at interface.

Exacting analysis of the physical process of charge carriers capture-emission at the deep levels was influenced by complexity of interaction of the electrically active defects by annihilation of the new formed radiation induced defects with the original ones within the a-Si:H(n)/cSi(p) structure.

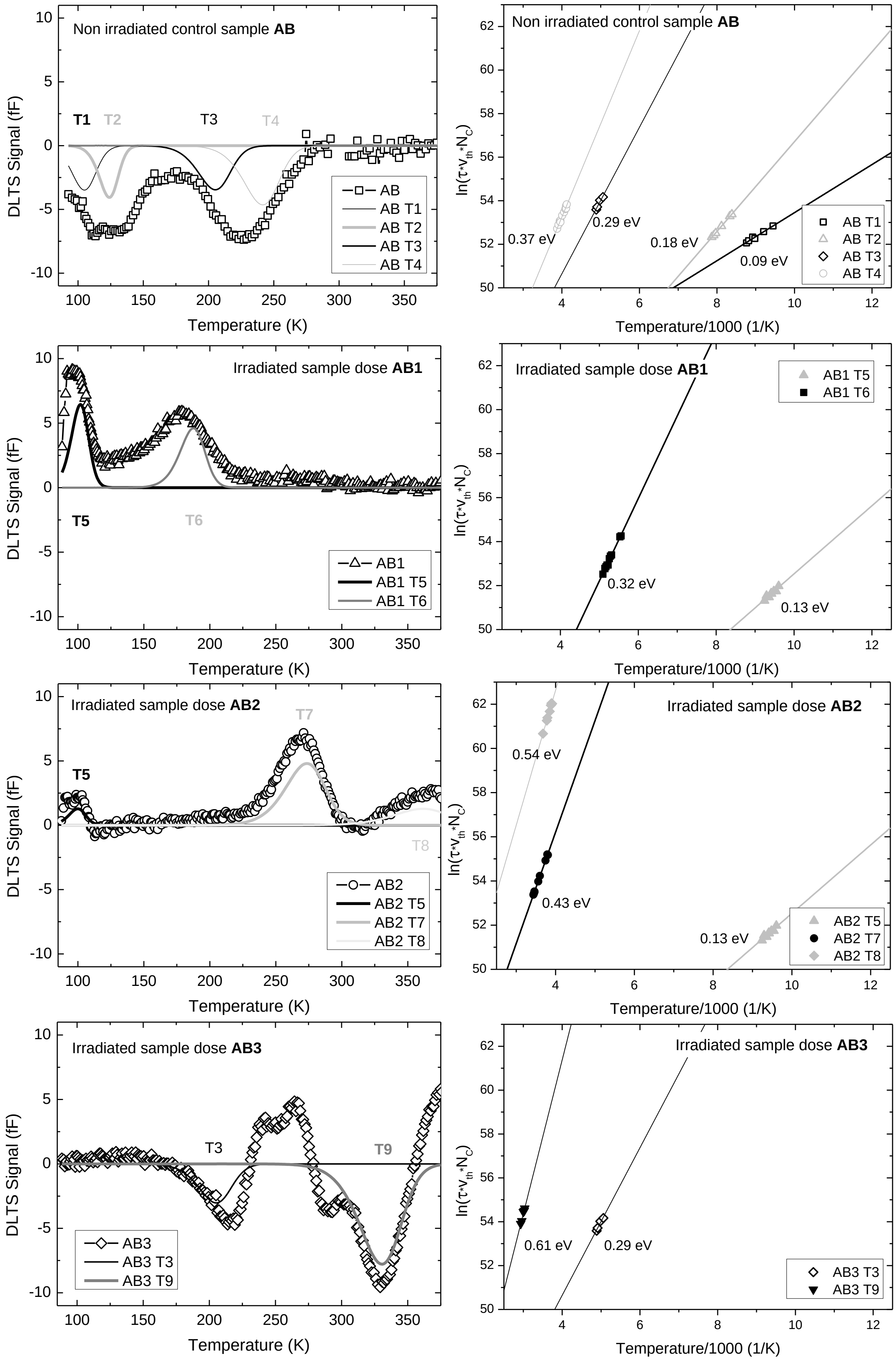

Fig.1:*The measured and simulated DLTS spectra on samples and calculated by Arrhenius plot.*

Tab. 1. *Summary of experimental data from the DLTS measurements.*

Trap	Sample	Energy ΔE_T (eV)	Cross-section σ_T (cm^2)	Concentration N_T (cm^{-3})	Probable origin of deep energy level
T1	AB	0.09	3.8E-19 for n 2.0E-19 for p	1.5E+13	Interface of a-Si:H(n)/cSi(p), [6]
T2	AB	0.18	1.7E-16 for n 8.7E-17 for p	1.7E+13	Interface of a-Si:H(n)/cSi(p) [6] For n 0.234 Zn-2 For p 0.203 Cu-aa, 0.240 Pt-a
T3	AB AB3	0.29	7.0E-17 for n 1.3E-18 for p	2.0E+13	For n 0.320 Ti-dd or 0.330 Pt-d For p Fe-5
T4	AB	0.37	2.0E-16 for n 1.0E-16 for p	2.0E+13	For n 0.417 Cu-a For n 0.360 Ag
T5	AB1 AB2	0.13	4.2E-17 for n 8.0E-17 for p	1.4E+13	Radiation defect - (A center) vacancy–oxygen complex [7]
T6	AB1	0.32	1.5E-15 for n 3.0E-15 for p	1.0E+13	Radiation defect for p vacancy-boron Ev+0.3-0.45 [8]
T7	AB2	0.43	1.4E-16 for n 2.0E-16 for p	3.5E+13	Radiation defect correspond also to for p 0.429 Fe-d
T8	AB2	0.54	2.9E-17 for n 5.7E-17 for p	1.0E+13	Radiation defect
T9	AB3	0.61	3.4E-15 for n 1.8E-15 for p	1.8E+12	Radiation defect correspond also to 0.599 eV Zn-aa, 305-000, xr

4. Conclusion

On the samples irradiated with the high energy heavy Xe ions, the many deep levels of electrically active defects were indicated in the space charge region of the heterojunction of amorphous and crystalline silicon by the capacitance DLTS method. The parameters of six of these defects were determined. With increased the heavy ions fluence, the nature and density of the radiation induced defects were changed. It was clearly registered the radiation induced A-centre traps, vacancy-boron and the different types of divacancies with a high value of activation energy.

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References:

[1] M. Tanaka, et al: *Jpn. J. Appl. Phys.*, **31**, 3518 (1992).
[2] A. Terakava, et al: In: *Proceedings of the 15th PVSEC*, Shanghai, 661 (2005).
[3] M. Mikolášek,et al: *Thin Solid Films*, **558**, 315 (2014).
[4] T. F. Schulze, et al: *J. Appl. Phys.*, **107**, 1 (2010).
[5] R. Fang,: *Appl.Phys.Letters*, **104**, 183507 (2014).
[6] M. Mikolášek,et al: *Appl. Surf. Science*, **312**, 152 (2014).
[7] F.D. Auret, *Rev. Sci. Instrum* **57**, 1597 (1986).
[8] C. A. Londos, *Phys. Rev. B* **34**, 1310 (1986).