CURRENT TRANSPORT MECHANISM IN AMORPHOUS SILICON/ CRYSTALLINE SILICON HETERO-JUNCTION SOLAR CELLS

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1. Introduction

Continuous reduction of fossil fuels reserves and growing demand for electrical energy forcing us to ask question: How we can improve other ways of obtaining electrical energy? There are several resources for production of electrical energy. One of the most perspective and, what is probably most important, almost inexhaustible source of the energy is the sun. Solar energy represents a huge potential for mankind and therefore represents a high motivation for research in the area of conversion of solar light to the electricity energy.

The most important task in the photovoltaic research is to achieve competitiveness with other commercial sources of energy. In other words, it is necessary to have high efficiency and low price of solar modules. Recent rapid development in the field of photovoltaic and continued growth of solar panels installed capacity causes a lack of production capacity of silicon substrates. This started to be a drawback for continued decreasing of the solar cells price. The limitations of silicon wafer based solar cells have become an incentive for increased research of solar cells with a-Si:H/c-Si heterojunction [1, 2]. Their attractiveness rests especially in possibility to combine high efficiency of silicon wafer based solar cells and typical low production costs of thin-film solar cells. An important prerequisite for high efficiency of heterojunction solar cells is good quality of a-Si:H/c-Si interface with low density of defect states. To reduce the interface defect states was at the interface added a thin layer of intrinsic amorphous silicon, which serves as a passivation [3]. It is necessary to know, how will this intrinsic layer change the properties at the a-Si:H(n)/c-Si(p) interface. In this paper we aimed to investigate the current transport mechanisms through an a-Si:H(n)/c-Si(p) heterojunction and the impact of introduced thin intrinsic layer with various thicknesses on those mechanisms.

2. Experiment

As substrates, we have used p-type, <111> oriented crystalline silicon with a thickness of 525 μm and the concentration of impurities 1.6×10^{21} m^{-3}. Prepared were three series of samples with and without intrinsic amorphous silicon passivation interlayer. The first series, A0, was prepared by deposition of 50 nm thick amorphous silicon n-type a-Si:H(n) layer on the c-Si(p) substrate. In case of second and third series was prior the deposition of 50 nm thick amorphous silicon layer deposited thin passivation layer of a-Si:H(i) with 5 nm and 10 nm thickness for sample AB and AC, respectively. A thin intrinsic amorphous layer at the interface serves as a passivation. Amorphous silicon layers and passivation intrinsic silicon interlayers were deposited by plasma enhanced chemical vapor deposition (PE CVD). Amorphous silicon layers were doped by phosphorus. The silicon substrates were prior the deposition etched in solution of HF. Amorphous silicon was prepared in the laboratory of photovoltaic materials and devices, TU Delft - Dimes, Netherlands.

Full area bottom contacts were created by evaporation of aluminum on the back side of samples. Top aluminum gate electrodes were evaporated through a metal mask with circular holes with 500 μm diameter. To remove high lateral leakage presented on the samples, a reactive ion etching was carried out through the amorphous silicon layers. Due the high selectivity of etching between Si and Al (600:1) top aluminum contacts were used as a mask.

3. Results and discussion

The measurements were performed using Keithley 237 and thermally heated MDC Duo Chuck CSM 16. Typical sets of dark *J-V* curves of studied heterojunction structures measured at different temperatures ranged from 297 to 393 K are depicted in Fig. 1. At low forward bias *J–V* characteristics follow an exponential law which can be described by [4]:

$$J = J_S\left[\exp(\mathrm{AV}) - 1\right], \tag{1}$$

where saturation current density (J_S) and temperature-dependent coefficients ($A=q/mkT$, where m is ideality factor) generally depend on temperature and provide information about the specific current mechanism. To determine, which is the dominant current transport mechanism, it is required to analyze these parameters at different temperatures.

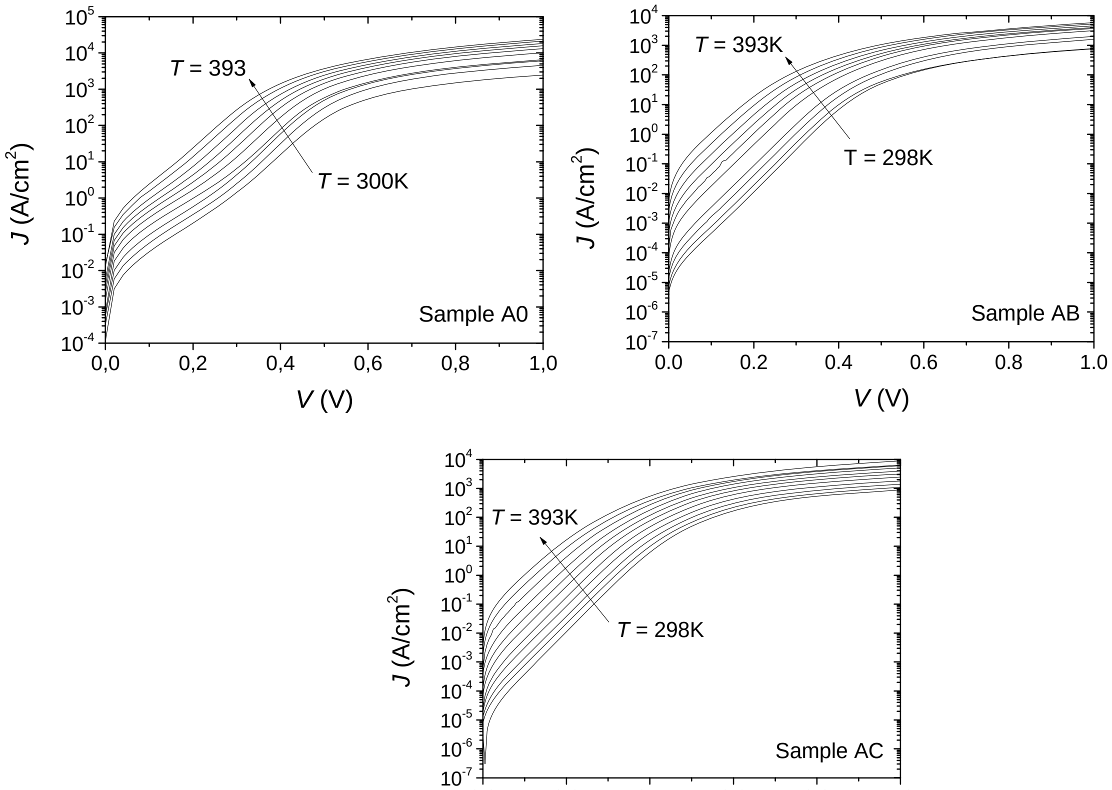

Fig. 1: *Current density-voltage characteristics under forward bias of studied samples measured at various temperatures.*

In order to provide this analysis, it is necessary to linearly approximate the forward biased *J-V* curves in semi-logarithmic scale. From the slope of this approximation an ideality factor

m and therefore also exponential factor A can be determined. The intersection of linear approximation with the y-axis gives us the saturation current density value.

For sample A0, we can distinguish two linear regions, which can be approximated by straight line to get the ideality factor m and saturation current value J_s (Fig.1). Analyzed were therefore transport mechanisms in two voltage regions: region 1 for voltage $V<0.3$V and region 2 for voltage $V>0.3$V. In case of sample AB (Fig. 1), we can observe one linear region, where we can analyzed m and J_s. Similar characteristics were obtained for samples AC. Parameter A for samples AB and A0 (voltage regions 1, 2) has very small slopes throughout temperature range 298 - 393K. It means that A is almost temperature independent as illustrated in Fig. 2. This behavior is typical for tunneling mechanism [4]. As can be observed in Fig. 2, the parameter A for sample AC has a linear dependence upon the temperature. This behavior is typical for recombination. The value of slope S near 0.5 represents the recombination in the space charge region (SCR). The values of slope A for studied samples are summarized in Tab. 1.

By analyzing the saturation current density Arrhenius plots we have determined the activation energy for particular samples (Fig.2). Results are summarized in Tab. 1. The value of activation energy helps us to better specify transport mechanism of charge carriers in heterostructure. From the inversion temperature dependence of saturation current we can assume multitunneling capture-emission process (MTCE) for samples A0 and AB [4]. The value of activation energy in these cases represent the position of trap level, via which is the tunneling provided. In case of sample A0, activation energy corresponds very well with peak of defect states according to the standard model of density of states in n-type doped amorphous silicon. The shift in case of sample AB is possible caused due to the presence of intrinsic amorphous interlayer, which has different density of states distribution compared to doped a-Si:H.

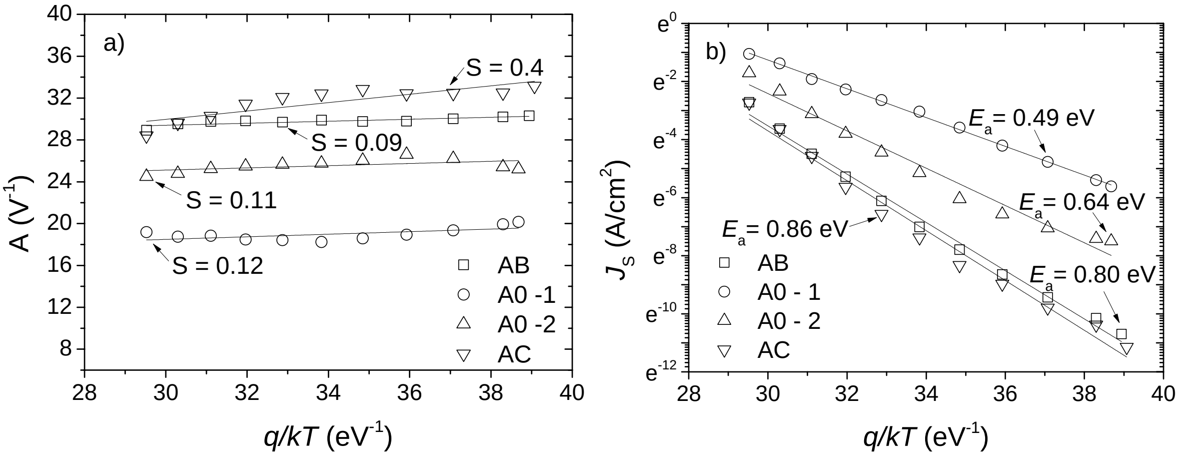

Fig. 2. *a) Exponential factor $A=q/mkT$ and b) saturation current J_s as a function of q/kT for studied heterostructure samples A0, AB and AC.*

Tab. 1. *Calculated parameters for studied heterostructure samples*

Sample	Volt. region	Slope of exp. factor *A* (V^{-1})	Activation energy E_a (eV)
A0	V<0,3	0,11	0,49
	V>0,3	0,12	0,64
AB		0,09	0,80
AC		0,4	0,86

In case of sample with 10 nm thick intrinsic interlayer (AC) the identified process is recombination in space charge region. From activation energy, however, we are not able to clearly distinguish the semiconductor region, in which is this recombination occurred. Change in the physical phenomena of carrier transport via the heterojunction can be associated with the 10 nm thick intrinsic passivation layer. We suppose that thicker intrinsic layer has lower transparency for tunneling, therefore the dominancy of tunneling process is suppressed in case of sample AC.

4. Conclusion

The carriers transport via the amorphous silicon/crystalline silicon heterojunctions is given by various mechanisms, from which usually one has dominant influence. To determine the dominant one, we have carried out an analysis of temperature dependence forward biased *J-V* characteristic in order to extract the diode ideality factor and saturation current density. In case of samples A0 and AB was identified as a dominant transport mechanism the multitunneling capture-emission process (MTCE). In case of sample with 10 nm thick intrinsic passivation layer, however, the dominancy of tunneling is significantly suppressed and a recombination in space charge region was identified as a dominant transport phenomena. We suppose that this is caused due to the lower tunneling transparency of thicker passivation layer. For all samples, the recombination via the a-Si:H(n)/c-Si(p) interface states was not identified. This predicts a good quality of the interface and therefore good output parameters of solar cell based on the same technology set-up as was used for preparation of studied samples.

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