DETERMINATION OF THE CONDUCTION BAND OFFSET IN THE A-SI:H/C-SI HETEROJUNCTION STRUCTURES FROM COPLANAR TEMPERATURE CURRENT-VOLTAGE MEASUREMENTS

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1. Introduction

The opportunity to put together low cost potential and high performance was the main driving force for the researchers to focus their attention on the solar cells with a-Si:H/c-Si hetero-junction. To fully utilize the potential of this technology, the study and optimization of hetero-junction was identified as the most important issue. In our previous numerical study we have shown that particularly the defect density and band offset at the hetero-junction have major impact on the solar cell performance [1]. Therefore, to know and optimize the value of these parameters is the key technological aim. The presence of an electron rich inversion layer in p-type crystalline silicon at the interface with n-type hydrogenated amorphous silicon was experimentally demonstrated from the coplanar conductance of a-Si:H(n)/c-Si(p) structures [2]. This inversion layer is very sensitive to the band mismatch between two semiconductors and thus offers the opportunity to study conditions at the hetero-junction [3]. Based on this aspect, we carried out the coplanar current voltage measurements in the wide range of temperature to gain the value of conduction band offset. Considering this value, the performance of solar cell with prepared a-Si:H/c-Si hetero-junction was estimated.

2. Experimental and simulation set-up

A phosphorous doped a-Si:H(n) layer of thickness 50 nm have been deposited using the AMOR PECVD deposition system in the Laboratory of Photovoltaic Materials and

Devices, TU Delft – Dimes, Netherlands on the p-type c-Si wafer ($p= 2.1\times10^{21}$ m^{-3}) and thickness 525 µm. The activation energy of amorphous layer is 0.2 eV. Aluminum coplanar contacts were evaporated, defined by lift-off technique and annealed at the temperature 150 ºC for 30 minutes in forming gas (90% N_2 + 10% H_2). Current-voltage measurements were carried out in the dark using Agilent 4155C analyzer at various temperatures in the range 100 K – 300 K controlled by a cryostat system BIO-RAD DL 8000. To analyze the dependence of electron sheet density (N_S) of the electron rich layer at the a-Si:H(n)/c-Si(p) interface as a function of temperature was measured. These data were taken to determine the conduction band offset (ΔE_C) using the *ASA* numerical simulation program. The parameter database of the TU Delft Dimes laboratory we used as input parameters of a-Si:H(n) layer.

3. Results and discussion

The coplanar conductance measurements of a-Si:H(n)/c-Si(p) sample reflects the condition of inversion layer at the interface. The sheet electron density at this interface can by calculated from *ASA* simulations through $N_s = \int_0^d n(x)dx$, where d is the c-Si wafer thickness and n(x) is the electron concentration. As is presented in the Fig. 1, band offset at the a-Si:H(n)/c-Si(p) hetero-junction has strong influence on the electron concentration profile in the c-Si(p) substrate and thus also on the calculated value of N_s. Moreover, Arrhenius plot constructed from the temperature dependence of calculated N_s revealed strong impact of the temperature on the interface inversion layer upon the value of conductance band offset (Fig. 2.). This dependence can be expressed through the activation energy (E_a) evaluated from Arrhenius plot and in this way a conversion graph between activation energy and conduction band offset can be constructed (Fig. 3). The strong dependence of E_a on ΔE_C is the key issue for precise determination of ΔE_C, which can be then easy obtained from conversion graph (Fig. 3).

The coplanar current voltage measurements of samples at various temperatures give us a value of inversion layer conductance upon the temperature. To analyze this plot using the numerical calculation, the value of the electron sheet density is evaluated through $N_s = GL / qh\mu_n$, where h is the length of the coplanar electrodes, L is distance between electrodes, G is conductance, q is electron charge and μ_n is electron mobility. The value of electron mobility in this equation is temperature dependent, which can by described using

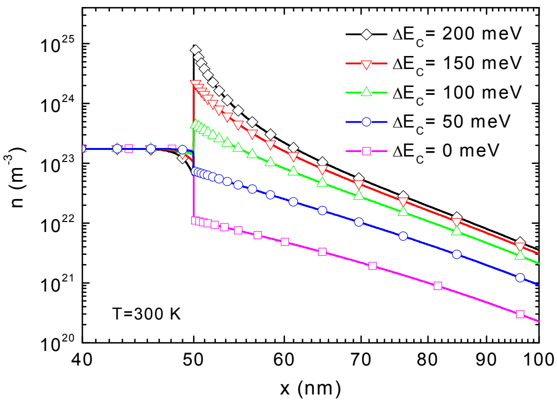

Fig. 1: *Electron concentration profile at the a-Si:H(n)/c-Si(p) hetero-junction for various values of conduction band offset.*

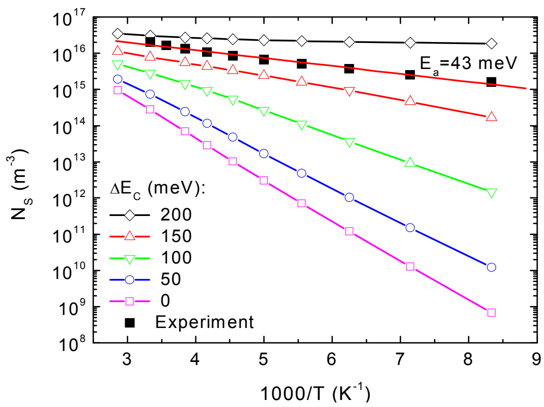

Fig. 2: *Temperature dependences of sheet electron density, simulation and experiment with calculated* E_a.

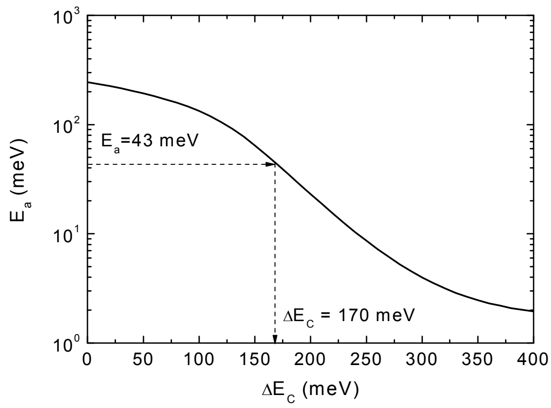

Fig. 3: *Calculated conversion relation-ship between measured activation energy and conduction band offset.*

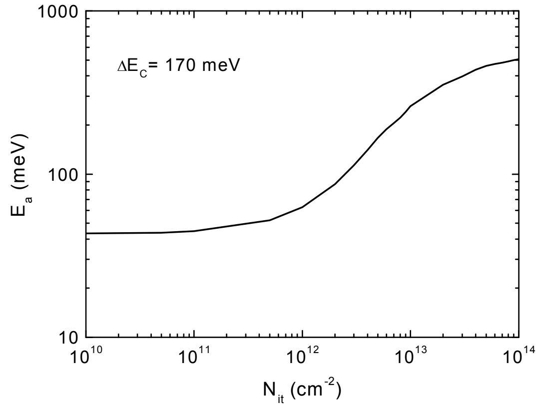

Fig. 4: *Calculated sensitivity of activation energy to the defect density at the hetero-interface.*

$\mu_n(T) = \mu_{300}(T/300)^{-\alpha}$, where μ_{300} is the mobility at T=300 K. Considering lightly doped silicon wafer and thus α = 2.4 [5], the N_s at various temperatures was calculated from current voltage measurements (Fig. 2). By calculating of the activation energy and using conversion graph in the Fig. 3, the conduction band offset of measured samples was determined, ΔE_C = 170 meV. This is in good agreement with the results of photoelectron spectroscopy [4]. As is shown in Fig. 4, activation energy for ΔE_C = 170 meV is insensitive to defect density at the interface of magnitude up to $N_{it} = 10^{12}$ cm^{-2}. Considering measured value of conduction band offset and assuming the defect density at the interface around $N_{it} = 10^{11}$ cm^{-2} we can calculate the open circuits voltage V_{OC}=0.620 V and the efficiency 15.2 % for solar cell based on one a-Si:H/c-Si hetero-junction prepared under same conditions as studied sample [6].

4. Conclusion

The conductance of electron rich inversion layer at the a-Si:H(n)/c-Si(p) interface was measured at various temperature and an activation energy was evaluated from Arrhenius plot. Strong dependence of calculated and measures activation energy on the band offset at the hetero-junction allowed us to determine the conduction band offset in the studied sample ΔE_C = 170 meV. Considering this value and assuming low defect density at the interface we were able to estimate performance of solar cell with one a-Si:H(n)/c-Si(p) hetero-junction prepared under similar conditions as our sample. The open circuit voltage of such solar cell is V_{OC} = 0.620 V and the efficiency is η = 15.2%. Increasing the conduction band offset, decreasing the defect density at the interface and improving the light management in the solar cell can attain further increasing of efficiency.

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