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Study of the effect of experimental conditions on polysilicon solar cells

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ABSTRACT

The aim of this work is to study the electrical and thermal characteristics of the PV module based on polysilicon solar cells elaborated with LPCVD processing of silicon. We shall proceed by using two structures of cells, taking into account the effect of two specific experimental features which are the thickness of the formed cells and the deposition temperature of the P-layer. The obtained results show a significant influence of both parameters on the performance of the PV module. Specifically, these parameters control the resistivity value in each cell forming the module.

Introduction

Recently, the polycrystalline silicon material has gained considerable importance in the development of microelectronic components, integrated circuits and photovoltaic generators [1]. In fact, continual improvement would be a priority while addressing the circuit complexity of this type of materials, and a high degree of component integration requires expertise and mastery of high quality [2–4]. In particular, thin-film solar cells based on polycrystalline Cu (In, Ga) Se2 (CIGS) and CdTe photovoltaic semiconductors have reached remarkable laboratory efficiencies [5]. On the other hand, the large-grain polycrystalline silicon has the potential for the large-volume production of low-cost solar cells [6]. However, electrical parameters efficiency of the photovoltaic generators is generally limited by the interface between two grains, i.e. grain boundaries possessing incomplete bonds that can represent trap states to the minority carriers [7,8]. Consequently, the reduction of these grain boundaries leads to a high improvement in the photovoltaic electrical parameters. Therefore, increasing the grain size can improve the efficiency of the solar cells produced from this type of materials [9].

Moreover, polycrystalline silicon thin films prepared by chemical vapor deposition of silane at very low pressures, known as Low Pressure Chemical Vapor Deposition (LPCVD) technique, have been extensively studied. In this technique, the achievement of a highly doped and short junction aims to both reduce dimensions and increase the speed [10]. Note that impurities diffuse much faster in polycrystalline silicon layers than in single crystal silicon substrates because of the grain structure of the poly-silicon (polycrystalline silicon) layers [11–13]. The grain size depends on many factors such as: sample preparation before deposition, deposit temperature and thickness of the poly-silicon layers, to name the most important.

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In this work, the evolution of the photovoltaic parameters of two series of cells used with heavily doped B-Si-LPCVD thin films has been studied as functions of the deposition temperature and the films thickness. Crystallinity of deposited films will be analysed with X-ray diffraction measurement (XRD), and electronic properties will also be investigated by resistivity measurement. A generalized photovoltaic current-voltage relationship is developed showing that the electrical properties of polycrystalline silicon depend on the properties of the grain boundaries.

Material and method

The photovoltaic cells were prepared by depositing polycrystalline silicon on the mono-crystalline N-type silicon substrate <111> oriented and doped with $1 \times 10^{19} cm^{-3}$, of 100 mm diameter and cut to size of 1,5 × 1,5 cm^2. After cleaning and etching the polished silicon surface, a layer of poly-silicon highly in-situ boron doped ($\approx 10^{20}$ cm^{-3}) is deposited in an industrial hot-wall LPCVD reactor from the decomposition of silane (SiH_4) at low pressure (0,4 Torr) using the LPCVD technique. The temperatures of the substrates on which the films were deposited were fixed at 520 °C and 605 °C. The chosen thicknesses of the P-layer are about 200 nm and 300 nm. The cell used with the P-layer deposited at temperature of 520 °C is named cell one (Cell 1); the cell used with the P-layer deposited at temperature 605 °C with 200 nm thickness, cell two (Cell 2); and finally the cell used with the P-layer deposited at 605 °C with 300 nm thickness, cell three (Cell 3).

Structural characterization

The crystallinity of poly-Si thin films was examined in detail by using the XRD. Under this context, the study was performed on a D8 Advance Bruker AXS diffractometer with CuKα radiation, equipped with a curved graphite monochromator. Data were collected in the 2θ range of 10–80 with a step size of 0.04° and a count time of 12s per step. Fig. 1 shows the XRD spectrum of the cells structure.

From this figure, we can clearly see the relationship between the deposition temperature and the intensities of the peaks (220), (111) and (222) of the polySi layers while taking the thickness of the different layers as a parameter. Obviously, the intensity of the predominant <111> orientation, which is the crystallographic orientation of the single crystal substrate, increases with the increasing temperature, and decreases while increasing the thickness of the different layers (see Fig. 2). However, the intensity of the <220> orientation is not predominant when compared with the <222> and <111> orientations.

Electrical characterization

The operation of a PV module, designed from the three above cited photovoltaic cells under light radiation, is simulated taking into account the effect of the usual experimental conditions, which are the thickness and the deposition temperature of the deposited P-layer. As mentioned before these parameters influence the resistivity of each cell forming the module. Values of the films average resistivity were obtained using the four point's traditional technique on P-layer deposits. The results of the estimated resistivity of the solar cells are gathered in Table 1.

The follow-up of the evolution of these films resistivity shows a variation according to the deposition temperature, from 2.772×10^{-3} Ω cm to approximately 3.867×10^{-3} Ω cm, with a clear increase starting from the deposit temperature of 605 °C. Thus, these films are more resistive than the films deposited at 520 °C when doped with the same amount of boron. This effect has been verified by another work [11–13]; the resistivity measured in the poly Si layers doped with boron deposited at various temperatures, was found to increase with the deposition temperature. However, the increase in thickness, as in the case of cells deposited at the same temperature (Td = 605 °C) caused the reduction of the resistivity value from 3.867×10^{-3} Ω cm down to 3.410×10^{-3} Ω cm. Similar dependence of the resistivity on the thickness and dopant dose was obtained by Yaron and Seto [14,15]. It is worth noting that an increase in the resistivity with a decrease in the film thickness is observed over the entire doping range. This strong dependence of the resistivity on the dopant dose and thickness is a major problem in controlling polysilicon film resistance.

Photovoltaic model

The equivalent electrical circuit of an ideal solar panel can be treated as a current source parallel with a diode, as shown in Fig. 3 [16]. As can be seen, some losses exist in the real operation of the solar panel. To pick up these losses, a series resistance R_s and a shunt resistance R_{sh} are added to the PV system.

The electrical characteristic of the solar cell used in the PN union is almost same as that of the diode, which is represented by the equation of Shockley [17–20]:

$$I = I_L - I_s\left[\exp\left(\frac{V + IR_s}{nVt}\right) - 1\right] - \left(\frac{V + IR_s}{R_{sh}}\right) \quad (1)$$

where I_L is the current generated by the incident light, I_S is the saturation current of the diode, I is the net current of the solar panel of the simplified model, V is the cell voltage, V_t is the thermal voltage and n is the diode ideality factor. Eq. (1) represents the generated output current which depends upon solar irradiance, voltage of the PV panel and ambient temperature.

Note that the strategy to study a PV module does not differ from that of modeling a PV cell since the used parameters are the same. However, the open circuit voltage is divided by the number of cells. The model of the PV module selected for simulation is the FP-VAP-F6-220W, manufactured by FON-ROCHE Pevafersa, which is formed by 60 series connected polysilicon cells; the main electrical characteristics are given in Table 2. The comparative study covers three different modules designed from the three cells previously presented, they are noted as: module1, module 2 and module 3.

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