



Fabrication of a solar cell from silicon doped with aluminium



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ABSTRACT

In this study thin films of p-doped silicon were deposited on glass substrate using the hot wire chemical vapour deposition. The deposition chamber of the hot wire chemical vapour deposition was modified such that co-evaporation of the doping metal could be possible. This resulted in the p-doped silicon film, which also has a polycrystalline microstructure. Aluminium metal was used as a dopant instead of the conventional boron. To grow a silicon crystalline p-layer using this method, physical evaporation of aluminium in the hot-wire chemical vapor deposition chamber takes place, while at the same time catalytically fragmenting silane gas on the resistively heated tantalum hot wire. The microstructure (which is polycrystalline) and the electrical characterization of the p-type doping film will be presented in this work. This layer was then used to manufacture n–i–p prototype solar cell. The open circuit voltage (V_{oc}) and the closed circuit current (J_{sc}) of the solar cell will also be presented in this study.

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1. Introduction

Hydrogenated amorphous silicon (a-Si:H) is an allotrope of silicon which has a fourfold coordinated atoms with a very short range tetrahedral structure. This film can be deposited using various types of thin film deposition techniques such as DC sputtering [1], plasma chemical vapour deposition [2] and hot wire chemical vapour deposition [3]. There has been various studies carried out to induce crystallization of the hydrogenated amorphous silicon (a-Si:H) in the past.

Several methods of crystallizing thin films of a-Si:H have been studied in the past. Solid phase crystallization (SPC) was one of the earliest methods that were used to crystallize a-Si:H [4–6]. This involved annealing the thin films in vacuum at elevated temperature for a longer duration. In order to increase the crystal size of the film, higher temperatures (600 °C) were necessary and the increase in annealing time is also required. Therefore these increased the process time and the cost of process due high energy being used. Furthermore cheap glass substrate could not be used for this process since at higher temperatures these substrates tend to fail

under stress [7–10].

Excimer laser annealing method to crystallize a-Si:H has been employed in order to lower the crystallization temperature of the a-Si:H, but the high cost of the process proved to be an obstacle for this process. Other studies reported on the non-uniformity of the crystal sizes as a major drawback of this process and the high surface roughness from the solid melt formed during the laser annealing [11,12]. Rapid thermal annealing (RTA) method for the crystallization of a-Si:H have also been investigated. In this method an infra-red radiation source which can have heating rate as high as 55 °C/s is used as a heating source. This had an advantage of not having collateral damage to the glass substrate which are infra-red radiation transparent. This process also had been reported to have high initial set-up cost [13].

The other alternative to crystallizing the a-Si:H was employing the metal induced crystallization (MIC) method whereby a thin layer of metal (i.e. nickel, aluminium or gold) are deposited onto the a-Si:H film and then heated to elevated temperatures to induce the crystallization of the film [14,15]. In this method there are three steps involved in order to crystallized the film: the first step would be to grow thin films of a-Si:H using chemical vapour deposition technique, followed by the deposition of a metal coating onto the film, then finally to anneal the film under vacuum at elevated temperatures. The advantage of this method is that the crystallized

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films were p-doped in nature and these films can be incorporated in an active solar cell as a p-layer [16].

In the MIC process whereby nickel was the metal deposited onto the a-Si:H thin film to induce crystallization has been widely known as metal-induced lateral crystallization (MILC). This name is attributed to the lateral phase transformation from the metal induced crystallization region to the part that is not coated with nickel. This crystallization is driven by silicide formed in the nickel-coated region. There are also other metals, which are eutectic forming metals that fall under this MILC process, but the driving mechanism for crystallization is the layer exchange between the metal and the silicon [17–19].

Aluminium has been one of the metals that has been mostly used in the metal induced crystallization processes of a-Si:H films, because the crystallization reaction of a-Si:H with aluminium takes place well below the eutectic temperature of aluminium-silicon system [14], this results in films which are not silicides. Since aluminium is a group III element, it can also act as a p-type donor in the process of crystallization instead of using boron as a dopant [16].

Because of the crystallization effect of aluminium on a-Si:H films, and that it can dope a-Si:H films in the metal induced crystallization process, a new process has been developed whereby a crystallized and p-doped film is grown in a hot-wire chemical vapour deposition (HWCVD) chamber. This is a single-step process which eliminates the need to first grow an a-Si:H film on a substrate, then evaporate an aluminium layer and annealing it to activate crystallization. In this process, aluminium is simultaneously evaporated in the HWCVD chamber while silane (SiH_4) is catalytically fragmented on the hot wire. The atomic species are proposed to react on their way to the glass substrate to grow a film that is both crystallized and p-doped. This is achieved via a single-step deposition process without the need of any post deposition annealing.

2. Experimental method

The p-type film was grown on a $1.5 \times 1.5 \text{ cm}^2$ Corning 7059 glass substrate in the HWCVD reaction chamber. The substrate was cleaned by a standard ultrasonic wash method, and it was then loaded into the HWCVD chamber. The chamber was then pumped down to a pressure of 1×10^{-7} mbar. The configuration in the HWCVD chamber was such that the filament to substrate distance was 1.8 cm, the substrate temperature was set at $280 \text{ }^\circ\text{C}$, with the tantalum filament temperature set to $1800 \text{ }^\circ\text{C}$ as measured by an optical pyrometer. Silane gas flow rate from the gas feedstock was carefully controlled by the mass flow controller and let into the chamber at a flow rate of 50 standard cubic centimeter (scm).

Aluminium of 99.999% purity was then placed in a tungsten evaporation basket inside the HWCVD chamber, and resistively heated with a direct current power source. The evaporation of aluminium took place in the reaction chamber while silane (SiH_4) was simultaneously fragmented on the hot tantalum wire. The operational pressure during the deposition was maintained at $60 \text{ } \mu\text{bar}$ using a butterfly control valve. The silicon and the hydrogen atoms from the fragmented silane are proposed to react with the aluminium vapour on their way to the heated substrate to grow an aluminium induced crystallized p-type layer.

3. Results and discussion

The deposited p-type film using the aluminium induced crystallization doping process was elementally quantified, this was done using energy dispersive spectroscopy (EDS) in a HITACHI X-650 scanning electron microscope analyser (SEM) with 139 eV

resolution. Fig. 1 shows energy dispersive plot of the deposited thin film, from the plot it can be clearly seen that aluminium was successfully incorporated into the grown film during the co-deposition process as evident by the peak at 1.5 keV which is a signature energy of aluminium x-ray emission energy. Also from the selected area scan of the sample the atomic percentage of the incorporated aluminium in the film was measured to be approximately 4 atomic %. The aluminium atomic percent incorporated in this film is much lower than the aluminium that is usually needed for the metal induced crystallization methods.

X-ray diffraction study was done using a θ - 2θ D8 Advanced Bruker XRD, using the copper $\text{K}_{\alpha 1}$ x-ray line with the wavelength of 0.154 nm. This machine was used to characterize the microstructure of the deposited film. The x-ray diffraction patterns plot in Fig. 2 shows that the grown film is poly-crystalline in its microstructure, and has a (111) preferential orientation. From the spectrum it can be seen that the film shows no amorphous signature that is usually shown by a hump centred at approximately $2\theta = 28^\circ$, instead there are only sharp crystalline peaks on the 2θ scale which are attributed to the polycrystalline phases of silicon, and a there also a (111) phase of aluminium. This observation confirms that crystallization took place throughout the bulk of the film and the crystallites sizes of polycrystalline silicon were determined using Derby-Sherer equation to be approximately 540 nm.

This x-ray diffraction pattern result is similar to those obtained when using the metal induced crystallization process whereby aluminium was used as the metal to induce crystallization of a-Si:H thin film [16,20]. It should be borne in mind that this microstructure of the film has been achieved without having to first deposit film of a-Si:H on a glass substrate, followed by coating the film with layer of aluminium and then annealing the sample at elevated temperatures to induce crystallization, but through a single-step co-deposition of aluminium and catalytic decomposition of SiH_4 on a hot tantalum wire in the HWCVD reaction chamber.

The Hall Effect study of the film was done and the van de Pauw four probe configuration was used to measure the carrier concentration of the holes and the magnitude of the holes was measured to be in the order of $3 \times 10^{12} \text{ cm}^{-3}$. This measurement was done with a current of 1 nA and a voltage of 0.5 V applied across the sample when the magnetic field strength is set at 0.1 T. The dark conductivity of the film was measured by evaporating two silver strips onto the film, the strips were 1 mm apart. The dark conductivity of the film was in the order of $1 \times 10^{-3} \Omega^{-1} \text{ cm}^{-1}$.

Thermal stability study of the film was done using real-time

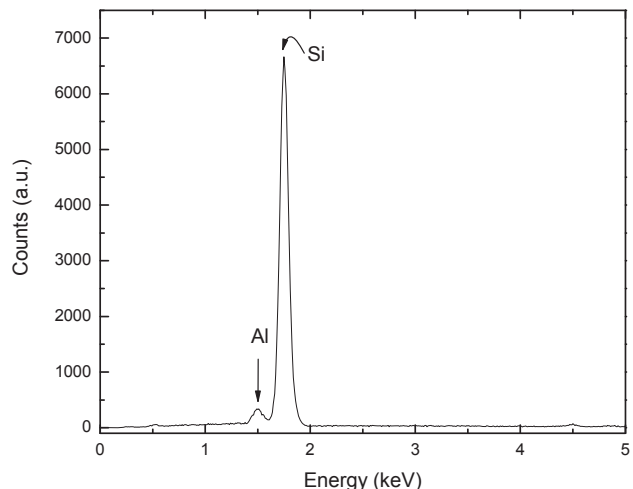


Fig. 1. Energy dispersive spectroscopy spectrum of the p-type polycrystalline film.

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