Understanding The Influence of Belt Furnace and Firing Parameters on Efficiency of Thin Film CIGS Solar Cells

ABSTRACT

Thin film photovoltaic's is a promising path for achieving higher efficiencies at lower costs. With advancements in materials and processing technologies, thin film photovoltaic's has been gaining significant importance in solar cell technology. Betwixt the various thin film technologies, CIGS solar cells have been reported as being the most efficient. Currently, extensive efforts are underway for improving the efficiency of CIGS solar cells while considerably increasing its production volume. This exertion will explain the processing of CIGS solar cells and the importance of the firing process. In addition, the study will shine light on an ideal belt furnace for selenization of CIGS solar cells.

INTRODUCTION

The ever increasing demand and growing cost of silicon has made thin film photovoltaic's a competing substitute to silicon solar. Thin film photovoltaic (PV) modules are seen as a realistic alternative for a cost effective generation of electricity from sunlight. They are often referred to as the second generation of photovoltaic technology. Some promising materials for thin film solar cells include amorphous silicon, cadmium telluride, CuInSe2 and its alloys. While all of these materials are low band gap, they are all polycrystalline as well leading to a loss in efficiency due to grain boundary recombination. Amid the polycrystalline thin film solar, CIGS solar cells have been documented in various pieces of literature as being unrivalled in efficiency.

A typical fabrication of a CIGS solar cell encompasses the sputtered deposition of molybdenum back contact material on a substrate. The substrate material can be a rigid soda lime glass or a flexible polyimide. The sputtering of the back contact is followed by the deposition of the CIGS absorber layer, CDS buffer layer and the final Zno contact layer. Molybdenum is primarily used as a back contact due to its ability to form an ohmic contact, as well as, inert behavior to corrosive gasses. Cadmium sulphide is used with CIGS material to form an n-type semiconductor material along with a p-type CIGS absorber material. Some of the widely used methods for depositing CdS include chemical bath deposition (CBD), sputtering and closed space sublimation (CSS). Zno is used as the front contact material due to its superior electrical and optical properties. Figure 1 illustrates a material stack up of the CIGS solar cell.

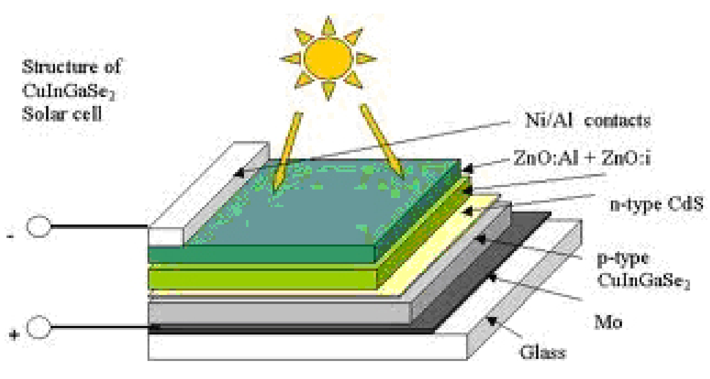

Figure 1: Material Stack up of CIGS solar Cell

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PROCESSING CIGS IN A BELT FURNACE

The fabrication of CIGS solar cells within a production environment contains the deposition of copper, indium and gallium on the selected substrate material while annealing them at elevated temperatures in controlled atmospheres. First, the substrate material is cleaned and then heated to an elevated temperature. Afterwards, copper, indium, gallium and selenium are deposited through a sputtering process and then the deposited parts are selenized in an elevated temperature profile. The selenization process involves ramping up from room temperature to 450°C in about 4 minute's. The samples are soaked at this temperature for 7 minutes and then elevated to 550°C for approximately 4 minutes. The samples are then held at 550°C for another 7 minutes and then cooled down. Finally, while held at an elevated temperature, hydrogen sulphide gas is introduced to sulphurization. A detailed profile is illustrated in Figure 2.

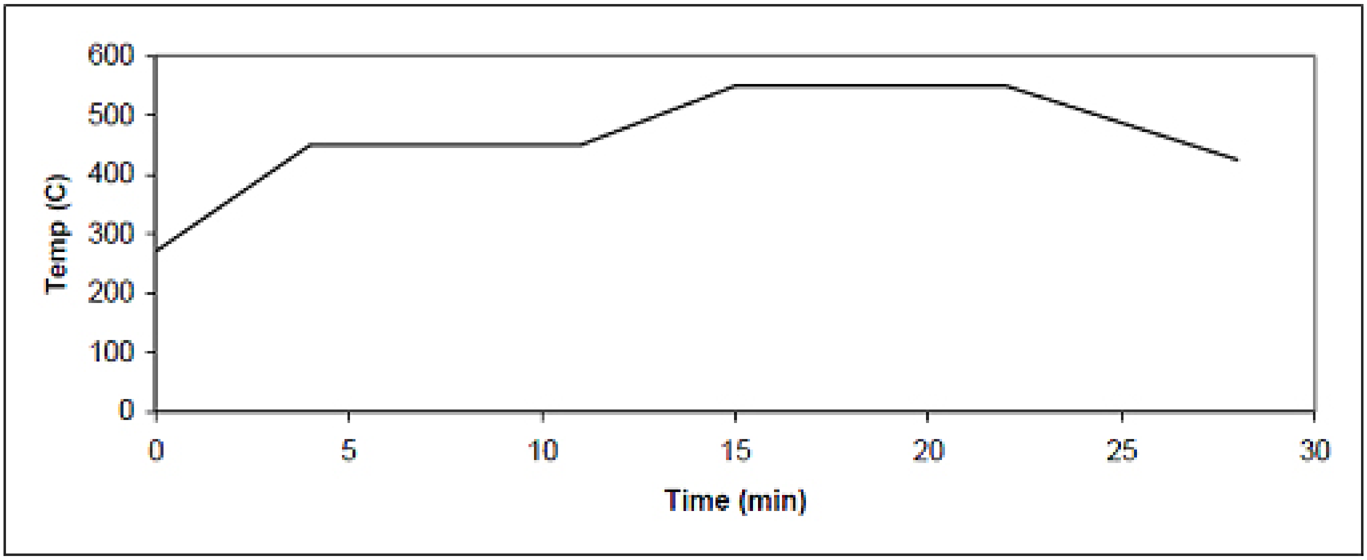

Figure 2: Selenization profile of CIGS solar Cell

EFFECT OF SELENIZATION PROFILE ON THE EFFICIENCY OF SOLAR CELL

The temperature and soaking times play two very important roles in determining the final efficiency of the CIGS solar cell. Many researches have revealed significant evidences for how the different sintering temperatures and soaking times have a direct impact on the efficiency outcome. The results of the experiment by Kadam et al demonstrate that a sintering temperature above 500 oC and a soaking period between 30 and 60 minutes can improve the efficiency of the cell significantly.

In his experiments, when the samples were selenized at 400°C for 10 minutes with a temperature ramp of 6°C per minute, it resulted in smaller, non-faceted grains. This is an indication that either the temperature or the soaking time is inadequate. When the soaking time was increased from 10 to 15 minutes, no significant improvements were noted in the results. Therefore, the ramp rates can be construed as having a larger impact on efficiency. In addition, Kadam et al studied the impact of various heating rates. Changes in the parameters were made: heating rate was increased from 6°C per minute to 20°C per minute and the temperature was increased to 425 °C with a soak period of 30 minutes. The resulting solar cell film appeared to be more homogeneous. Furthermore, the temperature was increased to see the effects on the grain size and cell efficiency, which indicated that at 475°C, the grain size ranged from 0.5 um to 1.5 um with an efficiency of 5.56%.

Condition Temp, Soak time	Grain size	Film thickness	Efficiency	Comments
400 °C, 10 min	Varies from <1-2 um	5 um	<1%	Inadequate parameters
475 °C, 30 min	0.5 – 1.5 um	3.5-3.6 um	5.56%	Better efficiency obtained
500 °C, 30 min	2 um	2.7-2.8 um, rough surface	4.8%	Non-uniform grain sizes
500 °C, 60 min	>1 um, well faceted	2.6 um	9%	High efficiency
515 °C, 50 min	>1 um, highly faceted	2.6-2.7 um	8%	High efficiency

Table 1. Effects of different sintering temperatures and soaking times

At the same time, they detected that increasing the peak temperatures above 500°C could also help with improving efficiency. However, at higher temperatures the grains become well faceted and less thick. It is fair to conclude that high quality CIGS solar cells should be prepared at temperatures above 500°C with an ideal soaking time between 30 and 60 minutes. Understanding that the heat rate, temperature, and soaking times are important factors in determining the ultimate cell efficiency, a belt furnace with a wide range of firing temperatures and a fast heat rate design are desired for constructing highly efficient solar cells.

BELT FURNACE FOR CIGS PROCESSING

A furnace that processes CIGS solar cells should be capable of operating to 650°C or higher. The aim is for a wider belt with superior cross belt uniformity so that larger substrates can be contained in the future. More over, a muffle is required to ensure a cleaner operating environment because various processes in CIGS processing, such as Sulpharization, involves the introduction of different gasses at different time periods. The muffle needs to have the capability to control the gas type and gas flow in each zone. With all of this in mind, Torrey Hills Technologies has designed a furnace that is well suited to match the requirements for thin film solar applications. Figure 4 illustrates a firing furnace that is capable of processing CIGS solar cells and Table 3 lists the technical specifications for the ideal CIGS furnace.

The designed HSA furnace uses ceramic heater boards in order to achieve elevated temperatures. Aside from the standard belt size of 350 and 650mm, wider belts have been designed as well to accommodate wider glass substrates. While a 700mm wide belt has been successfully engineered, efforts are underway to build a belt as wide as 1000mm. As a standard feature, this furnace is equipped with a steel brush for cleaning the conveyor belt, however, Ultrasonic belt cleaning is available as an extra option.

A microprocessor based PID controller is what controls the furnace. Type K thermo-couples are used in determining the zone temperatures and the controls are located on the right hand side of the furnace which can be viewed from the entrance. The central processing unit (CPU) is mounted under the exit table and the CPU is primed with a Windows operating system for easy computing. The computer system is pre-installed with a program for controlling the furnace parameters, including the belt speed and the zone temperatures. Temperature profiles can be stored and retrieved as well for future purposes. Thermocouple ports are located at the entrance table for connecting the profiling thermocouple directly into the microprocessor. This feature allows for the monitoring and recording of actual temperatures experienced by the part. Software is also included with the computer to capture, display, printout and store the furnace profile. Additionally, the furnace is equipped with a redundant overheat safety protection system which incorporates an additional type "K" thermocouple in the center of each controlled zone and the multi-loop alarm. The specification of a HAS 7503 belt furnace is listed in Table 2.

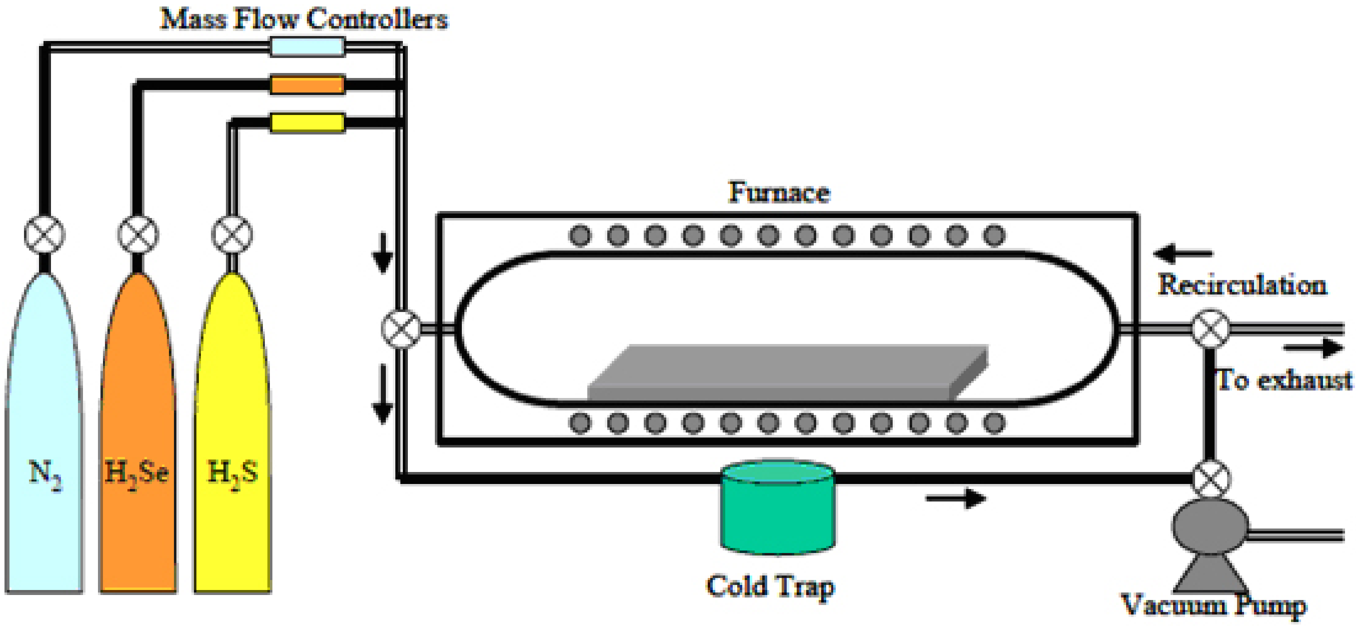

Figure 3: CIGS Sintering Furnace Requirement

Figure 4: HSA Series Belt Furnace

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Specification	HSA7503-08ZN
Rate Temperature	900 deg. C max, Normal operating: 850 deg C
Belt Width	30" (750mm)
Effective Above Belt Clearance	1" (25mm)
Control Zones	8
Conveyor Speed	2-8 IPM (40-200mm/min)
Loading Table	59" (1500mm)
Unloading Table	59" (1500mm)
Belt	Balanced V Weave, SUS314
Heating Elements	FEC Heater Board
Insulation	High quality ceramic fiber
Temperature Controller	Intelligent PID Shimaden Controller
Alarm	Thermocouple, Over Temp, Belt Stop. Audio and Visual Alarm
Atmosphere	6 pipes of dry clean air or N2. 2-6 m3/h, 1.1-3.3 CFM
Cooling	Forced Air cooling
Across Belt Temperature Uniformity	+/- 4 deg C
Overall System Width	60.5" (1540mm)
Overall System Length	343" (8705mm)
Overall System Height	54" (1,350mm)
Net Weight	2500kg
Power	Three-phase, 480VAC, 60Hz, 38 KVA MaxNormal operating power draw is about 15 KVA

Table 1: Specifications of HSH2503-0509 Firing Furnace

CONCLUSION

The selenization process has a significant impact on the efficiency of CIGS solar cells. The proposed HSA furnace has the capabilities to elevate at a much higher temperature, maintaining cross belt uniformity and achieving the required profile. At the same time, the muffle design allows the introduction of specific gasses in specific firing zones per requirement. In short, the HSA series is ideal for the selenization process in thin film photovoltaics.

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For more information on belt furnaces and CIGS manufacturing, please go to http://www.beltfurnaces.com for details.