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# Optimum Parameters for Obtaining Polycrystalline Silicon for Photovoltaic Application

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**Abstract:** The cost effective conversion of solar energy into electricity via solar cells remains an ongoing concern of researchers worldwide. The use of polysilicon has been suggested as a possible alternative to achieve this goal. The presence of traps in the grain boundaries having dangling bonds, however, limits the photovoltaic efficiency of solar cells synthesized from polysilicon. The present work constitutes search for optimal processing parameters for the development of polycrystalline silicon solar cells and their large scale manufacturing. The processing parameters depend essentially on the operating temperature, duration of the isothermal heating and the rate of growth of the polysilicon solar cell. These parameter in turn depends highly on the crystallographic states and purity of the material. The optimal processing parameters result in high nucleation rate followed by growth of the silicon grains. This process leads to the crystallization of polysilicon solar cells. In this study the processing parameters for the melting, crystallization and cooling have been optimized. The X-ray diffraction patterns of the samples show the presence of various crystalline phases. The study of crystal orientations by X-ray diffraction patterns shows the crystal orientation along (111), (110) and (100) planes. The (110) and (100) planes are present predominately on the material surface with an advantage for the (110) plane.

**Keywords:** Polycrystalline Silicon, Nucleation and Growth, Crystallographic Orientation, Solar Cells

## 1. Introduction

The efficient conversion of the solar energy to the electrical energy by silicon-based solar cells is the most technologically challenging and industrially demanding task. Though the conversion efficiency of the conventional solar cells made from monocrystalline silicon is good but they are highly expensive. Polycrystalline silicon-based solar cells have a number of advantages in the race for solar module production on a large scale. Indeed, they provide a capacity to produce large plates where the interconnection of cells is integrated with a very low material consumption and low energy consumption during the production cycle. In addition, they have the advantage of being sensitive to low intensity of light, and comparatively inexpensive than those manufactured based on monocrystalline silicon [1-4]. The new growth methods allow prepare polysilicon in the form of ingots [5], tapes [6] from the decommissioned silicon electronics [7] or a silicon powder produced directly from silane [8].

In the present study, the optimum processing parameters for the synthesis of polycrystalline silicon for large scale manufacture of solar cells have been presented. These parameters includes operating temperature, duration of the isothermal heating and the rate of growth of the polysilicon solar cell, which depends on the crystallographic states and purity of the material. This process leads to the crystallization of polysilicon solar cells. Additionally the processing parameters for the melting, crystallization and cooling have been optimized.

## 2. Experimental Condition

For the preparation of the polysilicon solar cells following steps have been followed: A predetermined quantity of silicon powder is placed in an evacuated quartz tube at room temperature. The evacuated quartz tube along with the powder is placed in the vertical furnace with the help of a pulley as shown in the Figure 1. The quartz tube is placed in the middle

of the furnace to ensure that the quartz tube remains in the isothermal temperature region during the processing. The silicon powder is heated at 1420 $^{o}$C for 60 min. After the melting of the silicon powder and the heating of the liquid for 320 min, the evacuated quartz tube is lowered along the furnace so as to achieve a decrease of 20 $^{o}$C in the temperature of the quartz liquid. This decrease in the temperature starts the progressive cooling of liquid and process of the crystallization of silicon starts.

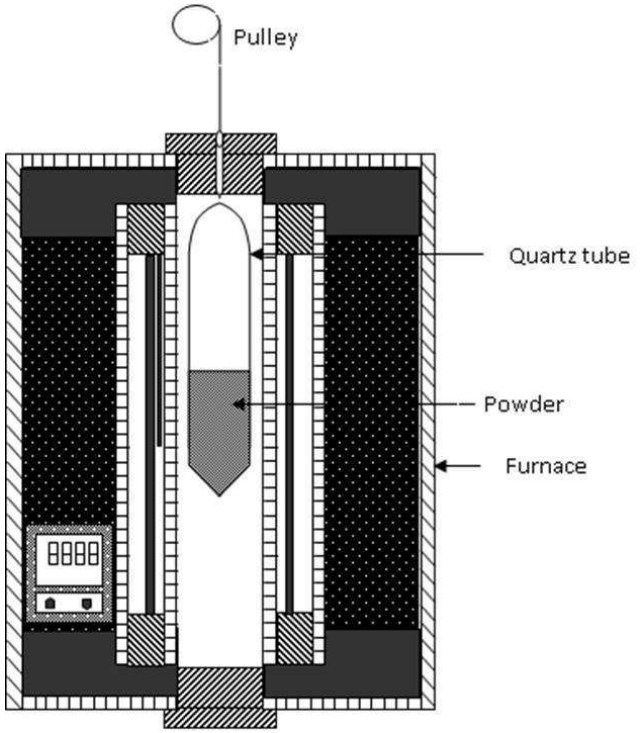


***Figure 1.*** *Schematic representation of a longitudinal section of a furnace containing quartz tube with silicon powder.*

# 3. Results and Discussion

The crystallization of the phase has been studied theoretically [9]. Using the temperature and the heating schemes for the preparation of polysilicon reported in the literature, the appearance of the cracks has been noticed on the samples. However, employing the linear temperature gradient during the cooling operation, the quality of the sample could be improved. To optimize and to obtain the standard curve of temperature and rate of cooling, several experiments have been performed. The theoretical model for the preparation of polysilicon consists of four stages namely heating, melting, cooling and crystallization as shown in the Figure 2.

### *3.1. Optimal Settings for Obtaining the Poly – Si*

After lowering the quartz tube into the middle of the furnace, the furnace was heated at the rate of 20 °C/min to a temperature of 1420 °C. The sample is heated at this temperature for 60 min. Then the tube is further lowered with a rate of 5 cm/h initiating the crystallization of the sample without proceeding to cooling of the sample by lowering the temperature at a rate of 20 ° C/min. It was observed that the material did not melt at 1420 $^{o}$C. This may be due to the fact that the temperature used was not sufficient for melting, and needed to be higher than the temperature employed.

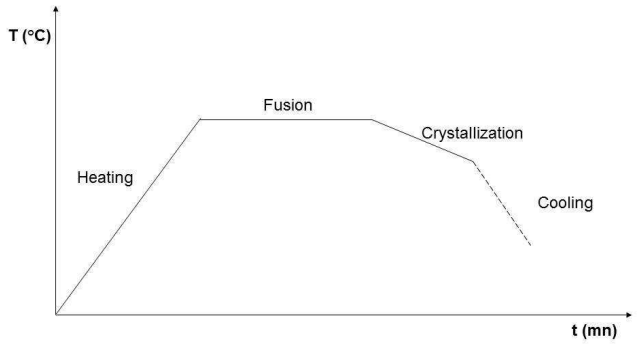


***Figure 2.*** *Schematic diagram of preparation operation.*

*(a). Melting temperature*

The experiment was further repeated keeping all the experimental parameters same, and increasing only the melting temperature to 1440 $^{o}$C. The furnace is heated with heating rate 20 $^{o}$C/min. The sample is heated until obtaining the 1440 $^{o}$C. At this temperature, the melting of the outer layer of the powder was observed. It can be deduced that 1440 °C is the correct value of the melting temperature, and to achieve complete melting of the powder, the powder must be heated for increased length of time isothermally.

*(b). Duration of the melt phase*

In this step of the experiment, the heating rate, the heating temperature and cooling rate is kept the same at 20 °C/min, 1440 °C and 20 °C/min respectively. The duration of the isothermal heating at 1440 $^{o}$C is varied so as to achieve the melting rate at 5 cm/h. The duration of the isothermal heating is increased from 60 to 60 minutes, until the melting of all the sample to form liquid. The sample is observed to melt completely after heating for a time period of 320 minutes. However, after the cooling, the silicon sample obtained is broken into two parts because of its poor morphology.

*(c). Crystallization rate*

In order to optimize the parameters for the cooling rate, the experiment were preformed keeping heating rate, isothermal heating temperature, isothermal heating time and cooling rate at 20 °C/min, 1440 °C, 320 minutes and 20 °C/min, respectively. The only parameter varied is speed of crystallization. The speed of crystallization is approximated as the speed of descent (5 cm/h) of the quartz tube in the furnace. The crystallization step (descent) must not decrease the temperature of the furnace 20 °C below the melting temperature which is 1440$^{o}$C in the present study. This also helps to avoid large and inhomogeneous temperature changes, which can affect the morphology of the sample thus obtained. To lower the rate of descent, the furnace was installed with a set of pulleys between the motor and the tube. With this system rate of descent, and therefore crystallization, has been controlled up to minimum of 0.5 cm/h which corresponds to 3 °C/h. The samples with rate of descent equal to 0.5 cm/h

have been used to synthesize the samples of silicon, with good morphology. However, the obtained sample was fragile, and broke during the cutting operation. This is probably due to the rapid cooling rate, which would have caused internal stresses in the sample, causing it to crack. In addition, literature [10] showed that the gradual cooling operation increases the length of the grains, thereby increasing the photovoltaic efficiency [11].

*(d). Cooling rate*

The heating rate of the sample, the heating temperature, duration of isothermal heating, the crystallization rate ie the rate of the decent is 20 °C/min, 1440 °C, 320 min and 0.5 cm/h, respectively. The rate of the decent has been varied to optimize and reduce the internal stresses. To avoid internal stresses in the sample was reduced to the maximum value of the cooling rate, doing it from 20 ° C/min to 1 °C/min.

*(e). Heating rate*

During heating, the temperature of the furnace shoots off up to almost 20 $^{o}$C after reaching the melting temperature fixed at 1440 $^{o}$C. The value of the temperature oscillates decreasing the shoot off temperature. Gradually furnace attains the melting temperature. This thermal variation affects the quality of the samples obtained by this process. To minimize these variations, the rate of heating is reduced to 10 °C/min in the first step and then, it was reduced to 2 °C/min in a second step from 1420 °C onwards.

Figure 3 shows a polycrystalline silicon sample obtained using optimized parameters presented in the present work. Figure 4 presents the schematic of the heating scheme employed in the present study. The optimized processing parameters are summarized as follows:

- Heating rate: 10°C/min, to 1420 $^{o}$C and 2 °C/min thereafter;
- Melting temperature: 1440 °C;
- Duration of the isothermal heating: 320 min;
- Quartz tube lowering speed (Crystallization speed): 0.5 cm/h;
- Cooling rate: 1 °C/min.

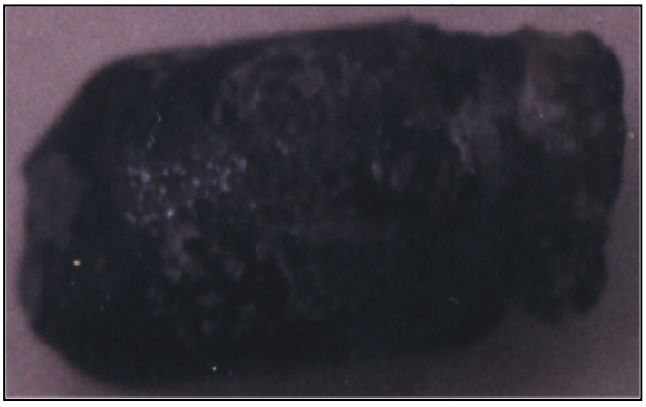

***Figure 3.*** *Polysilicon Sample obtained.*

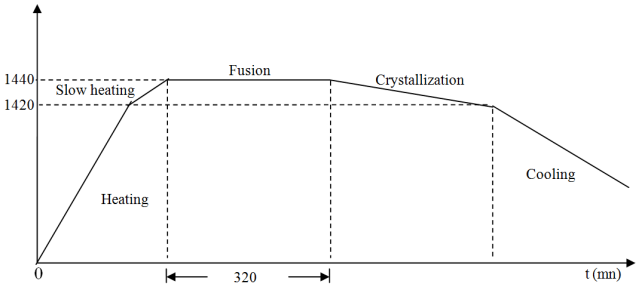


***Figure 4.*** *Plot of temperature variation as a function of time that must be followed for the preparation of polycrystalline silicon*

### *3.2. Crystallographic Study*

The samples prepared by this method were studied by the using the X ray diffraction and the preferred orientations obtained were determined. The low indices (h, k, l) such as (100) (110) (111) has been reported to be favorable for the high photovoltaic conversion efficiency [12]. The presence of (100) (110) (111) planes in the polysilicon ensures channel effect, which results a higher mobility of the charge carriers and increased diffusion length. The decrease in the density of atoms and concentration of recombination centers and traps improves the efficiency of the polysilicon. The interest of the demonstration of a preferred orientation, is the improvement of photovoltaic performance, which may result from the adaptation of the production process of solar cells. Indeed, for monocrystalline wafers, the method is adapted according to the orientation. Polycrystalline platelets consist of different crystallinity grains having different crystal growth directions specific to each grain [13]. The study is made by X-ray diffraction results obtained show that the (111) planes, (110) and (100) are predominant in the material surface with an advantage for the (110) plane. The crystallographic study can be refined by using the ECP method (Electron Channeling Pattern) [14].

## 4. Conclusion

The processing parameters for the synthesis of the polysilicon solar cells have been optimized in the present work. These parameters allow preparation of polycrystalline silicon that can be used as solar cells The processing parameters; Heating rate, melting temperature, Duration of the isothermal heating, Quartz tube lowering speed (crystallization speed) and cooling rate have been optimized to be 10 °C/min, 1440 °C, 320 min, 0.5 cm/h (equivalent to 3 °C/h), and 1 °C/min respectively. The fluctuations observed during the melting step can be avoided by reducing the heating rate up to 10 and then 2 °C/min.

Crystallographic study by X-ray technique showed the predominance of the planes (110) on the surface of the material obtained. The crystalline quality of the material can be improved by the use of a monocrystalline seed orientation preselected favorable to enhance photovoltaic efficiency during the nucleation and growth operation.

## References

[1] B. Zaidi, B. Hadjoudja, B. Chouial, S. Gagui, H. Felfli, A. Magramene, A. Chibani; Silicon; 7 (2015) 293–295.

[2] B. Zaidi, B. Hadjoudja, H. Felfli, B. Chouial, A. Chibani;Revue de Métallurgie; 108 (2011) 443–446.

[3] B. Zaidi, B. Hadjoudja, B. Chouial, S. Gagui, H. Felfli, A. Chibani; Silicon; 7 (2015) 275–278.

[4] B. Zaidi, B. Hadjoudja, H. Felfli, A. Chibani; Turk. J. Phys.; 35 (2011) 185–188.

[5] R. Kishore, J. L. Pastol, G. Revel; Solar Energy Materials; 19 (1987) 221-236.

[6] A. Eyer, A. Rauber, A. Goetzberger; Optoelec. Devi. Techn.; 5; No 2 (1990) 239-257.

[7] G. Revel, J. L. Pastol, D. Hania, N. D. Huynh; Revue Phys. Appl.; 22 (1987) 519-528.

[8] A. Eyer, N. Shillinger, I. Reis, A. Rauber; J. Cryst. Growth; 104 (1990) 119-125.

[9] P. Gadaud, J. Wopirgard; Revue Phys. Appl.; 23 (1988) 919-924.

[10] S. Pizzini, D. Narducci, M. Root; Revue Phys. Appl.; 13 (1988) 101-104.

[11] A. Laugier, J. A. Roger; « Les Photopiles Solaires » (1981).

[12] P. Andonov, P. Derwin, C. Esling; Revue Phys. Appl.; 22 (1987) 603-612.

[13] M. Zhu, Y. Cao, X. Guo, J. Liu, M. He, K. Sun; Sol. En. Mat. & Solar Cells; 62 (2000) 109-115.

[14] S. Mo, E. Peiner, A. Schlachtzki, R. Klockenbrink, E. R. Weber; Mat. Scien. Eng.; B56 (1998) 37-42.