Silicon Utilization in renewable energy generation

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ABSTRACT

The objective of this study is the availability of utilizing the silicon in production of renewable energy which is called clean energy. Since Egypt is sunny all over the year hence, it must produce a power from the sun by solar systems. In many applications and situations the solar system is the unique solution from the cost point of view. In this road map, we try to show the way to solar energy and the existing capabilities. In Egypt second nuclear research reactor, it has the ability to produce silicon ingots (float zone) up to 6 inches diameter with very high quality which can be used in fabrication of high class electronic devices and high power electronic devices. The efficiency of the solar cell depends on the wafer material weather poly-crystalline or mono-crystalline. This paper describes the recipe how to produce a float zone silicon wafer for solar cell use. The recipe includes the calculation of the neutron dose, decay time etching, annealing and characterization of electronic parameters.

INTRODUCTION

A solar cell is essential a PN junction with a large surface area. The N-type material is keep thin to allow light to pass through to the PN junction. Figure (1) shows the solar cell arrangement and electric power generation mechanism.

![Solar cell arrangement and electric power generation mechanism](image)

Figure (1) solar cell arrangement and electric power generation mechanism [1].

Light travels in packets of energy called photons. The generation of electric current happens inside the depletion zone of the PN junction. When photon of light is absorbed by one of these atoms in the N-Type silicon it will dislodge an electron, creating a free electron and a hole. The free electron and hole has sufficient energy to jump out of the depletion zone. If a wire is connected from the cathode (N-type silicon) to the anode (P-type silicon) electrons will flow through the wire. The electron is attracted to the positive charge of the P-type material and travels through the external load (meter) creating a flow of electric current. The hole created by the dislodged electron is attracted to the negative charge of N-type material and migrates to the back electrical contact. As the electron enters the P-type silicon from the back electrical contact it combines with the hole restoring the electrical neutrality [2].

*Neutron transmutation doping of silicon*

When silicon is irradiated the objective is to produce number of phosphorus atoms in the target sample in order to obtain a given resistivity after the treatment. The resistivity of the sample is decreased by the transmutation of the silicon, by neutrons, to phosphorus. Irradiation is carried out by thermal neutrons. The basic reaction of the process:

\[
\text{Si}^{30} (n,\gamma) \text{Si}^{31} \rightarrow \text{P}^{31} + \beta^{-1} (1.47 \text{ MeV}) \tag{1}
\]
The side reaction which tends to cause the number of doped nuclei obtained by the first reaction to disappear since the capture cross section here is only 0.2 barn the amount of sulfur produced is minute in doping terms. But longer half life for decay \( ^{32}P \) can impose restrictions on handling of low resistivity NTD (resistivity less than 10 ohm.cm) [3,4].

\[
P^{31} (n,\gamma) P^{32} \rightarrow S^{32} + \beta^{-1}\text{ (radioactivity)} \tag{2}
\]

\[
Si^{28} (n, 2n) Si^{27} \rightarrow Al^{27}\text{ (negligible)} \tag{3}
\]

\[
Si^{28} (n, \alpha) Mg^{25} \tag{4}
\]

This reaction produce high energy alpha particle. Even without reaction, the head on collision of 1 Mev neutron with silicon atoms will knock out about 200 silicon atom from their lattice sites. Thus thermal to fast ratio in irradiating silicon is critical. However there is another reaction occurs, which more important:

\[
B^{10} (n, \alpha) Li^{7} \tag{5}
\]

This reaction a total energy release of 2.5 Mev is associated with Alpha particle and Lithium, which leads to short range lattice damage. Boron has a very high thermal capture cross section greater than 755 barn (but the concentration or boron is very small). Figure (2) shows the silicon wafer production processes and we shall explain each step of the processes.

![Flow Chart](image)

**Figure (2) flow chart of silicon wafer production processes**

**Cleaning and etching steps**
1- Weighing the silicon sample.
2- Cleaning the sample using ultrasonic cleaner in trichloroethane followed in Acetone (or Alcohol) for about 10 minute.
3- Etching the sample.
4- Water cleaning by ultra-pure water.
5- Drying the sample using nitrogen gas.
6- Cleaning the sample using alcohol (ethyl alcohol).
7- Drying using nitrogen gas.
8- Weighing again to calculate the layer lost due to etching from:

$$\Delta x = \frac{\Delta w}{A} \times \frac{1}{\rho} \times 10^4$$

where:
- $\Delta x$ = the layer removed from the surface of the sample (micro-meter)
- $\Delta w$ = mass lost due to etching (gm)
- $A$ = total surface area of the sample (cm$^2$)
- $\rho$ = silicon density (gm/cm$^3$)

9- Ingot preparation for irradiation
1. Cover the sample (ingot) with aluminum foil.
2. Put the sample in the aluminum container.
3. Put the aluminum container in the irradiation position.
4. Calculate the needed fluence to get the target resistivity according to:

$$\varphi \cdot t = A \left( \frac{1}{\rho_{\text{final}}} - \frac{1}{\rho_{\text{initial}}} \right)$$

where:
- $\varphi$ = neutron flux n/cm$^2$.sec (measured by the self powered detector)
- $t$ = irradiation time in sec
- $\rho_{\text{final}}$ = required final resistivity (ohm.cm)
- $\rho_{\text{initial}}$ = measured initial resistivity (ohm.cm)
- $A$ = irradiation constant
5. Programming the data needed by the SDCS (Silicon Doping Control System).
6. Start the irradiation.
The neutron dose calculation

Since the resistivity of silicon for solar cell should be 0.5 – 10 Ω.cm for polycrystalline or C.Z silicon [5], and 0.5 – 30 Ω.cm for float zone silicon [6]. In the following section one can showing details calculation for different parameters such as initial resistivity, final resistivity and the thermal neutron flux. Figure (3) shows the irradiation time corresponding to the final resistivity for neutron flux (1 * 10^{21} n/cm^2.sec and 5 * 10^{21} n/cm^2.sec) the initial resistivity is 1000 ohm.cm. Figure (4) shows the irradiation time corresponding to the final resistivity for neutron flux (2 * 10^{21} n/cm^2.sec and 1 * 10^{21} n/cm^2.sec) the initial resistivity is 1000 ohm.cm

Figure (3) the irradiation time corresponding to the final resistivity for neutron flux (1 * 10^{21} n/cm^2.sec and 5 * 10^{21} n/cm^2.sec) the initial resistivity is 1000 ohm.cm

Figure (4) the irradiation time corresponding to the final resistivity for neutron flux (2 * 10^{21} n/cm^2.sec and 1 * 10^{21} n/cm^2.sec) the initial resistivity is 1000 ohm.cm

Figure (5) shows the irradiation time corresponding to the neutron flux and initial resistivity value. The final resistivity value is 5 ohm.cm, and the initial resistivity is taken 5000 ohm.cm and 2500 ohm.cm.
Figure (5) the irradiation time corresponding to the neutron flux and initial resistivity value to produce silicon ingot with final resistivity 5 ohm.cm

After silicon ingot irradiated, it stored under water away from neutrons for a certain time for induced radioactivity decay. The maximum radioactivity decay is about 10 days after irradiation which is related to 5 ohm.cm final resistivity. Figure (6) shows the decay time and relative radioactivity

![Decay Time and Relative Radioactivity](image)

Figure (6) the decay time and relative radioactivity

**Chemical etching of silicon**

The chemical etching of silicon (ingot or slice) is used to remove impurities or/and mechanical damage induced during the shaping steps and/or ingot surface grinding and slicing. The etchant can be either an acidic solution or a caustic etchant. The acidic system is mostly based on HNO₃-HF system (or with modifiers such as acetic acid CH₃COOH or water H₂O). For example HNO₃:HF:H₂O = 3:1:1 or faster etchant like, HNO₃:HF:CH₃COOH = 3:1:1 OR HNO₃:HF= 15:1 (last one is used in our case). these etchant sometimes call polishing solution[7]. The surface material removed is the result of two steps reaction. The silicon surface is first oxidized by HNO₃ to form SiO₂, followed by its removal by HF.

\[
\text{Si} + 2\text{HNO}_3 + 6 \text{HF} \rightarrow \text{H}_2\text{SiF}_6 + 2 \text{HNO}_2 + 2 \text{H}_2\text{O} \quad (8)
\]

The steps of the reaction are:

\[
\text{Si} + 2 \text{HNO}_3 \rightarrow \text{SiO}_2 + 2\text{HNO}_2 \quad (9)
\]

\[
\text{SiO}_2 + 6 \text{HF} \rightarrow \text{H}_2\text{SiF}_6 + 2 \text{H}_2\text{O} \quad (10)
\]
Acid etching produce shiny surface since the reaction is exothermic, temperature control is critical to maintain uniform etching (enough quantity of the solution to fix the temperature). Caustic etching solution such as KOH, offers uniform etching but produce rougher surface (about 120 nm) than acid etch. Hence the caustic etching has been used in solar cells wafer to minimize the light reflection. Figure (7) shows wafer etched by acidic etchant (A) and wafer etched by caustic etchant (B) [4,8].

![Image](image_url)

Figure (7) acidic etched wafer (A), caustic etched wafer (B)

Isothermal annealing of the silicon

Because of the damaged region and the disorder cluster that result from NTD, semiconductor parameter such as mobility (resistivity) and lifetime are severely degraded. In addition, most of the phosphor atoms (P) are not located in substitution sites. We must anneal the Silicon ingots which irradiated at an appropriate combination of time and temperature, in order to activate the phosphor atoms (P) and restore mobility and other material parameter. Analysis by numerous experiments suggests that the damage caused by radiation can be recovered to a great extent by heating the irradiated silicon ingot to a temperature of 600 to 1000ºC, in an inert atmosphere (N₂). The cooling rate is a very important parameter in annealing process. Heating rate vary between 10 ºC/min to 25 ºC/min from room temperature to 850 ºC. Fix the temperature at 850 ºC for maximum 60 minute to recover the damage. Hence the cooling rate should be 1 ºC/ min dawn to 300 ºC, after that cooling done by natural convection but in nitrogen gas flow inside the annealing furnace to prevent silicon dioxide layer formation in the silicon surface.

Characterization of the silicon

The characterization of the wafer or ingot should be including two important parameters. First, is the resistivity measuring using in line four point method. The second is the charge carrier life time measuring using photoconductive decay method. The characterization considers as quality assurance on the wafer that will be used weather in electronics industry or solar cells fabrication. The silicon ingot temperature during irradiation should be blew 100 ºC to makes the diffusion of the defects induced from radiation damage and impurities are minimum. Since, the defects and impurities act as
charge carrier trap. Hence, the resulting charge carrier life time is small. Figure (8) shows the charge carrier life time (electron) short life time (A) 7.66 micro second and normal life time (B) 138.6 micro second. Normally as the bulk silicon ingot resistivity decreases the charge carrier life time decrease but not sharply decreases.

![Figure 8](image)

Figure (8) charge carrier life time, short life time (A) and normal life time (B).

**CONCLUSION**

The solar energy is a clean energy but relatively expensive, so the researchers try to increase the solar cell panel efficiency and reducing the cost of generating electric power from the sun. The silicon ingot produce by float zone (F.Z) technique give higher efficiency than the Czochralski method (C.Z). The present work shows how to produce float zone silicon wafers. The neutron dose calculation presented for several initial and final resistivity and the neutron flux. The caustic etching is better than acidic etching in case of solar cell wafer due to the rougher surface which minimize the sun ray reflection and increase the efficiency of the module. The annealing can be done for one hour or less at 850 °C to remove the damage caused by radiation. The radioactivity decay time is about 10 days for silicon final resistivity of 5 Ω.cm.

**REFERENCES**

2) HTTP://crystal.biol.csufresno.edu:8080/projects/96.html.


8) "The effect of thermal treatment on crystal defects formation and the etching behavior during an isotopic etching in KoH solution", A. Hein, S. Finkbeiner, el. University of Berlin department of electrical engineering, Germany.