Fabrication of polycrystalline silicon solar cells showing high efficiency

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Abstract. The paper presents a methodology for fabrication of low-costing silicon solar cells with an efficiency of 10%. A polycrystalline silicon wafer, size 100×100 mm and thickness $450 \mu\text{m}$, was doped with phosphorus using POCl_3 as the dopant. While, the backside (*p*-side) of the wafer was printed with a paste of Ag + Al in the ratio of 25 : 1, the front side (*n*-side) was printed with a paste of silver. It was fired at 720°C for better ohmic contact. Chemical vapour deposition (CVD) method was adopted for antireflection coating. Pure oxygen gas was bubbled through a solution of TiCl_4 at 200°C . The fabricated cells gave a significant increase in efficiency in terms of open circuit voltage (V) 560 mV, short circuit current (*I*) of 2.7 amp, and fill factor of 0.73. The methods used are inexpensive, and suitable for production of efficient silicon solar on a commercial basis.

Keywords. Photogenerator carriers; anisotropic etching; oxidant; auger recombination.

1. Introduction

It is estimated by some experts that the fuel resources, including oil and natural gas, may last for less than half a century, while coal may last for hundred years. As an alternative and a sustainable source of energy, it is believed that the ultimate source to solve the energy crisis is solar energy. The most attractive source of this energy, at present, is a solar cell which is low costing as well as has high efficiency. Though quite a number of semiconductor materials are being used, amorphous, mono- and polycrystalline silicon are chosen for large-scale utilization. Cocorullo *et al* (1984), and Pereyra and Andrade (1984) tried to reduce cost of fabrication of the silicon solar cell by nickel deposition technique that resulted in the formation of nickel–silicon alloy at the silicon interface. Banerjee *et al* (1987) adopted optical concentrators to reduce the cost of the photovoltaic system, known as concentrator photovoltaic system (CPVS). For better results, hydrogen passivation technique was used by Wallace *et al* (1994). Development of low costing polycrystalline silicon solar cells has recently been achieved by improvement of substrate quality, enhancement of passivation effect etc by Nakaya *et al* (1994). Pugacz-Muraszkiewicz and Hammond (1977) reported that the matte surface structure, that contains pyramids of height of about $10 \mu\text{m}$, reduces reflectivity of the incident light falling on the cell surface and thus enhances the probability of light absorption, thereby

leading to increase of photo generator carriers; i.e. enhances the efficiency of the cells. Campbell and Green (1987) developed such textured surface by anisotropic etching, using an acid mixture $\text{HF} : \text{HNO}_3 : \text{CH}_3\text{COOH} :: 1 : 3 : 1$. Further, it is also known that the efficiency of the cell depends upon the thickness of the slices as well as the impurity, here phosphorus, in the semiconductor. The authors report simple methodology adopted by them for production of low-cost silicon solar cells with an efficiency of 10%. Different aspects involved in their fabrication are discussed below.

2. Methodology

2.1 Fabrication of *P*–*N* junction

A sample of multicrystalline silicon sheet of size 100×100 mm, and thickness of about $450 \mu\text{m}$, and with resistivity ranging from 0.5 to $5.0 \Omega\text{cm}$ of type *-P* with boron dopant was used. The surface was polished in 30% NaOH followed by treatment with an acid mixture, $\text{HF} : \text{HNO}_3 : \text{CH}_3\text{COOH} :: 1 : 3 : 1$ for 2 min.

2.2 Surface texturization

The surface was cleaned several times in deionized water and texturized using a solution of 1–2% KOH at 60°C . (While the acid etching produces pyramid structures that absorb about 56% of light striking the surface, and thereby increases the photo-generation capacity, potassium

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hydroxide acts as an oxidant and removes the dead layer of Si-P on the surface so that the photovoltaic effects are enhanced). The treated silicon sheet was kept in a hot air oven for about 2–3 h and was placed in a closed quartz tube through which a mixture of N_2 and O_2 (10 : 1) was passed. Diffusion was carried out at 900°C , using $POCl_3$ liquid diffusion for 1 h at 18°C ($\pm 1^\circ\text{C}$). The slices were arranged parallel to the direction of flow of the gas. To avoid decomposition of $POCl_3$, a system ($PCl_5 + H_2O$) cooled under ice was used as diffusion source. $POCl_3$ thus generated is stable in presence of nitrogen under normal conditions. Wallace *et al* (1994) and Agarwal *et al* (1997) showed that microscopic structural defects, resulting in surface recombination and auger recombinations during phosphorus diffusion process on silicon surface, were reduced at the chosen temperature of 900°C . After diffusion, while a photoresistant (PR)

coating was given on the frontside, the backside of the slice was etched with an acid mixture, mentioned earlier, for 15 sec. Trichloroethylene and isopropanol were used for the final cleaning of the surface.

2.3 Printing and metallization

The frontside of the cell was coated with silver paste to which about 6–10 drops of terpentine oil and rosin mixture was added as thinner. Different patterns were printed by selecting stainless steel mesh (#150) (figure 1). The cell was then dried for few min first in air and later under infrared lamp. In case of pattern design shown in figure 1d, it was observed that there was only 8% shading loss and hence higher efficiency.

The backside of the cell was coated with a paste of Ag + Al in the ratio of 25 : 1. It was sintered at about

Figure 1. Different patterns printed on silicon slices. (a) Diffused silicon wafer and (b)–(d) show pattern designs.

720°C in an open tube furnace using compressed air. Optimization of sintering temperature is given in table 1. The mixture of Ag+Al used as a paste for coating increased ohmic contact between the semiconductor and the metal.

2.4 Thickness of slices and efficiency

The transparency of the slices was studied up to the thickness of 370 μm (table 2). It was observed that the thickness of the slices as well as the impurity concentration in the semiconductor—in this case phosphorus atom—affect the extent of energy conversion. Since it is difficult to control impurity concentration in the semiconductor during phosphorus diffusion, the control is therefore managed by altering the thickness of the silicon slices. The thickness of about 450 μm recorded the maximum value of open circuit voltage (V) and short circuit current (I) (table 3).

2.5 Antireflection coating (ARC)

For antireflection coating, first chemical vapour deposition (CVD) with titanium isopropoxide using N_2 gas was tried. Since it was not successful, TiCl_4 and O_2 were used at the cell temperature of 200°C. The results given

in table 4 show that the reflectivity of the surface was reduced and more photovoltage generated. For domestic application $\frac{1}{2}$, $\frac{1}{4}$ cells and 1/16 cells were prepared from the original cell, and the quarter cells showed reasonable efficiency (table 5). A flow chart of fabrication process of polycrystalline silicon solar cell is given in figure 2.

2.6 V-I characteristics

The V-I characteristics of fabricated solar cells were studied, and are graphically represented in figure 3. The

Table 3. Optimization of thickness of the slices. The open circuit voltage (V) and short circuit current (I) were recovered at supply voltage of 235 volt.

Sl. no.	Thickness of the slices (μm)	V (mV)	I (amp)
1	450	539	2.72
2	350	527	2.27
3	250	520	2.10

Table 4. Effect of antireflection coating on open circuit voltage (V) and short circuit current (I) at supply voltage of 235 volt

Sl. no.	V (mV)	I (amp)	V (mV)	I (amp)
1	535	2.08	530	2.60
2	552	1.88	545	2.59
3	552	1.90	550	2.60
4	552	2.04	550	2.67

Table 1. Optimization of sintering temperature of the printed cell. After firing and antireflection coating the cells were measured at supply voltage of 235 volt.

Sl. no.	Sintering temperature ($^{\circ}\text{C}$)	V (mV)	I (amp)
1	650	515	1.30
2	700	525	1.71
3	710	530	1.96
4	720	543	2.52
5	730	520	1.67
6	750	523	0.70

Table 2. Dependence of light transparency of silicon slice on thickness. Measurement of open circuit voltage (V) at supply voltage of 235 volt. A cell giving $V=506$ mV originally was covered with silicon of different thickness shown in the table. The original value decreases from 506 mV to 182 mV.

Sl. no.	Thickness of the slices (μm)	After covering V (mV)
1	370	182
2	350	187
3	300	218
4	245	242
5	220	254

Table 5. Efficiency of cells of different sizes measured in terms of open circuit voltage (V) and short current (I) at supply voltage of 235 volt.

Nature of cell	Sl. no.	V (mV)	Average V (mV)	I (amp)	Average I (amp)
1/16 Cell	1	526	530	0.16	0.17
	2	532		0.18	
	3	529		0.15	
	4	531		0.17	
	5	532		0.19	
1/4 Cell	1	531	530	0.67	0.66
	2	533		0.69	
	3	527		0.64	
	4	530		0.65	
	5	529		0.63	
1/2 Cell	1	535	531.2	1.38	1.36
	2	520		1.27	
	3	541		1.44	
	4	531		1.37	
	5	529		1.36

Figure 2. A flow sheet diagram for the assembly of solar cell.

figure shows efficient ohmic behaviour of the cell under one sun, and half sun conditions. While six halogen lamps were used to simulate the natural sunlight under one sun, for half sun three halogen lamps were used.

3. Conclusion

For the production of commercial low-cost solar cells, the silicon slices of 450 μm thickness on which the P-N junction was made were selected. POCl_3 solution, maintained at about 18°C , was used as a dopant. Acid mixture $\text{HF} : \text{HNO}_3 : \text{CH}_3\text{COOH} :: 1 : 3 : 1$ was used for backside etching and a paste of $\text{Ag} + \text{Al}$ in the ratio of 25 : 1 to increase ohmic contact was used for backside coating of the cell. Close grid pattern on the frontside of the cell and use of TiCl_4 as antireflection coating, increased efficiency of the cell.

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Figure 3. V-I characteristics of the silicon solar cell under (a) one sun and (b) half sun.

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