CHAPTER IV

EXPERIMENTAL STUDIES

4.1 Introduction.

N-on-p silicon solar cells were fabricated to verify the numerical analysis given in chaper III. A number of solar cells were fabricated as the following.

Group 1 : Fabrication of n-on-p silicon solar cells with different junction depths, x_j.

Group 2 : Fabrication of n-on-p silicon solar cells with different substrate resistivities, ρ_b.

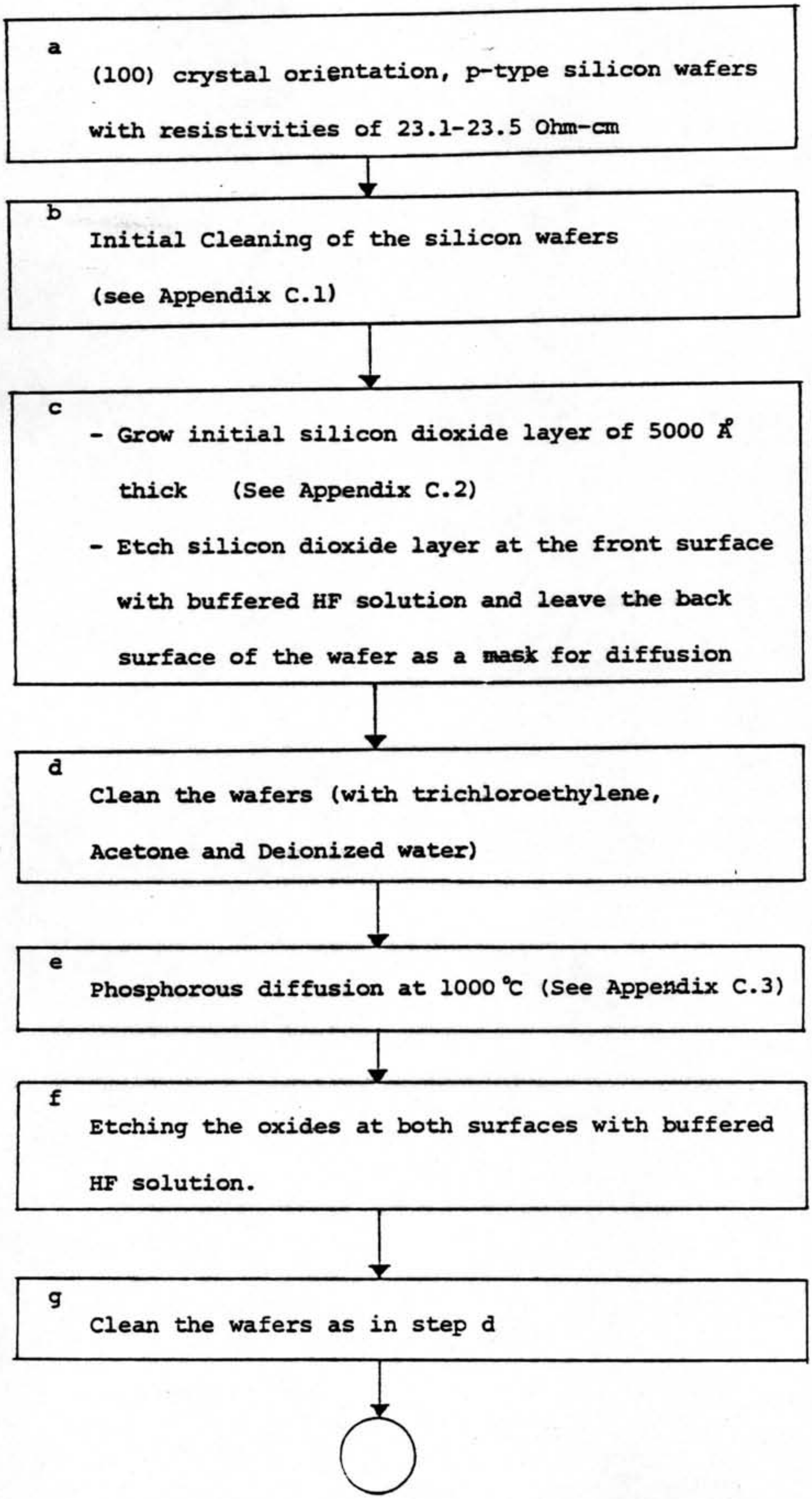
Group 3 : Fabrication of solar cells with peeled off surface by anodic oxidation.

Group 3 : Fabrication of Back Surface Field (BSF) solar cells.

All the solar cells were fabricated at Semiconductor Device Research Laboratory (SDRL), Faculty of Engineering, Chulalongkorn University, Bangkok. The contents of this chapter are the evaluation and verification of the experimental results against the numerical analysis.

4.2 Fabrication of Group I Solar Cells

Group I : Fabrication of n-on-p silicon solar cells with different junction depths.


a
(100) crystal orientation, p-type silicon wafers with resistivities of 23.1-23.5 Ohm-cm
b
Initial Cleaning of the silicon wafers (see Appendix C.1)
c
- Grow initial silicon dioxide layer of 5000 Å thick (See Appendix C.2)
- Etch silicon dioxide layer at the front surface with buffered HF solution and leave the back surface of the wafer as a mask for diffusion
d
Clean the wafers (with trichloroethylene, Acetone and Deionized water)
e
Phosphorous diffusion at 1000 °C (See Appendix C.3)
f
Etching the oxides at both surfaces with buffered HF solution.
g
Clean the wafers as in step d

h
Aluminium Evaporation at both surfaces with 5000 Å thick.

i
Make the front contact by the mask pattern in Fig. 26

j
Contact sintering at the temperature of 525 °C for 5 minutes.

k
Wire bonding the electrodes with silver paste

l
Solar Cells

m
Scribing all edges of the solar cells to remove all the current leakage areas.

n
Evaluation

The schematic representation of the group 1 solar cell is shown in Figs. 26 and 27.

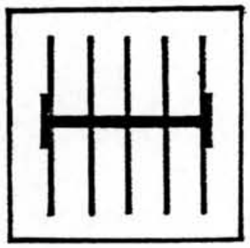


Fig. 26 Mask pattern of the front contact of a group 1 solar cell.

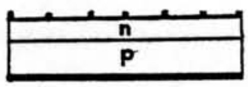
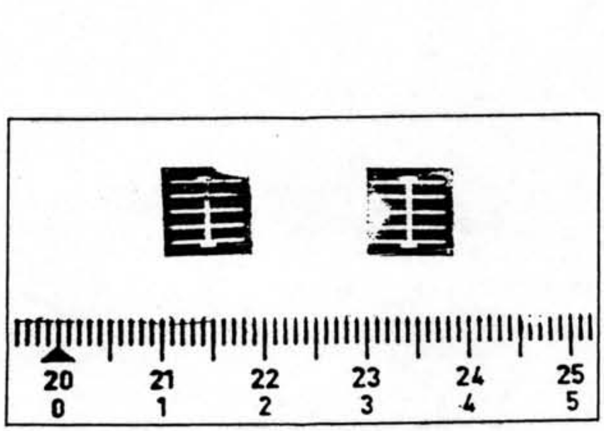


Fig. 27 Schematic representation of group 1 solar cell structure.



4.3 Fabrication of Group II Solar Cells.

Group II: Fabrication of n-on-p silicon solar cells with different substrate resistivities.

a

The starting materials are:

(110) crystal orientation, p-type silicon wafers with resistivities of 23.1 and 16.8 Ohm-cm.

(111) crystal orientation, p-type silicon wafer with resistivity of 1.9 Ohm-cm.

↓

b

Open oxide window at the front surface of wafers with the mask pattern in Fig. 28 a)

↓

c

The same as step c of section 4.1

↓

d

Phosphorous diffusion at 1000 °C

Predeposition time for wafers with resistivities of 23.1, 16.8 and 1.9 Ohm-cm is $7\frac{1}{2}$, 8 and 9 minutes respectively. (All have equal junction depths.)

↓

e

Etch oxide at the back surface with buffered HF solution and leave oxide at the front surface to serve as a mask for mask-alignment in step f

↓

(The same as steps f , g and h in section 4.1)

i
Make the front contact by the mask pattern in Fig. 28 b)

(The same as steps j , k , l , m and n in section 4.1)

The schematic representation of groups solar cells is shown in Figs. 28 and 29.

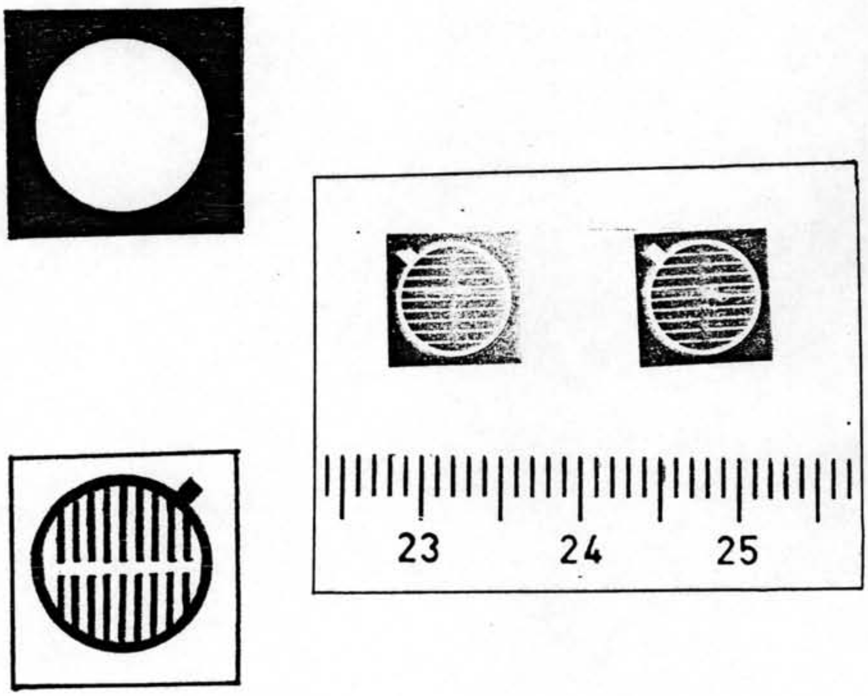


Fig. 28 The mask pattern for a) oxide window of the group II solar cell.
b) the front contact of group II solar cell.

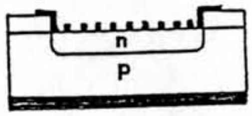


Fig. 29 Schematic representation of group II solar cell structure.

4.4 Fabrication of Group III solar cells

Group III: Fabrication of solar cells with peeled-off surface by anodic oxidation

The front surfaces of some solar cells in group I were peeled-off using anodic oxidation techniques.[20] Table 5 shows the new junction depth of solar cells after the surface is incrementally removed.

Fabrication of Solar Cells with Peeled-Off Surface by Anodic Oxidations.

Solar Cell (Group I) Number	Junction Depth (μm)	Thickness Peeled-off (μm)	The New Junction Depth (μm)
3	0.60	0.11	0.49
4	0.71	0.11	0.60
6	1.35	0.30	1.05

Table 5

4.5 Fabrication of Group IV Solar Cells.

Group IV: Fabrication of Back Surface Field (BSF) solar cells.

The starting materials used in this study are two (111) crystal orientation p-type silicon wafers with equal resistivities of 23.1 Ohm-cm and 200 μm thick. One was fabricated into an n-on-p junction solar cell, the other was fabricated into a BSF solar cell.

The n-on-p junction solar cell was fabricated as in section 4.1. The BSF solar cell was fabricated as the following steps.

a
(111) crystal orientation, p-type silicon wafer with resistivity of 23.1 Ohm-cm.

↓

b
Initial cleaning like step b in section 4.1.

↓

c
- Grow initial silicon dioxide layer 5000 Å thick.
- Etch silicon dioxide at the back surface with buffered HF solution and leave the front surface of the wafer as a mask for diffusion.

↓

d
Clean the wafer as step d in section 4.1.

↓

○

e

Boron Diffusion:

- predeposition 30 minutes at 1050 °C
- drive-in 150 minutes at 1000 °C

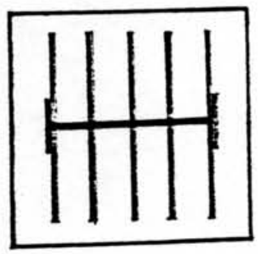
(see Appendix A. 4)

f

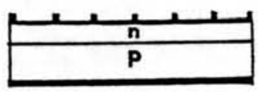
- Grow silicon dioxide layer of 2000 Å thick
- Etch silicon dioxide layer at the front surface with buffered HF solution and leave the back surface of the wafer as a mask for diffusion.

(The same as steps d through n in section 4.1)

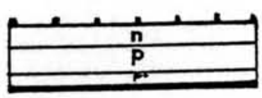
Typical schematic representation of group IV solar cells is shown in Fig. 30



a) Mask pattern for the front contact of group IV solars



b) A conventional n-on-p silicon solar cell



c) A BSF solar cell

Fig. 30 Schematic representation of group IV solar cells

4.6 Methods for Determination of Series Resistance, R_s, Shunt Resistance, R_{sh}, Reverse Saturation Current, I_s and Ideality Factor, n.

There are two methods for determining series resistance, R_s, shunt resistance, R_{sh}, reverse (diode) saturation current, I_s and ideality factor, n.

The first method was proposed by WARASHINA and USHIROKAWA.[14] This method can determine R_s and n from the tangents to the current-voltage curve at constant light intensity. Under illumination, the relation between current, I and voltage, V is well-known as

$$I = I_{ph} - I_s[\exp(q(v+IR_s)/(nkT)) - 1] - (v+IR_s)/R_{sh} \qquad (26)$$

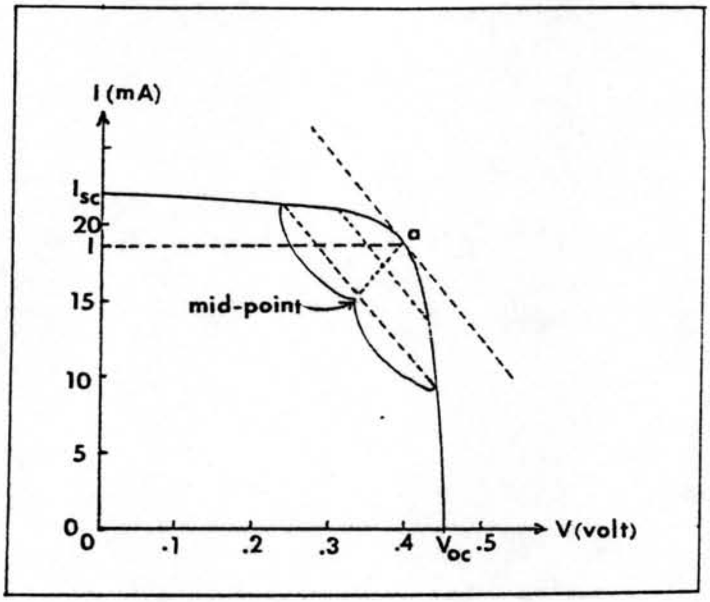
where $(\frac{kT}{q})$ is the thermal voltage, V_{th}

Then, the relation between $(\frac{dv}{dI})$ and $(I_{sc}-I)^{-1}$ as

$$-(\frac{dv}{dI}) = R_s + (nkT/q)\ (I_{sc}-I)^{-1} \qquad (27)$$

By considering that $\exp(I_{sc}R_s/V_{th}) \ll \exp(V_{oc}/V_{th})$

By plotting the values of $(\frac{dv}{dI})$ and $(I_{sc}-I)^{-1}$ at each current, I, R_s and n can be determined from the property of the straight line.



(14)

Fig. 31 How to draw the tangent current-voltage curve at point a.

The value of $(\frac{dv}{dI})$ can be determined from the tangent shown in Fig. 31.

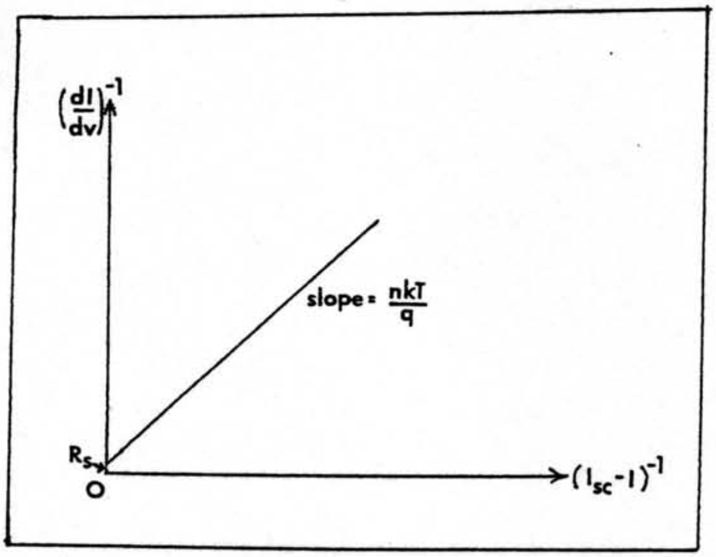


Fig. 32 Series resistance, R_s and ideality factor, n can be determined from the property of straight line.

Then, R_s and n can be obtained as depicted in Fig.32.

The shunt resistance, R_{sh}, can be determined from the slope of approximated straight line during reverse bias of the solar cell which is shown in Fig.33.

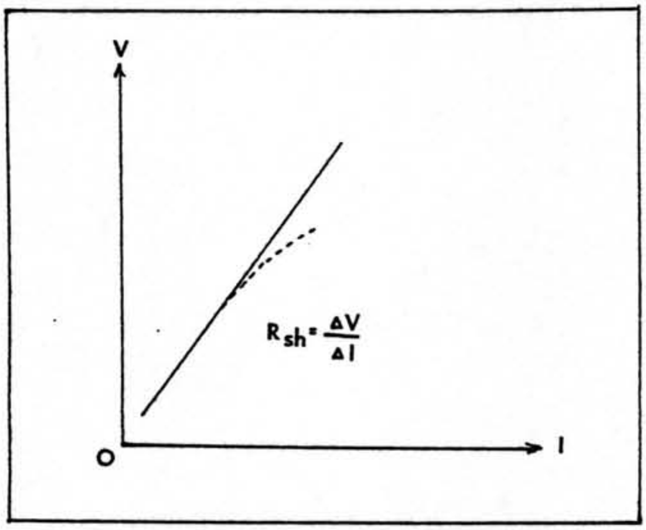


Fig.33 Determination of R_{sh} from the slope of curve.

By knowing the values of R_s, n and R_{sh}, the diode reverse saturation current, I_s, can be calculated from Eq.(27) by fitting their values in the experimental current-voltage solar cell curve (under illumination) as discussed in chapter I.

The other method is to determine R_s, I_s and n from the I-V characteristic curve under darkness.

The dark current equation of p-n junction solar cells, when the effect of shunt resistance is negligible, can be written as

$$I_D = I_s \left[\exp\left(\frac{V+IR_s}{nV_T} \right) +1 \right]$$

When $V \gg V_T$, it can be approximated as

$$I_D = I_s \exp\left(\frac{V+IR_s}{nV_T} \right)$$

$$(V+IR_s) \cong nV_T \ln \frac{I}{I_s}$$

The I-V characteristic curve of this expression can be plotted as in Fig.34.

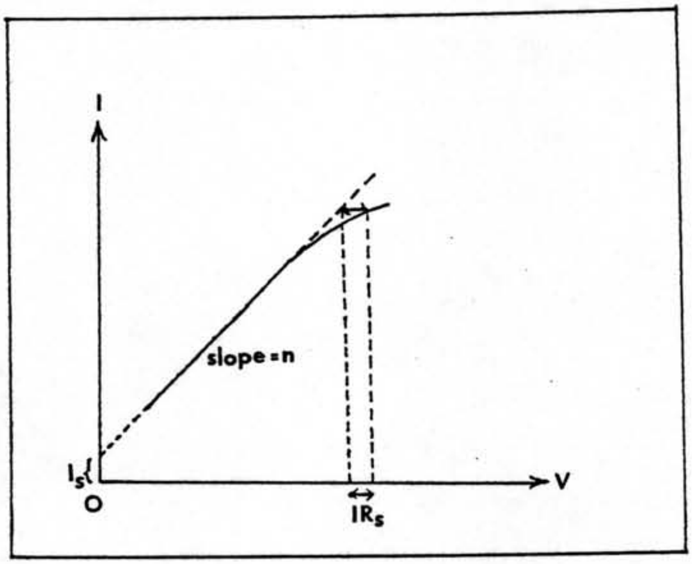


Fig.34 Determination of R_s, I_s and n from the dark I-V characteristic curve.

R_s, I_s and n are determined from the property of straight line in Fig.34.

In the experiment, series resistance is measured by using the circuit shown in Fig.35.

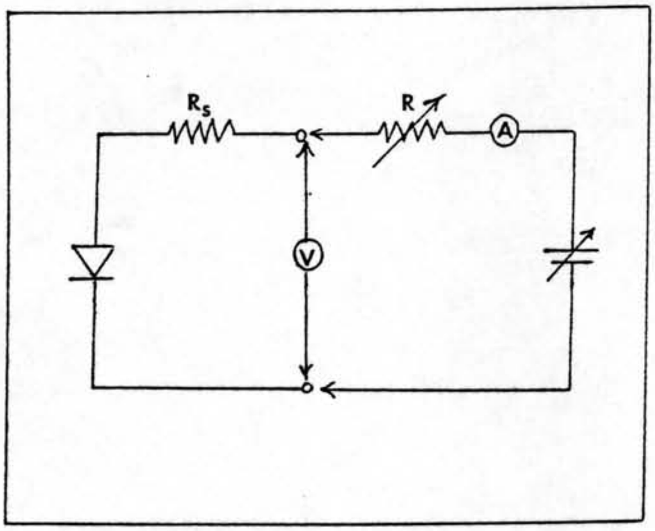


Fig.35 The circuit of dark I-V characteristics to determine R_s, I_s and n.

The dark I-V characteristic curve from the experiment is shown in Fig.36.

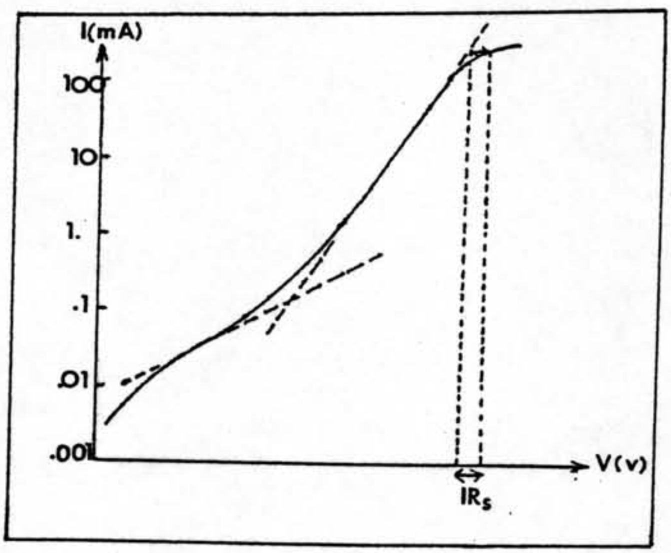


Fig.36 Current-voltage relationship of solar cells.

It should be noticed that the two values of n in the curve result from the two components of currents, that is, diffusion current and recombination current. And at low voltage, the current tends to decrease sharply due to the effect of shunt resistance.