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The Effect of Frequency of Electromagnetic Waves on Basic Electrical Elements in the Si of LCR Technique

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Abstract

In this study, the electrical properties of various silicon specimens with different conductivity types and different carrier concentration were characterized, using In-Line Four Probe (ILFP) technique and Resistivity Frequency variation technique (LCR technique) as well. The effect of the frequency on the electrical properties of these samples was also investigated. The results of the study demonstrate some conclusions and recommendations for improving the performance of silicon based solar cells as well as for further development in the field of Si technology.

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Keywords

In-Line Four Probe ILFP,
EM waves Gravel,
Bulk resistivity,
Solar cells.

Introduction

In-Line Four Probe ILFP is one of the precise techniques that measure resistivity, from which dopant density was estimated. There were many researches on the relation between resistivity and dopant density in silicon samples that were doped with Boron and Phosphorus, like Hall Effect and Thurber's curves.

In this study, Silicon samples doped with Boron and Phosphorus were exposed to electromagnetic waves with different frequencies. The difference between samples was investigated by LCR technique and curves tabulations, in order to know the most suitable samples in solar cell applications.

Considering that the silicon dopant systems constitute a weak electrolyte solid solution, it is concluded that the electrolyte solution theory provides a good physical model and mathematical framework to get a better understanding of solar cell's behaviour [2].

When more doping species are involved, as in compensated-Si, a numerical algorithm is used for solving multiple equilibrium systems. The study of such systems demonstrates a particular behavior known from buffered solutions, where adding dopant does not necessarily translate in a proportional response in conductivity (or inversely proportional in the case of resistivity) [2].

Materials and Methods

The specimens under test are imported from EL-CAT Company (USA) the specimens specifications are shown in Table 1.

The specimens had different doping elements like Boron and Phosphorus. They also differed in Type (P& n-Type).They had same diameter and thickness. Their resistivity is ρ_0 varied from 1-10 Ω.

Resistivity measurements

In this study, in line four probe technique was used. To measure resistivity of the sample is given by following relationship [9]:

$\Omega = \frac{RA}{L}$ In Ω-m or common Ω.cm (3.1, 1)

Where,

R= bulk resistance
A= Cross-sectional area (A=Wt)
W= width
t = thickness
L= distance between 2 ideal contacts.

In the four point probe technique, the two probes are used to inject current through the sample and the other two probes measure voltage drop as shown in the Fig 1.

To measure resistance, we use a device called Jandel, which is RM3000 test unit instructions. The RM3000 can join a constant current source and digital voltmeter (see Fig.2).

Frequency variation technique

Wayne Kerr analyzer model "6440B" (shown in Fig3) was used in order to determine the effect of frequency on resistivity levels. The device can also be used to measure the capacitance, inductance and resistance “LCR”. It was used in this experiment in order to determine the effect of frequency on resistivity levels. The main parameters of such equipment are listed in Table 2

Si specimens were subjected to different frequencies. The resistance was recorded for each frequency, and then was calculated according to equation (3.1, 1)

Results and discussion

Impurity determination

All measurements were carried out on several n and p-types silicon wafers, known as 1835 and 1822. These samples were obtained from EL-CAT Inc, USA, the following Table 3shows the obtained resistivity values.

The carrier concentrations N (cm^{-3}) in each Si sample were determined based on resistivity – impurity concentration theoretical curves given by Sze [9], (see Fig4) and Table 4.

Effect of doping

Measurement of resistivity (ρ)

In this study, the prepared this film had different doping elements (P &B) and different dopant density. In silicon chip resulted in 1835 dope boron. After EM frequency increases resistivity by increasing frequency. We found that phosphorus doped 1822 slide has a less resistivity with increasing frequency. As the rise often matters conductivity ρ = 1/σ which allows the passage of electric current field and due to the following related

$$J = E/\sigma$$

J= Current density
E= Electric field
The conductivity

Measurement of resistance (R)

When calculating the resistance after the influence of frequency on two slices of p-type, and n-type and we got results. As in table 6 below, results obtained in resistivity and this shows that proportional resistance has resistivity according to previous relationship (3.1, 1)

The effect of frequency of electromagnetic waves on resistance R (Ω) and on resistivity (**Ω**.cm**)** in the Si sample No.1835 is summarized in Table 5 and6. It has the frequency increases, the resistivity will be increased more than 2 to 5 times, but the Si sample No. 1822 is summarized in Table 5and 6. It has the frequency decrease due to the sudden change in charge carriers concentrations Δn (cm^{-3}) and Δp (cm^{-3}) for electrons and holes respectively [4].

In 1835 slide doped boron group elements in the third periodic table shows each electron with an electron of Silicon from elements of the collection in fourth place remains free electron hole silicon chip which can be receptive where their holes are. And the electrons replace holes as in Fig 5.a

While slide 1822 doped group 5 elements of phosphorus on the periodic table are linked to every electron of silicon atom with another electron of an atom of phosphorus [4].

Silicon merges is called electron which stays with phosphorus donor materials. Silicon takes p- type as Fig 5.b.

Measurement of mobility (μ)

In this study, the mobility had been measured following this equation

$$\mu = \frac{1}{\rho q N} \quad (4.2.3, 1)$$

Where

μ = mobility ($cm^2/C\Omega$)
q = electron charge ($1.6X10^{-19}$)
ρ = Resistivity (Ω.cm)

We noticed that the greater influence of the silicon chip EM wave frequency in both n& p type heats according to the relationship:

E = h. F (4.2.3, 2)
E = Thermal energy
h = Planck's constant
F = Frequency

The chip n-type causes thermal energy E_{th} to generate excess electron jumping into the conduction band and increases mobility of electrons μ_n results are called the donor level E_d nearby conduction band as in Fig 7.a.

That explains the concentration of electrons at that level, and slides p-type is getting holes in valence band E_v, which assumes a receptive level called level E_a that receives electrons to fill the holes of the other levels by getting holes and increase mobility of holes μ_p quality resistance ρ for the passage of electric current and the concentration of electrons in this level $N_a$as in Fig7.b [4]

Thurber from about 1975 to 1980, did research work to obtain an [2] accurate relationship between the resistivity and dopant density of Si.

Table.1 Specifications of silicon wafers

Item	**Technical specification**					
	Thickness	**Type**	**Dopant**	**Orientation**	**Diameter**	**Manufacturer Resistivity (Ω.cm)**
1835	300 ±25 μm	p-type	Si:B	[110] One side -polished	5.08cm	5-10
1822	300 ± 25μ m	n-type	Si:P	[110] One side -polished	5.08cm	1-10

Table.2 Main parameters for the LCR analyzer

DC Functions	
(R_{dc})	Resistance
AC Functions	
Capacitance	(C)
Inductance	(L)
Resistance	(R)
Conductance(G=1/R)	)G)
$2\pi \times frequency$	(w)
Current	(I)

Table.3 The Experimental data for resistivity measurements

Sample Wafer No	**Thick (cm)**	**I_f (ma)**	**V_f (mV)**	**R_f (Ω)**	**I_r (ma)**	**V_r (mV)**	**R_r (Ω)**	**R_m (Ω)**	**P (Ω.cm) Experiment**	**ρ_0 (Ω.cm) Company**
1835	0.03 cm	1.0	36	36	1.1	39.8	36.1	36.05	4.89	5-10
		5.0	188	37.6	5.0	176	35.2	36.25	4.94	
		10	380	38	10	395	39.5	38.75	5.27	
1822	0.03 cm	1.0	215	21.5	1.0	20.5	20.5	21	2.8	1-10
		10	400	40	10	390	39	39.5	5.37	
		15	330	22	15	350	23.3	22.0	3.1	

Table.4 The impurity concentration N (cm^{-3}) determination in Si wafers

Sample No	**(ρ Ω.cm) Average**	**(ρ Ω.cm) Experimental**	**(ρ_0 Ω.cm) Company**	**Type**	**N(cm^{-3})**
1835	5	4.89	5-10	p-type	2 x 10^{15}
		4.94			
		5.27			
1822	3.8 ~ 4	2.8	1-10	n-type	9 x 10^{14}
		5.37			
		3.1			
		4.7x10^{-3}			
		3.4x10^{-3}			

Table.5 Variation of resistivity doping density with impurity

Sample	**Impurity Doping)element)**	**N(cm^{-3})**	**Type**	**F(kHz)**	**ρ (Ω.cm)**
1835	Si-B	$20x10^{14}$	P-type	1	4.2E+08
				2	5.8E+08
				3	6.5E+08
				4	6.5E+08
				5	6.5E+08
				6	6.5E+08
				10	6.5E+08
				20	5.8E+08
1822	Si-P	$9x10^{14}$	n-type	1	38.88189
				2	38.22047
				3	37.67717
				4	37.15748
				5	36.66142
				6	36.2126
				10	34.79528
				20	31.44

Table.6 variation of resistance (R) dopes density with impurity

Sample	**Impurity Doping (element)**	**N (cm^{-3})**	**Type**	**F (kHz)**	**R (Ω)**
1835	Si-B	$20x10^{14}$	P-type	1	65E+04
				2	9E+05
				3	1E+6
				4	1E+6
				5	1E+6
				6	1E+6
				10	1E+6
				20	9E+05
1822	Si-P	$9x10^{14}$	n-type	1	16.46E+3
				2	16.18 E+3
				3	15.95 E+3
				4	15.73 E+3
				5	15.52 E+3
				6	15.33 E+3
				10	14.73 E+3
				20	13.31 E+3

Fig.1 Bulk resistance and its geometrical dimensions [1]

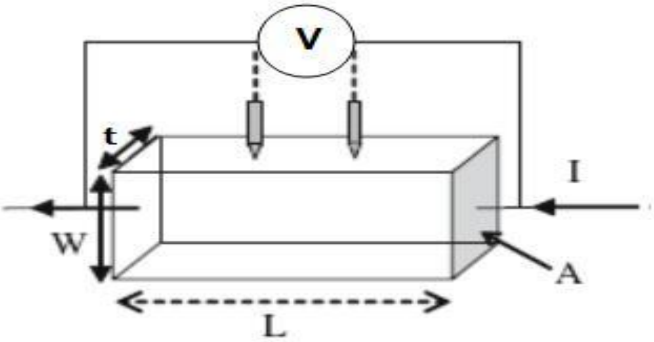


Fig.2 Device for measuring the resistivity probe with ILFP equipment, RM 3000 Test Unit Instructions [5]

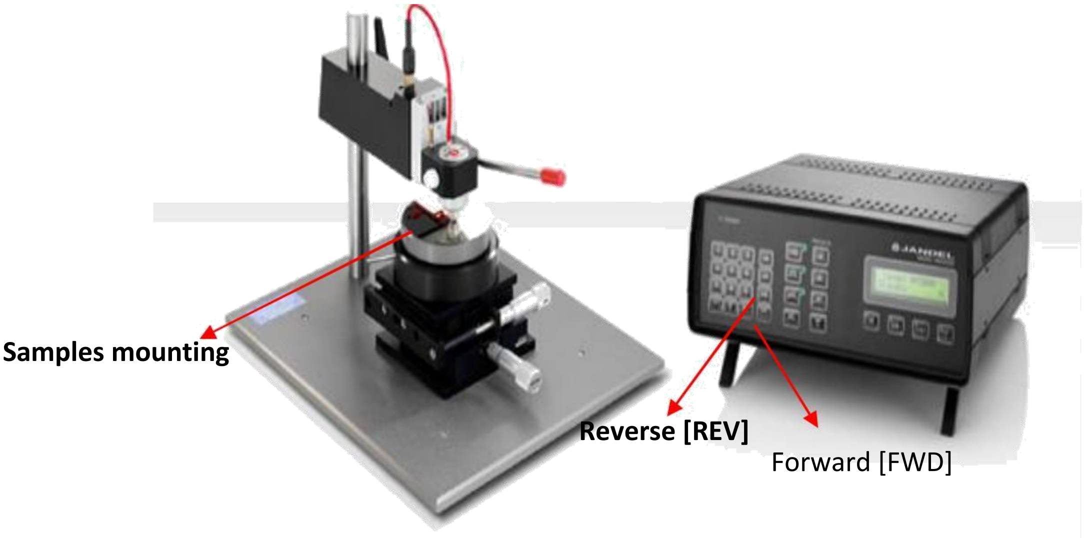


Fig.3 The LCR analyzer [10]

Fig.4 Resistivity versus impurity concentration for Si [9]

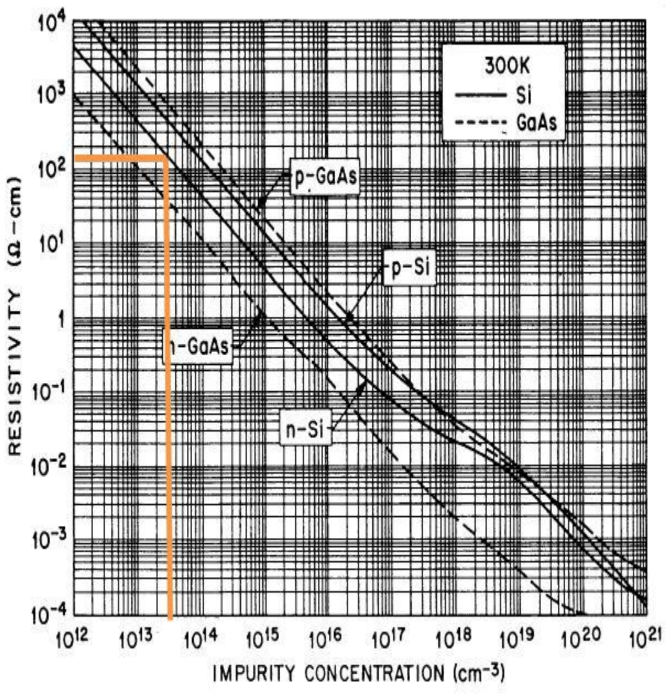


Fig.5a Schematic silicon lattice for p-type doping with donor atoms (boron)

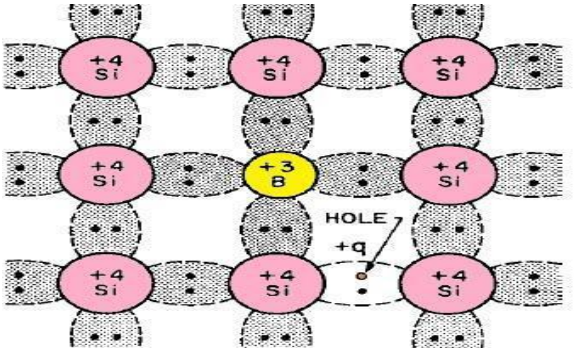


Fig.5b Schematic silicon lattice for n-type doping with donor atoms (arsenic or phosphorus)

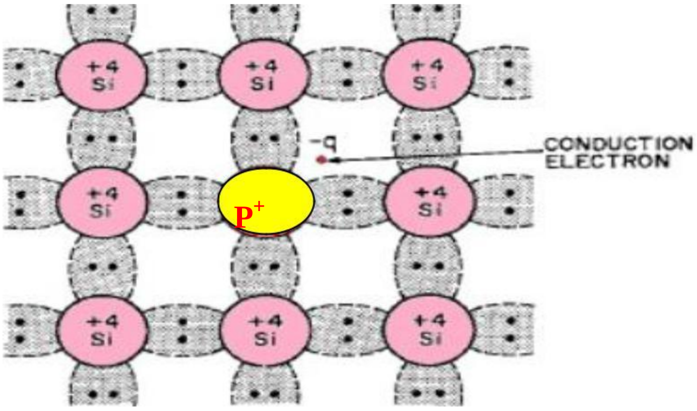


Fig.6 Describing relationships between carrier- motilities and dopant densities for boron (holes) and Phosphorous (free electrons)

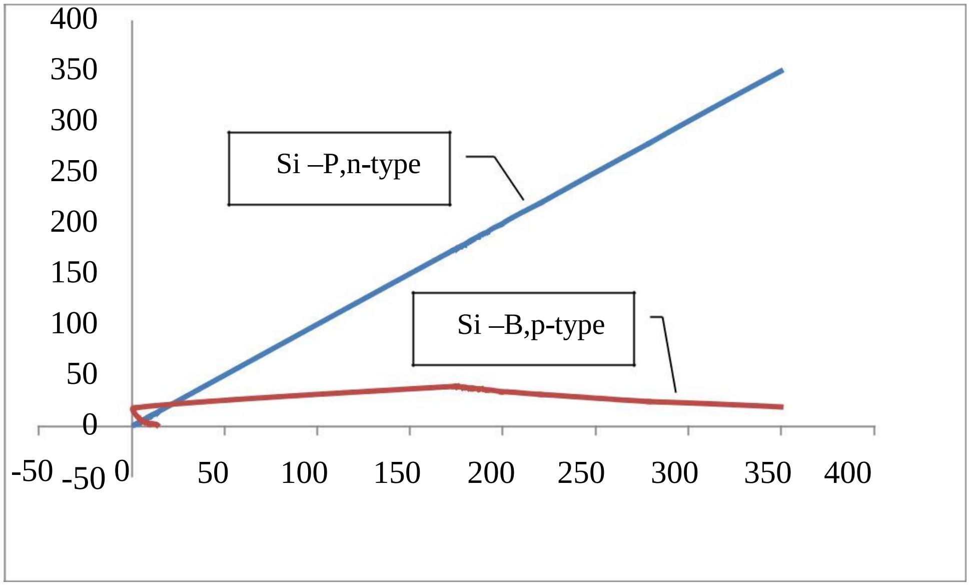


Fig.7 Ionization of a) a shallow donor and b) a shallow acceptor

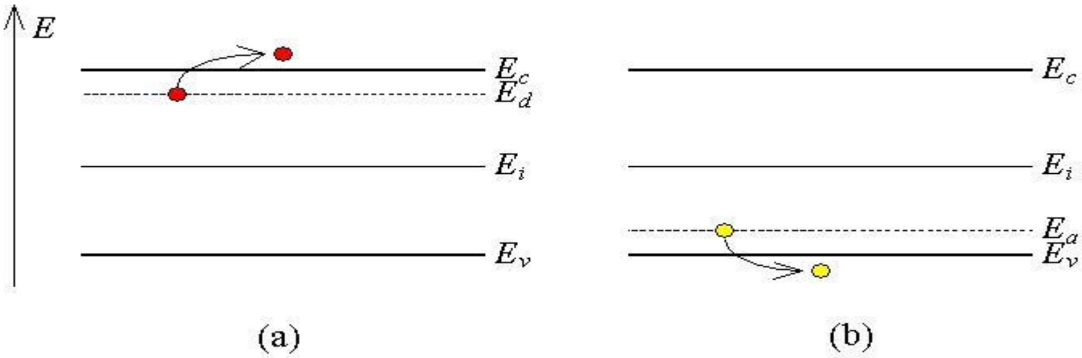


Fig.8 Variations of impedance (Z) with frequency (a-low, b-high)

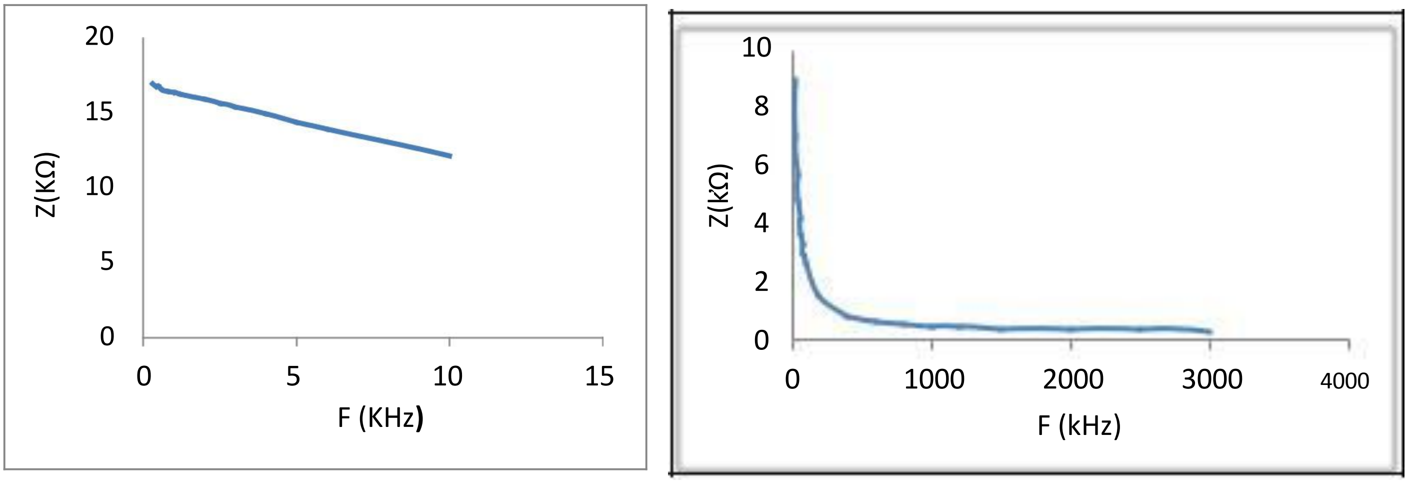
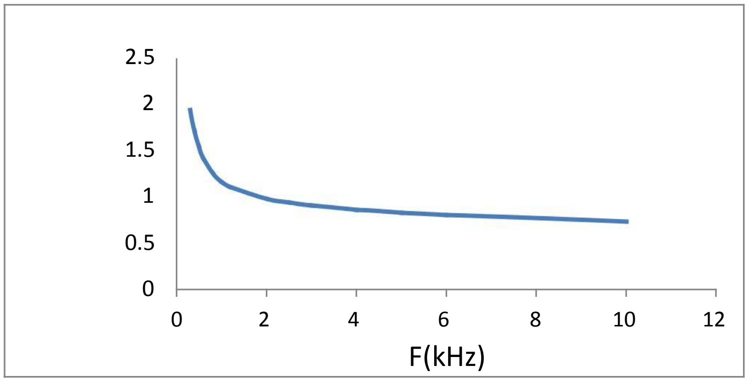


Fig.9 Capacitance variation with frequency (a-low, b-high)



(a)

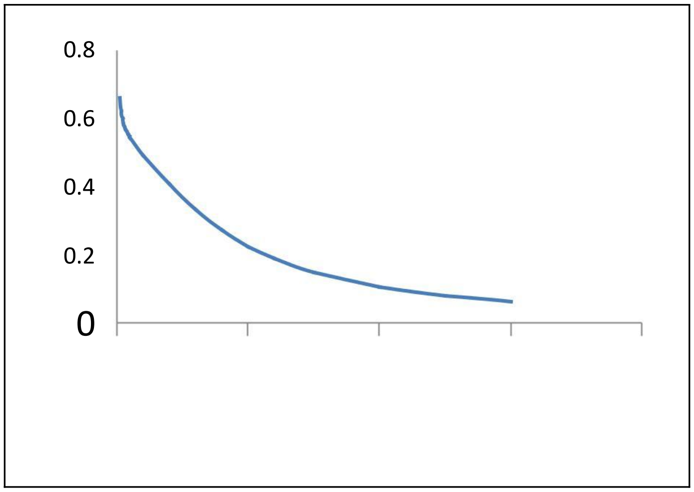


Fig.10 Silicon solar cell reported in 1941 relying on grown in junctions formed by impurity segregation in recrystallized silicon melts [8]

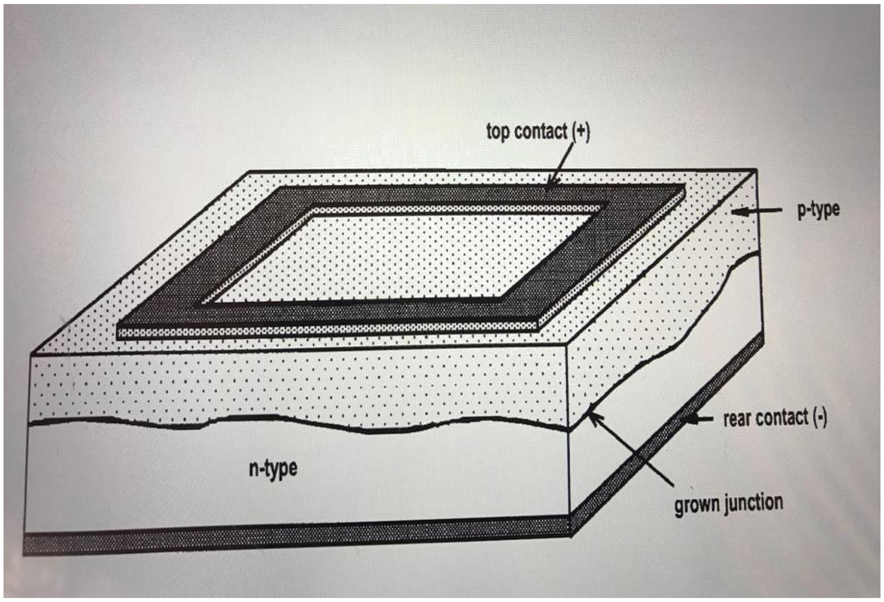
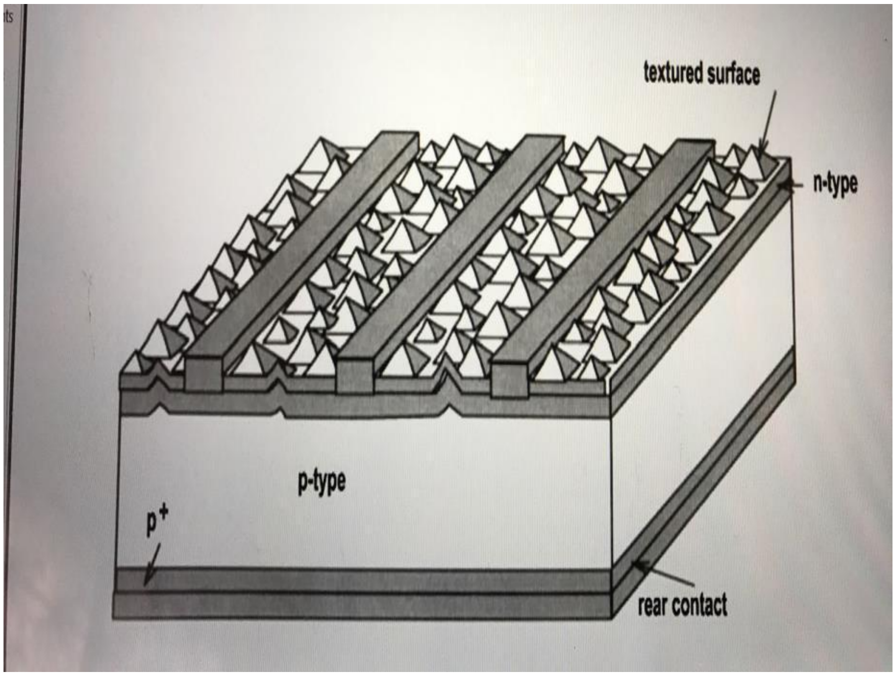


Fig.11 Standard silicon solar cell structure developed in the 1970 [8]



$$\rho_p = \frac{1}{q.\mu_p(N_a - N_d)} \qquad (4.2.3,3)$$

$$\rho_n = \frac{1}{q.\mu_n(N_a - N_d)} \qquad (4.2.3,4)$$

N_a, N_d: the acceptor and donor densities.

Effect of frequency

Increasing frequency cause increment of temperature, so it may vary the structure or the properties of thin films.

Frequency versus impedance (Z)

In general, the impedance is applied to a system with electrical contacts. It consists of a measurement of the electrical current, *I* (ω), at a certain angular frequency, v, when a certain voltage, *V* (ω), is applied to the system, or vice versa, a measurement of *V* (ω) at an applied *I*(ω). The impedance is [6]

$$z(\omega) = \frac{v(\omega)}{I(\omega)} \qquad (4.3.1,1)$$

During an impedance measurement, the system is (ideally) kept at a fixed steady state by imposing stationary constraints such as the dc current, illumination intensity, etc, and the *Z* (ω) is measured by scanning the frequency at a multitude of values as

In Fig8.a in low-frequency impedance Z (ω) gradually goes down while Fig8.b impedance Z (ω) very quickly at high frequency the electrical current, *I*(ω) increases with voltage *V* (ω) drop is applied according to the relationship (4.3.1) [6]

Frequency versus capacitor

From a fundamental standpoint, capacitance is the storage charge. It is expressed mathematically as C=Q/V where Q is the stored charge (in Coulombs), V is the applied Voltage (V), and C is the capacitance. The capacitance has units of Coulombs/Volt, often referred to as a Farad (1 Farad = 1 Coulomb/Volt). A Farad is a huge capacitance, and most common values are microfarads, nano farads, or Pico farads.

Through the high and low frequency effect of EM waves on silicon chip condenser capacitance is measured in all cases and resulted in the following (see Fig 9) [7]

From the results we observed that capacitor in high and low frequency unloading his charge in a circle and loses capacitance gradually.

The capacitor role in this case only allows the passage of current and does not store the capacitance according to [7] the following relationship:

$$c = \frac{1}{G \times 2 \times \pi \times F} \qquad (4.3.2,1)$$

Where (G) conductance=1/R

We noticed that the different concentration of electrons and holes in silicon chip due to doping. As a result to that difference of electrical properties in 1835 slide p-type by increasing the absorbed EM waves that led to increased resistivity and decreases electron drift motilities because electrons are free to replace all holes in the valence band. While 1822 slide n-type it changed due to the higher frequency and less resistance and increasing mobility of these electrons produces an electric current passage resistance, making it convenient to edit electrons and increasing mobility of these electrons and produces an electric current passage. This is vital point in manufacturing of photovoltaic in 1941.It manufactured rely on silicon chip grafted both n& p-type so that the lower layer is made of silicon chip n-type and the top layer is p-type that are exposed to sunlight as in Fig10 but they found in these solar cells that this combination is very slow in producing electric current compared to high voltage applied to them. In 1970 they change of solar cells structure where silicon chip n-type is the top layer as in Fig 11 led to the passage of an electric current too high efficiency photovoltaic's for good genre [8].

Finally, we studied the effect of high and low frequency Ac current on impedance capacitance and found low impedance and capacitance in electrical circuits that require an impedance such as speakers need constant frequency Dc current benefit more from AC and capacitors that require essentially presence in lighting devices They require high storage capacity.While the results come in Fig 9 in high and low frequencies alternately reduced capacity and become employed as conductance as the relationship (4.3.2,1)[3]

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