UMYU Scientifica, Vol. 2 NO. 1, June 2023, Pp 115 – 123
https://doi.org/10.56919/usci.2123.014
ISSN: 2955 – 1145 (print); 2955 – 1153 (online)
A periodical of the Faculty of Natural and Applied Sciences, UMYU, Katsina

ORIGINAL RESEARCH ARTICLE

Infrared Light Absorption Enhancement in Crystalline Silicon Wafer Textured with H_2SO_4 Solution

Muhammed Abdurrahman[1*], Liman Nura Chiromawa[2], Muhammad Ibrahim Bagudo[2], Ibrahim Abdurrahman khalil[1]
[1]Department of Basic and Applied Sciences, Hassaan Usman Katsina Polytechnic, Katsina, Nigeria.
[2]Department of Physics, Umaru Musa Yar'adua University, Katsina, Nigeria.

ABSTRACT
In recent years, the formation of microstructures on silicon wafer has gained popularity as a concept for increasing photon trapping and light absorption for optoelectronics applications. This study used three methods to improve infrared light absorption in silicon samples - sample preparation, Radio Corporation of America (RCA) cleaning, and chemical wet etching. The solutions used for Radio Corporation of America (RCA) clean were water (H_2O), Ammonium hydroxide (NH_4OH), hydrogen perioxide (H_2O_2), Hydrofluoric acid (H.F.). Three silicon wafers with a 1cm^2 orientation were cut and cleaned using RCA, and then surface-textured using a wet chemical procedure by etching into different chemical solutions of Sulfuric acid (H_2SO_4) of the same concentration. The wafers were removed at different etching time intervals (5, 10, 15 minutes) and analysed using an infrared spectrometer with Fourier transformation (FTIR) to study the absorptions of light. A mean absorbance of 0.9801 a.u, 0.9845 a.u and 0.977 a.u for 5, 10 and 15 minutes of texturization was obtained. The results showed a wafer that was etched by H2SO4 solution for 10 minute as the most enhanced silicon wafer for I.R light absorption. Hence, it is recommended to texture a silicon wafer for a period of 10 minutes in H2SO4 solution for better absorption.

ARTICLE HISTORY
Received February 11, 2023
Accepted March 26, 2023
Published March 30, 2023

KEYWORDS
Fourier transform infrared spectrometer, Aluminium-assisted chemical etching, Wet chemical anisotropic etching, Silicon wafer, Crystalline silicon

INTRODUCTION
The ratio of energy output from the solar module to energy input from the sun is known as a photovoltaic module's efficiency. It measures the proportion of solar energy shining on a P.V module that is transformed into usable power. Enhancing light absorption is a key goal of this research. Efficiency is a factor used to compare the performance of various solar modules. The solar module's efficiency is influenced by the solar panel's temperature and the spectrum and intensity of the incident sunlight. Hence to improve the device's performance under the conditions used to measure efficiency, the solar radiation must be appropriately captured by texturing the silicon wafers surface. None of the reviewed paper in this research find out the absorption of I.R light by the silicon wafers before fabricating solar cells and the best etching time when using sulfuric acid as an etchant (even though nobody have ever work with sulfuric acid as an etchant in improving light absorption by the silicon wafer) and none of the authors cited in this research found out light absorption but only worked on the light reflections, by knowing the intensity of light been absorbed even before fabricating solar cells one can tells the silicon wafer that would come out with the best solar cell performance efficiency because high absorption of light causes less reflection of light by the silicon wafer and this result in increasing the efficiency of any solar cell. Solar modules efficiency depends on its active area and the intensity of light

Correspondence: Muhammed Abdurrahman. Department of Basic and Applied sciences, Hassaan Usman Katsina Polytechnic, Katsina, Nigeria. ✉ abdolmohd7@gmail.com, Phone: 08067906886
How to cite: Muhammed A., Liman N. C., Muhammad I. B., Ibrahim A. K. (2023). Infrared Light Absorption Enhancement in Crystalline Silicon Wafer Textured with H_2SO_4 Solution. *UMYU Scientifica*, 2(1), 115 – 123. https://doi.org/10.56919/usci.2123.014

shining on it. That is the more direct irradiance the more efficiency the module will produce as the efficiency is given by the ratio of the maximum power (short circuit current (I_{sc}) multiply by open circuit voltage (V_{oc})) to the ratio of the direct irradiance multiply by active area. This clearly shows the relationship between these four (4) factors as mentioned above to the efficiency of any solar module. This research work created a means of attenuating the reflectance of light shining on the surface of the silicon wafer so that more light is taken (absorbed) by the silicon wafer as this will increase the efficiency of the solar module when fabricated.

In a study conducted by Liman *et al.,* (2014) studied the attenuation in the mid-infrared transmissions through poly (methyl methacrylate) PMMA film of different layer thickness on SiO_2 substrates for solar cell applications using Fourier transform infrared spectrometer. The experiment was conducted on four samples one without PMMA coat and the other three coated with PMMA film layer at different rotational speeds. The film thickness decreases with the increase in rotational speed and the infrared transmission decreases with the increase in film thickness. High transmission are detected at the range of wave number between 2900 cm^{-1} and 7800 cm^{-1}. The sample coated with 250nm thick layer of PMMA film has the highest infrared transmission at 7800cm^{-1} while the sample coated with 480.8nm have the lowest infrared transmission at the same wave number. Numerically, for an uncoated sample, at 7800 cm^{-1} the transmission efficiency of 92.14% was obtained, while for a sample coated with 250nm layer of PMMA at the same wave number 92.84% was recorded. Meanwhile for sample coated with 274.4 nm and 480.8 nm layers of PMMA, the transmissions of 88.40% and 60.69% were respectively obtained at 7800 cm^{-1} (Liman, *et al.,* 2014). In a study conducted by Yasir *et al.,* (2021) With reference to photon trapping and increased light absorption qualities for solar applications, the synthesis of black silicon via surface texturization of Si-wafer has recently gained popularity.

A wet chemical anisotropic etching method using IPA:KOH solution was used in this study to create micro-pyramidal surface patterns on mono-crystalline Si(100) wafers. Results show that the textured surface obtained from the wet chemical anisotropic etching process has successfully reduced the reflectance of the BSi wafer and surpassed the solar cell efficiency by 2%, which is mainly attributed to the optical confinement of the textured pyramids on the surface with a height of 1-2 μm and angles of 70 degrees (Yasir, *et al.,* 2021). In a study conducted by Uddin *et al.,*(2021) For photovoltaic (PV) applications, black silicon (b-Si) is a potential absorber material. The annealing temperature effects on the surface morphology and optical characteristics of b-Si produced by the aluminum-assisted chemical etching (AACE) technique are examined in this work. In this study, the AACE technique is implemented by sputtering an aluminum (Al) thin layer with a thickness of 12 nm onto crystalline silicon (c-Si) wafers, then annealing the wafers at 250-450°c in a nitrogen (N2) atmosphere. The wafers are then subjected to a 20-minute, room temperature, wet chemical etching process using hydrofluoric acid (H.F.), hydrogen peroxide (H2O2) and deionized water. From the findings, annealing the sample at 400°C leads to formation of b-Si nanopores with the deepest nanopores and the highest surface coverage. This temperature also leads to the lowest broadband reflection within 300-1100nm wavelength region. As a result, the highest average absorption enhancement of 1.61 is achieved when the absorption of the b-Si annealed at 400 °C is normalized to the absorption of the planar c-Si reference. (Uddin, *et al.,* 2021). In a study conducted by Abdur-Rahman *et al.,*(2017) wet chemical anisotropic etching was used to create micro-pyramid patterns on the surface of a mono-crystalline silicon wafer (100). The primary goal was to use the silicon surface reflectivity to gauge how well the etchant performed.

For the purpose of researching the total reflectance of silicon wafers, various isopropyl alcohol (IPA) volume concentrations (2, 4, 6, 8 and 10%) and etching periods (10, 20, 30, 40 and 50 min) were chosen to study the total reflectance of silicon wefers. The other parameters such as NaOH concentration (12% wt), the temperature of the solution (81.5°C), and range of stirrer speeds (400rpm) were kept constant for all processes. The surface morphology of the wafer was analyzed by optical microscopy and atomic force microscopy (AFM). The AFM images confirmed a well-uniform pyramidal structure with various average pyramid sizes ranging from 1 to 1.6 μm. A UV-vis spectrophotometer with an integrating sphere was used to obtain the total reflectivity. The textured silicon wafers show high absorbance in the visible region. The optimum texture –etching parameters were found to be 4-6% vol. IPA and 40 min at which the average total reflectance of the silicon wafer was reduced to 11.22% (Abdur-Rahman, *et al.,* 2017). In a study conducted by Ali *et al.,* (2020) One-step copper-assisted chemical etching (CACE) which offers a straightforward method for mass manufacture of inverted pyramid textured silicon surfaces, has been used to generate nano-texturing of a silicon surface. Systematically examining the impact of H_2O_2 concentration, etching duration and reaction temperature on the inverted pyramidal structure and anti-reflective property. The result shows that the lowest average reflectivity (4.3 %) in the wavelength range of 300-1000 nm was obtained under the optimum condition of 0.06 mol/L copper nitrate, 3mol/L H_2O_2 concentration and 2 mol/L hydrofluoric acid (HF) at 60°C for 5 minutes (Ali, *et al.*, 2020).

Regarding photovoltaic (P.V.), silicon is utilized as the raw material for mono-crystalline and multi-crystalline wafers and for thin-film silicon modules. crystalline silicon wafers are the foundation of more than 90% of the yearly manufacturing of solar cells. The most significant component of photovoltaic (P.V.) technology today is silicon (Muller *et al.*, 2006); although multi-crystalline silicon wafers are frequently utilized in the fabrication of commercial solar cells, they typically produce cells with significantly less performance than mono-crystalline wafers (Zhao *et al.*, 1998).

Silicon is a semiconductor with numerous uses, including solar cells and photodetectors (Schropp *et al.*, 1998) because of the variety of applications for these devices, a concept was devised to boost their efficiency by reducing surface reflection when light is captured. Researchers have developed many ways to improve the silicon solar cell's efficiency. Wet anisotropic etching, femtosecond laser and metal-assisted chemical etching (Halbwax *et al.*, 2008; Han *et al.*, 2014., Pal *et al.*, 2021). Light absorption was increased and light reflection was reduced by wet chemical etching on the surface of silicon wafers (Cao *et al.*, 2011, Basher *et al.*, 2018, Praveenkumar *et al.*,2019, Zou *et al.* ,2019, Hsu *et al.*, 2019, Dar *et al.*, 2020, Wei *et al.*, 2020, Liu *et al.*, 2020, Ali *et al.*, 2020, Wei *et al.*, 2022).

The primary goal of this study is to determine the optimal H_2SO_4 etching duration for silicon wafers to increase infrared light absorption utilizing an infrared spectrometer with a Fourier transform.

MATERIALS AND METHODS

Apparatus

Table 1 provides an apparatus utilized during this research together with their model number, year of manufacturing and purchased company.

The conical flask was utilized in hosting the chemical solutions during the process RCA clean and texturing of the silicon wafers, a burette is a volumetric glassware which was used in this research for the accurate dispensing of the chemical solutions inside the conical flask, retort stand is a piece of scientific equipment in supporting other pieces of equipment and glassware, the measuring cylinder is a common piece of laboratory equipment used to measure the volume of the chemical solutions in this research, hot plate was used in heating of the chemical solutions to the required amount of temperature while the thermometer was used in measuring the temperatures of the chemical solutions.

Table 1: Apparatus used in the Study

S/No	Apparatus	Model No.	Year	Purchasing company
1	Conical flask	BS 1792	2022	Technico
2	Burette	BS 1734	2022	Technico
3	Retort Stand	BS 1632	2022	Technico
4	Measuring Cylinder	BS 1743	2022	Technico
5	Hotplate	BS 1756	2022	Technico
6	Thermometer	BS 1746	2022	Technico

Chemicals Solutions

The chemical solutions utilized during this research were listed in table 2 together with their formula, % purity and purchasing company.

The chemical solutions used in the process of RCA cleaning of the silicon wafers include ammonium hydroxide, hydrogen peroxide, hydrogen fluoride, and hydrochloric acid while the sulfuric acid was used in texturing of the silicon wafers.

Table 2: Chemical solutions

S/No	Chemical	Formula	% Purity	Purchasing company
1	Ammonium hydroxide	NH_4OH	86%	Riedel-dehaen
2	Hydrogen peroxide	H_2O_2	95%	Riedel-dehaen
3	Hydro Fluoric acid	H.F.	85%	Riedel-dehaen
4	Hydrochloric acid	HCL	85%	Riedel-dehaen
5	Sulfuric acid	H_2SO_4	88%	Riedel-dehaen

In this experimental research, Fourier transforms infrared spectrometer (FTIR) was used and the obtained infrared light reflection by the samples, the FTIR spectrum is recorded between 4000 and 400 cm^{-1}. The spectroscopy having a model number INFRA 3000 Series produced in a year 2001 by Legal status of Firm Limited company (Ltd.pvt.Ltd) was used in obtaining different reflected light intensity from the samples.

METHODOLOGY

This research utilized three methods in enhancing infrared light absorption by the silicon samples. The three methods were sample preparation, radio Corporation of America (RCA) clean and chemical wet etching. In a sample preparation four (4) pieces of 1 cm^2 orientation wafers were cut from the spherical silicon wafer semiconductor then two method were employed namely:- Radio Corporation of America (RCA) and chemical wet etching technique.

The radio corporation of America (RCA) clean was carried out in order to cleaned and removed the organic residue and films from silicon wafers. This was achieved by immersing the four wafers of the same orientation (1 cm^2) in to the mixture of H_2O : NH_4OH : H_2O_2 having a volume of 25 ml, 5ml and 5ml as the concentration of the mixture for 10 mint at 80°C, in this step the organic residues from the wafers were removed in the process the wafers were oxidizes and leaves a thin oxide on their surfaces. The wafers were also immersed in to the mixture of H_20 : HF of volume 250 ml and 5 ml at room temperature for 20 sec and then the wafers were removed out of the mixture and further been immersed in to another mixture of HCL : H_2O_2 : H_2O having a volume of 5 ml, 5 ml and 30 ml respectively at 80°C for 10 mint and finally the wafers were rinsed with the distill water.

In the texturing process (chemical wet etching) three different mixtures of H_2SO_4: H_2O having the same volume and chemical concentration were prepared inside a conical flasks, the mixtures having a volume of 15 ml and 35 ml as their concentration. Three wafers from the RCA clean were immersed in to the different mixtures of the H_2SO_4: H_2O. The wafers were accordingly removed from these three different mixtures under a given time interval of 5, 10 and 15 mint respectively and the wafers were removed from the solutions and finally the samples were taken to FTIR for analysis.

RESULTS

Reflected Light Intensity On Un-Textured Silicon Wafer

Table 3 below shows the reflection of light intensity and the generated wave numbers by the un-textured sample. This result was obtained by using Fourier Transform Infrared spectrometer (INFRA 3000 series).

Table 3: Reflected light intensity by the un-textured silicon wafer

Peak number	Wave Number (cm-1)	Intensity
1	1215.112	80.42386
2	1364.206	83.8502
3	1736.939	86.97987
4	1986.671	93.78247
5	2102.219	93.05917
6	2322.131	92.79651
7	2642.683	93.8736
8	2970.688	94.39688
9	3436.605	95.42548

On the other hand, Figure 1 shows the graph representing the reflected light intensity by the surface of the un-textured silicon wafer at various points. The silicon wafer reflected a peak intensity of light of 95.42548 cd and least of 80.42386 cd respectively.

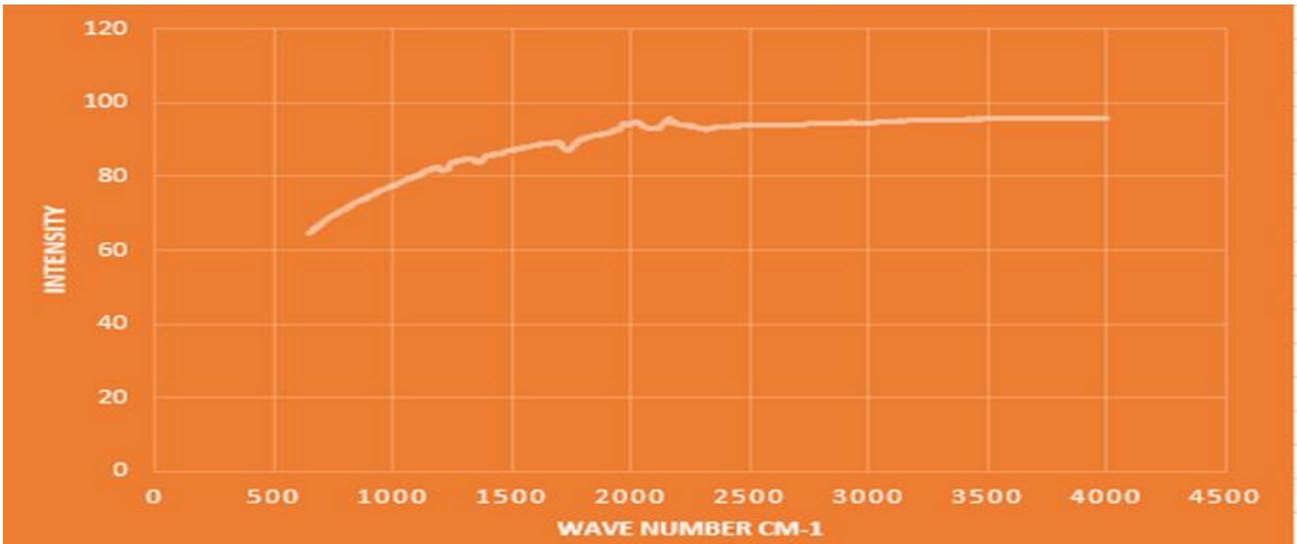

Figure 1: Graphical representation of reflected IR- Light on un-textured sample

Table 4 provides an information on the wavelength, frequency and reflected energies at various points on the un-textured silicon wafer using Max Planck's equations. As the electromagnetic radiation propagated, the wavelengths of the radiation were decreased from 8.2297 x 10-4 cm to 2.9098 x 10-4 cm and the frequencies and the energies increases from 3.6453 KHz, 2.4155 x 10-30 eV to 10.3099 KHz, 6.8315 x 10-30 eV respectively.

Table 4: Reflected energies by the un-textured silicon wafer

Peak No.	Wave Number(cm^1)	Wavelength (cm)	Frequency (khz)	E = hc/ λ
1	1215.11213	$8.2297x10^{-4}$	3.6453	$2.4155x10^{-30}$
2	1364.20565	$7.3303x10^{-4}$	4.0926	$2.7118\ x10^{-30}$
3	1736.93943	$5.7573x10^{-4}$	5.2107	$3.4530\ x10^{-30}$
4	1986.67107	$5.0335x10^{-4}$	5.9601	$3.9492\ x10^{-30}$
5	2102.21854	$4.7569x10^{-4}$	6.3066	$4.1788\ x10^{-30}$
6	2322.13147	$4.3064x10^{-4}$	6.9664	$4.6160\ x10^{-30}$
7	2642.68253	$3.7840x10^{-4}$	7.9281	$5.2532\ x10^{-30}$
8	2970.68826	$3.3640x10^{-4}$	8.9180	$5.9091\ x10^{-30}$
9	3436.60549	$2.9098x10^{-4}$	10.3099	$6.8315\ x10^{-30}$

Reflected Light Intensity On Textured Silicon Wafers

The tables below shows the raw data of the reflected IR-light that scatted on textured silicon wafers and the generated wave numbers at various points by using Fourier transform infrared spectroscopy (FTIR).

Table 5 shows the reflection of light intensity and the generated wave numbers by the 5 minutes textured sample. This result was obtained by using Fourier Transform Infrared spectrometer (INFRA 3000 series).

Table 5 Reflected light intensity on five minute textured sample

Peak number	Wave number (cm-1)	Intensity
1	775.2863	86.9548
2	879.6517	82.81472
3	1043.655	79.53496
4	1118.201	81.95092
5	1177.839	82.88047
6	1356.751	93.31106
7	1423.843	95.3992
8	1520.754	91.96082
9	1610.21	93.54912
10	1722.03	91.00943
11	2109.673	95.54158
12	2609.136	92.41585
13	2773.139	93.52447
14	2952.052	92.44964
15	3130.964	94.24891
16	3280.057	95.88779
17	3444.06	95.74405
18	3518.607	95.65524
19	3742.247	99.5932

Table 6 below is the reflection of light intensity and the generated wave numbers by the 10 minutes textured sample. This result was obtained by using Fourier Transform Infrared spectrometer (INFRA 3000 series).

Table 6: Reflection of light intensity by ten minute textured sample

Peak number	Wave Number (cm-1)	Intensity
1	1006.381	66.02619
2	1144.293	69.54831
3	1364.206	77.19665
4	1420.116	78.41149
5	1617.665	79.4554
6	1736.939	79.00649
7	1994.126	88.24605
8	2113.401	86.56345
9	2322.131	85.7396
10	2847.686	85.76573
11	2916.778	85.72435
12	3175.692	86.80019

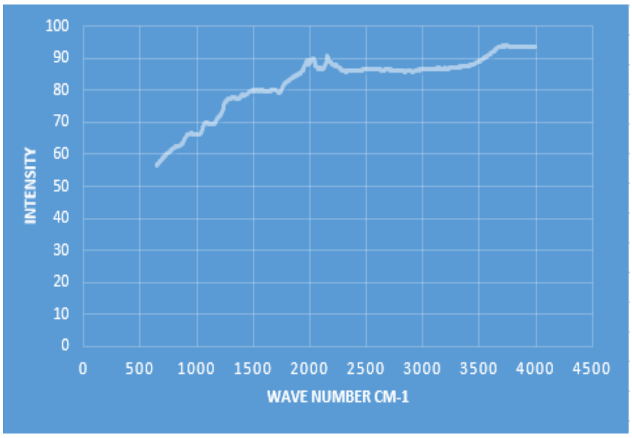

Figure 2: Graphical representation of the reflected IR- Light on ten minute textured sample.

Figure 2 shows the graph representing the reflected light by the surface of the 10-minute textured sample at various points. The silicon wafer reflected a peak intensity of light of 86.80019 cd and least of 66.02619 cd respectively.

Table 7 provides information on the wavelength, frequency and reflected energies at various points on the enhanced textured sample using Max Planck's equations. As the electromagnetic radiation propagated, the wavelengths of the radiation were decreased from 9.9366x10^{-4} x 10^{-4} cm to 3.1489 x10^{-4} x 10^{-4} cm and the frequencies and the energies increases from 3.019 KHz, 2.0005x10^{-30} eV to 9.5271 KHz , 6.3127 x10^{-30} eV respectively.

Table 7: Reflected energies by the ten minute textured sample

Peak Number	Wave Number(cm^{1})	Wavelength (cm)	Frequency (kHz)	E = hc/ λ
1	1006.38122	9.9366x10^{-4}	3.0191	2.0005x10^{-30}
2	1144.29272	8.7390x10^{-4}	3.4329	2.2747 x10^{-30}
3	1364.20565	7.3303x10^{-4}	4.0926	2.7118 x10^{-30}
4	1420.11572	7.0417x10^{-4}	4.2603	2.8229 x10^{-30}
5	1617.66462	6.1818x10^{-4}	4.8530	3.2261x10^{-30}
6	1736.93943	5.7573x10^{-4}	5.2108	3.4527 x10^{-30}
7	1994.12574	5.0147x10^{-4}	5.9824	3.9640 x10^{-30}
8	2113.40055	4.7317x10^{-4}	6.3402	4.2011 x10^{-30}
9	2322.13147	4.3064x10^{-4}	6.9664	4.6160 x10^{-30}
10	2847.68611	3.5116 x10^{-4}	8.5431	5.6607 x10^{-30}
11	2916.77819	3.4284 x10^{-4}	8.7504	5.7981 x10^{-30}
12	3175.69184	31489 x10^{-4}	9.5271	6.3127 x10^{-30}

Figure 3 below gives a comparative finding on the enhanced textured silicon wafer and un-textured silicon wafer, in the infrared region, the un-textured sample reflected a light intensity of 83.85020 cd while the enhanced textured sample reflected a light intensity of 77.19665 cd respectively.

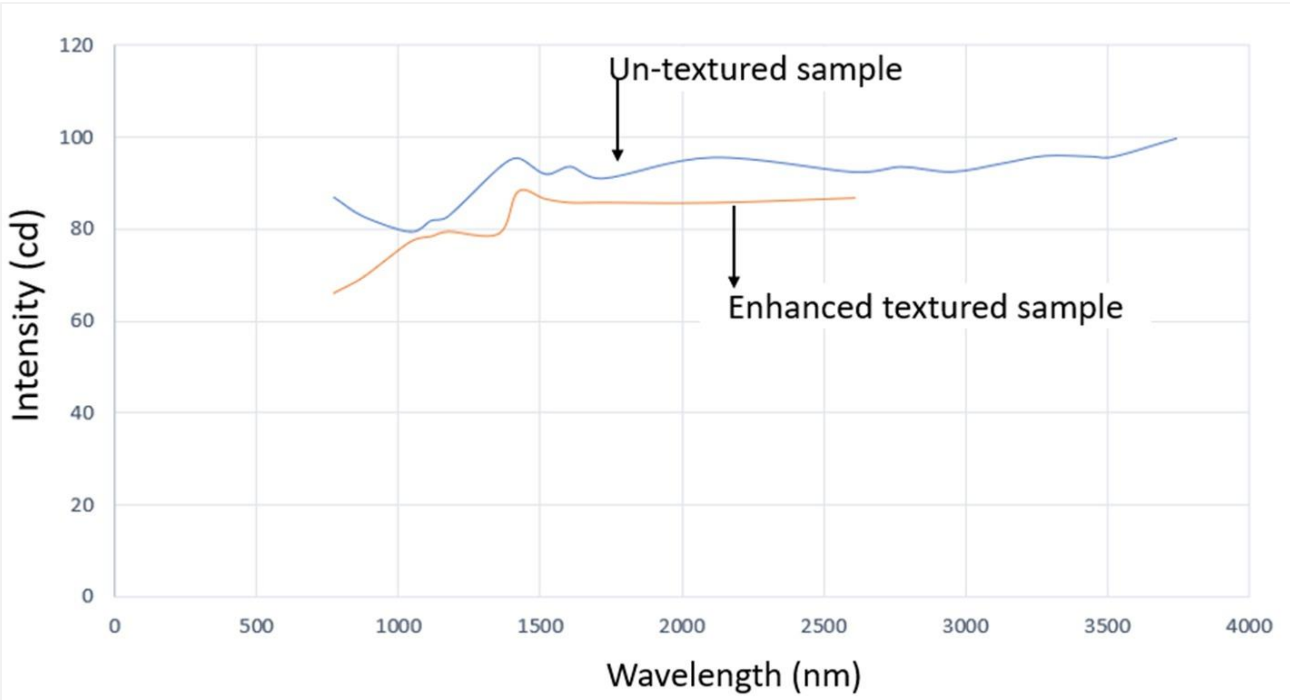

Figure 3: Comparative graph of the light reflection of the optimized textured crystalline silicon and un-textured crystalline silicon

Table 8 below is the reflection of light intensity and the generated wave numbers by the 15 minutes textured sample. This result was obtained by using Fourier Transform Infrared spectrometer (INFRA 3000 series).

Table 8: Reflection of light on fifteen minute textured sample

Peak No.	Wave number (cm^{-1})	Intensity
1	775.28627	96.90259
2	857.28770	97.58574
3	984.01719	97.65387
4	1051.10927	97.72044
5	1118.20135	97.87953
6	1177.83876	98.28460
7	1423.84305	98.72349
8	1520.75384	98.93834
9	1722.03008	98.33036
10	1915.85165	99.46045
11	2102.21854	99.45569
12	2318.40413	99.37935
13	2624.04584	99.24227
14	2952.05157	99.08166
15	3190.60119	99.39820
16	3458.96951	99.60380
17	3570.78965	99.54431
18	3742.24719	99.69165
19	3898.79538	99.74608

Table 9 below summarises the findings on the absorption of I.R light by the 5, 10 and 15 minute textured samples. The reflectivity is given by P = Gr /Gi, where P is the reflectivity, Gr is the reflected radiation by the samples surfaces and Gi is the incident radiation from the Fourier transform infrared spectrometer (FTIR).

Table 9: absorptions of the samples at different etching time

S/N	Five minute	Ten minute	Fifteen minute
1	0.982	0.99	0.978
2	0.984	0.989	0.977
3	0.985	0.986	0.977
4	0.984	0.985	0.977
5	0.984	0.985	0.977
6	0.979	0.982	0.977
7	0.978	0.982	0.97
8	0.98	0.982	0.977
9	0.979	0.983	0.977
10	0.98	0.983	0.97
11	0.978	0.980	0.978
12	0.98	0.982	0.977
13	0.979		0.977
14	0.98		0.977
15	0.979		0.977
16	0.978		0.977
17	0.978		0.97
18	0.978		0.976
19	0.977		0.976

The reflectance were obtained by squaring the value of the reflectivity of the wafers while the absorbance of I.R light by the 5, 10 and 15 minute textured samples were obtained from I = A + R = 1 but (T = 0 because the samples were opaque materials), where I is the total incident radiation from the Fourier transform infrared spectrometer (FTIR), A is the absorbance and R is the reflectance. The above result give a mean absorbance of 0.9801 a.u, 0.9845 a.u and 0.977 a.u for 5, 10 and 15 minutes texturization. The results show a wafer that was etched by H_2SO_4 solution for 10 minute is the enhanced silicon wafer for I.R light absorption.

Figure 4 below is the absorbance of light on the three different textured samples with respect to 5, 10 and 15 minute durations. It shows the highest light absorption on a sample textured for 10 minutes with an absorption of 0.99 and it also shows a peak absorption of 0.982 and 0.978 on the five and 15 minute textured samples, respectively.

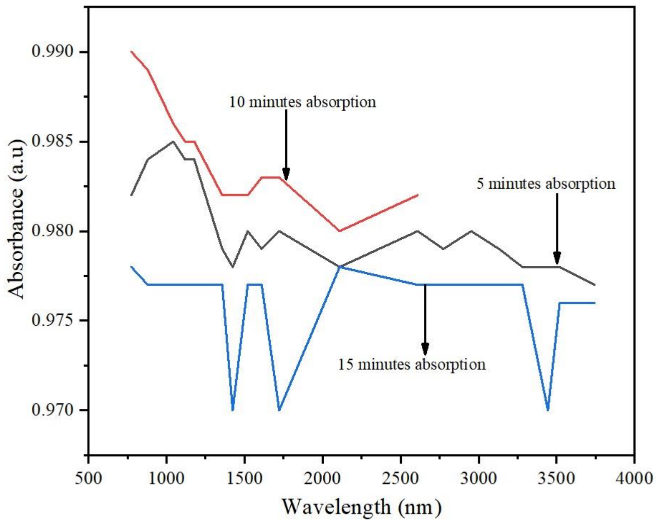

Figure 4: Absorbance of light on the three textured samples

DISCUSSION

High reflection of light causes low absorption of light by the surface of the silicon wafers and this result in reducing the performance efficiency of any solar modules when fabricated even though the efficiency of a solar module also depends on the irradiance and active area of the module. None of the reviewed paper in this research find out the absorption of I.R light by the silicon wafers before fabricating solar cells and the best etching time when using sulfuric acid as an etchant (even though nobody have ever work with sulfuric acid as an etchant in improving light absorption by the silicon wafer). Researchers like Hsu *et al.,* (2019), Zou *et al.,* (2019), Ali *et al.,* (2020), Liu *et al.*, (2020), Wei *et al.*, (2020), Yasir *et al.*, (2021), Uddin *et al.*, (2021) and none of the authors cited in this research found out light absorption but only worked on the light reflection. Any solar cell fabricated from a silicon wafer of high light absorption will have better performance efficiency as an output because the higher of the absorption of light the more efficiency a solar cell will produce and the higher the reflection of light the poor efficiency a solar cell will produce.

CONCLUSION

This research was mainly studied to explore the infrared light (I.R light) absorption by the different silicon wafers and to explore the best etching time in trapping and enhancing light absorption by the silicon wafer. This study's samples with identical orientations, chemical solution concentrations, and temperatures were etched at 5, 10 and 15 minutes at different time intervals. This research give a mean absorbance of 0.9801 a.u, 0.9845 a.u and 0.977 a.u for 5, 10 and 15 minutes texturization. The results show a wafer that was etched by H_2SO_4 solution for 10 minute is the enhanced silicon wafer for I.R light absorption. A recommendation is made to look at the pyramidal structure, angle, cross-sectional area and the structural bonding on the surface of the silicon wafers for further researches.

ACKNOWLEDGEMENT

All praise and thanks be to Allah who made it possible for me to carry out this research successful. Alhamdulillah. My gratitude goes to almighty Allah for giving me the privilege, directive, guidance and understanding so as to have a focus and goal to achieve. May Allah bless my dearly loved Family, especially my parents Alh Salisu Gambo Lawal and Maryam Garba Yaro for their care, steadfast prayers, encouragement, direction, motivation, moral support and financial support I am also grateful to the department of Physics staff at Umaru Musa Yar'adua University in Katsina for the helpful information they provided in their respective fields; their names are too numerous to mention.

REFERENCES

Abdur-Rahman, E., Alghoraibi, I., Alkurdi, H. (2020). Effect of isopropyl alcoholconcentration and etching time on wet chemical anisotropic etching of low-resistivity crystalline silicon wafer. International Journal of Analytical Chemistry. vol 2017. issue. 16878779. Pages 9. [Crossref].

Ali, A.A.O., He, Z., Hong, S., Chang, Y., Yu, J., Li, S., Ma, W., Liu, W., Elkolaly, W., Chen, R. (2021) Ultra-thin silicon wafer fabrication and inverted pyramid texturing based on cu-catalyzed chemical etching. Journal of solid state science and technology. Vol 12. ISSN: 18769918. Page 8-11. [Crossref].

Ali, AA.O., Yang. Y., Sheng, G., Li, S., Yu, J., Ma, W., Qiu, J., El kolaly, W. (2020). Nano-Texturing of silicon wafers via one-step copper-Assisted chemical etching. Journal of solid state science and technology. Vol 9. ISSN:18769918. Page 75. [Crossref].

Basher, M., Hossain, M., Uddin, M., Akand, M., Shorowordi, K. (2018) Effect of pyramidal texturing on the optical surface reflectance of mono-crystalline photovoltaic silicon wafers. International Journal of Analytical Chemistry. Vol 172. ISSN: 172 80181. Page 801-811. [Crossref].

Cao, Y., Liu, A., Li, H., Liu, Y., Qiao, F., Hu, Z., Sang, Y. (2011). Fabrication of silicon wafer with ultra low reflectance by chemical etching method. Applied surface Science. Vol 257. ISSN: 17. Page 7411-7414. [Crossref].

Dar, S.W., Yu, S.C., Peng, S.H., Quan, P.S., Guang, C.C. (2020). Effect of H_2O_2, $Cu(NO_3)2$ and HF temperatures on surface texturization diamond-wire-sawn multi-crystalline silicon wafer. solar Energy materials and solar cells. Vol. 212. ISSN: 110583. Page 765-768. [Crossref].

Halbwax, M., Sarnet, T., Delaporte, P.H., Sentis, M., Etienne, H., Torregrosa, F., Vervisch, V., Perichaud, I., Martinuzzi, S. (2008) Micro and nano-structuration of silicon by femtosecond laser application to silicon photovoltaic cells fabrication. Thin solid Films. Vol 516. ISSN: 20. Page 6791-6795. [Crossref].

Han, H., Huang, Z., Lee, W. (2014). Metal-assisted chemical etching of silicon and nanotechnology applications. Elsevier. Vol 9. ISSN: 3. Page. 271-304. [Crossref].

Hsu, C., Liu, S., Zhang, X., Cho, Y., Huang, Y., Zhang, S., Zhu, W. (2019). Low reflectance and low surface recombination rate nano-needle texture formed by two-step etching for solar cell. Nanomaterials. Vol 9. ISSN: 10. Page 1392. [Crossref].

Liman, N.C., Ibrahim, K., (2014). Infrared transmission through PMMA/SiO_2 for the applications in solar cells technology: Fourier Transform Infra-red (FTIR) Spectroscopy. International conference of Global Network for innovative Technology (IGNITE 2014). Vol 978-967-0167-14-5.

Liu, H., Zhao, L., Wang, W. (2020). HF/Hcl/H_2O/MnO_2 system for High-performance Texturization on Multi-crystallin Silicon. ECS Journal of solid state science and technology. Vol 9. ISSN: 125002. Page 567. [Crossref].

Muller, A., Ghosh, M., Sonnenschein, R., Woditsch, P. (2006). Silicon for photovoltaic applications. Materials science and Engineering: B. Vol 134. ISSN: 2-3. Pages 257-262. [Crossref].

Pal, P., Swarnalatha, V., Venkata, A., Rao, N., Kumar, A.P., Tanaka, H., Sato, K. (2021). High speed silicon wet anisotropic etching for application in bulk micromachining: a review. Micro and Nano systems letters. Vol 2021. ISSN: 9. Page 4. [Crossref].

Praveenkumar, S., Lingaraja, D., Mathi, M.P., Ram, D.G. (2019). An experimental study of optoelectronic properties of porous silicon for solar cell application. Optik. Vol 178. Page 216-223. [Crossref].

Schroop, R.E.I & Zeman, M. (1998). Amorphous and microcrystalline silicon solar cells: Modeling, Materials and Device Technology. Technology of solar cells. Vol 5. ISSN: 1386-3290. Page 3-7. [Crossref].

Uddin, M., Roslan, Md.H., Zamir, M.P. (2021). Effect of annealing temperature towards properties of black silicon fabricated by aluminium-assisted chemical etching. Materials Science in semiconductor processing. Vol 133. ISSN: 105932. Page 5-8. [Crossref].

Wei, H.W., Yen, H., Kai, P.L., Wang, L. (2022). Formation of inverted pyramid-like structures on surfaces of single crystalline silicon solar cells by chemical wet etching. Journal of Renewable and sustainable energy. Vol 14. ISSN: 013501. [Crossref].

Wei, x., Xiao, Z., Yue, Z., Huang, H., Zhou, L., material science in semiconductor(2020)115, Texturization of diamond wire sawn multi-crystalline silicon wafers by micro-droplet etching.

Yasir, Md.A., Aminul Islam, M., Wafi, A.M., Abdullah, F., Sieh, T.K., Amin, N. (2021). Study of black silicon wafer through wet chemical etching for parametric optimization in enhancing solar cell performance by pc1d numerical simulation. Crystals. Vol 11. ISSN: 8. Page 881. [Crossref].

Zhao, J., Wang, A., Martin, A.G. (1998). 19.8% efficient "honeycomb" textured multi-crystalline and 24.4% mono-crystalline silicon solar cells. Applied physics letters. Vol 73. ISSN: 1077-3118. Page 1991-1993. [Crossref].

Zou, S., Ye, X., Su, X. (2019). Complement etching behavior of alkali, metal-catalyzed chemical, and post-etching of multi-crystalline silicon wafer. Progress in photovoltaic's: Research and Applications. Vol 27. ISSN: 6. Page 511-519. [Crossref].