SUMMARY
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This study relates to develop highly transmittable, environmentally stable, chemical layer on glass surface by means of chemical treatments. After chemical treatment of glass substrate, studying transmittance of glass substrate and also studying on effect of concentration of aluminum ions and $\text{pH}$ on coating solution. We found that $\text{pH}$ range 8 to 8.5 and chemical composition ration gives higher transmittance with good thermal stability which can be used in very wide application like lenses, module of photovoltaic applications etc.

Anti-reflection coating on glass substrate with their potential for low cost, large volume production, shorter energy payback period and possibility of bio-degradability after their lifetime, are good candidates for a truly ‘green’ and economically viable technology.

There are many national and international research groups that have been working on Anti-reflection coating project, but the work is primarily at a increasing transmittance level, our focusing on develop high transmittance, environment stable coating on glass substrate.In this project we propose to proceed methodically and develop an anti-reflection coating glass substrate compatible with existing photovoltaic glass substrate.

Considering the fact that process stability is one of the crucial factors for any type of photovoltaic application, this point (work) would be differentiate it other research so we decided to re-look this technique specifically from this viewpoint and developing a dependable process so our target is developed chemical process would be having good transitivity, good heat stability, easy and cheap to produce.

Anti-reflection coating are used in a wide variety of applications where light passes throughout an optical surface, and very low reflection is preferred. An antireflective or anti-reflection (AR) coating applies to the glass surface and other visual or optical device to reduce reflection. This increases the effectiveness of the system, as less light is loss. To reduce reflection from surface of lenses and other optical devices, an antireflective or anti-reflection (AR) coating is a type of optical coating applied for that, this improves the effectiveness of the system since a lesser amount of light is lost.

Glass is an integral part of most common commercial photovoltaic modules, including both crystalline and thin films types. Incoming radiations passes through the incident glass substrate of solar cells before reaching the active layer of the solar cell. Radiation that is reflected by the incident glass does not makes it way in to active layers of the solar cells, thereby resulting in a
less efficient solar cell. In other words, it would be desirable to decrease the amount of radiation that is reflected by the incident substrate, thereby increasing the amount of radiation that makes its way to the active layer of solar cell. In particular, the power output of a solar cell module may be dependent upon the amount of light or numbers of photons within a specific range of the solar spectrum that pass through the incident glass substrate and reach the photovoltaic semiconductor.

One of the main loss mechanisms that any kind of Photovoltaic module is subjected to is the loss from the glass aperture on the entrance side. This is applicable for both conventional Si-based module as well as thin film based cell/module; in addition solar heating modules are also subjected to these losses. As much as 8% incident lights can be lost due to frontal reflection. Thus, one of the aims of Photovoltaic industry has been to find out an effective and economical way to improve the transmission profile of glass used in existing production process.

Broadly speaking, there are two kinds of techniques that are available for increasing in transmission of glass; 1) interference technique, achieved by deposition of anti-reflection coating on glass surface and 2) developing a graded refractive index profile [3] at the surface of glass. In the first method one needs multiple layers for making a broadband transmission window; also the increase in transmission is inversely proportional to incidence angle and decreases drastically at lower angle of incidence. The method is also expensive to produce and lastly and very important from Solar application point of view, this method suffers from environmental degradation severely. The second method, property of which was first enunciated by Lord Rayleigh (in 1886) involves chemical action on the surface of a glass, which causes selective etching/leasing of ions in the glass to cause a porous structure on the surface. Due to chemical reactions with the environment, the optical glasses available at the time tended to develop tarnish on its surface with age. The structure thus formed is non-uniform so that the refractive index formed is not linear but takes on a graded form and this causes a reduction in reflectance from the surface. This technique also has the potential to be cost effective from the point of view commercial manufacturing of solar panels.

The detail of this process was first described by Kinoshita (1964) and has been subsequently improved upon by various and researchers such as Nakajima (1987) and Disteldorf [4]. However, the above method and process described by all these authors are general in nature and does not address the key issue of developing a stable process for application in the solar industry. So many technics are available for reducing reflectance like by a circular polarizer,
reflections can be blocked. To eliminate reflections, a laminated circular polarizer to a surface could be used, the polarizer transmits the light by one chirality or handedness of circular polarization. After the polarizer is transformed into the opposite ‘handedness’, light can reflected from the surface, that light could not pass back throughout the circular polarizer because its chirality has totally changed like from “right circular polarized to left circularly polarized”.

Considering the fact that process stability is one of the crucial factors for any type of photovoltaic application, this point (work) would be differentiate it other research so we decided to re-look this technique specifically from this viewpoint and developing a dependable process set which could be used for reliable prototype samples. The paper describes results of experiments that we have conducted to study the change in transmission properties of glass over the entire visible wavelength range after chemical etching and also describes the environment stability analysis of such chemically treated glass.

The objective of the present work is to develop an anti reflecting coating on glass substrate, which would be good transitivity, environmentally stability, good heat stability, easy and cheap to produce. All those entire criterions would be fulfills by the chemical etching of glass substrate. Simply due to apply chemical treatment process on glass substrate we can achieved overall an increase of transmittance on both side of glass substrate as well as Environmentally stable chemical layer.

It is proposed to carry out the work with the following specific objectives-

- To increase transmittance of glass substrate.
- Optimizing the optical characteristics of glass substrate.
- Transmittance value interpretation by using UV-VIS spectrometer.
- Establish the process condition.
- Process stability identification.
- Confirmation of environmentally stability as verified through IEC 61646 standard.
- Determine the top layer textured of treated and untreated glass by using instrumentation like Atomic force microscope (AFM).
- Making photovoltaic modules using treated glass substrate and check efficiency of photovoltaic modules.
• Calculation of Pmax and Isc after preparation of photovoltaic modules.

According to theory glass, those used for optical purposes, typically contains SiO$_2$ (65-75%), Alkali metal oxide (5-20%), Alkali earth metal oxide (0-15%) & other elements (0-5%) by wt. When treated suitably, the surface of the glass becomes porous up to a depth of hundreds of nanometers. In addition the glass surface may actually be etched out depending upon the process condition. This porous layer should exhibit antireflective behavior for a very broad wavelength range. Two effects contribute to the formation of the overall effect:

Leaching process: This is formed when Protons in aqueous solutions replaces alkali ions in glass so as to form a Aoyake layer as shown

\[ \text{---Si---O----R} + \text{H}_2\text{O} \rightarrow \text{---Si---OH} + \text{R}^+ + \text{OH}^- \]

Where, R = Na, K Li etc

Etching process: The Si-O bond in the glass forming the skeleton is destroyed and the glass is slowly dissolved.

\[ \text{----Si----O-----Si} + \text{OH}^- \rightarrow \text{----Si----OH} + \text{----Si-----} \]

Leaching process effectively reduces Na, Ca, Al atoms and alkaline earth metals in the surface of the glass.

We can summarized all research experiment work in two phases like-

Phase 1. Developed ARC glass substrate
Phase 2. Fabrication of solar module by using ARC glass

**Phase 1. Developed ARC glass substrate:** For developing ARC glass substrate, the experimental work can be carried out in following steps-

- Choosing a suitable form factor
- Cleaning of glass substrate
- Pretreatment of glass substrate
- Chemical treatment
- Heat treatment (Annealing)
We have used low iron toughen glass for our experiment and taken a form factor of 75mm x 25mm x 3.2mm for all experiments. After selection glass substrate, cleaned glass substrate with soap solution, de-ionized water than IPA & Acetone. After cleaning of glass substrate we require pretreatment of glass substrate for that substrate kept in 20% solution of nitric acid (72% purity) for 20 minute at 90°C temperature. After 20 minute remove substrate from nitric acid solution then cool it at room temperature then clean it with DI water. After completion pretreatment of glass substrate, now prepared anti reflecting coating (ARC) solution for further treatment. For preparing ARC solution we required following chemicals:

- Acetone
- Iso Propyl Alcohol
- Nitric Acid (HNO$_3$)
- Sodium hypo phosphite
- Sodium Acetate
- Aluminum tri chloride
- Potassium silicate

The chemical recipe was identical for different types of glasses. Al$^{3+}$ was added in the range of 6.2-8.1 x 10$^{-3}$ M, Sodium Acetate in the range 7.5-8.2 x 10$^{-3}$ M, Sodium Hypophosphite in the range 7.5-9.0 x 10$^{-3}$ M, Potassium Silicate at the concentration of 2.1 x 10$^{-3}$ M. pH was kept constant in the range of 7-8 that is near neutral condition. The temperature of the system was kept at 80°C. Depending upon the surface area to be treated the volume of the solution has to be used appropriately after selecting a suitable S/V ratio. For our purpose, we have selected S/V value of 0.2. On this value we find that typical wavelength where minimum reflectivity will occur in between 500nm to 600nm. For our case we varied from 28 Hrs to 48 Hrs. After processing, the substrates were thoroughly washed in DI water and dried. The treated substrates would be annealed at 85°C for up to 124 Hrs. for improving strength of coating. The substrate was now ready to be used.

**Phase 2. Fabrication of solar module by using ARC glass:** After developing ARC glass substrate now we fabricate different mini solar module by using with or without ARC coated glass and compare the electrical parameters test data. For fabrication of photovoltaic modules we require following materials:

- Tedlar (polyvinyl fluoride-PVF) films
- Ethyl vinyl acetate (EVA)
- Crystalline silicone solar cell
- Metal alloy wire
- Treated and untreated Glass substrate

After completion all experiments like developed ARC coated glass than fabricate solar module with or without ARC glass, we require method characterization for process setup so characterization of ARC solution and ARC glass substrate, require following instruments-

**pH Meter**: pH meter is used for pH characterization of ARC solution, maintain the pH of ARC solution by adding potassium silicate for kept the pH range b/w 7.0 to 8.0.

**UV-VIS Spectrometer**: The treated glass substrates measured for their transmittance using UV-VIS spectrophotometer (Perkin-Elmer Lambda 35) also measure the transmittance before treated the glass substrate as a blank. Integrating Sphere accessory used in UV-VIS spectrometer for analysis of transmittance in glass substrate.

After developing experimental setup and fine-tuned the process we treat the glass substrate and repeat the same experiment up to four to five times. We summarized all data and found approx 2.77% to 3.58% increment of transmittance.

**Atomic Force Microscope**: After chemical treatment of glass substrate, the surface morphology of the glass substrate was investigated by Atomic force microscope. Analysis Roughness data by using Atomic Force Microscope (AFM). After chemical treatment of glass substrate, we take 2D or 3D images of ARC glass substrate, roughness value of treated glass surface increases as compare to untreated glass but that roughness will not be affected the increment of transmittance.

**Climate Test Chamber**: So many chemical treated methods are available for increasing transmittance on glass substrate for application in solar module but environmental stability is crucial factor for this layer. In this study we observe the effect of different environment conditions like temperature, humidity on anti reflective coated glass substrate and analyze visual defects, peak wavelength shifting of transmittance and the reduction of transmittance. These characteristics have isolate this process to other exists developing process. Due to analysis of process stability we carried out Thermal cycle test, Damp heat test and Humidity freeze test. For all those entire environment tests we used Climate test chamber-WK340/40 (Environment Chamber). It is the main focus area of our research that treated substrate layer
would be environment stable. The temperature change test shall be executed in accordance IEC 61646 standard. It characteristics will isolate this process to other exist developing process. Due to analysis of process stability we would be require following environment test i.e. (a) Thermal cycle test (b) Damp heat test (c) Humidity freeze test. Transmittance would be measure before and after taken environment test. We mention conditions for different environment test i.e.

Thermal cycle test: This environment test consist 50,100 & 150 thermal cycle and each cycle consist - 40° to 85° C temperature for 6.0 Hrs.

Damp heat test: During this environment test substrate putting for 1000Hrs.at temperature 85° C and 85%RH.

Humidity freeze test: 85°C to – 40°C @ 85%RH 10Cycle each cycle=24Hrs.

During experiments we focused on which parameters those would be directly affected ARC process like S/V ratio, pH, Treatment time, Bath temperature, Concentration of salt, Aluminum ion concentration, Annealing temperature, Annealing time etc. so we carried out so many experiments with above said different process parameters and compare the data for optimization the process and find out actual suitable limit of process control parameters. After then we focused on different environment test data of ARC coated glass substrate, its indicates that when treated glass is introduce in different environment conditions, its affected the anti reflection coating but we found overall 2.0 to 3.0% increment in transmittance against without treated glass but maximum transmission wavelength shifting after environmental test.

Characterization Technique of solar modules: Following instruments would be require during fabrication of Solar module and their characterization-

Differential Scanning Calorimeter (DSC): In our experiment Differential Scanning Calorimeter is used for thermal analysis of tedlar and EVA materials, which materials used in fabrication of solar modules.

Sun simulator machine (Spectranova) for I – V Characterization: Sun simulator machine is used for current-voltage characterization of solar module. For characterization of fabricated solar module, we carried out different trial data of electric parameters on Sun simulator machine. Different electric parameters of solar module are as following

Voc: The $V_{occ}$ found when there is no any current passing through the cell like
\[ V \text{ (at } I=0) = V_{OC} \]

\textbf{Isc}: The \( I_{SC} \) corresponds to the short circuit condition when the impedance is low and is calculated when the voltage equals 0.

\[ I \text{ (at } V=0) = I_{SC} \]

Max. Power (\( P_{max} \)), Current at \( P_{max} \) (\( I_{max} \)), Voltage at \( P_{max} \) (\( V_{max} \)): At the \( I_{SC} \) and \( V_{OC} \) points, the power will be “0” and the max value for power will occur b/w the two.

\textbf{%Fill Factor}: It is find out by compare the max power to the hypothetical power (\( P_{T} \)) that would be output at both the Voc & Isc together.

\textbf{%Efficiency}: Efficiency is the ratio of the electrical power output \( P_{out} \) with compare to the solar power input, \( P_{in} \), into the photovoltaic cell. \( P_{out} \) can be taken to be \( P_{MAX} \) since the solar cell can be operated up to its max power output to obtain the max efficiency.

\[ \eta = \frac{P_{out}}{P_{in}} \Rightarrow \eta_{MAX} = \frac{P_{MAX}}{P_{in}} \]

After completion of all experiment we get overall conclusion are that

- The increase in transmittance depends on type of glass up to a certain extent but low iron toughen glass is a most suitable glass for that purpose.
- Over all 3.0 to 5.0% transmittance increment occurred after developing anti reflection coating on glass substrate.
- Varying the process condition can shift the peak wavelength of transmittance.
- Roughness value of treated glass surface increases as compare to untreated glass but that roughness will not be affected the increment of transmittance.
• Many environment factors have directly effect anti reflection coating of solar module glass so due to that facts environmental test is must for solar module glass.

• Overall transmittance of anti reflection coating glass substrate reduce after environment test approx 1.50% on both side but change in transmittance lies with in spec.

• UV chromatograms also show that Maximum transmission wavelength shifting after environmental test.

• The developed chemical process is; good transitivity, good heat stability, easy and cheap to produce.

• The above observations point to the fact that treated glass will be a good candidate for making solar photovoltaic modules.

• Increasing trend show in output of maximum power (Pmax) and in short circuit current (Isc)) from modules made with treated glass (ARC glass) as compared to modules with untreated glass.