

# Researches on Anti-reflection Coating (ARC) Methods Used in PV Systems


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**Abstract**—With the development of PV systems' technology over the years and the reduction of production costs, PV systems are now being used for electricity generation. PV systems are listed among the renewable energy sources as the only requirement is solar energy and electricity generation is carried out without any fuel and waste. Solar cells used in PV systems are adversely affected by extremes of temperature, shading, reflection, and pollution. It is known that before sunrays reach the cell's surface, some of them disappears from the protective glass surface and are reflected back from the cell through the glass surface. Anti-reflection coatings (ARC) are used to reduce the energy loss and increase solar cell efficiency and output power.  $\text{SiO}_2$  and  $\text{MgF}_2$  are the most commonly used solutions among these coatings. It has been seen that the most efficient applications, with anti-reflection coatings as single, double, triple and more layers, are in triple layers applications. It has been observed that applications to the protective glass surface have self-cleaning properties, and  $\text{TiO}_2$  and  $\text{ZrO}_2$  are frequently used for this. The reflectance index of the protective glass, which is normally 1.51, can be reduced to 1.20 in silicone cells and 1.28 in thin film surfaces with the AR coatings.

**Index Terms**—PV systems, Anti-reflection, Anti-reflective Coating, Reflection index.

## I. INTRODUCTION

IN RECENT YEARS, the share of fossil-fuelled energy sources in electricity generation has been reduced, so renewable energy sources now have more share. When fossil-fuelled resources are used for electricity generation, they release hazardous wastes to the environment. Recently, some studies have been carried out on the environmental pollution caused by these wastes, whose effects lead directly or indirectly to major problems [1]. The use of renewable energy does not generate any waste, so this is a key advantage for nature and human health. Including solar, wind, hydro and biofuel as sources, the use of renewable energy sources as an alternative to fossil fuel usage has gained momentum worldwide. One of the most important renewable energy sources is solar energy. The most common method is the production of electricity by photovoltaic panels, although methods such as solar chimney, condensed solar energy used in electricity generation from solar energy are used. Until 2030, the electricity demand in the world is predicted to increase by 76%.

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The energy of 5100J per hour that reaches the earth from the sun is the amount of energy consumed by all people in a year. It is known that in photovoltaic systems, 30% of the solar energy is reflected back from the panel surface, and about 70% of the solar energy reaches the solar cell [2]. In this context, solar energy is benefited by the conversion of the energy it contains with the photovoltaic systems to electricity.

Looking at the types of solar panels used in photovoltaic systems, monocrystalline (SC-Si) and polycrystalline (MC-Si) panels appear to be at the forefront. In 2014, 92% of total production was achieved with monocrystalline and polycrystalline panels [3]. The percentage of thin film surfaces ( $\text{CdTe}$ ,  $\text{CuSe}_2$  (CIGS)) is less than that of silicon-based surfaces [4]. On the other hand, the production cost of thin films is lower than that of Silicon cells, and thus the production of thin films has accelerated in recent years [5]. The production cost in the silicon panels was 8.5 USD / w in 1995 and 1.1 USD / w in 2015 [6]. Despite the decrease in production costs, the photovoltaic systems which are more expensive and have newer technologies than other electricity generation methods have a share of 1.5% in world electricity generation in 2016. The share of fossil-fuelled resources is 75.5%, which indicates that PV systems are very backward in the same year [7].

## II. PV TECHNOLOGY

The applications to utilize solar energy, both in heating and in electricity generation, have been date back to 1960s. The structure of a solar panel consists of a solar cell and protective outer glass. Solar cells vary in their physical and chemical form with the yield, based on the nature of the material, such as silicon (Si) or gallium-arsenide (GaAs). An air gap is the necessity of the distance between the solar cell and the protective glass to zero. The sun's rays entering the air gap will scatter and break, as well as they will cause oxidations in the connections of the cells. For these reasons, there should be no air gap. The protective exterior glass structure is made to be straight and as thin as possible, but it is manufactured resistant to physical factors. In addition to making the protective glass straight, there are also solar panels manufactured by the Fresnel eye method [8].

The efficiency of solar panels is decreased by the effect of temperature increase or overheating, due to solar radiation scattered or reflected by the dirt on the surface, and atmospheric phenomena such as low solar radiation and cloudiness [9]. The real danger for solar panels is reduced efficiency due to overheating. Therefore, cooling technologies are being developed. Up to 20% efficiency increase was observed in the oil cooling operation [10].

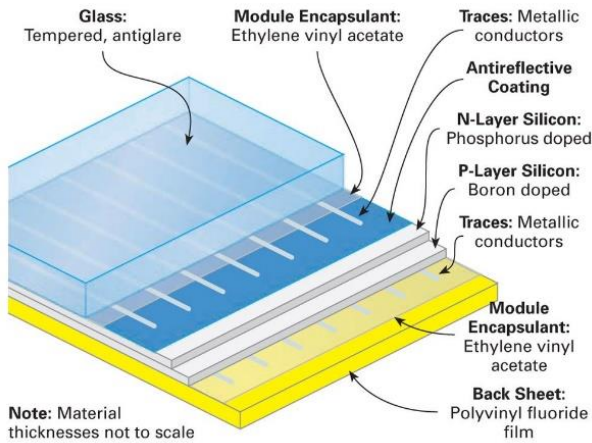


Fig.1. Layers of Solar Cell

Recent studies to increase the efficiency of solar panels have concentrated on Anti-reflective Coating (ARC). The purpose of this study is to analyse the studies in this area and to examine these coating studies according to different cell types and application methods.

To investigate anti-reflection coatings, it is first necessary to classify solar panels according to cell types. Solar cells are made of Silicon Crystal based or Thin Film technology.

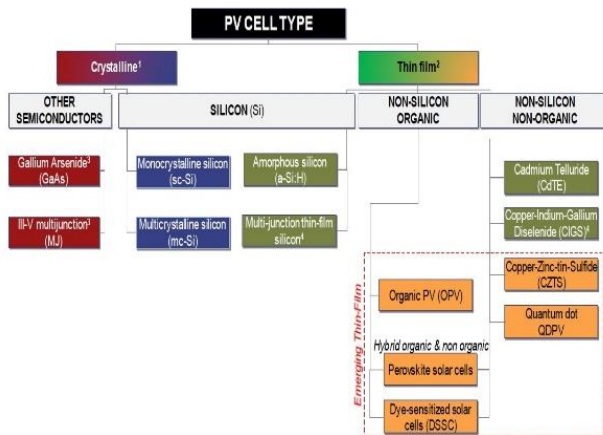


Fig.2. Classifying of PV Cells [11]

III. RESEARCH AND METHOD

Considering the studies of increasing the efficiency of solar panels, coating methods are applied according to cell types. Anti-reflection (AR) is defined as preventing reflection or refraction of sunlight coming to the cell surface. Anti-reflection applications technics are;

- Physical vapour deposition
- Chemical vapour deposition
- Thermal spraying
- Electro deposition
- Electro-less deposition
- Diffusion coating
- Laser based [12].

When the general properties used in these methods are examined, it is seen that the permeability of the coatings is less than 2.5 μm. In seasonal conditions, such as rain or snow, the

physical properties of the coatings are expected to remain unchanged and must be resistant to corrosion and oxidation [2]. Another common feature of anti-reflective coatings is that they can remain stable over long periods of temperature changes and various seasonal weather conditions. Another expectation with this seasonal change is that the surface is well adhered. The resistance against seasonal conditions is on the foreground in the coatings made on the glass surface.

The protective glass reflectance index used for solar panels is 1.51, the silicon cells are 4.71 and the air is 1.0 [13]. Anti-reflection coatings are expected to bring the reflectance index on the glass surface to zero. Because of the mechanical properties of the thin film surfaces, the solar panels used for the silicon cells achieved more efficient results [14]. In studies to reduce the reflectance index, it has been found that SiO<sub>2</sub> is coated with a lower index as a substrate and a different mixture. Implementing double layer coating (DLARC) on the coatings on the cell gave better mechanical and electrical results than single layer coating (SLARC). However, multi-layered coatings (MLARC) made from thinner layers than single- and double-layer coatings also showed favourable results from single- and double-layer coatings.

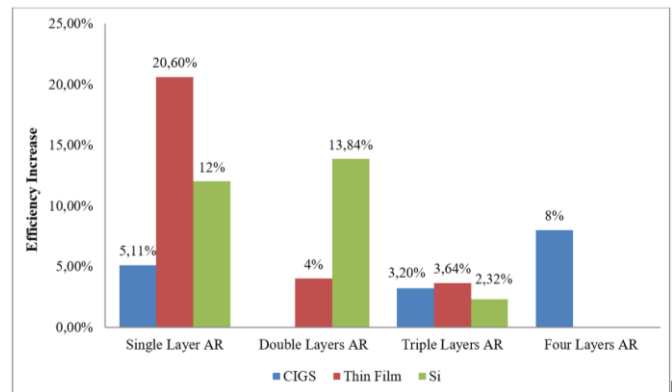


Fig.3. Effect of Anti-reflection Coating to Efficiency

When the literature studies are investigated, the anti-reflection coating works are concentrated on single, double and triple layer coatings. In case of working with four or more floors, the light transmittance decreased due to the increase of coating thickness, which led to decrease in efficiency and open circuit voltage. Silicon cells used as working surfaces have been studied with other thin film cell types, especially CIGS Thin film solar cells.

In the column of single-layer studies, an efficiency increase of 5.11% was obtained in CIGS cells. GIGS cell efficiency which is normally %16.7 increased to 17.6% with a single layer coating. MgF<sub>2</sub> was used at a thickness of about 120 nm [15]. In the case of investigating other thin film types, the efficiency was increased from 1.31% to 1.65% after coating and a total increase of 20.60% was obtained. ZnO cell coating of 80 nm thickness was performed [16]. A single layer of Ag + SiO<sub>2</sub> coating was applied to the silicon cells and a 12% efficiency gain was achieved by supporting this coating with a lens for light condensation [17].

In the two-layer anti-reflection applications; SiO<sub>2</sub> and nano TiO<sub>2</sub> applied to the silicon cell surface and was obtained 400 nm thickness coating. With these coatings, a maximum

efficiency increase of 16% was achieved while an average increase of 13.84% was achieved [18]. In another study on thin-film cells, the SiO<sub>2</sub> mixture was applied and the efficiency of the thin-film surface, which is 9.83%, was increased to 10.24%. The thickness of this two-layer application was around 90 nm [19].

Si-HC is coated on CIGS thin-film cell as a triple-layers antireflective coating. A thickness of 120 nm was obtained and an efficiency increase of 3.2% was obtained [20]. With SiO<sub>2</sub> coating on ZnO thin film, the thickness was 300 nm, and the triple layers coating efficiency increased by 3.64% [21]. In the triple-layers coating applied on the silicon cell surface, the protective glass was removed and TiAl<sub>2</sub> mixture solvent was used. This solvent was applied to the cell surface in triple layers and after each layer was dried the next layers were applied. With this mixture, 2.32% efficiency increase was obtained in silicon cells. The open circuit voltage was increased from 9.49 volts to 10.31 after coating [2].

The CIGS surface was used in four-layer coatings. This is why MgF<sub>2</sub> used does not decrease the required reflectivity when a single-layer coating is applied and does not increase the efficiency. For this reason, HfO<sub>2</sub>, TiO<sub>2</sub> and ZrO<sub>2</sub> were used in the bottom and 2nd and 3rd layers respectively, and 2μm MgF<sub>2</sub> was used as the anti-reflection layer in the outermost layer. Optical losses decreased from 9% to 4%, while CIGS cell efficiency increased by 8% [22].

In addition to these coatings, a mold was placed on the protective glass surface to serve as a lens, after which SiO<sub>2</sub> was applied on the mold, and an efficiency increase of 7.88% was achieved with this combination [23].

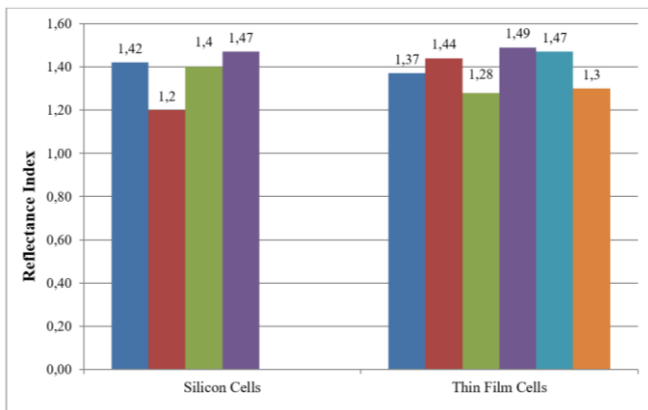


Fig.4. Effect of Anti-reflection Coating to Reflectance Index

It is aimed to pass the sunrays from the surface to the solar cell without any loss by the anti-reflection coatings. These studies are applied on the cell surface, protective glass surface and both cell surface and protective glass. In anti-reflection workings, it is usually seen to be applied to the protective glass surface and between the cell and the glass surface.

Coatings applied on silicone cells were investigated; a triple-layer SiO<sub>2</sub> coating was applied on a polycrystalline solar cell with an index gain of 5.9% and reduced to 1.42. In a study on a monocrystalline surface, a reflectance index of 1.19-1.21 was obtained [24]. In the study on radiation-hardened high-efficiency silicon cells (RHES), single-layer tested with the SiO<sub>2</sub> mixture resulted in 1.46, and 1.4 reflectance index when

triple-layers were applied [25]. In another study, the application of nano-ZnO on the protective glass of silicon cells was modelled. The thickness of the nano-ZnO coating modelled by the finite element method is considered to be 400 nm. The loss of 4% within this coating between the air and glass was estimated to be reduced to 1.5% and the reflection index to be 1.47 [26].

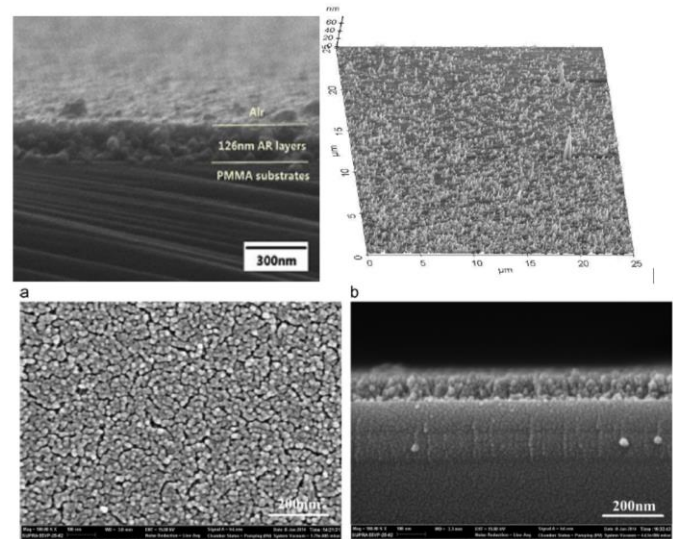


Figure 5. Electron microscopy images of anti-reflection coating studies [12, 19 27]

When working on the thin film; a self-cleaning feature was applied to the protective glass. TiO<sub>2</sub> and SiO<sub>2</sub> are used for the self-cleaning. The TiO<sub>2</sub> solution prepared was mixed with SiO<sub>2</sub> and coated with the spin coating method. With only TiO<sub>2</sub> applying, the reflection index of 2.71 was reduced to 1.37 by using 15% SiO<sub>2</sub> mixed [28]. In a study on the protective outer layer of the CdTe thin film solar cell, a multi-layer coating method was preferred. To reduce the loss due to the 4.2% reflection on the thin film glass, ZrO<sub>2</sub> with high reflectance index was first applied and SiO<sub>2</sub> with low reflectance index was applied above this ZrO<sub>2</sub> layer. A four-layer coating was obtained. The deposition was carried out by evaporation after the layers were made. Reflection losses were reduced to 1.36% and an index of 1.44 was obtained. However, in this application, the flexibility of the properties of the thin films led to the deterioration of this coating. When the thin films were flexed, it was observed that the coating deteriorated [29]. In another study where the SiO<sub>2</sub> coating was applied on BZO (Boron-doped Zinc Oxide) thin film surface, the light transmittance of about 92% was increased to 95%. Using the sol-gel dip coating method, a thickness of 90 nm could be obtained and this coating which is a reflectance index of 1.28 was found to be resistant to adverse weather conditions [19].

In another application, firstly, ZrO<sub>2</sub> was applied to the glass on the thin film surface and then secondly SiO<sub>2</sub>, thirdly ZrO<sub>2</sub> again, and SiO<sub>2</sub> as the last layer. In this work, ZrO<sub>2</sub> has high index and low index SiO<sub>2</sub>. In this way, a total thickness of 277 nm was obtained and the reflectance index decreased by 1.22% to 1.49. In the same study, 335 nm thicknesses were obtained with six-layer (3 ZrO<sub>2</sub> + 3 SiO<sub>2</sub>) AR coating obtained using the same method and the reflectance decreased by 1.49%. The reflectance index of the six-layer application was 1.47 [30]. In

the study on the CIGS (CuInGaSe<sub>2</sub>) thin film, the SiO<sub>2</sub> and WO<sub>3</sub> photocatalyst which has the self-cleaning Anti-reflective coating was applied. Due to the use of tungsten, the color of the surface coating is blackened and the reflectance index is measured as 1.3 [20].

#### IV. CONCLUSION

Because of the refraction and reflections from the surface when the sunrays meet the surface of the solar cell, there is a loss of efficiency even if the cell is positioned at the right angle. The solar cells meet with more solar rays and it is desired to increase the open circuit voltages and the energy intensities to obtain more power output. It is desired that to increase the open circuit voltages and the energy intensities to obtain more power output by meeting the solar cells with more solar rays.

Many methods and materials have been observed when investigating anti-reflection (AR) studies. In these studies, it was observed that the anti-reflective coatings (ARC) could be applied to the protective glass surface, to behind the glass and directly applied to the cell surface. The coating on the protective glass is very useful because they can be applied to existing PV energy systems and PV power plants without any change. It has also been shown that all of the work used in this method has been supplemented with self-cleaning materials and anti-reflection materials. With this combination, PV power plants will be able to achieve huge efficiency gains.

It has been observed that triple-layers of coatings are more durable and stable than the other multi-layers and also give results that are suitable for each type of solar cell. SiO<sub>2</sub>, MgF<sub>2</sub> and TiO<sub>2</sub> were used in the coatings. While SiO<sub>2</sub> can be used as an anti-reflection coating alone, higher efficiency is obtained when it is supported by high reflection index materials such as ZrO<sub>2</sub>. ZrO<sub>2</sub> was used as an alternative to TiO<sub>2</sub>. As an alternative to TiO<sub>2</sub>, ZrO<sub>2</sub>, HfO<sub>2</sub>, Ta<sub>2</sub>O<sub>5</sub> and Nb<sub>2</sub>O<sub>5</sub> are proposed.

It was observed with the difficulty of 4 or more layers of coatings and the adverse effect of increased thickness and the coatings were pulled away from the thin film surface during the test phase.

If an anti-reflective coating with self-cleaning properties is not used, anti-reflective coatings with a low reflectance index between the protective glass and the cell surface will provide solar cells with longer duration of use and efficiency.

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### BIOGRAPHIES



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