



Improvement of the Performance of Self Cleaning Solar Panel

KEYWORDS

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ABSTRACT *This study aims to give a comprehensive state-of-the-art review of the self-cleaning glazing products available on the market today and investigate methods for measuring the self-cleaning effect. Various future research pathways and opportunities for the self-cleaning products of tomorrow are also explored within this study, with emphasis on solar energy application areas such as daylight, solar radiation transmission, electrochromism, building integrated photovoltaics (BIPV), solar cell glazing and solar cells in general. Self-cleaning products from several manufacturers that utilize two different self-cleaning technologies of either photocatalytic hydrophilic or hydrophobic capability are presented.*

1.INTRODUCTION:

The objective of this paper is to attain a clear overview of the self-cleaning glazing products available today, to investigate methods for measuring the self-cleaning effect, and to explore various future research pathways and opportunities for the self-cleaning glazing products of tomorrow. To comply with these purposes, this study is divided into three parts. The first part suggests and investigates possible methods for measuring the cleaning effect of self-cleaning glazing products. The second part is a state-of-the-art review of all the large self-cleaning glazing manufacturers and their available products of today. The third and last part is a possibility study of the research and development being performed on the subject as of now, in addition to illustrate possible solutions and products for the future. The products in question in this study are mainly glass components and applications to such, e.g. windows and window treatment products. Nonetheless, the potential for self-cleaning surfaces in general, including ice and snow free surfaces, is huge. Therefore this study also encompasses various wall and roof surfaces, photovoltaic solar cells, solar thermal panels, cars, road signs, etc.

As the name suggests, a self-cleaning glazing is capable of cleaning its own surface. This effect can be achieved through photocatalytic reactions within a titanium dioxide (TiO₂) thin film coating. However, the thin-film must be activated to be operational. The activation occurs by virtue of UV radiation, where the TiO₂ reacts with the oxygen and water molecules in the air and produces free radicals leading to oxidative species [1].

This process needs some daylight exposure, usually about one week, to ensure full activation. When dirt, dust and other deposits later may fasten to the surface as a result of natural weathering, the UV radiation causes oxidative species that results in photogenerated electrons and holes. Electrons will then reduce oxygen to water (vapor) and holes will oxidize the organic matter, and thereof deteriorating the dirt and dust [1,5].

Since UV radiation is abundant even on cloudy days or in shaded areas, this process is in operation non-stop during daytime.

To perform measurements in the field without disturbing factors such as changing solar conditions, one could do the testing during nighttime, as the only light source to power the solar cell on the inside would be the measurement lamp on the outside, more or less. If not, an apparatus that is attached

on the outside of the test specimen, which block out all solar radiation and only allow the measurement lamp to transmit light through the specimen and power the solar cell on the inside of the specimen.

Furthermore, the test room in which the solar cell is placed should be arkened. If one follows the mentioned considerations and precautions when evaluating the selfcleaning factor in accordance with either Equation 2 or 3, the results should give a good indication on the self-cleaning effect of the test specimens, within the measurement accuracy.

The relationship between the traveled distance of radiation and the transmittance of radiation may thereof be defined as:

$$I = I_0 \exp(-\alpha x) \rightarrow T = (I / I_0) = \exp(-\alpha x) \dots\dots\dots (1)$$

where I and I_0 are defined as the incident and transmitted radiation intensity, respectively, α is the absorption coefficient of the substance, x is the traveled distance of the radiation, whereas T represents the transmittance of radiation through the substance. Consequently, the transmittance of light through a dirty self-cleaning glazing product will decrease exponentially with increasing thickness of the deposit layer.

The SunClean self-cleaning coating can be used in conjunction with solar control glass, in order to achieve a high energy efficiency and other benefits in addition to the self-cleaning property. The SunClean coating is a durable and transparent coating of titanium dioxide that is factory applied to hot PPG glass panes during the formation process, creating a strong and long-lasting bond between the coating and the glass. This process makes the coating an integral part of the outer surface and yields a durable photocatalytic and hydrophilic surface, which is easy to clean, dries quickly and causes minimal spotting and streaking. The SunClean is dependent upon UV radiation, as any other photocatalytic surface, in order to function correctly, and is therefore only used externally. The energy within the UV radiation is able to disintegrate organic dirt and dust, however, the coating is not able to loosen inorganic deposits, such as sand or paint and cement runoff. Occasional cleaning and maintenance is necessary, also in periods with little or no rain to wash away loosened deposits. Still, the sheeting-action of water on the glass surface enables quick cleaning with minimal effort. [3,5]

The products from Reflex Glass promote two main features;

solar protection and easy cleaning. The latter property is achieved through use of a polymeric hydrophobic coating on the outer glass surface, which is permanently bonded to the glass surface during the factory production process. The difference between the two glass products, Reflex and Reflex+, is the magnitude of their main properties; where the latter has the highest reflection of IR and UV radiation, offers a lower U-value and external reflection. The Reflex+ unit does also have a conspicuous azure tint. These products are suitable for external use only, because of their functional dependency of UV radiation.

However, the effect of lashing rain with regard to photocatalytic surfaces is not as apparent as with smooth hydrophobic surfaces, due to the degrading of organic matter on the TiO₂-surface. This statement is supported by the results from Chabas et al. (2008), where it was observed that the self-cleaning action on TiO₂-surfaces took place, even in absence of rain [6].

In elucidation of the above mentioned, the self-cleaning performance comparison between photocatalytic hydrophilic TiO₂-coated glass and hydrophobic polymer coated glass seems reasonable. However, the self-cleaning performance advantage of ordinary clear float glass over smooth hydrophobic glass in Figure 5 remains to be explained. Nonetheless, it appears as if hydrophobic glass requires regular manual cleaning to decontaminate the surface and prevent accumulation of dirt and dust, thus could more appropriately be defined as an easy-to-clean product rather than a self-cleaning product. [7]

1.1 Cell Assembly: Low-cost, Continuous and Ecological Foil Cleaning for Photovoltaics:

Atmospheric plasma cleaning protocols are gaining early adoption within thin film PV foil cleaning processes. APT prevents chemical waste effluents. Etch, cleaning and bonding trial data confirm system efficacies.

1.2 Atmospheric plasma cleaning protocols are gaining early adoption within thin film PV foil cleaning processes:

Atmospheric plasma cleaning protocols are gaining early adoption within thin film PV foil cleaning processes, with some of the key drivers being its use of a continuous, roll-to-roll (R2R) process, significantly lower production floor footprint, and lower capital cost. The highly efficient method for removing organic surface contaminations from PV foils prevents generation of chemical waste effluents found with wet-cleaning processes. Researchers, examined plasma cleaning systems and details etching, cleaning and bonding trial data confirming system efficacies.

Metal foils are in widespread use in photovoltaic (PV) applications, and particularly with copper indium gallium selenide (CIGS) cells in the form of polycrystalline thin films. CIGS PV manufacturers require specific metal foil alloy formulations and dimensions, which are not uncommon formulations for metal foil providers. With the use of foil-based cells, copper and other materials replace silicon as the semiconductors. Key advantages of solar cells constructed with flexible foils include their ability to withstand high temperatures during further processing; they experience low impact from evaporation; they are highly etchable; and they can contain side electrodes that act as contacts for powering auxiliary units. However, moisture transport, adhesion, and corrosion protection of PV module packaging materials rely in part on clean foil surfaces for improving adhesion to glass and polymer (encapsulant, backsheet) component surfaces to prevent ingress and maximize efficiency. Atmospheric plasma pre-cleaning of foils in continuous roll-to-roll processes has been found to be a low cost, dry, and highly efficient method for removing organic surface contaminations from PV foils without the generation of chemical waste effluents compared to wet-cleaning processes. This paper examines these systems and details etching, cleaning and bonding trial data confirming system efficacies. [8]

1.3 Atmospheric plasma systems:

The use of plasma surface modification technology in PV cell manufacturing has heretofore been used primarily in applications such as the deposition of amorphous hydrogenated silicon nitride (SiN) layers in a vacuum plasma-enhanced chemical vapor deposition (PECVD) process to create anti-reflection and surface (and bulk) passivation on thin-film solar cells, or the use of vacuum plasma etching to perform edge isolation in some remaining fabrication processes. As PV cell manufacturing processes evolve, and with the added pressures of increasing hazardous chemical waste disposal costs, there has been interest in atmospheric plasma systems as efficient dry etching, surface cleaning and adhesion promotion process tools. [9]

1.4 Micron- and Nanometer-Scale Features Make Superhydrophobic Surface:

Using two different types of chemical etching to create features at both the micron and nanometer size scales, researchers have developed a surface treatment that could boost the light absorption of silicon photovoltaic cells in two complementary ways.

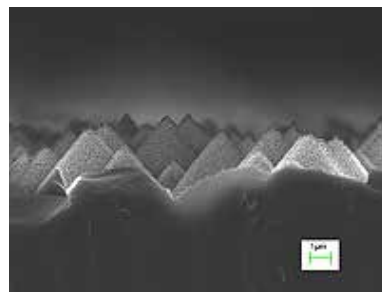


Fig.(1)Image shows silicon pyramid structures etched for one minute using a hydrogen fluoride/hydrogen peroxide/water solution.

The resulting structure has roughness at the micron and nanometer scales. The surface treatment increases absorption both by trapping light in three-dimensional structures and by making the surfaces self-cleaning –allowing rain or dew to wash away the dust and dirt that can accumulate on photovoltaic arrays. Because of its ability to make water bead up and roll off, the surface is classified as superhydrophobic. “The more sunlight that goes into the photovoltaic cells and the less that reflects back, the higher the efficiency can be.”Our simulations show that we can potentially increase the final efficiency of the cells by as much as two percent with this surface structure.”

The silicon etching treatment mimics the superhydrophobic surface of the lotus leaf, which uses surface roughness at two different size scales to create high contact angles that encourage water from rain or condensation to bead up and run off. As the water runs off, it carries with it any surface dust or dirt – which also doesn't adhere because of the unique surface properties. [18]

The figure(2) shows Lotus-Leaves-Inspired Self-Cleaning Photovoltaic Arrays.



Figure(2) Lotus leaves

in which it is dispersed, the greater the refractive light scattering. it is only necessary to compare the refractive indices of Rutile and Anatase with those of other commercial white pigments and paint vehicles. The larger the difference between the refractive index of the pigment and that of the medium in which it is dispersed, the greater the refractive light scattering.

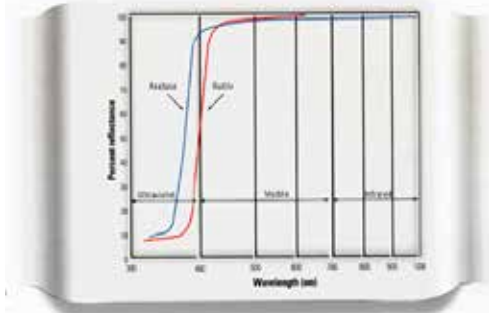


Figure (3) the relationship between the refractive index and the wavelength. [19]

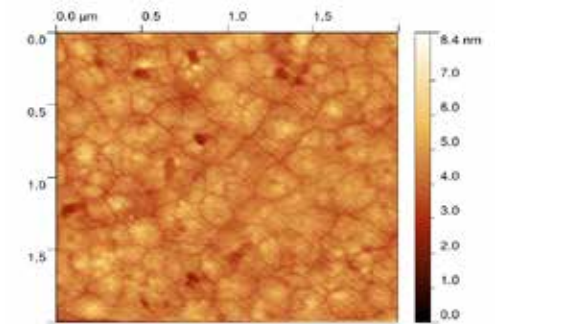
2. Experimental details:

2.1 Single Thin-film Analysis:

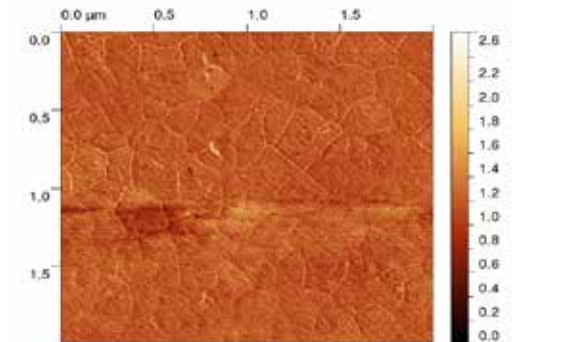
To understand the interplay of the individual layers which build up the organic solar cell, this section characterizes single layers.

2.1.1. Indium Tin Oxide:

ITO substrates were investigated after the cleaning procedure by AFM and compared with a rinsed ITO sample. Fig.4. shows the cleaned surface, on which ITO grain boundaries can be identified. Several holes in Fig.4.a indicate the bombardment during ultrasonic bath. Averaged RMS surface roughness was 0.55 nm. Solely rinsed ITO had a RMS roughness of 0.28 nm and the grains were not visible. Sheet-resistance remained constant at 20Ω/ [20]



(a) ITO after cleaning, topography. RMS surface roughness: 0.51 nm



(b) ITO after cleaning, phase

Figure 4.: AFM image of ITO, which was cleaned for 30 min in ultrasonic bath and brushed with a toothbrush.

2.1.2. Titanium-oxides:

The Ti-oxide thin films were analysed using GIXRD, UV-Vis and the AFM. Thicknesses were measured with the profilometer and the sheet-resistances with a 4-probe scan head. All samples showed high sheet-resistances in the G /-range. With the used 4-probe setup, exact determination was not possible (high accuracy up to 200M, given in specifications). To summarize, Table 1 lists the results. Regarding the phase, small crystallization is indicated with "phase--" for indicated, going to "phase" for recognizable and "phase++" for high crystallinity.

DATE	O ₂ [%]	Temp (°C)	power	h (nm)	RMS roughness	phase on glass	phase on ITO
EB001	20	RT	150	48	-	amorph	-
EB002	40	RT	150	32	-	amorph	-
EB003	60	RT	150	35	-	anatase-	-
EB004	80	RT	150	32	-	ana-, rut--	-
EB005	40	RT	200	69	-	ana-, rut-	-
EB006	40	200	150	46	-	anatase	-
EB007	80	RT	200	39	~ 0.5 nm	amorph	ana-, rut--
EB008	80	200	200	40	~ 0.7 nm	anatase+	anatase++
EB009	80	RT	200	35	~ 2.7 nm	amorph	rutile-
EB010	40	200	200	37	~ 0.6 nm	-	anatase++
EB011	15	200	200 DC	110	~ 7.3 nm	rutile++	rutile++

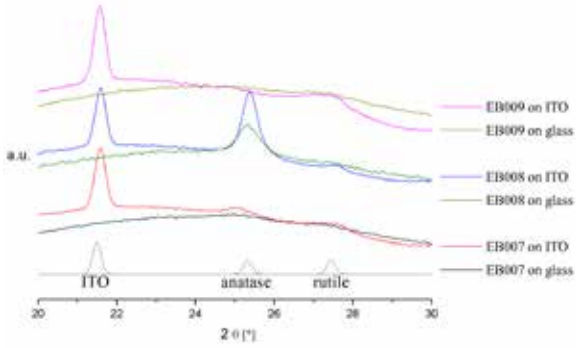
Table 1.: Properties of sputtered Ti-oxides.

First TiO₂ thin films were deposited on glass. These were mostly amorphous. The 4th sample (EB004, 80% O₂) had small crystallization, compared to first samples (EB001-003) with lower O₂ content in the Ar-plasma. Crystallization to anatase phase was obtained by heating the substrate to 200. during deposition. After the 6th run, the TiO₂ thin films were deposited on glass and on ITO, to produce solar cells and analyze the films simultaneously. Because the deposition rate was slow, the RF power was enhanced from 150W to 200W, which reduced the deposition time for a ≈ 40 nm thin-film from 4.8h to 3h. The films fabricated during the same run on different substrates (glass or ITO) were not equal regarding x-ray diffraction (see Fig.3a) and UV-Vis absorption (Fig.4.5a). The films deposited on ITO had stronger crystallization than films deposited on glass. This can be identified in Fig.5-a, where the anatase phase peak of EB008 (deposited at 200.) is more pronounced on ITO than on glass. EB009 on glass is amorphous, whereas EB009 in ITO shows a small rutile peak. [19,20]

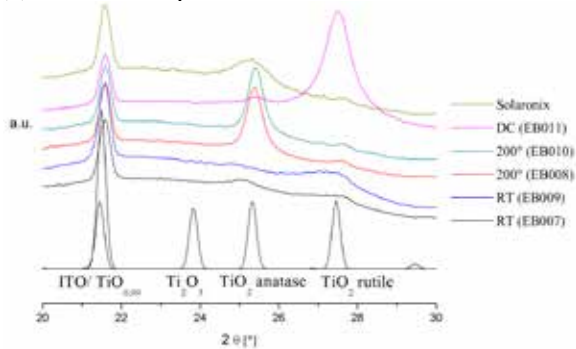
To obtain rutile phase, high O₂ content and low total pressure were chosen at room temperature (EB009) [18]. This did not lead to a high crystalline rutile phase. But sample EB011, sputtered with DC conditions instead of RF-magnetron sputtering, showed rutile phase (Fig.5. b), and was thick (110 nm) compared to the other TiO₂ thin films (L 40 nm).

The Solaronix TiO₂ film showed its claimed anatase character, but the peak was rather wide and less pronounced, meaning the anatase crystals were rather small compared with the sputtered anatase thin films (Fig.5b).

RMS surface roughness was measured by AFM. The 8_8_m2 scans of the Solaronix and sputtered anatase films are shown in Fig.6. Solaronix TiO₂ films had a high RMS roughness of 11:5 nm compared with the sputtered anatase Ti-oxides, which had a RMS roughness below 1 nm. The rough surface of the Solaronix film could be attributed to the suspension, which contained TiO₂ anatase nanoparticles with a diameter of ≈ 9 nm.

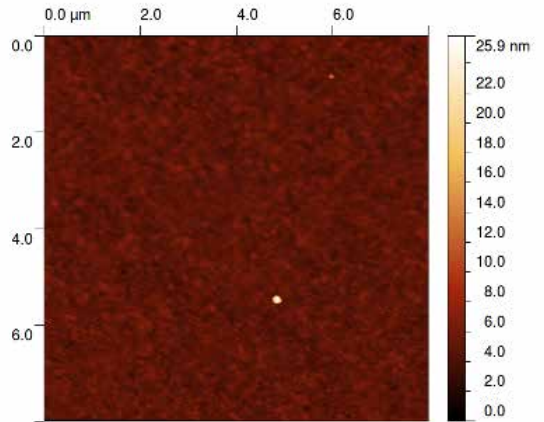


(a) Substrate comparison

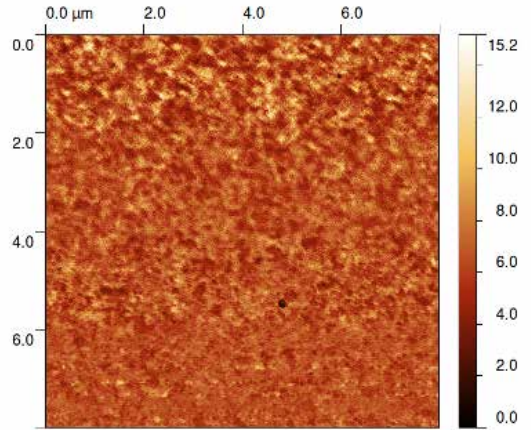


(b) All TiO₂ thin-films on ITO.

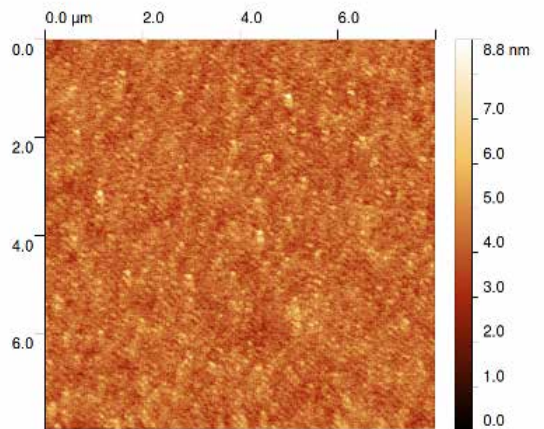
Figure(5):. GIXRD measurements of the different TiO₂ thin-films.



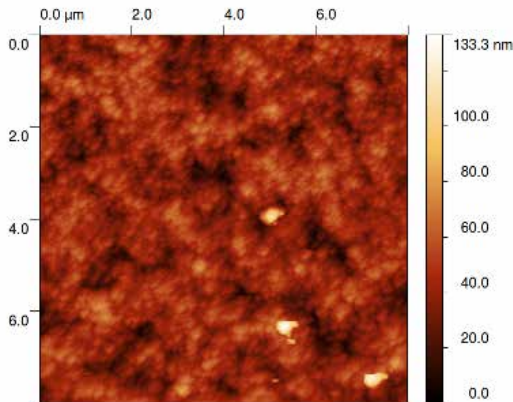
(c) EB008, topography.
RMS surface roughness: 0.7 nm
(d) EB008, phase
(e) EB010, topography.
RMS surface



(d) EB008, phase

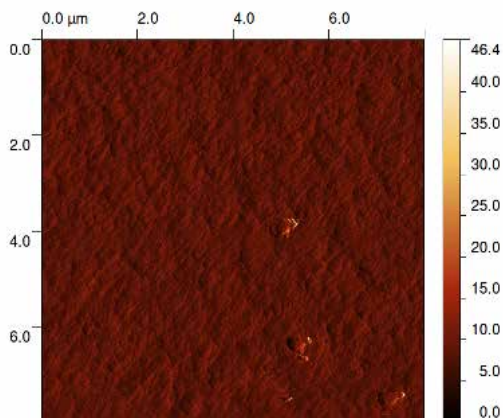


(e) EB010, topography.
RMS surface roughness: 0.6 nm

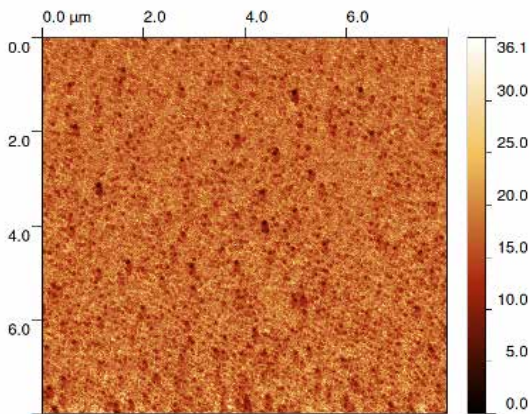


(a) Solaronix, topography.

RMS surface roughness: 11.5 nm



(b) Solaronix, phase

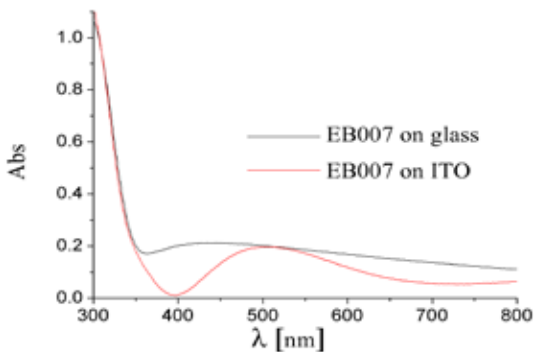


(f) EB010, phase

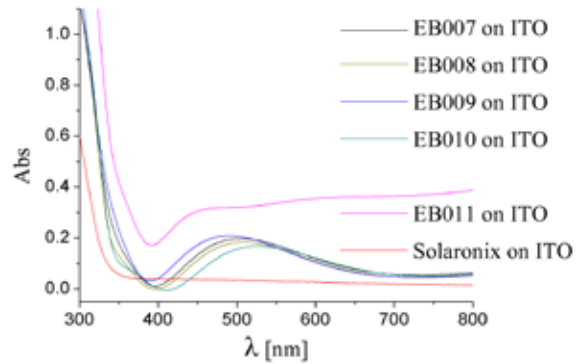
Figure (6).: AFM images of anatase phase TiO₂

As can be seen in Fig.7a, the sputtered TiO₂ films have on ITO a hump at ≈ 500 nm and absorb $\approx 18\%$ of the incoming light. Towards the band-gap of the Ti-oxide (≈ 400 nm), the absorption decreases to ≈ 0 before the light is absorbed completely.

The theoretical band gap of anatase is $3:2$ eV ≈ 388 nm, and the gap for rutile is slightly smaller at $3:0$ eV ≈ 414 nm. The trend from anatase (Solaronix) to rutile (EB011) is shown in Fig.7b, although the spectra for the Solaronix starts its absorption at ≈ 350 nm and EB011 at ≈ 400 nm.



(a) Substrate comparison of amorphous EB007 on glass and ITO

(b) TiO₂ films on ITO. Solaronix (anatase, ≈ 45 nm) and EB011 (rutile, ≈ 110 nm) are the edge cases.Figure 7.: UV-Vis absorption spectra of sputtered TiO₂.

3. Conclusion:

Atmospheric plasma cleaning protocols are gaining early adoption within thin film PV foil cleaning processes. The key drivers for this trend of conversion from chemical wet cleaning processes include continuous, roll-to-roll process; significantly lower production floor footprint and lower capital cost; no VOCs or chemical effluent disposal costs; and no water supply costs.

One goal was to fabricate several Ti-oxide thin films and their comparison. Using reactive RF magnetron sputtering, different TiO₂ thin films were obtained by changing sputtering conditions. Deposited TiO₂ films with anatase or rutile phase were acquired on ITO, which served as a seed layer for the crystals (Fig.5). On amorphous glass, with the same sputtering conditions less crystalline films were deposited. The substrate has a strong influence on the film, also the similar sol-gel route resulted in different TiO₂ for depositions on ITO and FTO. In publications about RF sputtered TiO₂, usually films of several hundred nm deposited on highly crystalline substrates are discussed. Here, crystalline.

REFERENCE

- Keränen, Jetta. "Nano-structured self-cleaning coated glasses: modelling and laboratory tests for fundamental knowledge on thin film coatings, EC normalization and customer benefits". Self-Cleaning Glass, 36M Publishable activity report, Self-Cleaning Glass Consortium, 2007 | 2. Chabas A, Lombardo T, Cachier H, Pertuisot MH, Oikonomou K, Falcone R, et al. "Behaviour of self-cleaning glass in urban atmosphere". Building and environment.43, 2124-2131, 2007 | 3. Jelle, BP, Hynd A, Gustavsen A, Arasteh D, Goudey H, and Hart R. "Fenestration of today and tomorrow: A state-of-the-art review and future research opportunities." Solar Energy Materials and Solar Cells, 96, 1-28, 2011 | 4. Jelle, BP and Gustavsen A. "Solar radiation glazing factors for electrochromic windows for building applications." Proceedings of the Building Enclosure Science & Technology (BEST 2), Portland, Oregon, USA, 12-14 April 2010 | 5. Mellott, N.P., C. Durucan, C.G. Pantano, og M. Güglielmi. "Commercial and laboratory prepared titanium dioxide thin films for self-cleaning glasses: Photocatalytic performance and chemical durability." Thin Solid Films, 502,112-120, 2006 | 6. Pilkington Group Limited. How Self-Cleaning Glass Works. Pilkington. 2012, retrieved March 14, 2012: <http://www.pilkingtonselfcleaningglass.co.uk/how-it-works/7>. Balcony Systems Solutions Ltd. FAQs. Balcony Systems Solutions Ltd. 2012, retrieved March 7, 2012: <http://www.balconano.com/FAQ.aspx?ID=0> | 8. Ritec International Ltd. ClearShield 'Non-Stick' Glass Frequently Asked Questions. Ritec International. 2012, retrieved March 7, 2012: http://www.ritec.co.uk/clearshieldsystem/clearshield_faqs | 9. Saint-Gobain Glass. Home page. Saint-Gobain Glass. 2009, retrieved March 7, 2012: www.saint-gobain-glass.com | Submitted for publication in Solar Energy Materials and Solar Cells, 2012 27 | 10. Miyashita, K., S. Kuroda, T. Ubukata, T. Ozawa, og H. Kubota. "Enhanced effect of vacuum-deposited SiO₂ overlayer on photo-induced hydrophilicity of TiO₂ film." Journal of Materials Science, 36, 3877-3884, 2001 | 11. Fürstner R, Barthlott W, Neinhuis C and Wazel P. "Wetting and Self-Cleaning Properties of Artificial Superhydrophobic Surfaces." Langmuir, 21, 956-961, 2005 | 12. Keränen, Jetta. "Nano-structured self-cleaning coated glasses: modelling and laboratory tests for fundamental knowledge on thin film coatings, EC normalization and customer benefits". Self-Cleaning Glass, 36M Publishable executive summary, Self-Cleaning Glass Consortium, 2007 | 13. Cardinal Glass Industries. Cardinalcorp. Cardinal Glass Industries. 2011, retrieved March 19, 2012: <http://www.cardinalcorp.com/products/neat-glass/> | 14. Fuyao Group Ltd. Products - A&D Glass - Self-cleaning Glass. Fuyao Group Ltd. 2007, retrieved April 24, 2012: http://www.fuyao.com/en/products/deep_cleaning.html | 15. PPG Residential Glass. SunClean - Features. PPG Residential Glass Ltd. 2010, retrieved March 7, 2012: <http://www.ppg.com/corporate/ideascape/resglass/homeowners/product/sunclean/Pages/SunCleanFeaturesOLD.aspx> | 16. Press Glass SA. Our glass - Advantages of our solutions - Ease of cleaning the glassunit. Press Glass SA. 2012, retrieved March 8, 2012: | 17. Reflex Glass. Reflex Glass - FAQ. Reflex Glass. 2007, retrieved March 19, 2012: <http://www.reflexglass.co.uk/faq.php> | 18. Viridian. Products - Renew. CSR Building Products Ltd. 2008, retrieved March 7, 2012: <http://www.viridianglass.com/Products/renew/default.aspx?ProductType=Specifier> | 19. Rain Racer Developments. FAQ. Rain Racer Developments. 2012, retrieved March 7, 2012: <http://www.rainracer.com/pb2/faq.htm> | 20. Jelle BP, Breivik C, and Røkenes Drolsum H. "Building integrated photovoltaic products: A state-of-the-art review and future research opportunities." Solar Energy Materials and Solar Cells, 100, 69-96, 2012