PHOTOVOLTAIC TECHNICAL CONFERENCE - ADVANCED MATERIALS AND PROCESSES TO INNOVATIVE APPLICATIONS 2015, MAY 27-29, AIX-EN-PROVENCE, FRANCE

TiO_2-BASED NANOCOATING WITH SELF-CLEANING AND ANTI-REFLECTIVE PROPERTIES: EFFECTS ON PV PERFORMANCE

E. Kaplani[1], Y. Panayiotatos[2], and J.K. Kaldellis[3],
[1]R.E.S. Laboratory, Technological Educational Institute of Western Greece, Patra, GREECE
[2]Mechanical Engineering Dept., Technological Educational Institute of Piraeus, Athens, GREECE
[3]Soft Energy Applications and Environmental Protection Laboratory, TEI of Piraeus, Athens, GREECE

1) Context / Study motivation

Photovoltaic modules operating in field conditions exhibit a significant reduction in their power output due to dust accumulated on their surface. Depending on the amount of dust accumulated the reduction in peak power has been reported in the range of 5-15% [1,2,3]. The accumulated dust is linked to meteorological and environmental parameters such as humidity, precipitation, solar radiation, ambient temperature, dusty winds, air pollution, etc., but also to the location and surroundings of the installation and the period for which the PV modules have been left without cleaning. To reduce the effect of dust, research has been recently focused on coatings with self-cleaning properties that may be applied on PV glass surface [4,5]. Also, coatings with spectral selective properties have been investigated to enhance PV performance [6].

The purpose of this study is to examine the effect of a nanocoating with self-cleaning and anti-reflective properties on the performance of a PV module when applied on its glass surface. Particular interest is given to its anti-reflective properties which are assessed for angles-of-incidence of solar radiation greater than 40°, where reflectance is generally higher. The performance of two same PV modules one with and one without the coating is compared.

2) Description of approach and techniques

A coating based on Titanium dioxide nanoparticles was developed for the purposes of this project. Nanoparticles of TiO_2 and SiO_2 were dissolved in an aqueous solution with pure ethanol as a solvent. The nanocoating was applied on a c-Si PV module of 80 W_p using a spray deposition technique. The estimated thickness of the coating is approximately 200nm.

For the evaluation of the optical properties of the coating, it was also applied on an extra-clear low iron glass sample. The spectral transmittance and reflectance of the glass with and without the nanocoating was measured via means of a UV-3600 Shimadzu spectrophotometer and MPC-3100 compartment with integrating sphere. The average transmittance was calculated in the solar region weighted by the solar spectral distribution, and in the visible region weighted by the spectral distribution of the CIE standard illuminant D65 and the CIE standard spectral luminous efficiency function for photopic vision. The average transmittance in the solar cell region was calculated for the wavelengths 300-1100nm where the solar cell responds. The effect of the nanocoating on the PV module was assessed through the I-V characteristic before and after the coating was applied. Furthermore, evaluation of the performance of the PV module with the nanocoating was carried out by direct comparison with that of a same PV module without any coating. The I-V characteristic was captured via means of an I-V curve tracer. Experiments were carried out at near normal angle-of-incidence (AOI) of solar radiation, as well as at higher AOI angles from 40° to about 80°. The effect of 1 month heavy dust accumulated on the PV modules was assessed through a comparison of the STC normalized I-V curves for the PV module with and without the nanocoating.

3) Results / Conclusions / Perspectives

The evaluation of the optical properties of the nanocoating sample applied on glass substrate gave evidence of higher transmittance and lower reflectance than the reference glass in the UV, VIS and NIR parts of the spectrum, as shown in Figure 1. The weighted average transmittance of the nanocoating sample compared to the reference glass, exhibits a relative increase of 1.7% in the solar region, 300-2500nm, 1.3% in the solar cell response region, 300-1100nm, and a relative increase of 1.1% in the visible region (see Table 1). The STC normalized I-V characteristic of the PV module before and after the application of the nanocoating is displayed in Figure 2 and shows that when the coating is applied on PV glass the module delivers higher current. The relevant increase in the STC normalized short circuit current (I_{sc}) is 1.6%, with a relative increase in STC normalized peak power (P_m) of 1.1%. With respect to different AOI, the STC normalized I_{sc} exhibits a relative increase of 2.4% at 40° AOI and up to 9% at 70° AOI (Figure 3).

The effect of dust on the PV modules with and without the coating was further examined for the worst case scenario of 1 month heavy dust accumulated on the modules as a result of southern winds carrying dust from Sahara, dusty rains and high temperatures in June (see Figure 4). The I-V curve analysis gave a 2.3% relative increase in STC normalized I_{sc} for the dusty PV module with the nanocoating compared to the dusty module without the coating at a 14° AOI, Figure 5. This results in nearly 1% increase due to self cleaning properties. Thus, preliminary results of the nanocoating applied on PV module glass revealed both self-cleaning and anti-reflective properties with increased PV performance of about 2.3% for operation with accumulated dust, and up to 9% increase at high AOIs due to anti-reflective properties.

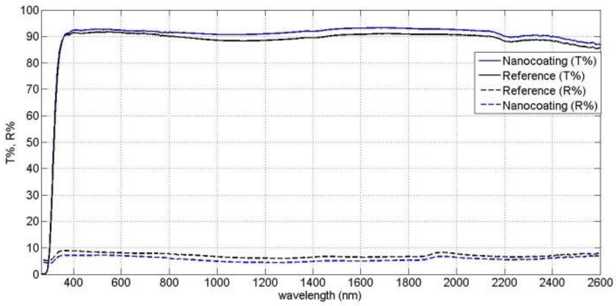

Figure 1: Measured total spectral transmittance and reflectance of nanocoating and reference glass samples.

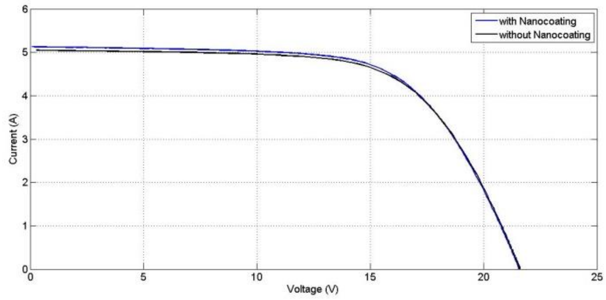

Figure 2. I-V curve translated to STC for PV module before and after nanocoating was applied on PV glass surface.

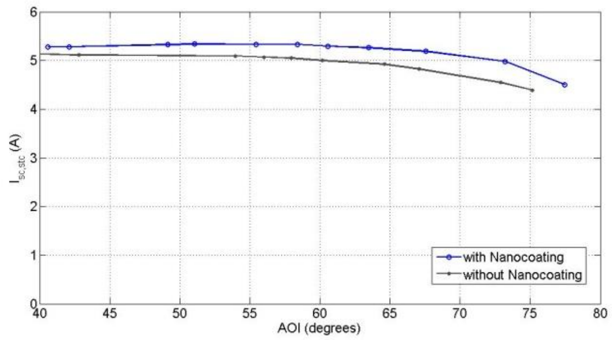

Figure 3: Effect of AOI on the STC normalized short circuit current, for the PV with and without the nanocoating.

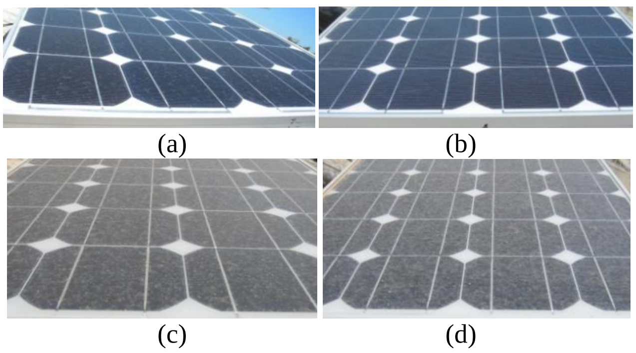

Figure 4. PV module (a) without and (b) with nanocoating after 2 weeks of naturally accumulated dust;(c) without and (d) with nanocoating after 1 month of heavy dust accumulation due to southern winds carrying dust from Sahara, dusty rains and high temperatures in June.

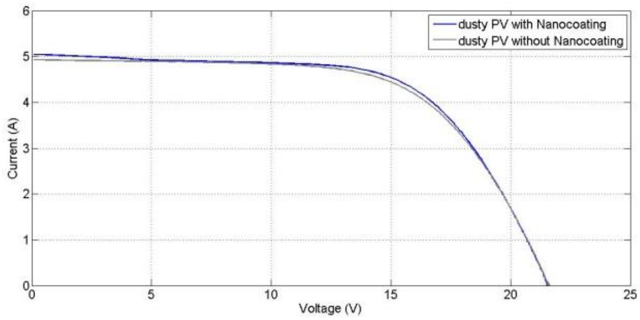

Figure 5. I-V curve translated to STC for dusty PV modules with and without the nanocoating.

Table 1. Weighted average transmittance and reflectance for the nanocoating and reference glass samples calculated from the spectral transmittance and spectral reflectance.

sample	**Transmittance %**			**Reflectance %**
	Tsol	*Tcell*	*Tvis*	*Rsol*
Reference glass	90.2	90.4	91.5	7.6
Glass with nanocoating	91.7	91.6	92.5	6.1

REFERENCES:

[1] M. Mani, R. Pillai, "Impact of dust on solar photovoltaic (PV) performance: Research status, challenges and recommendations", Renewable and Sustainable Energy Reviews, vol.14, pp.3124-3131, 2010.

[2] J.K. Kaldellis, M. Kapsali, “Simulating the dust effect on the energy performance of photovoltaic generators based on experimental measurements”, *Energy*, vol.36(8), pp. 5154-5161, 2011.

[3] S.A. Kalogirou, R. Agathokleous, G. Panayiotou, "On-site PV characterization and the effect of soiling on their performance", *Energy*, vol.51,pp.439-446, 2013.

[4] J. Son, S. Kundu, L.K. Verma, et al., "A practical superhydrophillic self cleaning and antireflective surface for outdoor photovoltaic applications", *Solar Energy Materials & Solar Cells*, vol.98.pp.46-51, 2012.

[5] X. Lu, Z. Wang, X. Yang, et al. "Antifogging and antireflective silica film and its application on solar modules", *Surface & Coatings Technology*, vol.206, pp.1490-1494, 2011.

[6] E. Kaplani, S. Kaplanis, D. Panagiotaras, E. Stathatos, "Optical properties of ITO nanocoatings for Photovoltaic and Energy Building Applications", *in AIP Conference Proceedings of 10th Int. Conf. of Computational Methods in Sciences and Engineering (ICCMSE 2014)*, Athens, Greece 4-7 April 2014, Vol. 1618, pp.348-353.