PHOTOVOLTAIC MODULE LABORATORY REFLECTIVITY MEASUREMENTS AND COMPARISON ANALYSIS WITH OTHER REFLECTING SURFACES

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ABSTRACT: Reflectivity measurements off the surface of PV modules and other reflecting surfaces were performed in the laboratory. The measurements were done using dedicated instruments of very high accuracy and focused on the visible light wavelength, i.e. 380nm to 700nm. The results proved that the reflections coming from PV modules are significantly less intense than others resulting from other surfaces, particularly those coming from vehicles. At large angles of incidence, when reflectivity is maximised, PV modules show advantageous behaviour due to the high absorption compared to other surfaces like car windshields and paints.

Keywords: Reflectivity – 1; Optical Properties – 2; Light Trapping – 3

1 INTRODUCTION

In recent legislative measures concerning environmental matters, the issue of PV module reflectivity under direct sunlight has been discussed. Practically, this could become a major barrier for the development of PV systems, especially in “sensitive” areas, such as civil and military airports, urban areas, etc. In the past, certain concerns on the reflectivity levels of PV modules have been reported by aviation authorities, environmental organisations, etc. Studies on reflectivity evaluation methods, apparatus set up and measurements have also be reported by others, see [1] to [4].

In this report, the reflectivity of c-Si modules is measured in the laboratory. For comparison purposes, reflectivity measurements were also performed on surfaces of other commonly used materials, such as car paint, windshield, etc.

2 APPROACH AND SCIENTIFIC INNOVATION

In a hemisphere, solar light reaches a surface from different directions. Possible incident angles r between a light source and an observer with respect to the vertical vary from 0^o and $\pm 90^o$, as shown in the following Figure 1.

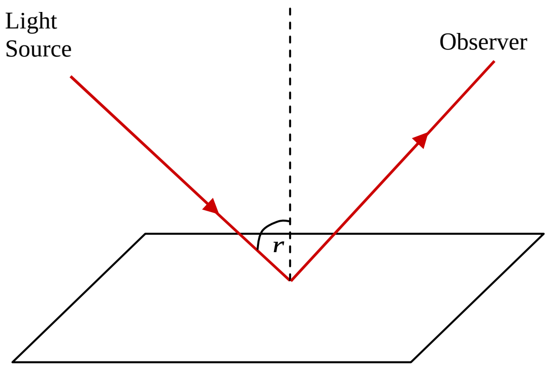

Figure 1: incident angle r on a surface with respect to the vertical

Radiation from a light source may be absorbed by a material, penetrate it or reflect back to exit, see mechanism in a PV module in Figure 2. In theory, high incident angles r means increased percentage of the reflected radiation. Thus, it is expected that incident angles of more than 70^o, will result in high reflectivity levels.

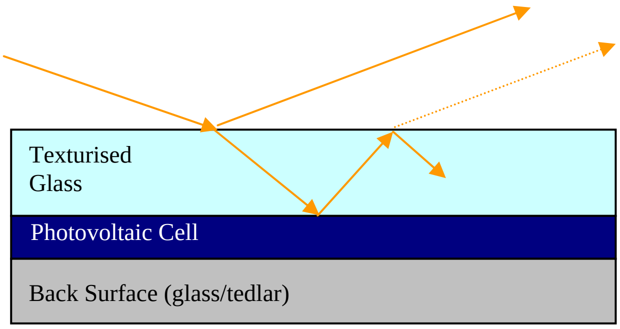

Figure 2: cross section of a PV module (reflectance mechanism)

3 LABORATORY EQUIPMENT AND SET UP

A laboratory set up was arranged and reflectivity measurements on the surface of polycrystalline silicon PV module samples were performed at the experimental facilities of CRES. The measurements were done using dedicated instruments of very high accuracy. The spectrometer used was a Perklin-Elmer type Lambda 9/19 with accessories a Labsphere RSA-PE-19 reflectance spectroscopy and a Spectralon integrating sphere. These instruments are shown in Figures 3 and 4 below.

Figure3: Perklin-Elmer Lambda 9/19 Spectrometer

Figure 4: Labsphere RSA-PE-19 reflectance spectroscopy accessory and Spectralon integrating sphere

The specifications of the equipment described above refer to reflectivity measurements in the ultraviolet and visible spectrum, i.e. 200nm to 900nm, with accuracy is ±0.2nm at full scale. In principle, the spectrometer emits a light beam to the sample under evaluation and a second reference beam. The diffusion angle is less than 5^{o}. The reference beam and the reflected light are sensed by intension light detectors and the measurements are recorded to a computer through dedicated software.

The samples used to measure reflectivity were the front glass of a polycrystalline module, a windscreen of a car and two typical metallic paints of vehicles, i.e. silver light and dark graphite. The particular samples used in the experiments are shown in Figure 5. The positioning of the PV module sample in the spectrometer is shown in Figure 6.

(a) (b) (c) (d)

Figure 5: samples that were used for the reflectivity measurements
(a): c-Si PV module
(b): car windscreen
(c): silver metallic paint
(d): graphite metallic paint

Figure 6: PV module sample during the reflectivity measurement

4 RESULTS

The measurements performed focus on the visible light wavelength, i.e. 380nm (violet) to 700nm (red). Reflectivity measurements for incident angles higher than 80^o were not taken as in this case the direct radiation from the light source would practically have a considerably higher effect to the observer than any reflectivity from a surface.

In the following Figures 7 to 10 are shown the reflectivity measurements from a metallic graphite and silver car paint, a car windscreen and a c-Si PV module respectively. In each sample, the light beam had four different incident anglers, namely 0^o, 45^o, 70^o and 80^o.

4.1 Metallic Paints

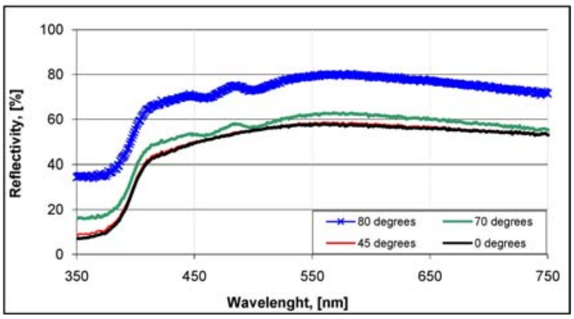

Figure 7: reflectivity of a graphite metallic paint

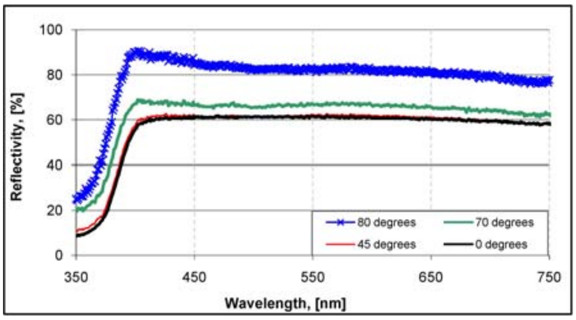

Figure 8: reflectivity of a silver metallic paint

As expected, vehicle paints have high reflectance levels, irrespective the darkness of the colour, see Figures 7 and 8 above. Up to 70^o incident angle, reflectivity does not vary significantly compared that of the vertical, i.e. r=0^o. For silver metallic paint and incident angle 80^o, reflectivity can be as much as 85%.

It is noticeable that in the ultraviolet region, reflectivity is slightly reduced meaning that light is either absorbed or penetrates the paint.

4.2 Vehicle Windscreen

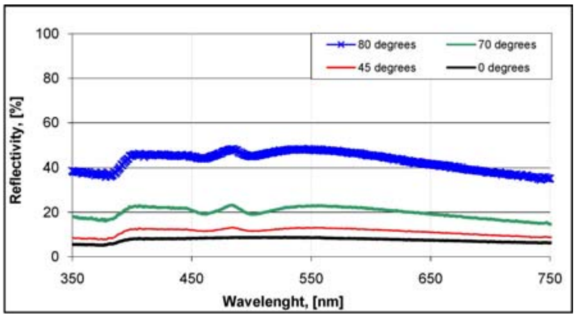

Figure 9: reflectivity of a car windscreen

The windscreen sample that was evaluated has little reflectance levels of average around 15% for incident angles up to 45^o. This is certainly a useful safety characteristic for vehicle drivers when driving under direct sunshine periods. However, in higher r angles, reflectivity is doubled as noticed in Figure 9 above.

4.3 Polycrystalline Silicon PV Module

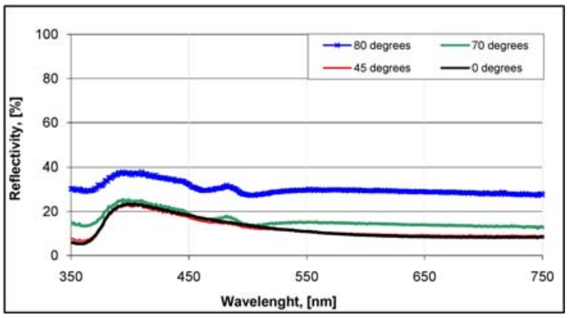

Figure 10: reflectivity of a PV module

Quite similar to the measurements with the car windscreen, PV module reflectivity lies in the region of average 15%, even at high incident angles of up to 70^o, Figure 10. The excellent optical characteristics of the front surface of a typical polycrystalline silicon PV module are evident even at very high r angles of 80^o, with reflectivity levels around 30% in the whole range of the visible wavelength.

Although a PV module is not transparent, as happens e.g. in a car windscreen, the reflecting light from the encapsulated in the module cells is added to the total PV module reflectance. On the other hand, the special optical specifications of the front glass that is used in the PV industry eventually retain the overall reflectivity at lower levels to any other surface examined. Such specifications refer to low iron in the glass compound, resulting in higher transparency as well as, texturised surface for lower reflectivity.

Photovoltaic cells are processed in such a way so as to absorb as much sunlight as possible, keeping reflectivity level low. In polycrystalline modules, the reflected light increases in the region between 400nm to 450nm reaching 20%. That is a characteristic of polycrystalline material and gives the known light blue colour to the cells. In dark blue monocrystalline modules, reflectivity is expected to be even lower.

5 CONCLUSIONS

The results presented above indicate that the reflections coming from PV modules are significantly less intense than others resulting from other objects, particularly those coming from vehicles as well as, other commonly used materials.

In particular, at large angles of incidence, when reflectivity is maximised, PV modules show advantageous behaviour due to the high absorption compared to other surfaces like car windshields and paints. Particularly, at 0^o incidence angle, a typical PV module reflectance was measured less than 10% for most of the visible range, while silver and grey metallic paint would reflect over 60% and 50% of the light respectively.

At the extreme of 80^o angle of incidence of the light source, metallic paints reflect back more than 70% and 80% of the incident light, depending on the colour, while an ordinary car windshield reflects 45% on average. In the visible range and the same angle, PVs have optimum optical characteristics and the average reflectivity level was measured below 30% for most wavelengths.

The reflectivity measurements from the PV module samples were compared and found to be in accordance with published measurements from other research institutions performing similar work.

6 ACKNOWLEDGEMENT

The scientific work presented in this paper was performed by the two authors in 2002 during their employment at CRES – Centre for Renewable Energy Sources, Department of Photovoltaic & Hybrid Systems, see details in: www.cres.gr.

All laboratory equipment and devices used for the determination of the reflectivity levels of the surfaces under evaluation belong to CRES. The full report is CRES–PV–002/2002 and is available in Greek language through the internet.

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