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# PV cells enhancement using nanostructured materials

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### Abstract

Renewable resources have infinite potential for sustainable energy. An inexhaustible and abundant renewable resource is the solar energy. One of the finest ways to harness the solar energy is photovoltaic systems (PV). They are commonly used in industrial and commercial buildings in order to reduce the energy costs and contribute to the global demand of $CO_2$ reduction. Nanotechnology is regarded as key technology for improvements in PV cells. The use of nanostructured materials could give a boost in the improvement of the efficiency of PV cells. Commercial polycrystalline cells are tested before and after coating process for both visible and UV light. Silicon nanoparticles and Silicon Oxide are applied to polycrystalline cells via Plasma Enhanced Chemical Vapour Deposition (PECVD). The electrical performance of the coated cells is compared with that of the uncoated cells. Moreover, structure and composition analysis are held. The results proved that both of the used nanoparticles may increased the band gap of the cells as it was observed an improvement on the performance characteristics.

**Keywords:** Photovoltaics, nanoparticles, Plasma Enhanced Chemical Vapor Deposition (PECVD), Silicon Oxide.

### Introduction

It has been observed that the global energy demands have increased outstandingly. Moreover, the greenhouse gases due to the use of conventional ways of energy production have resulted in remarkable adverse effects to the environment and to the climate as well. Meanwhile, according to the 2009 Renewable Energy Directive, it is out of great importance that the carbon emissions to be diminished by 20% and the goal of 20% energy consumption by using renewable resources has to be achieved until 2020 (European Parliament and the Council of the European Union, 2009). Thus, there is an imperative need, the research interest to be focused on clean and green solution to be followed for a more sustainable environment. Renewable resources have infinite potential for sustainable energy. One of the most effectively inexhaustible and abundant renewable resource is the solar energy and one of the finest ways to harness the solar energy is the photovoltaic systems. Their principle is to divert directly the sunlight into electricity. Hence, a clean and a climate friendly resource is offered (Z Dehouche, M Kolokotroni, 2011) (IEA, 2011). By improving their efficiency, PV systems could be more cost-effective and therefore, more attractive solutions for the energy production because this will lead to a significant cost reduction. Nanotechnology is regarded as key technology for technological improvements in many fields of technology. The use of nanostructured materials could give a boost in the improvement of the efficiency of PV systems ( L Wolfgang, 2008). There is also further help by the fact that nanostructures have low fabrication cost (Ch B Honsberg et al., 2006). Several nanostructured materials coat the PV cells in order to enhance their efficiency ( L Wolfgang, 2008).

**Nanostructured-based concepts**

The goal that should be achieved is to exceed the Shockley-Queisser limit (W Shockley, H J Queisser, 1961). There are several concepts that have been researched in order to evaluate the possibility to achieve this goal. The “third Generation” of PV cells, which is based on nanotechnology, is the Generation that has a great potential due to its novel band structures to reach higher efficiencies than the previous two generations, Generation I and Generation II. The Generation I PV cells are consisted of bulk silicon PV cells while Generation II PV cells are the thin film PV cells (L Tsakalakos, 2008).

Nowadays there has been a significant amount of researches for several types of nanostructures that could be applied to PV cells. These types are categorized into four types; the nanocomposites, a 3D structure, the quantum wells, a 2D structure, nanowires and nanotubes, a 1D structure and finally the nanoparticles and quantum dots, 0D structure(L Tsakalakos, 2008). This project investigated the use of nanoparticles and quantum dots in the performance of PV cells. The processes that are widely used to apply quantum dots on PV cells are low cost processes such as, chemical vapor deposition, electrochemical deposition, and sputtering. Further research in the control of the size, shape and location of the nanoparticles are also required for higher efficiencies and lower costs (L Tsakalakos, 2008). One major challenge is the control of the interaction between the donor-acceptor materials, in other words how the materials of the PV cells reacts to the nanoparticles that are applied on them (Y Wang, G Scarpa et al, 2009).

**Methodology and Equipment**

The methodology followed in order to perform the research of the effects that nanoparticles have the potential to cause on the PV cells, was initially to investigate the results from three coated PV cells but each with different nanoparticles. These polycrystalline PV cells from the company Gintech was coated by Diamond-like carbon (DLC) coating that produce a Silicon carbon layer, by Silicon nanoparticles with the use of Tetramethylsilane (TMS-$Si(CH_3)_4$) as a precursor and by Silicon Oxide by using TMS and potassium permanganate ($KMnO_4$) as precursors. The coating process was done with the Plasma Enhanced Chemical Vapor Deposition (PECVD) technique. The PV cells, before and after coating were exposed to visible and Ultraviolet (UV) light and the I-V curves as well as the maximum power output were obtained. Their electrical characteristics were tested on a light box, which by the use of Fresnel lens and a mirror send a beam of the visible light (halogen 50W lamp) to a hole where the PV cell is located and connected by wires with the Array Electronics load. The Array Electronics load has the potential to be simultaneously a voltmeter, ammeter and a variable resistance. The same procedure were followed for the UV light but the tested part of the PV cell was exposed directly to the UV light (75W lamp) without the lens as UV light in general does not travels through the lens. A comparison between the electrical performance of the three coated PV cells was evaluated and the nanoparticle that gave the better results was used for further investigations. Another three PV cells, multicrystalline, from Q.cells company were coated with Silicon Oxide but this time the coating conditions under the PECVD technique was changed as far as the time of deposition and the grams of $KMnO_4$ are concerned. The dependence of the open circuit voltage (Voc) to the solar irradiance was investigated for both coated and uncoated cells. Moreover, the changes of the PV cells' reflectance that the coating layers caused were tested by the UV/Vis Spectroscpy as well as the surface and the composition analysis were done by the Scanning Electron Microscopy (SEM)

**Results**

The experiments commenced with the Gintech company PV cells. The results showed that the power output and the efficiency of them were increased in all of the coating cases. The figure 1 shows the results that obtained for each different coating in comparison with an uncoated Gintech PV cell. The best enhancement in the efficiency was achieved by the Silicon Oxide coated PV cell as an increase of 0.6% was observed. Meanwhile the temperature coefficient of the coated PV cell droped by 0.10%.

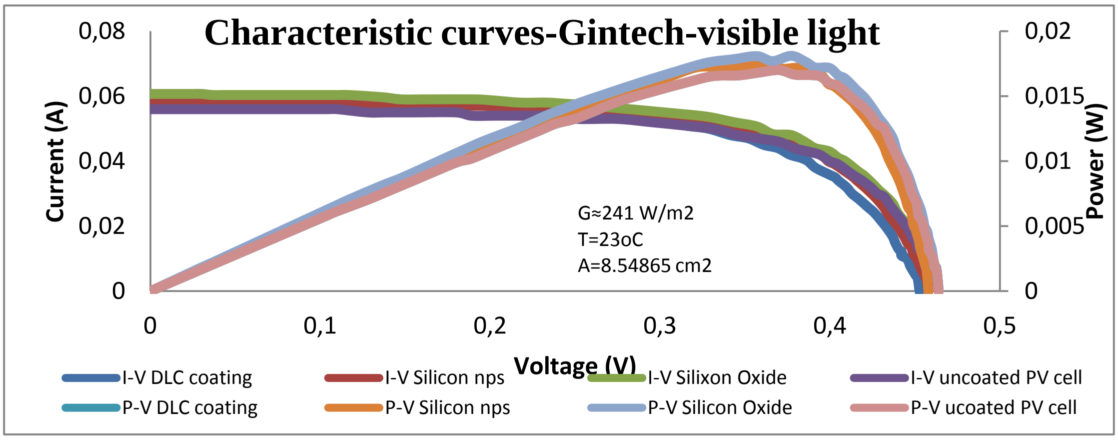


Figure 1: Characteristic curves of Gintech polycrystalline PV cells before and after coating under visible light

As far as the experiments that held under UV light, the Silicon Oxide layer gave better and a significant enhancement. The efficiency of the PV cell was increased by 2.71% while with the Silicon nanoparticles a 1.47% rise was observed. Additionally to these results, the Fill Factors (FF) of the coated PV cells were increased in both these situation. However the increase in the efficiency with the DLC coating (0.97%), the FF remained the same.

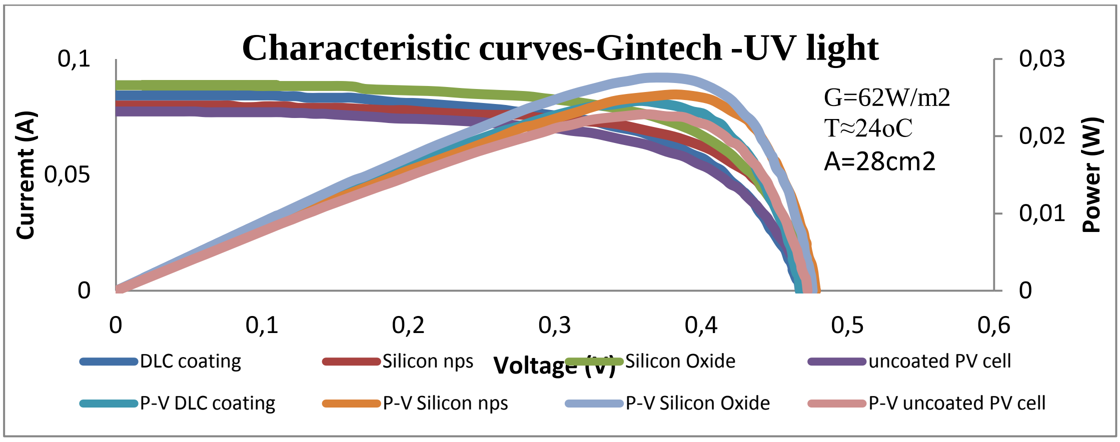


Figure 2:Characteristic curves of Gintech polycrystalline PV cells under UV light

The PV cells from the Q.cells company was measured under visible light and was observed that they had higher efficiency than the Gintech PV cells. The characteristic curves that occurred after the coated processes were shown in the figure 3 and the one that a 10gr of $KMnO_4$ was used as precursor presented the best enhancement. However the fact that the more time of deposition into the PECVD chamber resulted in the same enhancement in the efficiency of the coated PV cells (Gintech PV cell coated with Silicon Oxide with 10gr of $KMnO_4$ and10 minutes deposition, Q.cells PV cell coated with Silicon Oxide with 10gr of $KMnO_4$ but15 minutes deposition), the general performance of the Q.cells coated PV cell were became worse as the FF and the temperature coefficients dropped significantly.

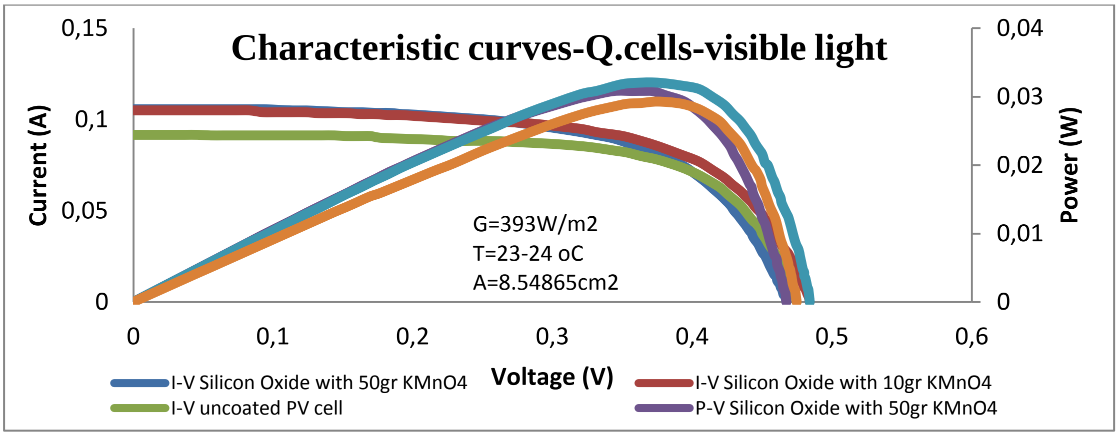


Figure 3:Characteristic curves of Q.cells multicrystalline PV cells under visible light

According to the results, the performance of the coated PV cells from the Q.cells company under the UV light were not as good as the ones observed for Gintech PV cells. An enhancement of 0.79% was found for the one coated with the precursor of 10gr $KMnO_4$ while a rise of 0.70% was measured for the other with the precursor of 50gr of $KMnO_4$. Similarly to the results under the visible light, the temperature coefficients also were increased.

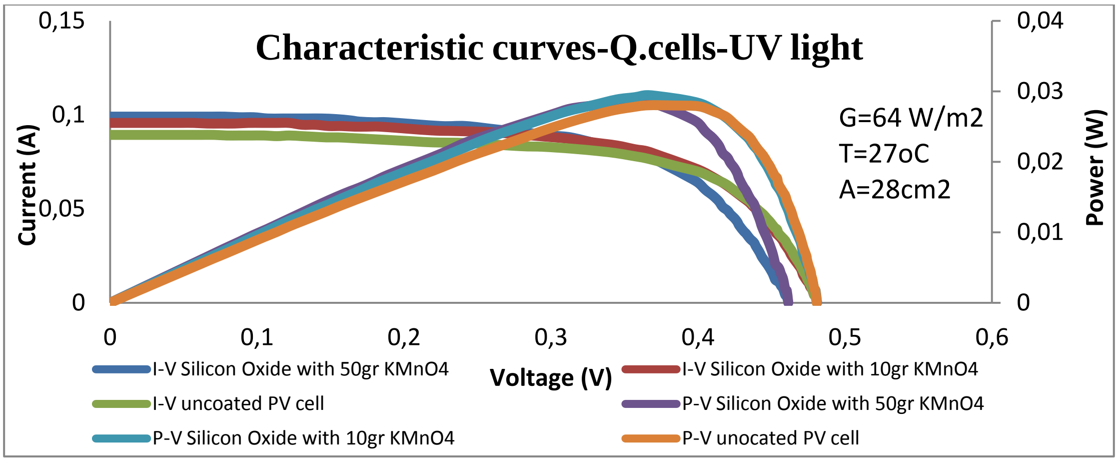


Figure 4: Characteristic curves of Q.cells multicrystalline PV cells under UV light

Hence, the general performance of this PV cells presented an improvement. This was clear also by its reflectance that observed to be diminished remarkably in the UV wavelengths (200nm-400nm). The uniformity of the coating layer was not remained in the whole surface of the PV cells as differences in color occurred. The two PV cells with the better enhancement were tested by the SEM. It was proved that the coating process was successful in both situations (Gintech and Q.cells PV cells with Silicon Oxide and 10gr of $KMnO_4$ as a precursor). A coating layer observed on the surface of the Gintech coated PV cell with thickness between 10.99μm to 16μm. In addition, an amount of 11.45% of Oxygen appeared on this layer. On the other hand, an amount of 7.12% of Oxygen was found on the surface of the coated Q.cells PV cell and the thickness of the layer was not possible to be measured. However, the image of the surfaces did not present visible difference.

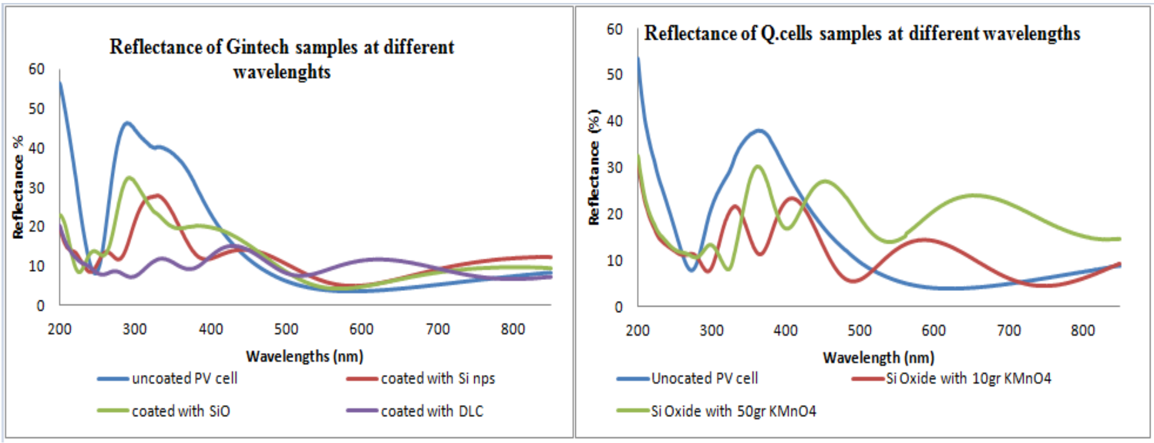


Figure 5: Changes in the reflectance of PV cells before and after coating for Gintech and Q.cells

The dependence of the voltage from the irradiance is shown in figure 6 where the Voc of the coated and uncoated PV cell was tested under various irradiances. It was observed that the coating layers did not change the behavior of the PV cell's Voc under different irradiance. These results refer to each PV cell independently their company. The figure presents the behavior of the Gintech PV cell that finally had the better enhancement among every tested cell.

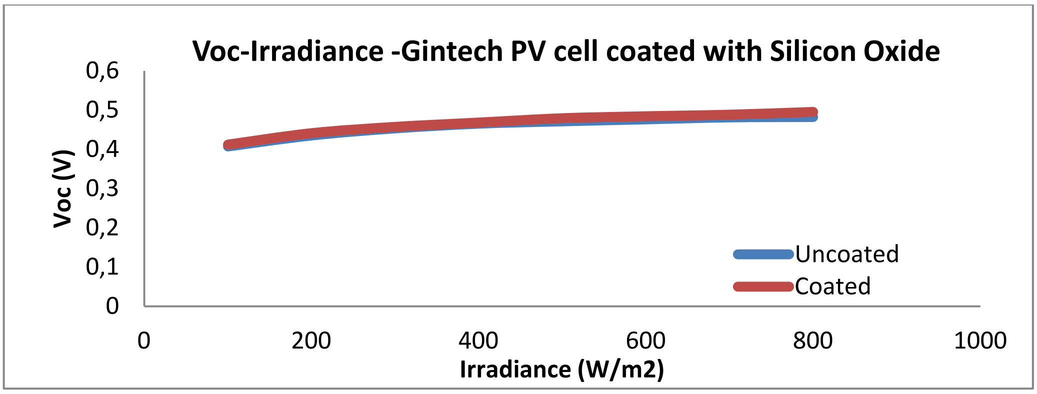


Figure 6: Open circuit voltage dependence from solar irradiance for the Gintech polycrystalline PV cell

## Conclusions

The use of nanoparticles for coating the surface of the PV cells proved to introduce an increase as far as their efficiency is concerned. In particular, the Silicon Oxide gives a substantial enhancement of its general performance as not only the efficiency was increased but the FF as well, whilst the temperature coefficients dropped. The absorption of the PV cells is increased and hence more energy is produced.

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