Light Harvesting Through Citrus × Aurantium Leaf Textured Films

Khurshid Ahmad*, Salman Manzoor†, Abdus Saboor Ahmad‡

Abstract

Reflection losses in solar energy harvesting devices need to be reduced for increasing their efficiencies. One of the fascinating ideas could be the use of bioinspired surfaces. In this study, we have used the textures found on the leaf of citrus × aurantium (CA) for reduction of the reflection losses and increasing light harvesting efficiency. The results showed that CA leaf-textured surfaces can reduce the reflection losses for almost all wavelengths in the range of 300 nm to 1200 nm. External quantum efficiency measurements revealed that these textures can considerably increase the efficiency within the wave length range of 400 nm to 600 nm.

Keywords: Photovoltaics; Nano-textures; Efficiency; Reflection; Scattering.

Introduction

Photovoltaic cells are one of the fast growing sources of power generation around the world (Saga, 2010). As the solar market is growing, research for finding new solar cell materials, novel solar cell designs and improving efficiency is also underway with a rapid pace (De Wolf et al., 2012; Holman et al., 2012; X. Huang et al., 2017; Zhao et al., 2016). So far, Silicon based solar cells has been successfully deployed in most of parts of the world. Currently, a large number of efforts are directed towards improving the power conversion efficiency of the cells (De Wolf et al., 2012; Green, 2009; Holman et al., 2012). One of the key methods to improve the efficiency of the existing solar cells is the proper light management. Previous research has shown that surface textures can improve solar cell light management and power conversion efficiency (Manzoor et al., 2017). Pyramid textures obtained through chemical etching of silicon wafers, have been successfully used for boosting the efficiency of the solar cells (Bailey et al., 1979; Chu et al., 2009; Saga, 2010; Vazsonyi et al., 1999). It has also been found that PDMS replica of the silicon surface textures can be used for increasing the power conversion efficiency of the solar cells which lack the pyramid textures on the front side (Manzoor et al., 2017). Apart from the silicon pyramid textures several other types of textures have been used for improving the

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*Corresponding Author: US Pakistan Center for Advanced Studies in Energy, University of Engineering and Technology Peshawar, Peshawar 25000, Pakistan, engrkhurshid@gmail.com

†School of Electrical, Department of Computer and Energy Engineering, Arizona State University, Arizona 85287-5706, United States, salman.manzoor@asu.edu

‡Department of Computer System Engineering, University of Engineering and Technology Peshawar, Peshawar 25000, Pakistan, abdussaboor@uetpeshawar.edu.pk

light management and efficiency which include nanowires, random textures, pyramids etc. (Anttu & Xu, 2013; Brongersma et al., 2014; Schneider et al., 2014; Sivasubramaniam & Alkaisi, 2014).

Recently, the bioinspired surfaces have drawn worldwide attention due its enhanced capabilities including properties like super hydrophobicity, strength, enhanced wear resistance, light scattering etc. (Ahmad et al., 2017; Boden & Bagnall, 2010; Han et al., 2012; Munch et al., 2008; Nishimoto & Bhushan, 2013; Schmager et al., 2017; Wegst et al., 2015). It could be interesting to mimic natural designs and textures from animals and plant surfaces for enhancing solar energy harvesting efficiency of devices including solar cells. Such surfaces may include replicas of moth eye skin, butterfly wing and viola flower (Boden & Bagnall, 2010; Han et al., 2012; Schmager et al., 2017). It has been found that the naturally inspired textures enhance the power conversion efficiency (Schmager et al., 2017). Plant leaves, petals and flowers inhere textures which could be helpful in better light management. Therefore, we have studied the effect of CA leaf textured PDMS film on reflection losses, light scattering through these textures and power conversion efficiency. The results are discussed in the following sections.

Materials and Methods

Polydimethylsiloxane (PDMS), Spectrometer (PerkinElmer Lambda 950), External quantum efficiency (EQE) tool (QEX10), Digital Microscope (Olympus), Plant Leaf (citrus × aurantium), De-ionized (DI) water.

Sample Preparation

Single leaf of citrus × aurantium (CA) was cut into pieces. The leaf pieces were thoroughly rinsed with DI water. Each of them was cleaned in ultrasonic sonication bath for three minutes. The leaf samples were dried using clean compressed air. The leaf samples were placed in a petri dish. Afterwards, the PDMS and co-binder were mixed in a 10:1 (w/w) ratio and poured on to the leaf in the petri dish. The solution was cured at room temperature for 24 hours. The leaf as well as the negative replica of the leaf were examined using digital microscope (Olympus, Japan). The digital images of the CA leaf textures and the PDMS replica are given in Figure 1. The digital images show a number of random textures on the CA leaf imprinted on the PDMS film.

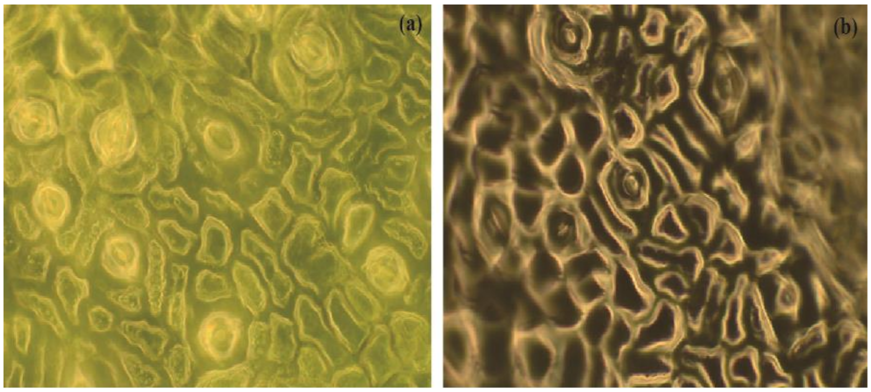

Figure 1: (a) CA leaf textures (b) Negative PDMS replica of CA leaf textures.

Results and Discussion

Reflectance and Scattering Measurements

The reflection from a polished silicon wafer with and without the CA leaf textured PDMS was measured using PerkinElmer Lambda 950 spectrophotometer. The wave length range varied from 300 nm to 1200 nm. The results are given in Figure 2.

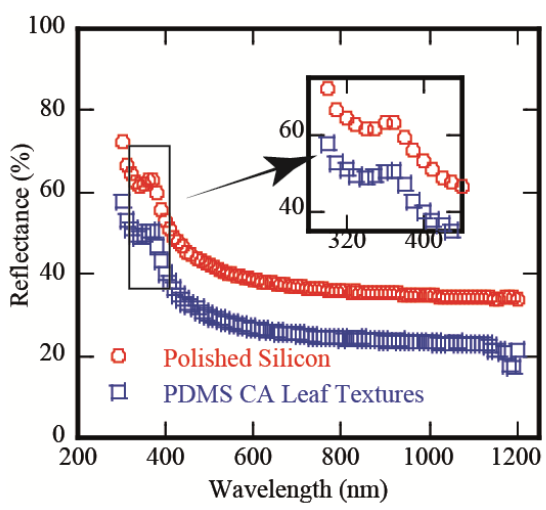

Figure 2: Reflectance from clear glass with and without the CA leaf textured PDMS film.

It can be seen in Figure 2 that the reflectance has been significantly reduced (blue line) through the use of textured PDMS film. The results also suggest that the reflectance has been reduced for almost all of the wavelengths in the range of 300 nm to 1200 nm. An automated reflectance/ transmittance analyzer (ARTA) was used to find the angular-resolved reflectance through a clear glass slide and a glass slide covered with the CA leaf textured PDMS, over and angular range of -60º to 60º. The results are given in Figure 3. The results suggest that the textured film enhance the scattering. Unlike the clear glass, reflection has been detected in the range of -20º – 20º. However, the light scattering is not high enough as compared to other textures (Manzoor et al., 2017).

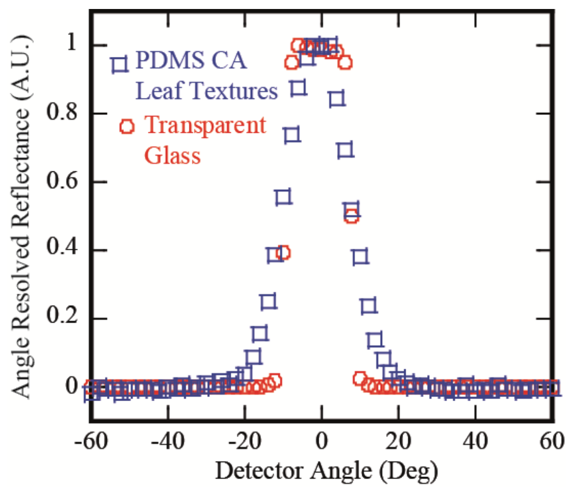

Figure 3: Angle resolved reflectance from clear glass with and without the CA leaf textured PDMS film.

External Quantum Efficiency Measurements:

The external quantum efficiency (EQE) of non-textured silicon solar cell with and without the CA leaf textured PDMS was measured with the help of QEX 10. Firstly, the EQE of the silicon solar cell without any textures was measured. Afterward, the textured PDMS was placed on the solar cell. Cares were exercised to remove any trapped air in between the solar cell and the textured PDMS. The PDMS was used without applying and refractive index matching fluid. The light wave length for the EQE measurements ranged from 300 nm to 1200 nm. The results are shown in Figure 4.

It is evident from Figure 4 that the efficiency of the non-textured solar cell has been increased by the use of textured PDMS. The EQE has been considerably increased for the wave length range of 400 nm to 600 nm. In this study we used the CA leaf PMDS negative replica for improving the light scattering, reducing the reflectance and increasing the efficiency. The experimental data collected showed that all these parameters could be enhanced satisfactorily by the use of similar textures. This could be attributed to the random textures of the CA leaf. Such type of surface could be used for improving the efficiency of cells and other solar harvesting devices by reducing the reflection losses (Schmager et al., 2017).

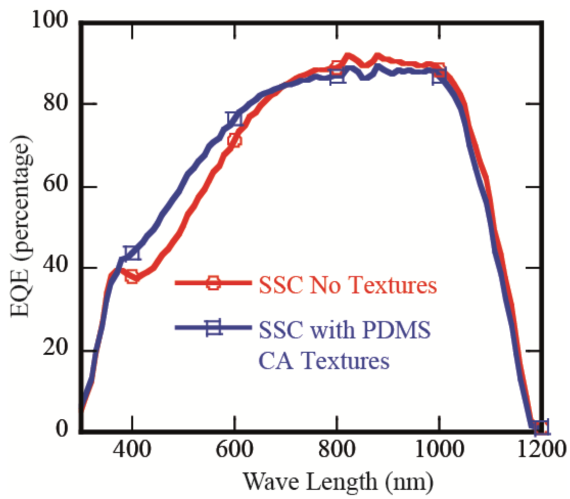

Figure 4. External quantum efficiency of non-texture solar cell with and without the CA leaf textured PDMS film. Where SSC stands for silicon solar cell.

Comparison of External Quantum Efficiency

Results of previous studies show that pyramid-structured surfaces which are used in solar cells has an external quantum efficiency (EQE) comparable to the efficiency of the CA replica solar cells. However, production of pyramid-structured surfaces is comparatively a time consuming, costly, and complex process as compared to CA replica production. In the same way, it has been noted that fabrication of silicon nanowires surfaces also have challenging, expensive, and time-intensive procedures (Yu et al., 2018). In comparison of textured and non-textured surfaces enhancement in quantum efficiency of textured surfaces compared with silicon nanostructures cells can be seen (Parsons et al., 2017). Results show that moth-eye inspired surfaces reduce the reflection of light, and these surfaces can be used in production of antireflecting coatings, these surfaces have been used for enhancing the power conversion efficiency of the solar PV cells. Leaf structures mimicking method has been used for enhancing the efficiency and reported 17% gain in PV efficiency (Ahn et al., 2012; Wilson & Hutley, 1982). Replication is a cost-effective and versatile approach for fabrication of efficient solar harvesting systems. Rose petal replica has been used for enhancing efficiency of solar energy harvesting systems (Powalla et al., 2016). Similarly it has been noted that leaf surfaces replication can enhance the efficiency of light harvesting systems (Z. Huang et al., 2015).

Conclusion

Bioinspired textured surfaces can be helpful in reducing the reflection losses that occur in solar energy harvesting devices like solar cells Random textures found on the CA leaf can help in reducing the reflection losses from the solar cell surfaces. These textures can also improve the power conversion efficiency of the solar cell. Such textures are more effective for light wave lengths ranged from 400 nm to 600 nm.

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References

Ahmad, K., Zhao, X., & Pan, Y. (2017). Effect of surface morphology on measurement and interpretation of boundary slip on superhydrophobic surfaces. *Surface and Interface Analysis, 49*(7), 594-598.

Ahn, H.-J., Kim, S.-I., Yoon, J.-C., Lee, J.-S., & Jang, J.-H. (2012). Power conversion efficiency enhancement based on the bio-inspired hierarchical antireflection layer in dye sensitized solar cells. *Nanoscale, 4*(15), 4464-4469.

Anttu, N., & Xu, H. (2013). Efficient light management in vertical nanowire arrays for photovoltaics. *Optics express, 21*(103), A558-A575.

Bailey, W. L., Coleman, M. G., Harris, C. B., & Lesk, I. A. (1979). Texture etching of silicon: method: Google Patents.

Boden, S. A., & Bagnall, D. M. (2010). Optimization of moth-eye antireflection schemes for silicon solar cells. *Progress in photovoltaics: research and applications, 18*(3), 195-203.

Brongersma, M. L., Cui, Y., & Fan, S. (2014). Light management for photovoltaics using high-index nanostructures. *Nature materials, 13*(5), 451-460.

Chu, A., Wang, J., Tsai, Z., & Lee, C. (2009). A simple and cost-effective approach for fabricating pyramids on crystalline silicon wafers. *Solar energy materials and solar cells, 93*(8), 1276-1280.

De Wolf, S., Descoeudres, A., Holman, Z. C., & Ballif, C. (2012). High-efficiency silicon heterojunction solar cells: A review. *green, 2*(1), 7-24.

Green, M. A. (2009). The path to 25% silicon solar cell efficiency: History of silicon cell evolution. *Progress in photovoltaics: research and applications, 17*(3), 183-189.

Han, Z., Niu, S., Shang, C., Liu, Z., & Ren, L. (2012). Light trapping structures in wing scales of butterfly Trogonoptera brookiana. *Nanoscale, 4*(9), 2879-2883.

Holman, Z. C., Descoeudres, A., Barraud, L., Fernandez, F. Z., Seif, J. P., De Wolf, S., & Ballif, C. (2012). Current losses at the front of silicon heterojunction solar cells. *IEEE journal of Photovoltaics, 2*(1), 7-15.

Huang, X., Fu, H., Chen, H., Zhang, X., Lu, Z., Montes, J., Iza, M., DenBaars, S. P., Nakamura, S., & Zhao, Y. (2017). Nonpolar and semipolar InGaN/GaN multiple-quantum-well solar cells with improved carrier collection efficiency. *Applied Physics Letters, 110*(16).

Huang, Z., Yang, S., Zhang, H., Zhang, M., & Cao, W. (2015). Replication of leaf surface structures for light harvesting. *Scientific reports, 5*(1), 14281.

Manzoor, S., Zhengshan, J. Y., Ali, A., Ali, W., Bush, K. A., Palmstrom, A. F., Bent, S. F., McGehee, M. D., & Holman, Z. C. (2017). Improved light management in planar silicon and perovskite solar cells using PDMS scattering layer. *Solar energy materials and solar cells, 173*, 59-65.

Munch, E., Launey, M. E., Alsem, D. H., Saiz, E., Tomsia, A. P., & Ritchie, R. O. (2008). Tough, bio-inspired hybrid materials. *Science, 322*(5907), 1516-1520.

Nishimoto, S., & Bhushan, B. (2013). Bioinspired self-cleaning surfaces with superhydrophobicity, superoleophobicity, and superhydrophilicity. *Rsc Advances, 3*(3), 671-690.

Parsons, R., Tamang, A., Jovanov, V., Wagner, V., & Knipp, D. (2017). Comparison of light trapping in silicon nanowire and surface textured thin-film solar cells. *Applied Sciences, 7*(4), 427.

Powalla, M., Lemmer, U., Colsmann, A., & Gomard, G. (2016). Plant epidermal structures for enhanced sunlight harvesting in solar cells. *SPIE Newsroom, 10*(2.1201611), 006701.

Saga, T. (2010). Advances in crystalline silicon solar cell technology for industrial mass production. *npg asia materials, 2*(3), 96-102.

Schmager, R., Fritz, B., Hünig, R., Ding, K., Lemmer, U., Richards, B. S., Gomard, G., & Paetzold, U. W. (2017). Texture of the viola flower for light harvesting in photovoltaics. *ACS photonics, 4*(11), 2687-2692.

Schneider, B. W., Lal, N. N., Baker-Finch, S., & White, T. P. (2014). Pyramidal surface textures for light trapping and antireflection in perovskite-on-silicon tandem solar cells. *Optics express, 22*(106), A1422-A1430.

Sivasubramaniam, S., & Alkaisi, M. M. (2014). Inverted nanopyramid texturing for silicon solar cells using interference lithography. *Microelectronic Engineering, 119*, 146-150.

Vazsonyi, E., De Clercq, K., Einhaus, R., Van Kerschaver, E., Said, K., Poortmans, J., Szlufcik, J., & Nijs, J. (1999). Improved anisotropic etching process for industrial texturing of silicon solar cells. *Solar energy materials and solar cells, 57*(2), 179-188.

Wegst, U. G., Bai, H., Saiz, E., Tomsia, A. P., & Ritchie, R. O. (2015). Bioinspired structural materials. *Nature materials, 14*(1), 23-36.

Wilson, S., & Hutley, M. (1982). The optical properties of'moth eye'antireflection surfaces. *Optica Acta: International Journal of Optics, 29*(7), 993-1009.

Yu, L., Batmunkh, M., Dadkhah, M., Shearer, C. J., & Shapter, J. G. (2018). Pyramid-Textured Antireflective Silicon Surface In Graphene Oxide/Single-Wall Carbon Nanotube–Silicon Heterojunction Solar Cells. *Energy & Environmental Materials, 1*(4), 232-240.

Zhao, Y., Boccard, M., Liu, S., Becker, J., Zhao, X.-H., Campbell, C. M., Suarez, E., Lassise, M. B., Holman, Z., & Zhang, Y.-H. (2016). Monocrystalline CdTe solar cells with open-circuit voltage over 1 V and efficiency of 17%. *Nature Energy, 1*(6), 1-7.