IFERP
connecting engineers... developing research

ISSN (Online) 2394-6849

International Journal of Engineering Research in Electronics and Communication Engineering (IJERECE)
Vol 4, Issue 8, August 2017

Photonic Crystal Based Solar cells

[1] Dr Vijay Janyani
MNIT Jaipur

1. Photonic Crystals as light trapping structures

One of the prominent approaches being explored is thin film solar cell (TFSC) technology, which offers prospects of lower material costs and enables larger units of manufacture than conventional wafer based technology. However, TFSC technologies suffer from one major problem; they have lower efficiencies than conventional wafer based solar cell technologies. This lesser efficiency is based on a number of reasons, one of which is that with less material, there is less volume for the absorption of incident photons. This shortcoming leads to the need for optical light trapping; which is concerned with admitting the maximum amount of light into the solar cell and keeping the light within the structure for as long as possible. In practice, no structure is ideally reflective over all wavelengths, however it is possible to get a structure that is effective at reflecting at least the band we are most interested in, i.e., close to the silicon band edge.

A photonic crystal (Fig. 1) is a periodic arrangement of dielectric or metallic materials with a lattice constant comparable to the wavelength of an electromagnetic wave. The simplest example is a 1DPhC, where alternating layers of material with different refractive indices are stacked to form a structure that is periodic along one direction. The interaction of an electromagnetic wave with a periodic dielectric structure results in an interference pattern that allows for some light to propagate or be reflected from the different layers of the structure. This phenomenon is described in a band structure, which maps out the range of frequencies that are permitted to propagate and those that are disallowed. The parameters that determine the band structure are the refractive index contrast and thicknesses of the corresponding layers [1-3]. One dimensional photonic crystal finds many applications including, functioning as high reflectance mirrors and selective light filters. Early work on the incorporation of photonic crystals into solar cells to enhance light trapping was performed by James Gee [4] who put forth the idea that the statistical limit for optical enhancement, shown by Yablonovitch to be 4n2 (where n is the refractive index of the material - about 50 for silicon), could be surpassed over a narrow spectral and angular range using photonic band gap materials. More recently several groups have also been working on combining photonic crystals with gratings to enhance the light trapping capabilities of solar cells [5].

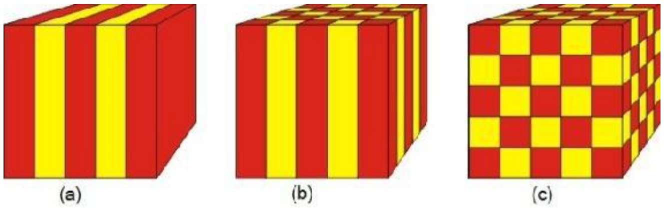
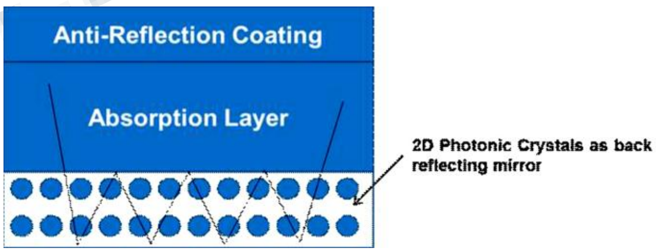


Figure 1. (a) 1-D Phtonic crystal structure, (b) 2-D photonic crystal structure, (c) 3-D photonic crystal structure

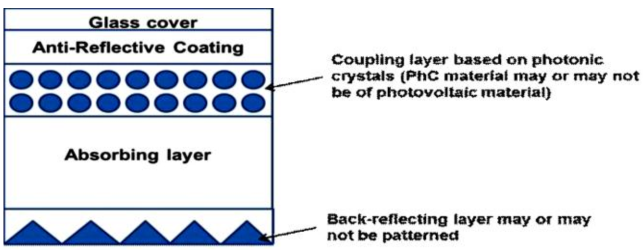
2. Various light trapping designs using photonic crystals [6, 7]

Researchers in this field created many designs, in which photonic crystals were implemented in different ways to enhance absorption of incident solar spectrum.

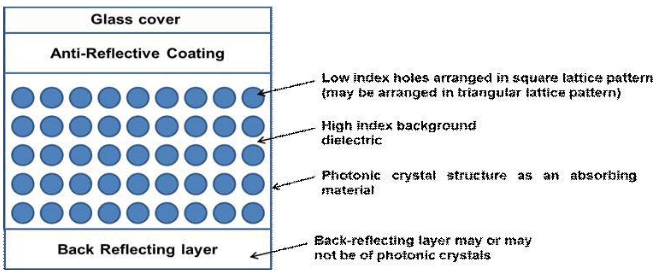
i. PhC as back reflector



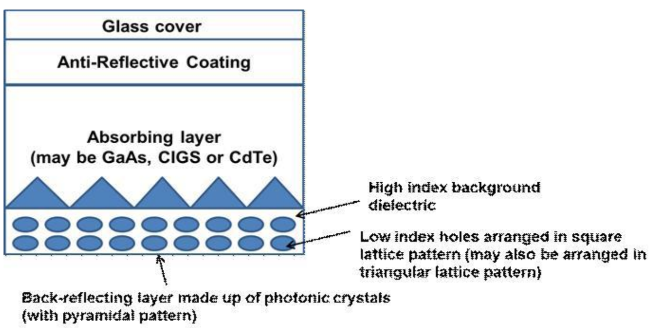
ii. PhC at top for increased transmission and better coupling of incident light



iii. PhC as absorbing material



iv. PhC in combination with texture pyramidal structure as back reflector



3. Results and Conclusion

N.D. Gupta and Vijay Janyani achieved a conversion efficiency of 26.3 % for a thin film GaAs solar cell in which photonic crystal is used on top of the solar cell [8]. The photonic crystal structure as light trapping scheme thus helps solve a most fundamental problem faced by all thin film photovoltaic devices, i.e., how to efficiently harness incident sunlight. This problem directly relates to the efficiency of devices, material usage and overall associated costs. Thin film solar cell technologies are still yet to reach their full potential, typical efficiencies range from between 10 – 18% for commercial products as opposed to 26% for the best available silicon wafer based modules [9-11]. In theory, efficiencies of up to 26% are possible for very thin (< 10 micron) silicon solar cells. In a more recent work, Abhinav Bhatnagar and Vijay Janyani demonstrated theoretical conversion efficiency even higher that the Shockely Queisser limit (SQ) of 33% for an ultra thin film GaAs solar cell which utilizes a combination of PhC and textured pyramidal structure at the back to enhance photon recycling [12].

REFERENCES

[1] J. G. Mutitu, S. Shi, C. Chen, T. Creazzo, A. Barnett, C. Honsberg and D. W. Prather, "Thin film silicon solar cell design based on photonic crystal and diffractive grating structures," Optics Express, vol. 16, pp. 15238-15248, 2008.

[2] J. D. Joannopoulos, S. G. .Johnson, J. N. Winn and R. D. Meade, Photonic Crystals: Molding the Flow of Light. ,2nd ed.Princeton University Press, 2008.

[3] D. W. Prather, S. Shi, A. Sharkawy, J. Murakowski and G. Schneider, Photonic Crystals: Theory Applications and Fabrication. John Wiley and Sons, 2009.

[4] Zeng, L., Bermel, P., Yi, Y., Alamariu, B. A., Broderick, K. A., Liu, J., Hong, C., Duan, X., Joannopoulos, J. and Kimerling, L. C., "Demonstration of enhanced absorption in thin film Si solar cells with textured photonic crystal back reflector," Appl. Phys. Lett. 93, 221105 (2008).

[5] Bielawny, A., Rockstuhl, C., Lederer, F., and Wehrspohn, R. B., "Intermediate reflectors for enhanced top cell performance in photovoltaic thin-film tandem cells," Opt. Expr.17, 8439 (2009).

[6] N. D. Gupta and V. Janyani, "Optical and Electrical Simulation Studies of Light Trapping in GaAs Thin Film Solar Cells Using 2D Photonic-Crystal," Journal of Nanoelectronics and Optoelectronics, vol. 11, no. 3, pp. 368- 376, 2016.

[7] K. Ishizaki, A. Motohira, M. De Zoysa, Y. Tanaka, T. Umeda and S. Noda, "Microcrystalline-Silicon Solar Cells With Photonic Crystals on the Top Surface," in IEEE Journal of Photovoltaics, vol. 7, no. 4, pp. 950-956, July 2017. doi: 10.1109/JPHOTOV.2017.2695524.

[8] N. D. Gupta and V. Janyani, "Design and Analysis of Light Trapping in Thin Film GaAs Solar Cells Using 2-D Photonic Crystal Structures at Front Surface," in IEEE Journal of Quantum Electronics, vol. 53, no. 2, pp. 1-9, April 2017, doi: 10.1109/JQE.2017.2667638.

[9] M. A. Green, K. Emery, Y. Hishikawa and W. Warta, "Solar cell efficiency tables (Version 33)," ProgPhotovoltaics Res Appl, vol. 17, pp. 85-94, 2009.

ISSN (Online) 2394-6849

International Journal of Engineering Research in Electronics and Communication Engineering (IJERECE)
Vol 4, Issue 8, August 2017

[10] Namwoo Kim et al., “18.4%-Efficient Heterojunction Si Solar Cells Using Optimized ITO/Top Electrode”, ACS Appl. Mater. Interfaces, 2016, 8 (18), pp 11412–11417, DOI: 10.1021/acsami.6b00981.

[11] M. A. Green, K. Emery, Y. Hishikawa, W. Warta,E. D. Dunlop, Solar cell efficiency tables (version 45).Prog.Photovolt. Res. Appl. 23, 1–9 (2015), doi: 10.1002/pip.2573.

[12] Abhinav Bhatnagar and Vijay Janyani, “Cost Effective and High-Power Conversion Efficiency Ultra-Thin Film GaAs Solar Cell”, in IEEE International Conference – COMPTELIX July 2017 (Accepted).