Numerical study of efficiency enhancement of nanostructured Silicon-Perovskite tandem thin film solar cells.

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***Abstract*—Solar cells are one of the most promising sustainable, renewable and clean energy sources. Reflection loss is one of the major concerns in thin film solar cells technology. Nano-structuring of the top surface is one of the best methods to reduce the solar cell's reflection losses. Tandem technology enhances the absorption of sunlight in a broad spectrum. Nanostructured Si-Perovskite tandem thin film solar cells significantly improve the absorption efficiency of solar cells. Perovskite materials play an important role in solar cell technology due to their low cost and highly efficient materials. The major advantages of using perovskite (ABX_3) structure-type materials are the flexibility and tunability of the bandgap by changing the element components of the materials. In this paper, we study a silicon-perovskite heterostructure for tandem thin film solar cells where we incorporate the square and triangular lattice nanostructured pattern with parabolic morphology to enhance the optical absorption efficiency of solar cells.**

Keywords—Nano-structuring, tandem thin film solar cells, heterostructure, Si-Perovskite tandem solar cells, absorption, tunability, flexibility, parabolic morphology.

I. Introduction

Perovskite-silicon-based tandem solar cells have gained significant contributions due to their high power conversion efficiency (PCE) in photovoltaics industries. The solar cell is one of the best techniques to convert renewable energy into electricity. The low cost and highly efficient solar cells play a crucial role in the industrialization of solar cell based technology. Conventional solar cells are based on silicon materials. Nanostructured silicon perovskite tandem thin film solar cell have significant contribution to reduce the reflection losses and improve the overall efficiency of a tandem solar cells [1]. According to the Shockley-Queisser limit, the maximum efficiency of 33.16% can be attained by considering all the radiation losses at the top and bottom surface of the solar cells at the energy bandgap of 1.34 eV for a single junction solar cell [2]. The efficiency of tandem solar cell technology can go beyond the Shockley-Queisser limit. In tandem solar cells, the upper active material has a high energy band gap, and the lower material has a low energy band gap. Si-Perovskite tandem thin film solar cells have much demand due to their high efficiency, low production cost, and high reliability. The structuring of the surfaces play a major role in absorption of sunlight. Methyl ammonium mixed bromide-iodide lead perovskite materials are commonly used as a perovskite materials in tandem solar cells [3]. There are many numerical studies show that the significant enhancement in the efficiency of the silicon-perovskite tandem solar cell [4]. The photon management in the silicon perovskite tandem thin film solar cells can reduce the losses and maximize the power conversion efficiency of the solar cells. The parabolic structured Si-Perovskite tandem solar cell design have significant improved efficiency [5]. The nano-structuring in the top layer and in between the interfacial layer can increase the absorption of sunlight within the materials by the nano-photonics phenomenon. The efficiency of Si-perovskite tandem thin film solar cells can be enhanced by doing the nano-structuring of different layers of the solar cells [6]. Tandem thin film solar cells are an important device in the photovoltaic industry. Incorporating the nano-structuring in the Si-Perovskite tandem thin film solar cells can reduce the materials cost and improve the efficiency of the solar cells [7]. Recent development of silicon perovskite tandem thin film solar cells, the power conversion efficiency of tandem thin film solar cells over time has increased from 13.7% to 33.9% [8], [9]. The lead free perovskite material has also important in the tandem thin film solar cell for sustainable development and many numerical studies show that the significant improved efficiency of the tandem solar cells [10].

II. Numerical Model

The numerical simulation model of this paper has been depicted in the following Figure 1. The model is based on the absorption of the light, incident by the plane source by the silicon and perovskite materials.

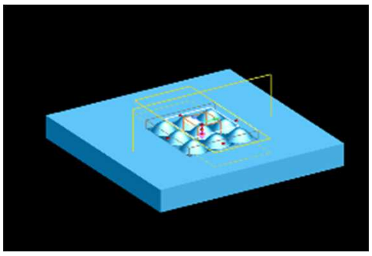

Figure 1. The schematic diagram of the simulation model

The nano-structuring of the surfaces that has been created by the scripting file. Further, the structuring has been generated in the different lattice sites. The first one is simple square lattice and the another is triangular lattice. The shape of the lattice point has can also be changed. The shape and the lattice structures play an important role in enhancing the absorption of light and overall efficiency of the solar cells.

III. Results and Discussion

The nano-structing of the surfaces of the silicon-perovskite tandem thin film solar cells have significant improvement in the absorption of sunlight and the power conversion efficiency of the solar cells. Figure 2, gives the numerically computed optical absorption for a spectral

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region of 400 nm to 1200 nm where the schematic of lattice structure of the nanostructured thin film has been shown in the inset of Figure 2 (a-b). From the graphs, it is clear that the light absorption has been enhanced in nanostructured surface as compared to planar sample. The absorption in nano-structured thin film is enhanced by means of proper geometrical lattice structure and morphology on the surface. In the present Si-perovskite tandem solar cell scheme, the absorption is enhanced in visible region and as well as in the near infra-red region that will also enhance the overall efficiency of tandem solar cell. We further give over all rationale of the design and diverse near and far field of optical analysis or the spectral region of study. We extend our study to the complete electrical characterization in order to estimate the I-V characteristics as well as the short circuit current density of the heterostructure thin film, in order to investigate the overall performance of the studied thin film solar cell.

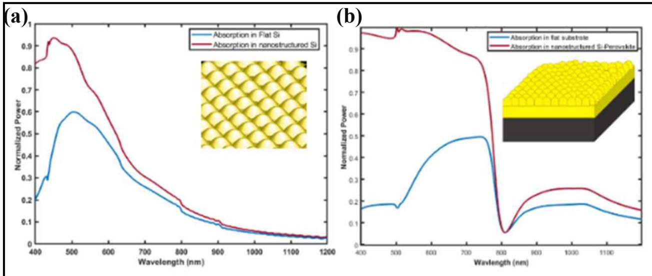

Figure 2: Optical absorption spectra of a nanostructured thin film in comparison to a planar sample. **(a)** Silicon thin film (~500 nm) **(b)** Tandem silicon-perovskite heterostructure (Silicon thickness: 500 nm and Perovskite thickness: 300nm.

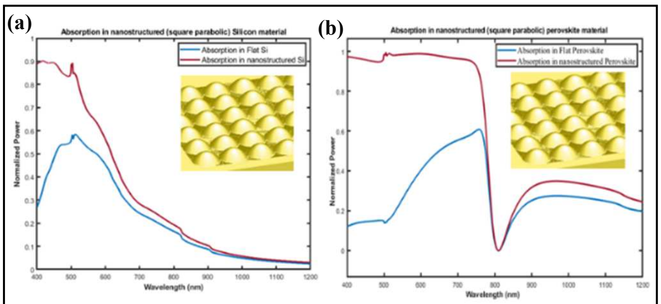

Figure 3: Optical absorption spectra of a nanostructured (square lattice) thin film (red) in comparison to a planar sample (blue). **(a)** Silicon thin film (~500 nm) **(b)** Perovskite thin film (Perovskite thickness: 300nm).

In Figure 3, the optical absorption of the planar and nanostructured surfaces has been studied. The lattice in this nano-structuring is the simple square lattice. The Fig. 3 (a-b) have the comparison studies of optical absorption of silicon and perovskite materials in planar as well as nanostructured surface in the square lattice structures. Nano-structuring surface with triangular lattice of silicon-perovskite tandem thin film solar cells have more efficient as compared to the square lattice nanostructured surfaces.

The electric field distribution at the two end points of wavelength 400 nm and 1200 nm have been studied in this simulation model. Figure 4, the electric field distribution shows that the most of the sunlight has been absorbed in between this two-wavelength range. This distribution shows that the visible light as well as the near infra-red light is absorbed by this proposed Si-Perovskite tandem thin film solar cells.

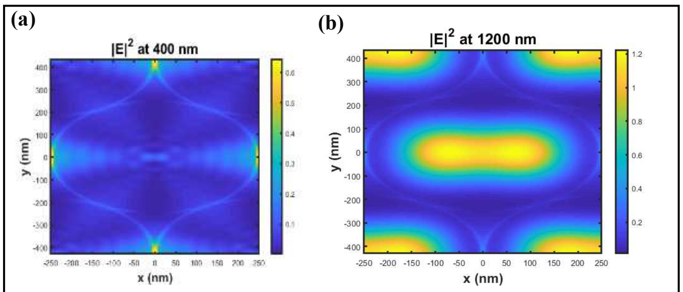

Figure 4. Electric field distribution at two different wavelengths **(a)** 400 nm and **(b)** 1200 nm

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