Texturing Design for a Light Trapping System using Topology Optimization

Hyunjun Soh[1], and Jeonghoon Yoo[2]
[1] Graduate School of Mechanical Engineering, Yonsei University
262 Seongsanno, Seodaemoon-gu, Seoul 120-749, Korea, hjsoh@yonsei.ac.kr
[2] School of Mechanical Engineering, Yonsei University
262 Seongsanno, Seodaemoon-gu, Seoul 120-749, Korea, yoojh@yonsei.ac.kr (corresponding author)

Abstract — In a thin film solar cell, a light trapping system in the light absorbing layer is employed for the converting efficiency enhancement. The propagating wave reflects on the metal surface coated with thin Transparent Conducting Oxide (TCO) material and it scatters on the top TCO by total internal reflection. The reflected wave passes through the silicon absorbing layer. For raising the reflection efficiency, extending the wave path length is considered; therefore, surface textures on the back reflector and the top TCO are used. This research suggests a texture design method using topology optimization. The 800nm wavelength of the passing wave is used and the performance of the optimized system is improved more than three times compared with the initial one.

I. INTRODUCTION

Silicon based thin film solar cell has advantages such as using the semiconductor fabrication and the inexpensive silicon deposition processes without using expensive silicon crystalline ingot and wafer. However, since it has relatively low converting efficiency comparing with the wafer based silicon solar cell, the efficiency enhancement of the system is inevitable. Therefore, an efficient light trapping system in the light absorbing layer is required.

The light trapping system is composed of the light absorbing silicon layer, a back reflector and the top Transparent Conducting Oxide (TCO) layer. The schematic model of the light trapping system is displayed in Fig 1. The wave passes through the silicon absorbing layer between the top TCO and the back reflector layer [1]. TCO layer works as the electrode and the initial wave passes through the top TCO layer. The light reflects and scattered by total internal reflection, occurred by the refractive index difference of absorbing silicon and TCO [2], [3].

The back reflector is composed of the metal film layer coated with the TCO material and the coating thickness and the surface outline of TCO affect the light reflection and the system efficiency. Textures on back reflector surface can make the wave direction change for wave path-length enhancement and the wave energy can be condensed [4]-[9]. Springer *el al.* compared the reflection at the back reflectors coated and uncoated ZnO layer according to the surface roughness variation [4], [5]. As the texture of the back reflector, the photonic crystal was considered; however, its shape was limited to two-dimensional regular rectangle [6], [7]. Ferry *et al.* considered 290nm diameter of hemisphere cell and compared results according to the cell pitch [8].

This study is to design the texture shape using topology optimization scheme and it differs from previous researches starting from pre-defined texture shapes.

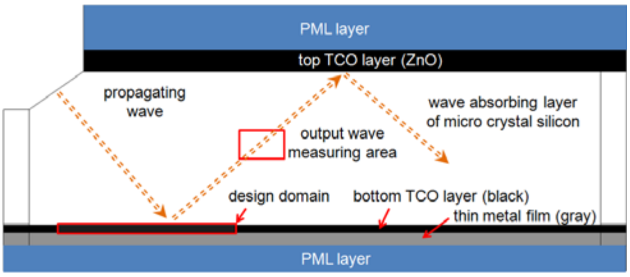

Fig. 1. Schematic diagram of the light trapping system

Topology optimization is generally regarded as an effective method to get an initial conceptual shape [10] and can be applied to the wave propagating problem. The Solid Isotropic Material with Penalization (SIMP) method is employed as an optimization scheme.

II. ANALYSIS MODEL AND DESIGN METHOD

The schematic model of light trapping system is displayed in Fig. 1. The design domain and the output wave measuring area are designated in Fig. 1. The material of the metal film and TCO are Ag and ZnO, respectively and micro crystal silicon is adopted for the wave absorbing layer. The thickness of bottom TCO, top TCO and micro crystal silicon layer are set to 150nm, 800nm and 3000nm, respectively [1].

Because textured shape on the back reflector surface can make the wave direction change, obtaining the optimal surface texture is targeted using topology optimization. The design domain is set on the bottom TCO layer, which is between the silicon (Si) and the metal film. Textured shape is designed on the TCO surface beneath the Si layer. The boundary between the TCO and the metal layer is assumed to be flat. For the SIMP method application, the material property of the design domain can be stated as [10]

$$n_{design} = \rho \cdot n_{TCO} + (1-\rho)^p \cdot n_{Si} \,. \qquad (1)$$

where n represents the refractive index having a complex value for Si material. ρ and p represent the design variable, and penalization parameter, respectively.

In time-varying electromagnetic field, wave equations generated from Maxwell's equations are employed for governing equations. The wave propagation in two-dimensional transverse magnetic (TM) mode without considering the time-varying effect, i.e., with a fixed excitation frequency ω, can be analyzed based on the following the governing equation:

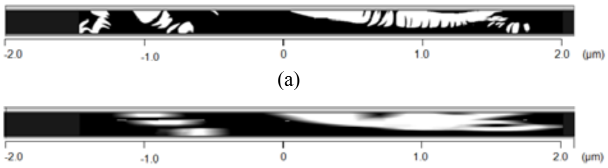

Fig. 2. Optimally designed texture shapes for (a) without filtering scheme and (b) with filtering scheme.

$$\frac{1}{\varepsilon_0}\left(\nabla\cdot\frac{1}{\varepsilon_r}\nabla H_z\right)-\omega^2 H_z=0\,. \qquad (2)$$

where ε_r is the relative permittivity of the analysis area and H_z means the z-directional magnetic field strength. The refractive index can be stated as Eq. (3) and it varies according to the wave frequency.

$$n=\sqrt{\varepsilon_0\varepsilon_r} \qquad (3)$$

In this research, 800nm wavelength for the incident light is adopted considering the absorbing band of the micro crystal solar cell having the band range from 650nm to 1100nm [1]. The refractive indexes of Si and TCO in 800nm wavelength are 3.651+j0.006 and 1.959, resplectivley. The relative permittivity of Ag is set to -27.953+j1.523. Perfectly matched layer (PML) domains are applied on the upper part of the top TCO layer and the bottom end of the Ag reflector layer to avoid wave reflection from open boundaries [11]. The commercial finite element analysis package, COMSOL ver. 3.4, is used for the analysis.

In this research, the optimization problem is set to raise the energy concentration of the wave flux on the defined domain. The optimization problem is defined as follows:

$$Maximize \quad \int_{\Omega_{measure}} P d\Omega \qquad (4)$$

where the domain Ω is the measuring area displayed in Fig 1 and P is the poyning vector representing the flux energy in the electro magnetic field. The poynting vector is stated as follows:

$$P=-\frac{1}{2\varepsilon_0}H_z\left(\frac{1}{j\omega\varepsilon_r}\frac{\partial H_z}{\partial x}\right) \qquad (5)$$

III. OPTIMIZATION RESULT

The texture shapes from topology optimization results are displayed in Fig 2. Fig. 2(a) shows the result without using any filtering scheme and it has sharp pillars as displayed. Fig. 2(b) displays optimized result using a filtering scheme for eliminating the sharp pillars; however, it has the gray regions along the outline. Therefore, in the future work, the optimization process will be modified to obtain a clear and fabricable texture shape for the light trapping system. Fig. 3 shows the comparison of the wave propagation plot resulted from initial non-textured and optimal textured case. Energy concentration can be verified in the figure and the objective values in Eq. (4) for Fig. 3(a) and (b) cases are computed as 0.085 and 0.273, respectively.

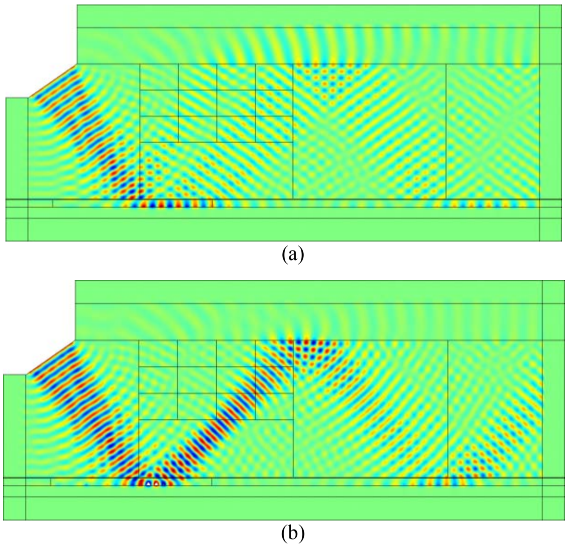

Fig. 3. H_z contour plot of the wave propagation for (a) flat back reflector and (b) texture back reflector.

IV. ACKNOWLEDGEMENTS

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