Numerical Analysis of heat dissipation in photovoltaic module through highly thermal conducting backsheet

Taemin Kim and Namsu Kim*

Department of Mechanical Engineering, Konkuk University, Seoul, +82, Republic of Korea

comktm@naver.com
**nkim7@konkuk.ac.kr*

ABSTRACT

The performance of photovoltaic module is largely dependent on the temperature of photovoltaic cells. Hence, the heat management for PV module is crucial to increase the performance of cell as well as to predict the generated energy from PV module. In this study, the temperature of PV module was calculated based on numerical simulation and the mechanism of heat dissipation in the module was investigated. Based on numerical simulation results, efficient structure of PV module and appropriate range of thermal conductivity for efficient heat dissipation can be suggested.

1. INTRODUCTION

Photovoltaic (PV) modules are widely used because they can be used in a variety of environments and the amount of generated energy per volume is higher than other renewable energy sources. The efficiency of single crystalline silicon cell which has been widely used in PV module is closely related to the temperature. Higher temperature of module decreases the conversion efficiency of cell. To solve this problem, various approaches have been developed and suggested to lower the cell temperature as well as to maintain a certain level of efficiency.

In this study, the PV module which was experimentally tested in the previous study (N. Kim et. Al., Energy, Vol. 113, 515-520, 2016) was modeled using the finite element method and heat dissipation mechanism was investigated based on numerical simulation.

2. MODELING AND SIMULATION

The governing equations and constitutive equations in the analysis of the PV module are as follows.

The heat flux of conduction in the PV module could be calculated by Eq. (1):

$$q_x'' = -k\frac{dT}{dx} \tag{1}$$

where *k* is thermal conductivity and *T* is temperature.

The heat flux of the convection between the module surface and air could be calculated by Eq. (2):

$$q'' = h(T_S - T_\infty) \tag{2}$$

where T_S is surface temperature and T_∞ is ambient temperature.

Table 1. Thermal conductivity and thickness of materials in the simulation model.

Material	Structure	Thermal conductivity (W/m·K)	Thickness (mm)
Glass	Top layer	2.00	3.20
EVA	Adhesive layer	3.11×10^{-1}	4.60×10^{-1}
Polycrystalline Silicon	PV cell layer	1.30×10^{2}	2.00×10^{-1}
PO	Backsheet layer	2.00×10^{-1}	1.00×10^{-1}
PET	Backsheet layer	4.00×10^{-1}	2.38×10^{-1}
Graphite	Backsheet layer	2.40×10^{1}	5.00×10^{-1}
Aluminum	Backsheet layer	2.37×10^{2}	1.50×10^{-1}
PVDF	Backsheet layer	1.80×10^{-1}	3.00×10^{-2}

Table 2. Optical properties of materials in the simulation model.

Material	Reflectivity	Absorptivity	Transmissivity
Glass	4.00×10^{-2}	4.00×10^{-2}	9.20×10^{-1}
EVA	2.00×10^{-2}	8.00×10^{-2}	9.00×10^{-1}
Polycrystalline Silicon	8.00×10^{-2}	9.00×10^{-1}	2.00×10^{-2}
W-PO/PET/PO	8.60×10^{-1}	1.28×10^{-1}	1.20×10^{-2}

Below is the equation expressing the effect of T_C on η_C which was referenced the previous study (N. Kim et. Al., Energy, Vol. 113, 515-520, 2016, Skoplaki E et Al., Sol Energy, Vol. 83, 614-624, 2009, Zondag HA et Al., Renew Sust Energ Rev, Vol. 12, 891-959, 2008).

$$\eta_C = \eta_{T_{ref}}\left(1 - \beta_{ref}\left(T_C - T_{ref}\right) + \gamma \log_{10} G_T\right) \qquad (3)$$

where $\eta_{T_{ref}}$ is the module's electrical efficiency at a reference temperature (T_{ref}) and a solar radiation flux of 1000 W/m^2. β and γ are the temperature coefficient and the solar radiation coefficient, which is 0.4 %/℃[1] and 0.12, respectively. G_T is the solar radiation flux (irradiance) on the module plane (W/m^2).

Table 3. Internal heat generation of materials in the simulation model.

Material	Heat generation (W/m^3)
Glass	1.13×10^{4}
EVA3	4.14×10^{5}
EVA2	4.35×10^{5}
EVA1	1.13×10^{5}
PV cell	3.09×10^{6}
W-PO	2.61×10^{5}

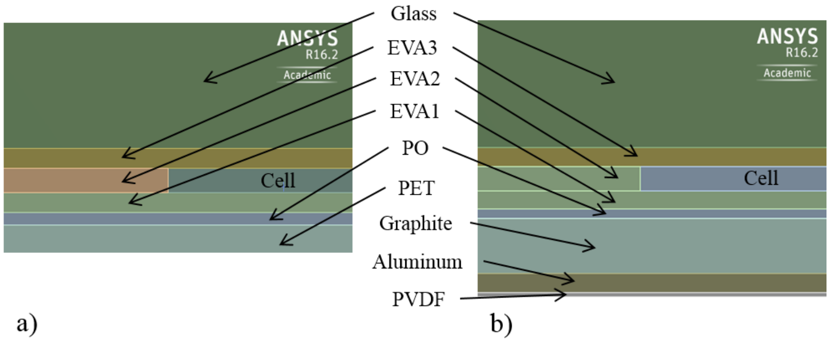
2.1. Modeling

In this study, we used a mini module made of one cell rather than a PV panel with multiple cells to evaluate the PV module on lab scale. This mini module consists of glass, EVA, PV cell and backsheet. The size of glass, EVA, and backsheet was 190 mm*190 mm and PV cell was 156 mm*156 mm. The thermal conductivity and thickness of each material of the structure were listed in Table 1. The cross section of the module was shown in Figure 1. Module, frame, and stage were segmented to create a fine mesh, and each object was recognized as one in simulation using the "form new part" function in Ansys Workbench.

In this study, several assumptions were employed as below. The PV cell conversion efficiency at temperature at 25 ℃ was presumed to be 17%. The light entering the frame were ignored because frame's volume was very bulky compared to the area of irradiation. The convective heat transfer coefficient was constant with temperature. The convective heat transfer coefficient of inside frame is 0.5 times that of the outside. Based on ISO 7730, the air velocity was assumed to be 0.25 m/s in laboratory. The light coming into the module was perpendicular to the surface. The stage had a much larger thermal mass than the module, so the temperature of stage was remained constant.

2.2. Boundary Condition

The ambient temperature was set at 28 ℃, which was the same as the previous experiment. The convective heat



a) b)

Figure 1. Cross section of backsheet for (a) the reference backsheet and (b) the highly thermal conducting backsheet

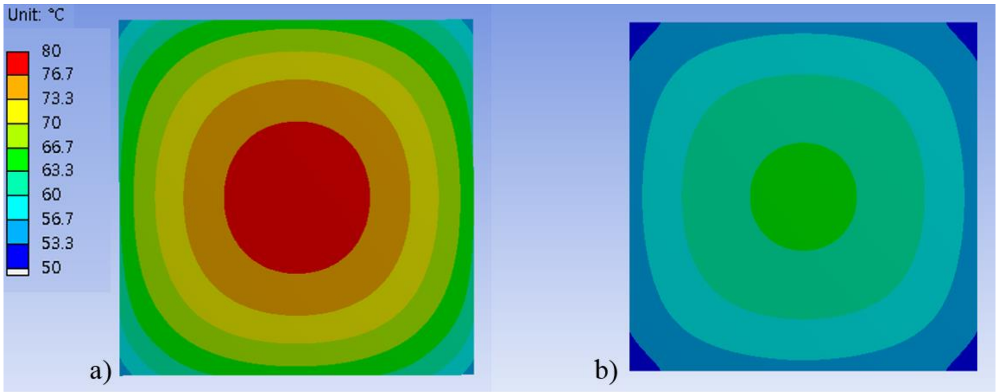


Figure 2. The temperature of the PV cell for (a) the reference backsheet and (b) the highly thermal conducting backsheet

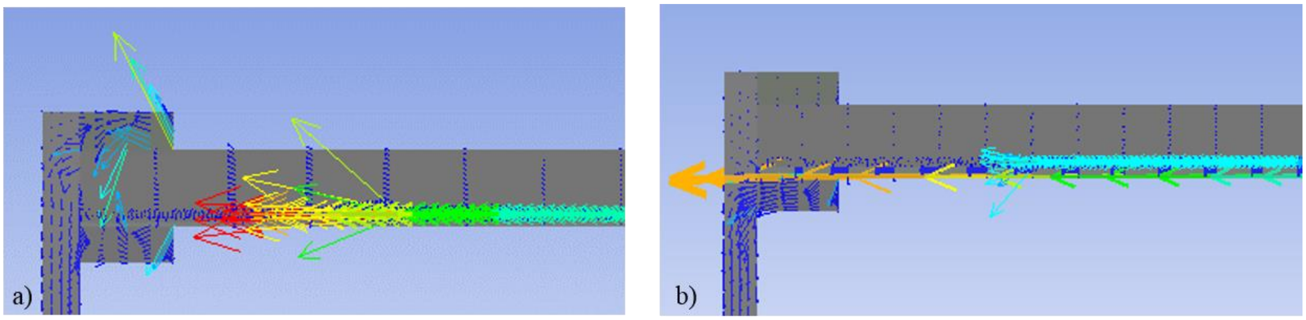


Figure 3. The heat flux of the PV module for (a) the reference backsheet and (b) the highly thermal conducting backsheet

transfer coefficient is highly dependent on the wind speed, which was calculated by the following equation.

$$h = 5.82 + 4.07u \tag{4}$$

where u is the air velocity. Since the simulation environment is assumed to be indoor, the air velocity of 0.25 m/s is used as in the previous assumption. The convective heat transfer coefficients of the outer and inner surfaces of the module were calculated 6.84 $W/m^2 \cdot K$ and 3.42 $W/m^2 \cdot K$, respectively.

The internal heat generation of each layer was calculated by the following equation.

$$Q = \frac{(1-\eta_c)G\alpha A}{V} \tag{5}$$

where η_c is the electrical conversion efficiency of the polycrystalline silicon PV cell, G is the solar irradiance, α is the absorptivity, A is the area and V is the volume. The internal heat generation of each layer was calculated based on Eq. (5) and summarized in Table 3.

3. RESULT AND DISCUSSION

The temperature gradients shown in Figure 2 show that the module with highly thermal conducting backsheet (Figure 2 (b)) dissipates heat more efficiently through in-plane direction compared to that with reference backsheet. Hence, the maximum temperature of module with highly thermal conducting backsheet as well as overall temperature is relatively low. In order to investigate the mechanism of heat dissipation in details, the heat fluxes through the module with different backsheets were calculated and these were shown in Figure 3. For both cases, due to higher thermal conductivity of silicon cell, most of generated heat dissipates through silicon cell from the center to the edge. Then, in the case of reference backsheet, the heat at the edge of silicon cell dissipates in all direction including glass. In particular, it can be seen that most of heat is released through glass because the thermal conductivity of glass is higher than those of other layers including the reference backsheet. Dissipated heat through glass is released by convection on the surface of glass. On the other hand, in the case of a PV module with highly thermal conducting backsheet, similar heat dissipation mechanism until the edge of silicon cell occurs due to same reason.

However, it can be found that the heat at the edge of silicon cell dissipates dominantly through the backsheet due to higher thermal conductivity of backsheet. Dissipated heat through backsheet is efficiently released through the module frame and stage by conduction. Hence, that is the main reason that the maximum as well as overall temperatures of module with highly thermal conducting backsheet are lower than those of module with reference backsheet.

4. CONCLUSIONS

In this study, the temperature and heat dissipation mechanism of a PV module with a backsheet having different thermal conductivity are investigated using numerical simulation. The use of a backsheet with a low thermal conductivity will cause more heat dissipation through the glass resulting in convective heat transfer from glass surface to environment. On the other hand, the PV module with highly thermal conducting backsheet has dominant heat dissipation through in-plane direction of backsheet by conduction. From these numerical simulation results, backsheet with higher thermal conductivity was more effective in lowering the module temperature. More systematic studies with different thickness and thermal conductivity of each layer in the module and their impacts on the overall temperature of module will be investigated.

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BIOGRAPHIES

Taemin Kim was born in Changwon, Republic of Korea in 1989. He was graduated in Department of Mechanical Engineering at Konkuk University, Seoul, Republic of Korea. He is completing master's degree in Mechanical Design at Konkuk University Graduate School, Seoul, Republic of Korea. He served in the ROKA Army from 2009 to 2011. In recent years, he is interested in how to improve the efficiency of PV modules.

Namsu Kim is an assistant professor of mechanical engineering at Konkuk University, Seoul, Korea. From 2010 to 2015, he was with Korea Electronics Technology Institute as a senior researcher, where his researches focus on the reliability and analysis of mechanical and electrical component. He received B.E., M.S., and Ph.D. degree in mechanical engineering from Hanyang University, University of Texas at Austin, and Georgia Institute of Technology in 1998, 2005, 2009, respectively. His current research interests include the design and optimization of mechanical and electrical component.