Finite Element Modeling and experimental validation of Concentrator Photovoltaic module based on Surface Mount Technology

K. Kouame[1,2], D. Danovitch[1,2], P. Albert[1,2], A. Turala[1,2], M. Volatier[1,2], V. Aimez[1,2], A. Jaouad[1,2], M. Darnon[1,2], G. Hamon[1,2]

[1] Laboratoire Nanotechnologies Nanosystèmes (LN2) - CNRS UMI-3463 Institut Interdisciplinaire d'Innovation Technologique (3IT), Université de Sherbrooke, 3000 Boulevard Université, Sherbrooke, J1K OA5 Québec, Canada

[2] Institut Interdisciplinaire d'Innovation Technologique (3IT), Université de Sherbrooke, 3000 Boulevard Université, Sherbrooke, J1K OA5, QC, Canada

Abstract

Concentrator photovoltaics (CPV) is a type of renewable energy and has set a record efficiency of 47.6% under 665 suns [1]. Nonetheless, CPV modules manufacturing has historically been challenging and expensive due to the sequential nature of wire bond interconnections and the need for multiple pick and place processes. To simplify the assembly process, a novel technique based on Surface Mount Technologies (SMT) has been developed [2]. The efficient heat dissipation is important in preventing premature degradation of solar cells (SC). Cell manufacturers recommend to operate below 100°C to 120°C, and recent research [3] suggests that a temperature below 80°C could minimize early failure. The heat dissipation in a module depends on the geometry and thermal properties of its materials. Finite Element Modeling (FEM) serves as a predictive tool for optimizing the design and projecting temperatures for various solar module technologies [4]-[6]. In this study, thermal performances of such an assembly was investigated and optimized using FEM. To compare experimental and FEM predicted temperatures, a 4-solar-cell CPV SMT module was fabricated. Thermal simulation results for the 4-cell module and the IR camera experimental measurements of backsheet temperature are shown in Fig. 2-a and 2-b. The numerical model's maximum temperature (38.3°C) closely aligned with the IR camera's measurements of the module one (37.9±2°C). Nevertheless, discrepancies were noticed at specific points, for example, for numerical model minimum temperatures (30.4°C) and IR camera (20.5±2°C), attributable to lamination bubbles and connecting wire effects. These issues can be mitigated through specialized lamination techniques and suitable PCB designs. So, the experimental data of the 4-cell module prototype validates the simulation model.. To emulate the large-scale SMT-based CPV module, the model was expanded to an infinite number of SC after being validated. The optimal dimensions were determined by identifying the module parameters that affect cell temperature: 1) area and thickness of the metal ribbon on the backside of the SC, 2) metal coverage on the transparent glass Printed Circuit Board (PCB) on the frontside of the SC. Fig.3 show the parametric studies using the FEM model extended to conditions of a large-scale CPV module, which indicates that the choice of the thickness-surface area dimension pair of the metal ribbon on the back of the solar cell and the metal coverage ratio of the PCB is crucial to limit the maximum temperature of the solar cell to 80°C or less.

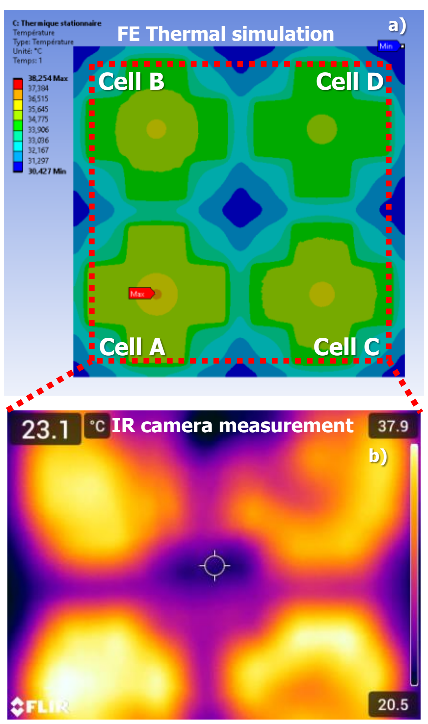

Figure 2. a) Results of the thermal simulation of the 4 solar cell model, b) experimental measurements of the backsheet temperature using the IR camera.

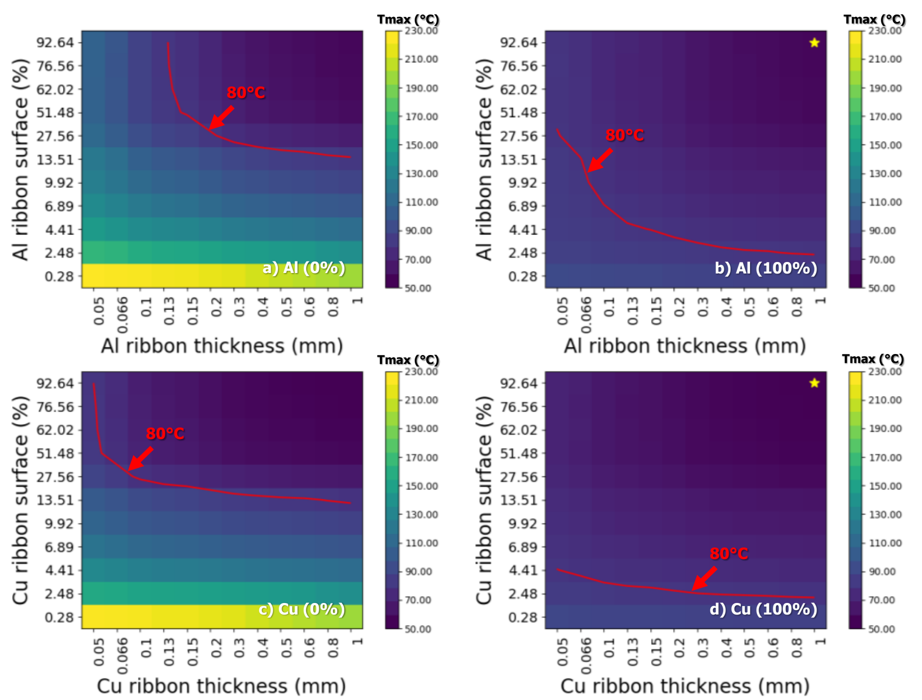

Figure 3. Evolution of the maximum temperature of the solar cell as a function of the thickness and the surface of the Cu and Al ribbon. The simulations were performed for a metal coverage of the PCB of 0% and 100% i.e., 0 or 100% of the PCB surface is covered with metal except for the active area of the solar cell which is 9 mm². a): Al (0%), b) Al (100%), c) Cu (0%), Cu (100%). The red curves represent the 80°C levels for each simulation case. The yellow stars mark the simulation points corresponding to the lowest maximum temperatures for the solar cell.

References

[1] M. A. Green et al., « Solar cell efficiency tables (Version 61) », Prog. Photovolt. Res. Appl., vol. 31, no 1, p. 3-16, janv. 2023, doi: 10.1002/pip.3646.
[2] K. Kouame et al., « New Triple-Junction Solar Cell Assembly Process for Concentrator Photovoltaic Applications », in 2023 IEEE 73rd Electronic Components and Technology Conference (ECTC).
[3] P. Espinet-González et al., « Temperature accelerated life test on commercial concentrator III-V triple-junction solar cells and reliability analysis as a function of the operating temperature: Temperature accelerated life test », Prog. Photovolt. Res. Appl., vol. 23, no 5, p. 559-569, mai 2015, doi: 10.1002/pip.2461.
[4] T.-L. Chou et al, « Thermal performance assessment and validation of high-concentration photovoltaic solar cell module », IEEE Trans. Compon. Packag. Manuf. Technol., vol. 2, no 4, p. 578-586, 2012.
[5] M. Wiesenfarth et al., « Technical boundaries of micro-CPV module components: How small is enough? », CPV-17, Freiburg, Germany / Online, 2022, p. 030008. doi: 10.1063/5.0099878.
[6] J. F. Martínez, M. Steiner, M. Wiesenfarth, S. W. Glunz, et F. Dimroth, « Thermal analysis of passively cooled hybrid CPV module using Si cell as heat distributor », IEEE J. Photovolt., vol. 9, no 1, 2018.