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Coupled Multi-physics Modeling of Integrated Photoelectrochemical Hydrogen Processing Devices using Concentrated Irradiation

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Introduction

Direct conversion of solar energy and water into chemical energy via photoelectrochemcial (PEC) processes is one viable route for renewable fuel processing and energy storage. Integrated PEC devices, i.e. composed of an integrated traditional photovoltaic component and an electrolyzer component, allow to circumvent some of the challenges imposed by solid-liquid interfaces in traditional PEC devices, and can operate at higher efficiencies than externally wired (non-integrated) PV plus electrolyzer devices [1]. In order to ensure the economic competitiveness of integrated devices compared to traditional PEC devices, concentration of irradiation is considered. We proposed a novel integrated device design, shown in Fig. 1, combining EC, PV and concentrator[2].

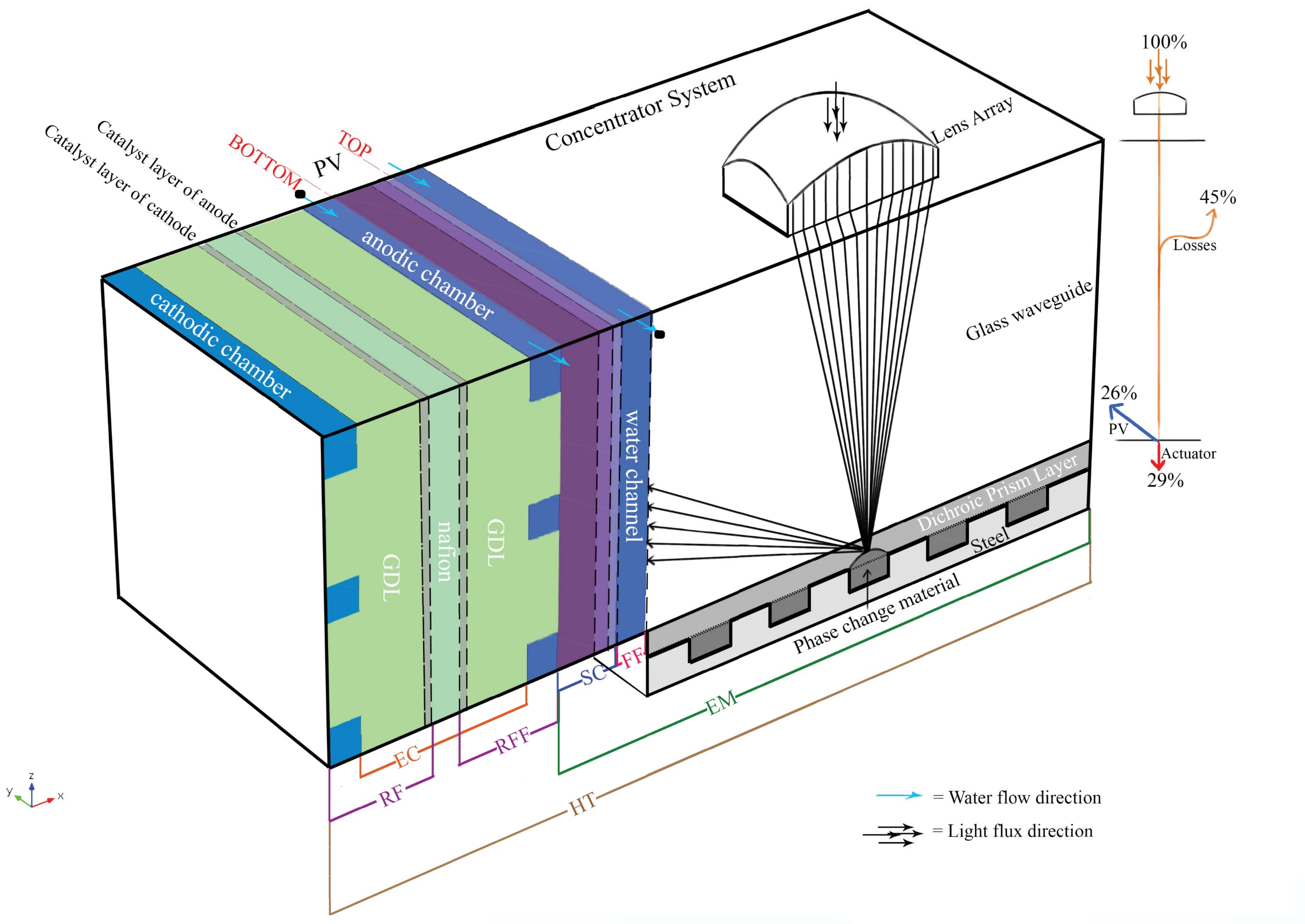

Fig. 1 3D schematic (not to the scale) of the integrated PEC. 2D simulation domain is the *xy*-plane.

Methodology

We developed a coupled 2D multi-physics model of the proposed concentrated PEC device. The simulation flow is shown in Fig. 2.

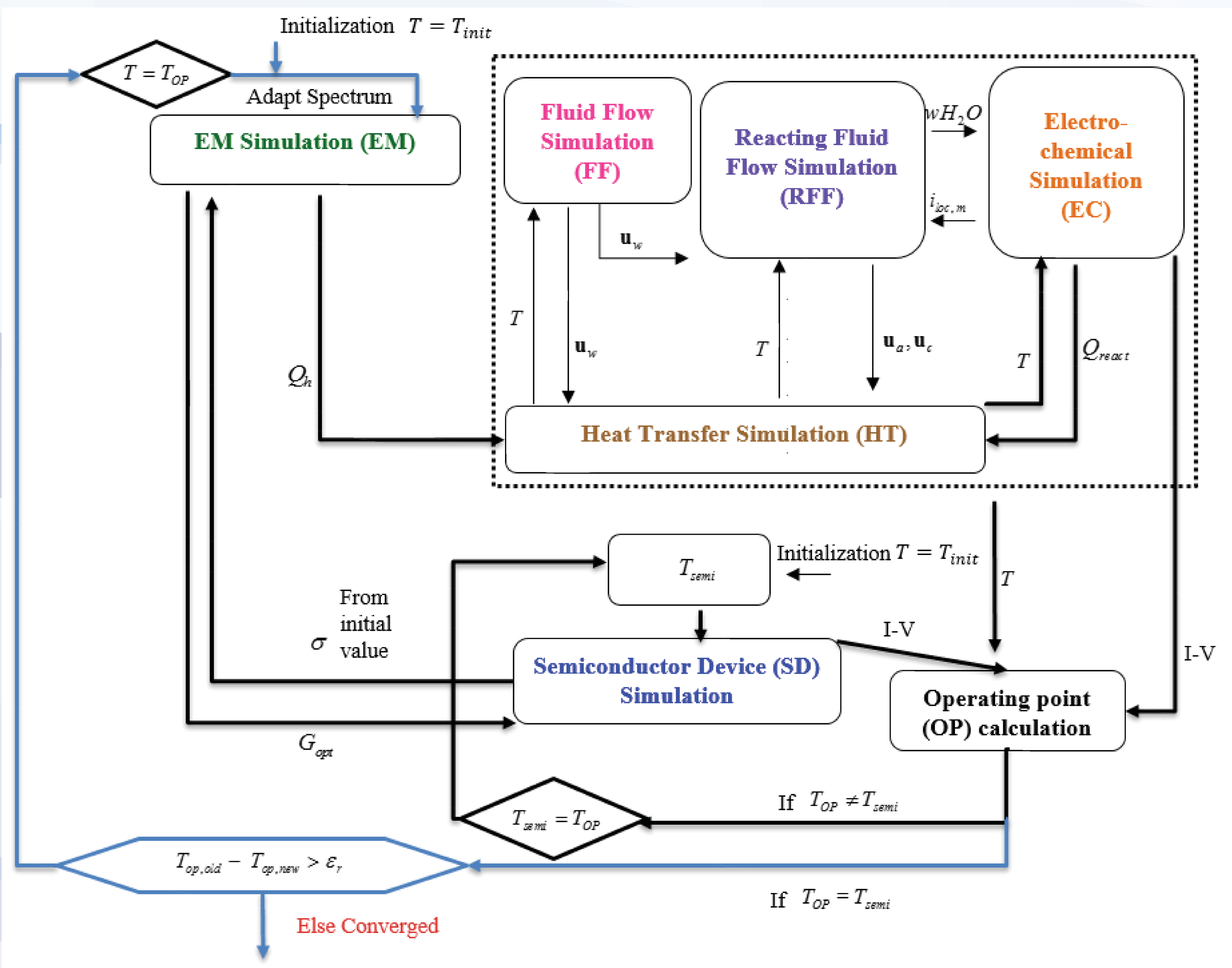

Fig. 2 The simulation flow of the integrated PEC device.

Acknowledgement

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References

[1] S. Haussener et al., Energy Environ. Sci., Vol. 6, pp. 3605-3618, 2013.

[2] V. Zagolla et al., Optics Express, Vol. 22, Issue S2, pp. A498-A510, 2014.

Results

The radiation absorbed by the actuator heats up the cylinders filled with phase change material and produces a vertical expansion of around 50μm, causing actuation (see Fig. 3).

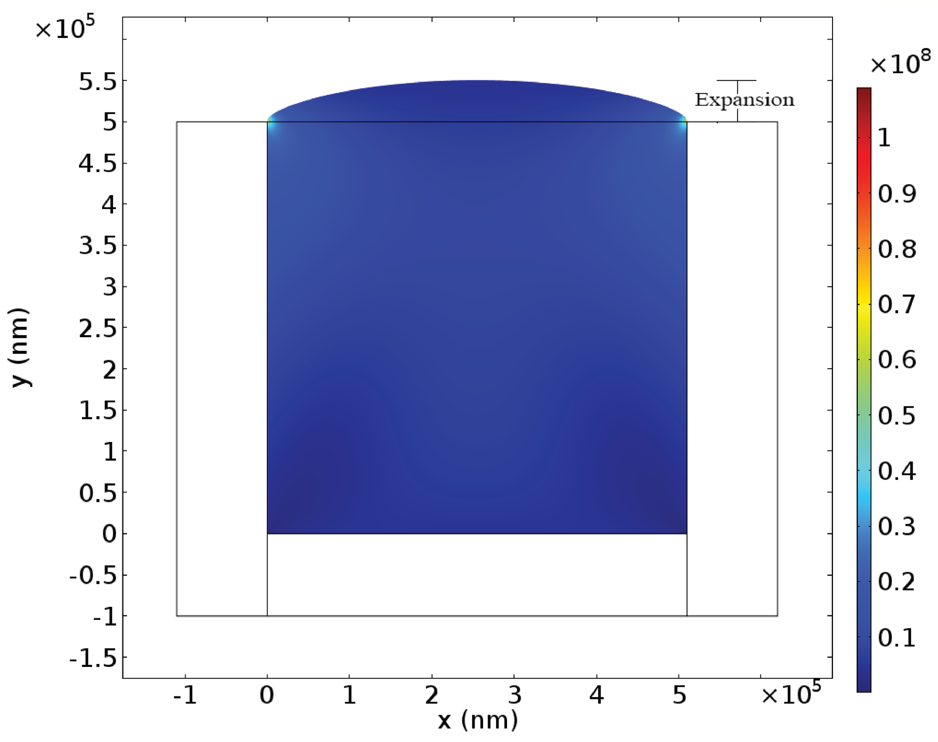

Fig. 3 Schematic showing thermal expansion (in nm) and stress profile (in N/m^2) of the phase change material.

Only 80% of the radiation reaching the actuator is needed for actuation; the remaining 20% is used for heating the water in channels beneath the concentrator.

The spectral behavior of the dichroic prism layer covering the actuator affects the PV performance significantly, as can be seen in Fig. 4, and needs to be optimized for best PV performance.

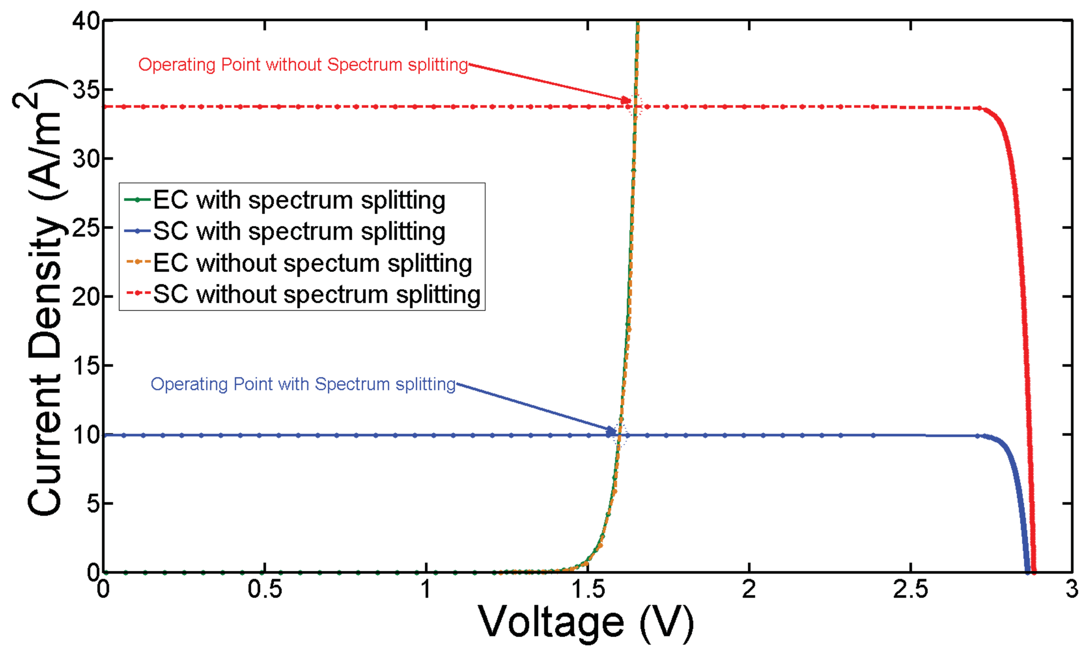

Fig. 4 Current-voltage characteristics of the integrated PEC device with and without spectrum separation by dichroic prism layer with an effective optical concentration of 1.

The cooling power of the water is found to be dependent on its mass flow rate and length of the water channel. Fig. 5 presents two cases to analyze the thermal behavior of the PEC device.

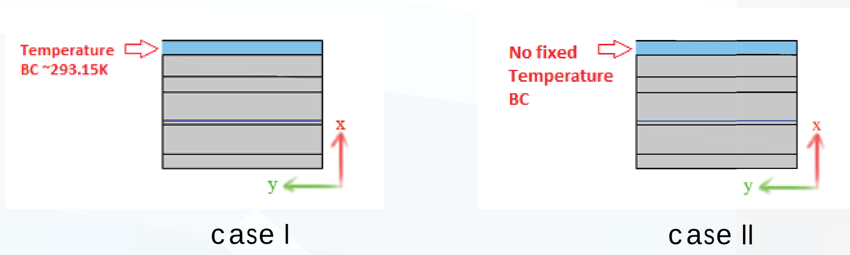

Fig. 5 Schematics showing two cases with and without water inlet boundary condition (BC).

The average temperature (Fig. 6) in case I is much lower than in case II signifying the importance of cooling water.

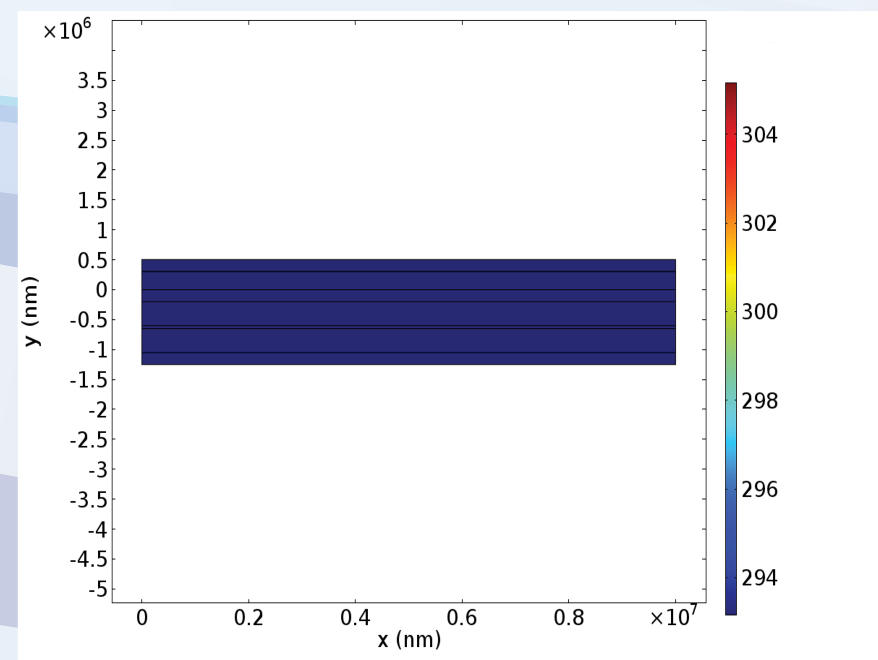

Fig. 6(a) Temperature profile (in K) of the integrated PEC device with water inlet fixed temperature BC (case I).

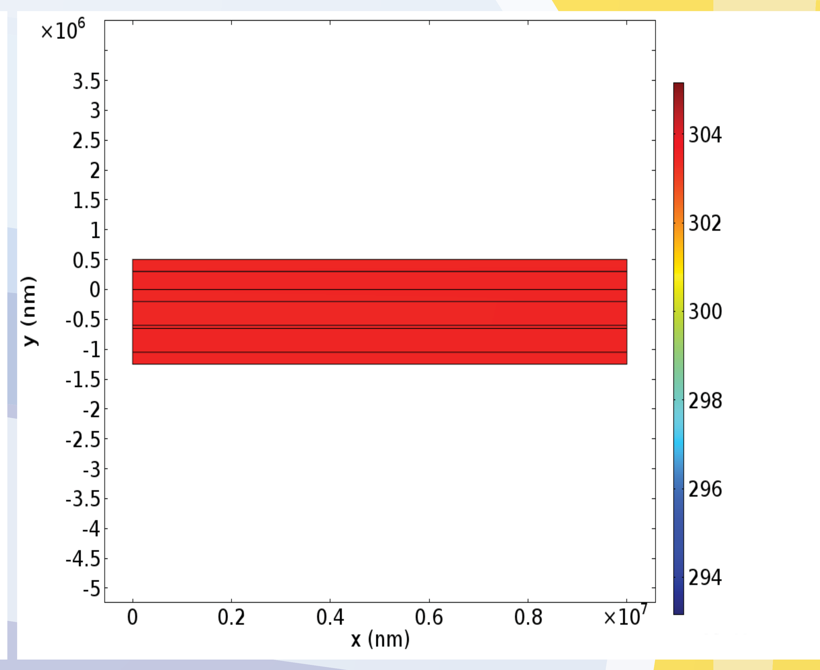

Fig. 6(b) Temperature profile (in K) of the integrated PEC device without water inlet fixed temperature BC (case II).

The PV performance benefited with decreasing temperature (water acting as coolant, removing the heat from the PV) while the electrochemical performance benefited from the increasing temperature (heated water used as reactant). The amount of hydrogen produced increased with light concentration.

Conclusion

The model developed shows promise to be a valuable design and optimization tool for integrated PEC devices working with concentrated irradiation and at elevated temperatures.

Solar Concentration Components