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Design guidelines based on coupled multiphysics modeling for Integrated PEC devices working with concentrated irradiation

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Introduction

Integrated PEC devices, which are composed of an integrated traditional photovoltaics (PV) component and an electrolyzer (EC) component, allow to circumvent some of the challenges imposed by solid-liquid interface in traditional PEC devices, and operate at higher efficiencies than externally wired (non-integrated) PV plus EC devices. To make the integrated devices economically competitive, we have employed concentration of irradiation.

We proposed a novel integrated design, shown in fig. 1, combining EC, PV and concentrator [1]. We developed, a coupled 2D multi-physics model of the proposed concentrated PEC device. The model includes radiative heat transfer in the concentrator, electromagnetic wave propagation in the semiconductors (a triple/dual junction solar cell), charge generation and transport in the photoabsorbers and the integrated electrolyzer (polymeric electrolyte and solid electrode), electrochemical reaction at the catalytic sites, fluid flow and species transport in the channels delivering the reactant (water) and removing the products (hydrogen and oxygen), and heat transfer in all components.

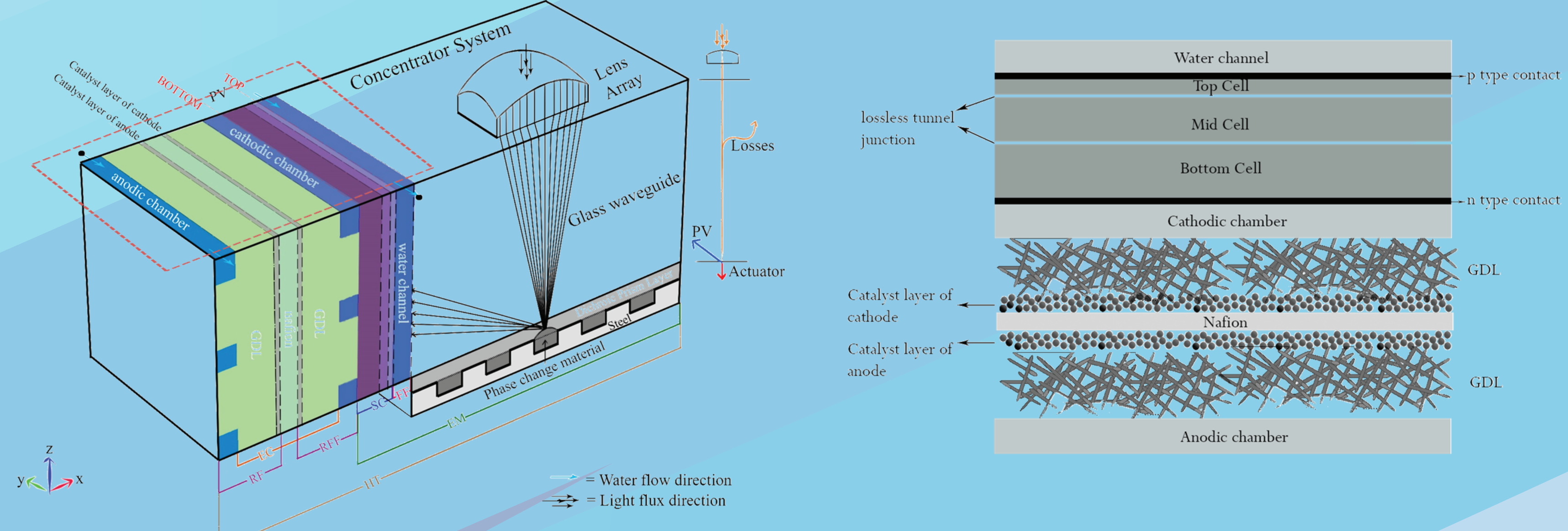


Fig. 1 3D schematic (not to the scale) of the integrated PEC. 2D simulation domain is the *xy*-plane.

Methodology

We have completely automatized the simulation flow using multiple interactions between MATLAB, COMSOL and wxAMPS [2], shown in fig. 2, for our 2d coupled multiphysics model of the proposed concentrated PEC device.

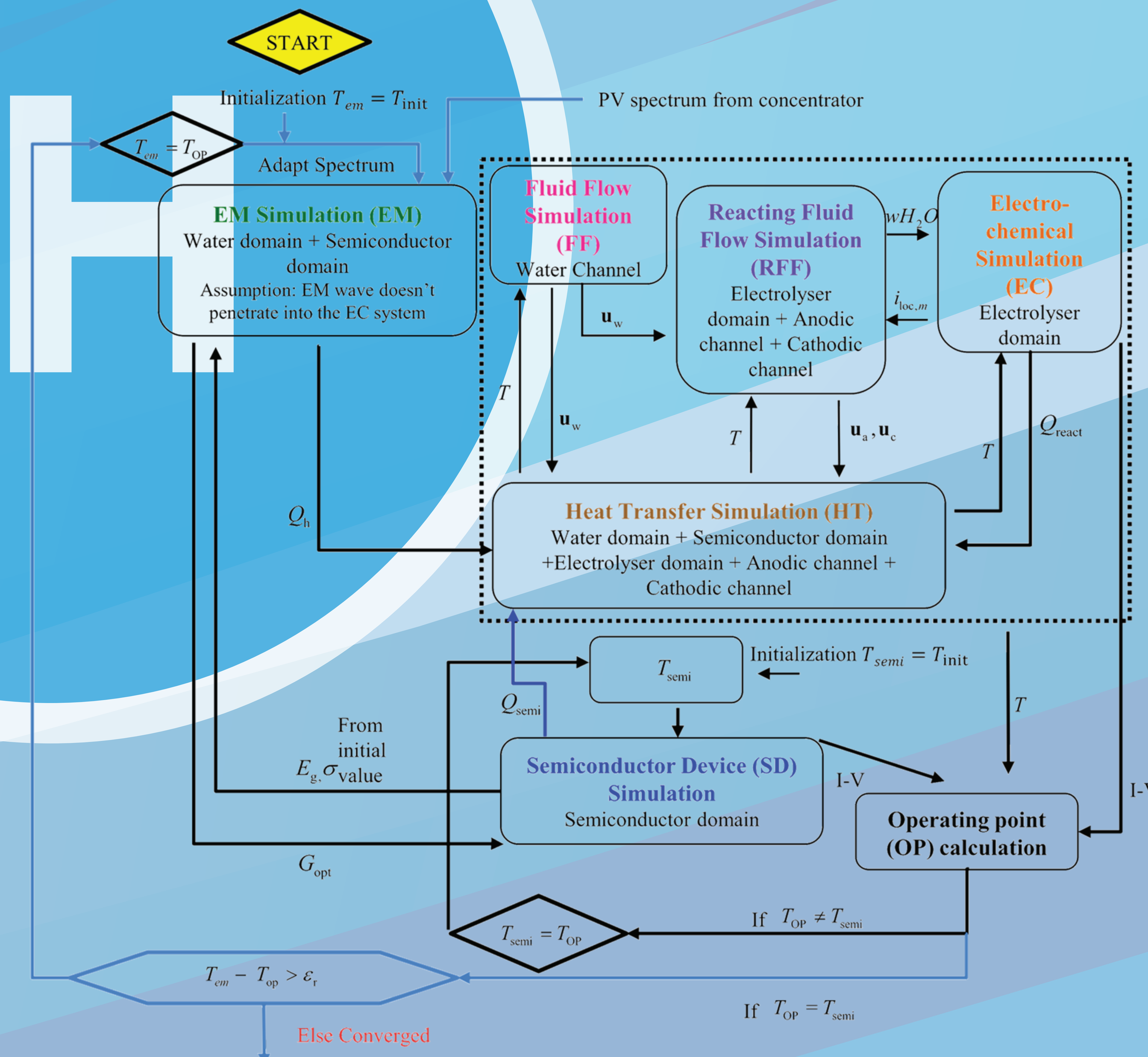


Fig. 2 The simulation flow of the integrated PEC device.

Results

We analyzed the effects of top cooling water channel, on PV's absorption.

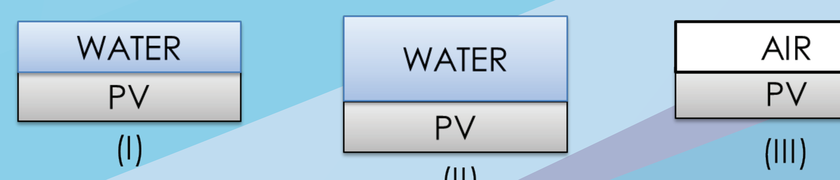
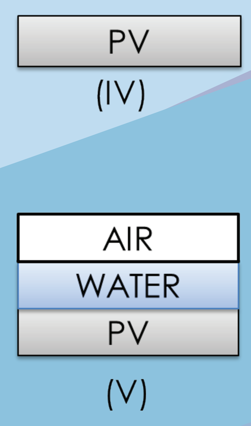



Fig. 3 Water analysis cases

The fig. 4 compares the generation rates for the 5 cases shown in fig. 3; the respective performance curves are presented in fig. 5. Case I and II depict that the absorption in the water channel is negligible for the wavelengths corresponding to absorption spectrum of PV (aSi-ucSi-ucSi). The case V is better than case III implying that top - water channel, apart from cooling, is also beneficial for reducing reflections on top surface.

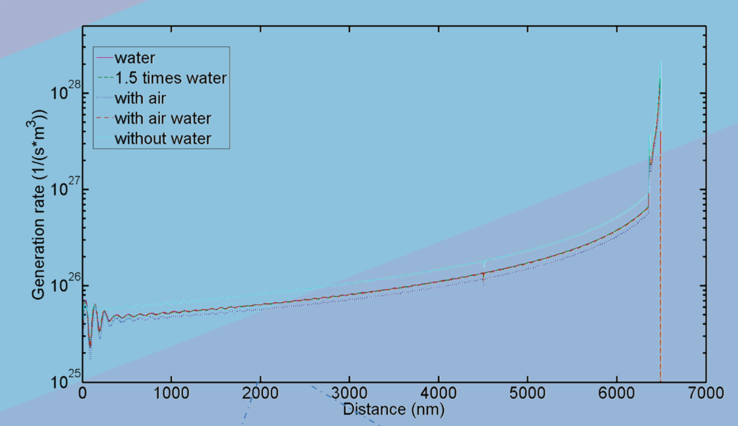
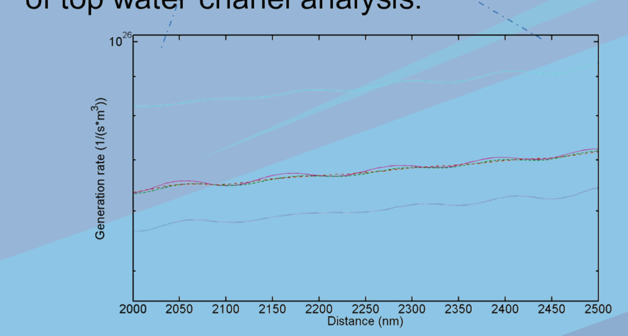


Fig. 4 Generation rate curves for the 5 cases of top water chanel analysis.



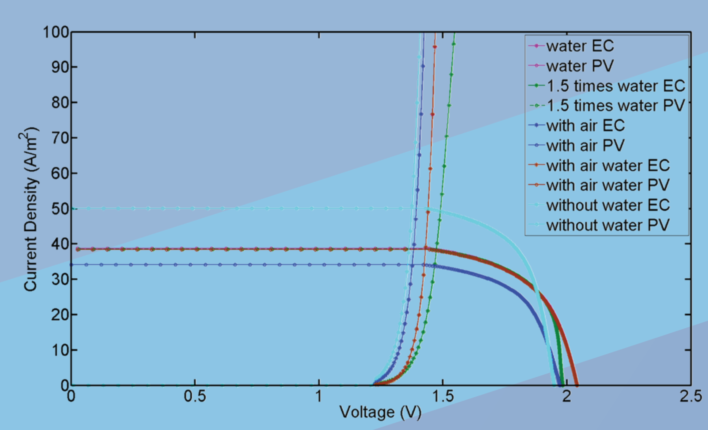


Fig. 5 J-V characteristic of the integrated PEC with aSi-ucSi-ucSi cell for the 5 cases of top water chanel analysis.

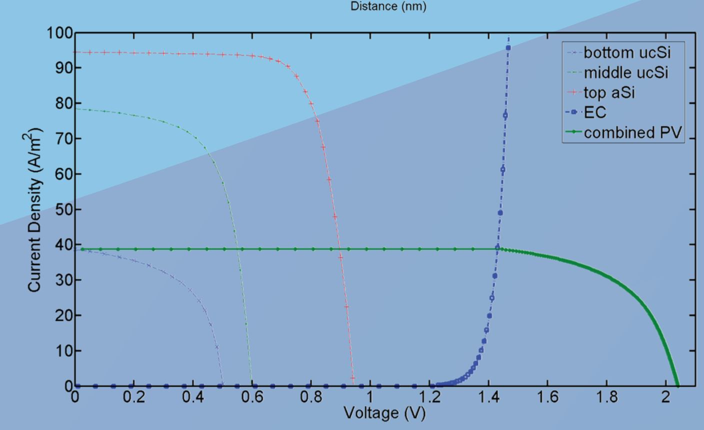


Fig. 6 J-V characteristic of the integrated PEC with aSi-ucSi-ucSi cell at irradiance concentration=1.

Results

Irradiance concentration (C) upper limit for PV cell is solely decided by ratio of electrolyser's saturation current to PV's current at maximum operating point(MPP) at C=1. Fig. 7 shows that as per the J-V curve for aSi-ucSi-ucSi (fig. 5), the theoretical upper limit on 'C' would be ~400.

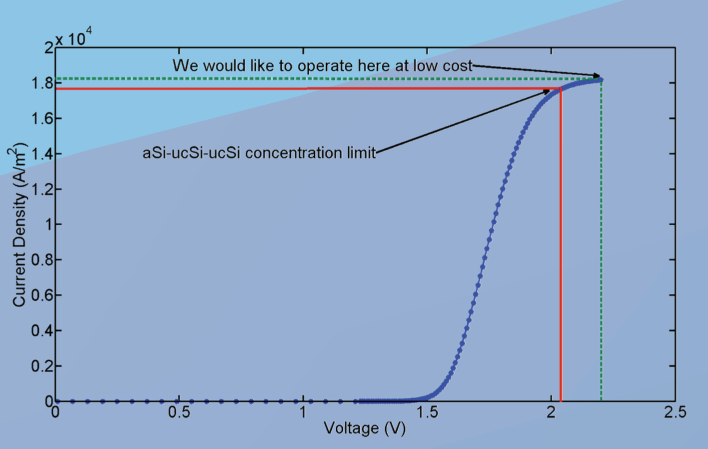


Fig. 7 Electrolyser performance curve with Pt cathode & Ir-Anode at C=1 with aSi-ucSi-ucSi triple junction cell

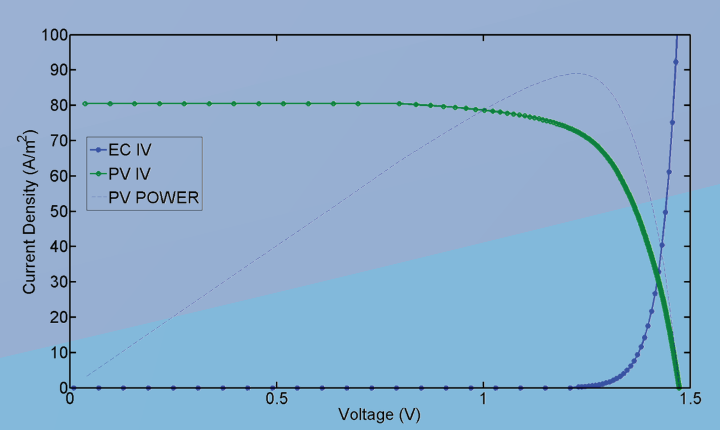


Fig. 8 J-V characteristic of the integrated PEC with aSi-ucSi dual junction cell at irradiance concentration=1.

A dual aSi-ucSi cell provides just enough Voc (fig. 7) for electrolysis at C=1. The integrated PEC with aSi-ucSi can be operated at PV's MPP by increasing EC's temperature but a dual cell would not be useful from the context of operating at highest current.

Aim = Higher Hydrogen production

Higher operating current

EC's saturation area decides the PV configuration

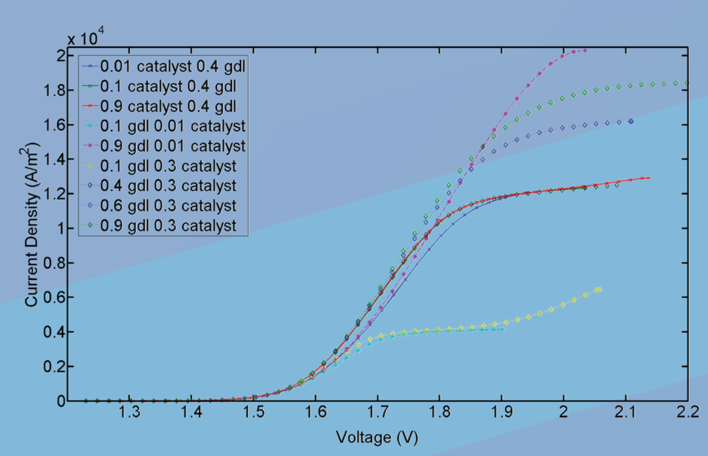


Fig. 9 Electrolyser performance curves with changing porosity at 300K

The current increases with increasing porosity of porous materials (catalyst and gas diffusion layers (GDL)) in EC (fig. 9). Changing porosity of thick (400 um) GDLs shows significant rise in saturation current as opposed to minimal current change for thin (100 nm) catalyst layers.

The higher temperature performance curves of the integrated PEC are shown in fig. 10. As evident from the fig., the cooling for the PV is a must however the EC's J-V curves reverse trend after a certain point. Below this crossing point a thermal isolation between PV and EC is recommended.

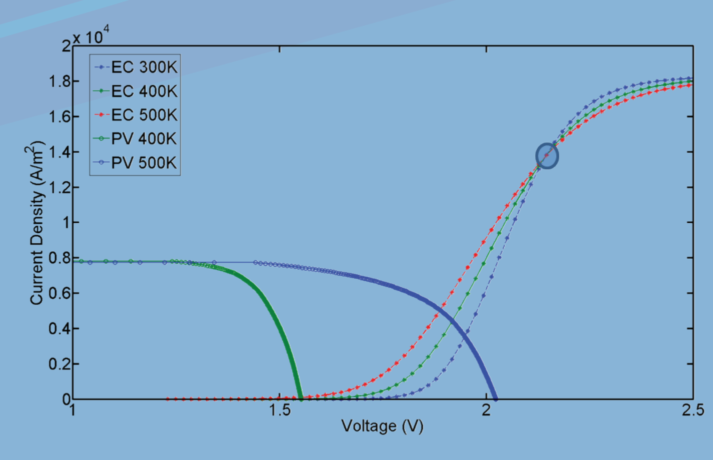


Fig. 10 PV and EC performance curves for high temperature operation of integrated device

Acknowledgement

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References

[1] S. Tembhurne et al., 15th International Heat Transfer Conference, Kyoto, Japan, 2014.
[2] Y. Liu et al., Solar Energy Materials and Solar Cells, 2012 .

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, and highlights that the smart thermal management can help in achieving increased low cost production of solar fuel.

With completely automatized simulation flow and detailed multiphysics coupled with rigorous employment of efficient computational power saving techniques, our model is one of the most detailed yet computationally economical.