Recent Advances in Multiphysics Simulation of Tandem Solar Cells: Towards Comprehensive Opto-Electro-Thermal Analysis and Light Management

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As the demand for renewable energy sources continues to grow, photovoltaic (PV) technology has positioned itself as a cornerstone in addressing global energy concerns. While PV solar cells are engineered to absorb sunlight effectively, only a limited portion of the captured solar energy is converted into usable electricity, with the rest being lost as heat. This heat dissipation can cause the temperature of solar modules to rise to between 50 and 60 °C under real-world conditions, which subsequently impacts both the efficiency and longevity of the cells.

This study aims to thoroughly review the latest progress in the simulation of PV cells, thermal dynamics, and the application of radiative cooling strategies. Accurate modeling remains critical in overcoming the challenges faced in PV performance enhancement. In the first part of this presentation, we will focus on an advanced physical model for simulating solar cells, with an emphasis on utilizing coupled multiphysics models. These models provide new insights into the difficulties associated with capturing the full solar spectrum, which ranges from the ultraviolet (UV) at 300 nm to the long-wave infrared (LWIR) at 40 µm. Modeling this spectrum with high precision is crucial for a complete understanding of both light absorption and the associated thermal effects within solar cells. Additionally, the fully integrated opto-electro-thermal model we developed offers a fresh perspective on optimizing silicon solar cell designs for actual operational conditions.

In the second part of the presentation, the focus will shift to light management strategies under realistic conditions, where both the solar spectrum and the sun's orientation vary. This analysis goes beyond the standard conditions typically used in studies, such as the AM1.5 spectrum and a perpendicular angle of incidence. We will examine how changes in the solar spectrum and incident angles throughout the day and year influence the performance of tandem perovskite/perovskite cells. Thermal aspects will also be integrated, taking into account the rise in temperature that occurs under non-standard conditions, which can further affect both the electrical output and the overall energy yield. These factors are critical for optimizing the real-world performance of tandem cells and represent a significant departure from conventional simulations that assume stable, ideal conditions.

In the final part of the presentation, we will offer insights into the impact of these technological advancements on the long-term energy production capabilities of solar modules, illustrating the potential improvements in energy yield through the adoption of next-generation PV technologies, including perovskite/silicon tandems.