Evaluating The Effects Of EVA Degradation On Solar Cell Power Efficiency

L. Fromme[1], L. Osmani[2], A. K. Schnatmann[1]

[1]Institute for Technical Energy Systems (ITES), Hochschule Bielefeld – University of Applied Sciences and Arts (HSBI), Bielefeld, Germany

[2]Faculty of Engineering and Mathematics, Hochschule Bielefeld – University of Applied Sciences and Arts (HSBI), Bielefeld, Germany

Abstract

Energy generation from sunlight is a cornerstone of the renewable energy future. In this context, photovoltaic (PV) modules, particularly those based on silicon, play a central role. However, the lack of circularity in the PV industry could lead to millions of tons of PV waste worldwide by 2050. To address the challenges regarding lifetime and recycling of these modules, short-term measures to extend the lifetime by reuse (second-life) and long-term approaches for a circular design of PV modules are investigated.

Reusing PV modules saves resources and reduces emissions generated during production. It also enables the full utilization of a module's service life. Despite the advantages of the second-life concept, numerous challenges must be overcome, which leads to economically unsustainable business models. A key factor in this context is the durability of the modules. Therefore, research efforts focus on conducting condition assessments and long-term measurements to create a performance database and develop actionable recommendations for the second-life sector. One major challenge affecting durability is the yellowing of the Ethylene-Vinyl Acetate (EVA) encapsulation. Prolonged ultraviolet (UV) radiation exposure and other environmental factors lead to degradation, resulting in reduced optical transmission and decreased solar cell performance. Simulating PV modules allows for a detailed, isolated analysis of the factors that influence durability.

To evaluate the impacts of yellowing on the performance of silicon solar cells, simple 1D simulations with the COMSOL Semiconductor Module have been performed. The modeling includes the p-n junction with carrier generation and Shockley-Read-Hall recombination. Similar to COMSOL's tutorial model [2] some assumptions are made: The Si wafer has a thickness of 150 µm and an area of 126.6 cm^2. The n-doping of the bulk is set at 10^{16} cm^{-3}, while the p-doping concentration of the front surface is at 10^{19} cm^{-3}. The charge carrier generation mechanism is not modeled in detail. Instead, a spatially dependent generation rate is defined based on the silicon absorption spectra and different transmission spectra at different levels of yellowing (see Figure 2). The Shockley-Read-Hall model is used for recombination, where charge carriers are separated at the space-charge region of the p-n junction.

The results of the modeling focus on the current-voltage and power-voltage characteristics of the solar cell (see Figures 3 and 4). When the yellowing degree is known, this modeling approach allows for the estimation of power loss in the solar cell. If the degree of yellowing in used PV modules can be experimentally determined, it may be possible to develop aging and performance predictions. However, further investigations into other aging processes, such as contact corrosion or the failure of individual cells, are necessary to ensure the overall reliability and longevity of PV modules.

In conclusion, modeling the yellowing effects of PV modules represents a significant research field. It requires interdisciplinary approaches to address the challenges of sustainability, lifespan extension, and recycling. Adapted business models and innovative technologies can play a crucial role in optimizing the efficiency and environmental impact of PV technologies, thereby securing their contribution to the global energy transition.

Reference

[1] Schnatmann, A. K.; Schoden, F.; Schwenzfeier-Hellkamp, E. Sustainable PV Module Design—Review of State-of-the-Art Encapsulation Methods. Sustainability, 2022, 14 (16), 9971. DOI: 10.3390/su14169971.

[2] COMSOL, Si Solar Cell 1D, Application Gallery, Application ID: 35661, as of July 2025, https://www.comsol.com/model/si-solar-cell-1d-35661.

[3] Mahdi, H. A.; Leahy, P.; Morrison, A. Predicting Early EVA Degradation in Photovoltaic Modules From Short Circuit Current Measurements. IEEE J. Photovoltaics, 2021, 11 (5), 1188–1196. DOI: 10.1109/JPHOTOV.2021.3086455.

Figures used in the abstract

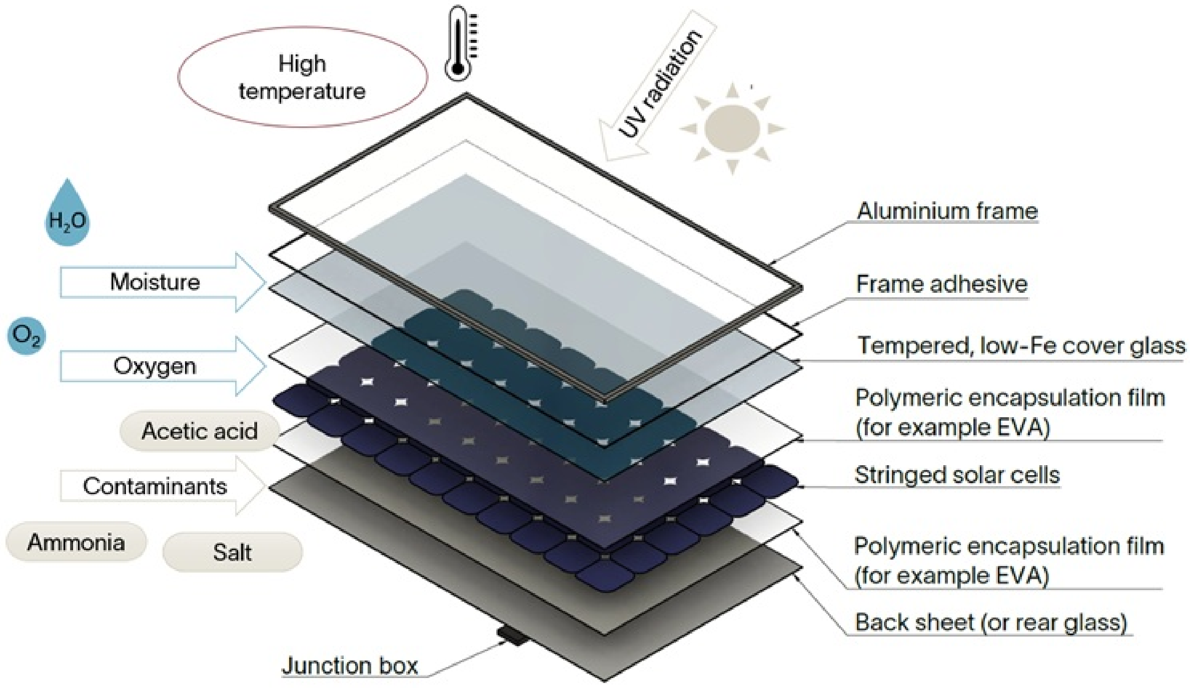

Figure 1 : Structure of PV Modules from [1] and a schematic illustration of the environmental stressors.

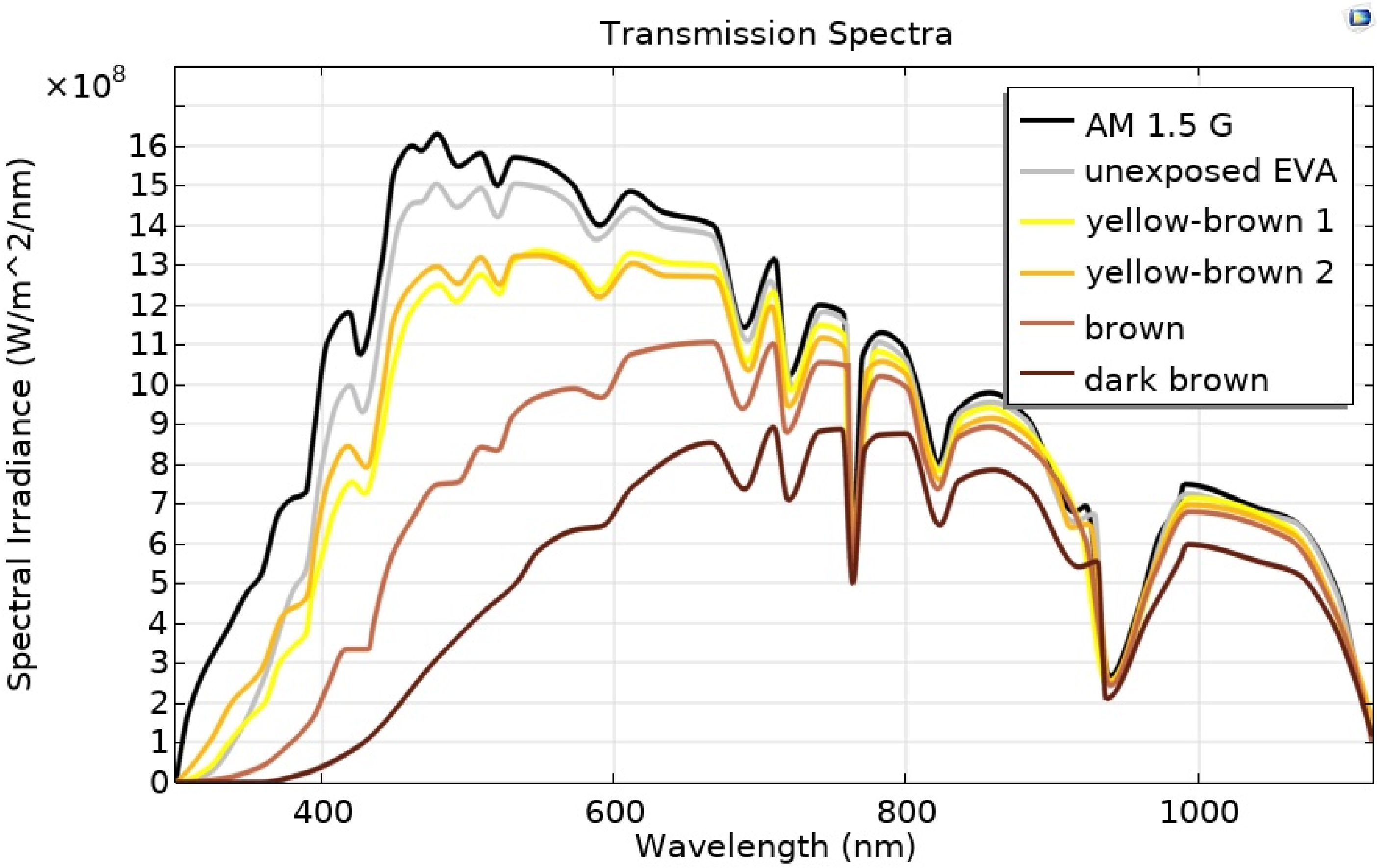

Figure 2 : Transmission spectra at different levels of yellowing, data taken from [3].

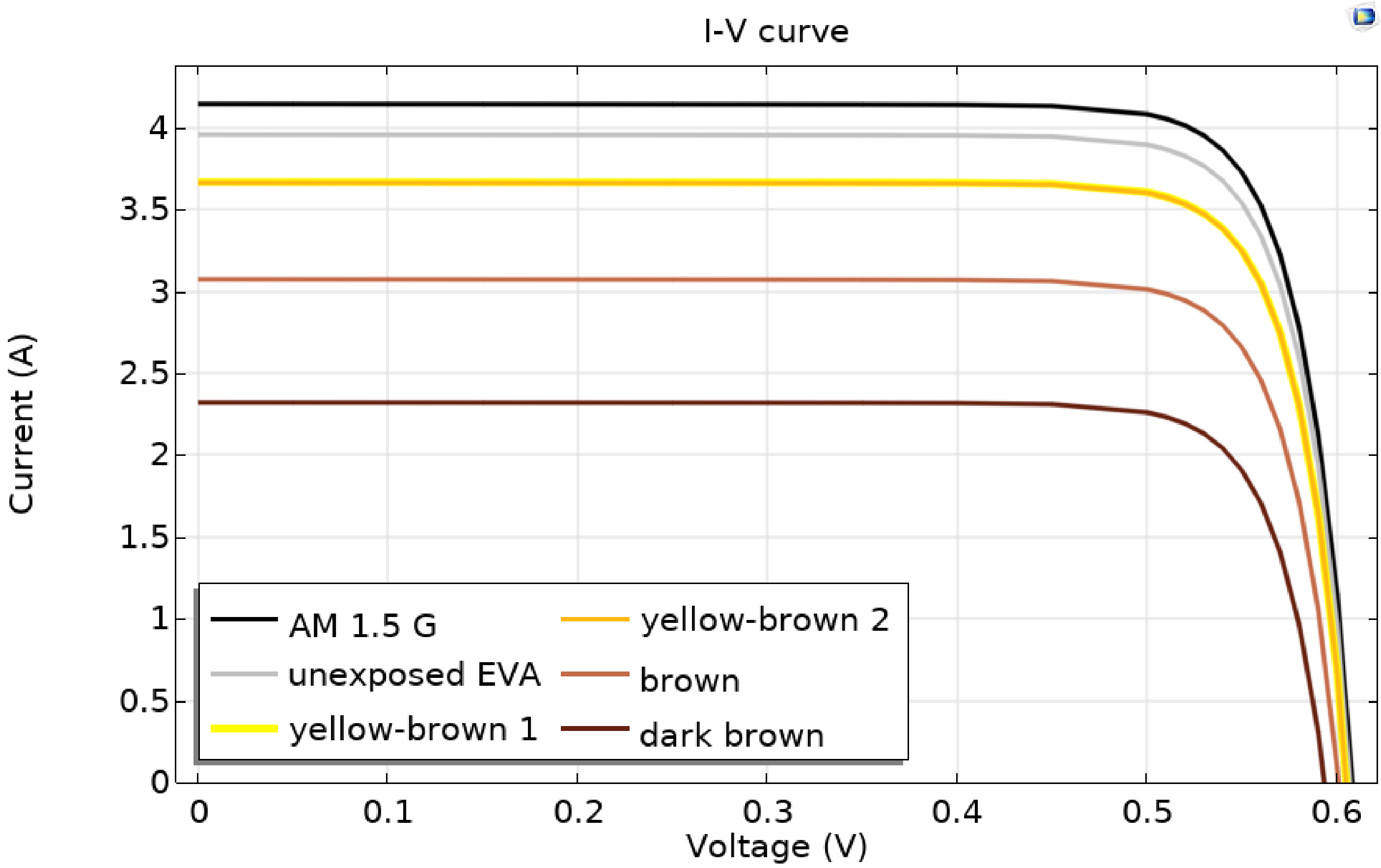

Figure 3 : I-V curve of the solar cell at different levels of yellowing.

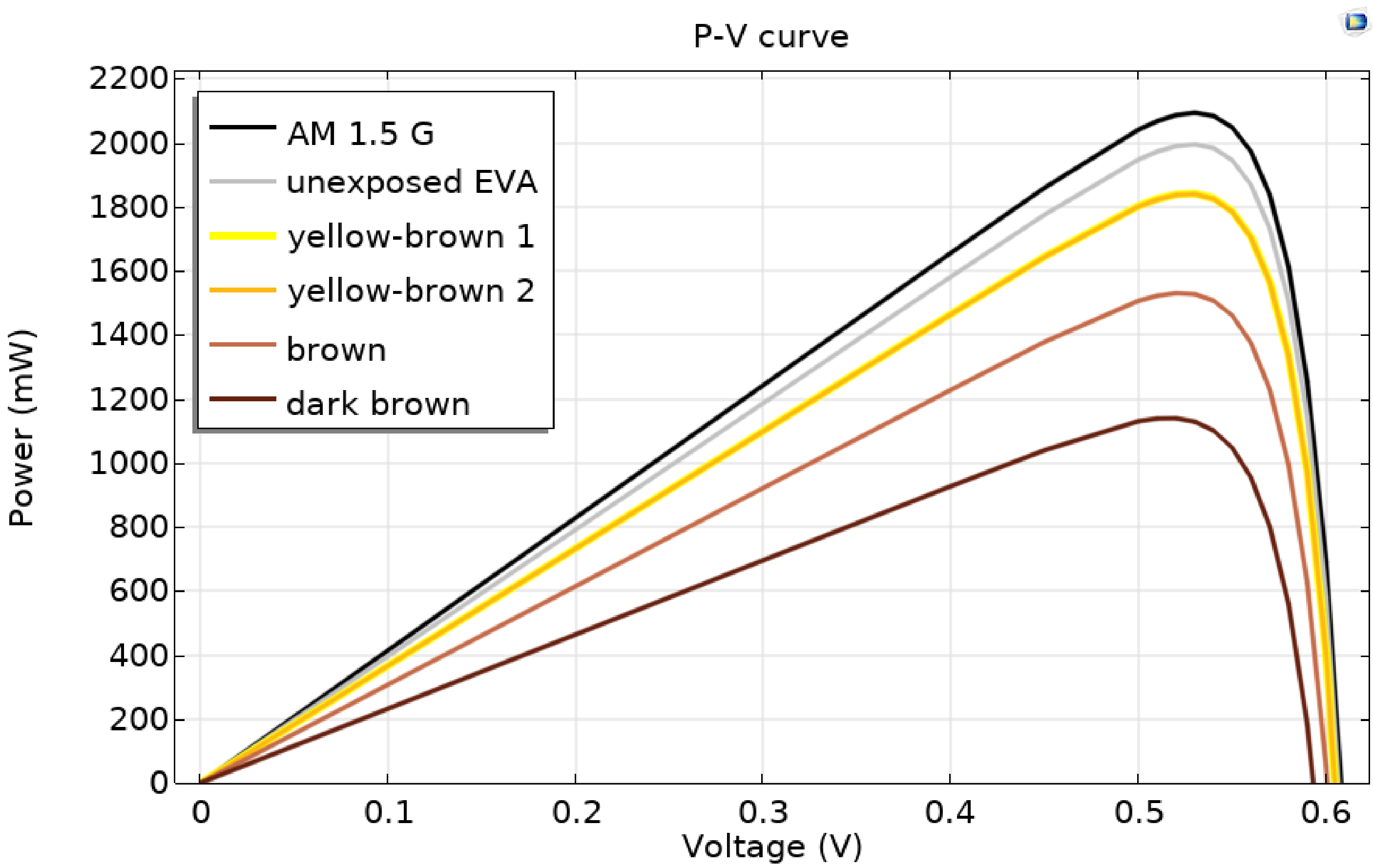

Figure 4 : P-V curve of the solar cell at different levels of yellowing.