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The Impact of Perovskite/Silicon Tandem Module Design on Hot-Spot Temperature

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With suitable bandgap tuning, organic-inorganic hybrid perovskite solar cells are promising candidates for use as the top cell in tandem with silicon (Si) bottom cells [1,2]. Although perovskite solar cells have been reported with the ability to withstand damp heat exposure (85 °C, 85% relative humidity) [3], the long-term performance stability of perovskite cells under real operational temperatures in the field is of concern. The hot-spot effect, a well-known reliability issue often experienced by conventional silicon PV modules, occurs when the current generation capacity of one or a few cells in a series-connected solar module is compromised. The affected cell(s) may be reverse biased if the max current generation is less than the module operating current determined by the external circuit. We simulate the impact on perovskite/silicon tandem module of elevated temperature arising from cell current mismatch caused by fault conditions. We present plausible tandem module designs, based on the conventional Si module design for the 2T module as in Figure 1(a), and a blend of conventional Si module and thin-film module designs for the 4T module as in Figure 1(b).

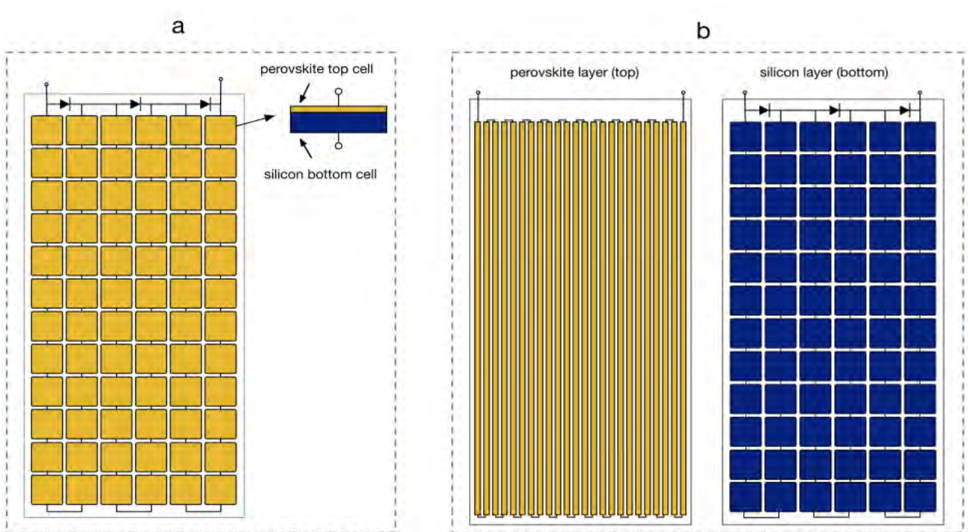

Figure 1. Cell shapes and connection configurations for (a) 2T and (b) 4T PSC/Si tandem-cell modules.

The *IV* curves of PV modules were simulated and presented in Figure 5 (a) using a Matlab-based module simulator that utilises explicit solutions to the one-diode equivalent model for solar cells and the reverse breakdown model by Bishop [4]. The word 'shade' is used to represent the reduction of cell current. The shade area investigated in this study is in the range of the area of the bottom Si cell as it causes the most significant hotspot effect in the Si layer. The unite-area parameters used in the one-diode model are based on the latest reported cell parameters with highest efficiency [1,2]. The unit-area reverse bias characteristics of the top perovskite cells are chosen according to the measurements of perovskite cells fabricated in ANU. While typical reverse bias *IV* characteristics of front-emitter mono crystalline silicon (c-Si) solar cells are used for silicon bottom cells in the 2T tandem module [5], two types of reverse bias properties including mono c-Si cells and Interdigitated-Back-Contact (IBC) cells were considered for the 4T tandem module. IBC solar cells are reported to have soft breakdown behaviour that allows for uniform reverse leakage current and therefore limits the max reverse bias built in PV modules [6]. The hotspot cell temperatures in IBC modules are reported to be considerably lower than front-emitter PV modules [6]. A Si module was also simulated as a reference. The module operating current is fixed at the maximum power current when the module is not shaded as marked with dashed line in Figure 5 (a). The operating points of all the reverse biased cells in each module are presented in Figure 5 (b). Figure 2 (c) presents the heat dissipation while Figure 3 (d) shows the simulated perovskite cell temperature in each module for shade area from 0% to 100% of the Si bottom cell area.

When interconnected in a 72-cell PV module, the high voltages of 2T tandem solar cells would lead to significant reverse breakdown when partially shaded. The reverse bias is also expected to cause higher heat dissipation and perovskite cell temperature compared with the Si reference module. As the long strips of perovskite cells are not reverse biased when shaded by an area no larger than the bottom Si cell, the perovskite cell temperature in both 4T modules are lower than the Si reference module. The perovskite cell temperature maintains below 80 °C in the 4T module using IBC Si cells.

We provide two potential module-level solutions to the hotspot issues in perovskite/silicon tandem modules, including increased number of bypass diodes and mixed series and parallel cell connections. The simulated maximum perovskite cell temperatures are presented in Figure 4 (e) and (f). According to the simulated results, both methods can potentially reduce the maximum perovskite cell temperature to below 100 °C.

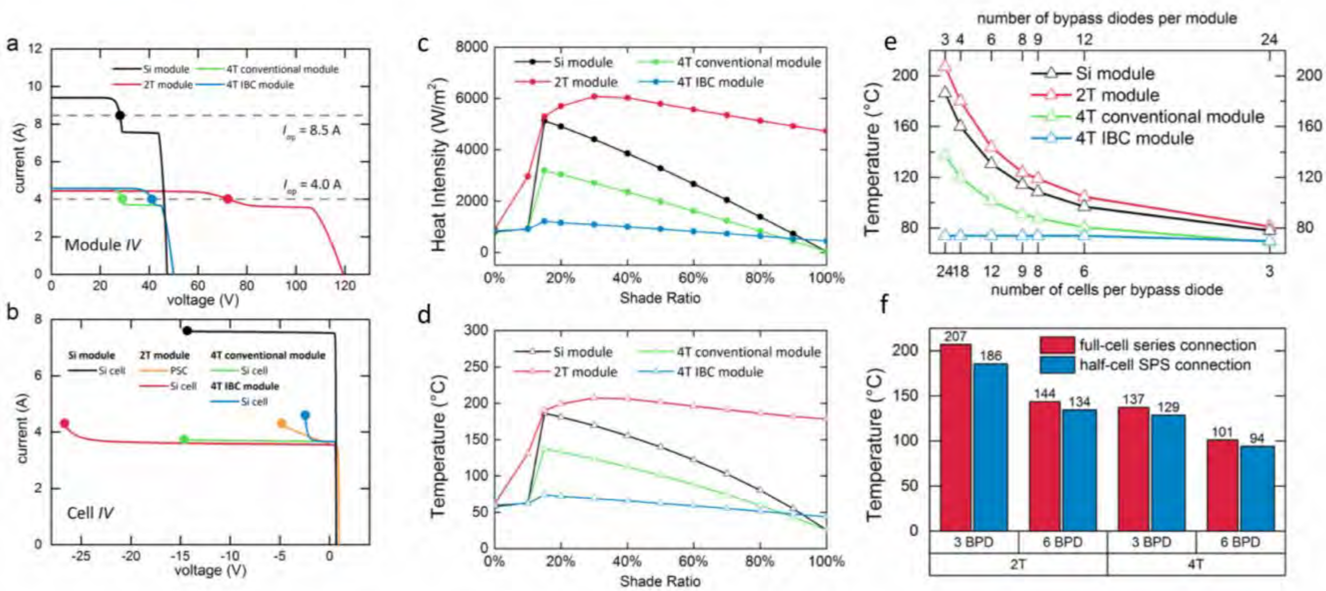

Figure 5 (a) Module IV curves when 20% of a Si cell is shaded, with the operating points marked by dots and determined by fixed externally-imposed operating current (I_{op}); (b) *IV* curves of reverse-biased cells (negative voltage) in the simulated modules, with the operating conditions marked by dots; (c) intensity of the aggregated heat dissipation from the PSC and Si cells; (d) simulated temperatures of the PSC in the 2T module and the Si cell in the 4T conventional module, the 4T IBC module, and the Si module; (e) simulated peak cell temperature for the perovskite cells with different number cells per bypass diode; (f) temperature decrease by using half-size silicon cells with a series-parallel-series configuration for 3- and 6-diode configurations.

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