

Analytical Lambert-W Single-Diode Modelling of Temperature-Dependent Mismatch in Two Terminal Perovskite/Si Tandem Solar Cells

András Bálint Mészáros, Ahmad Halal and Balázs Plesz

Budapest University of Technology and Economics, Department of Electron Devices

Introduction

Perovskite/Silicon tandem solar cells series-connect a wide-bandgap perovskite top cell with a silicon bottom cell in a two-terminal (2T) configuration, where output current is governed by whichever sub-cell produces less photocurrent. In the Bottom-Limited (BL) scenario the current is limited by the silicon bottom cell, in the Top-Limited (TL) scenario by the perovskite top cell. Under real operating temperatures (10–80°C), the two sub-cells respond in opposite directions, as in silicon the short-circuit current rises with temperature while perovskite's falls. This work quantifies how these competing trends drive tandem performance across both BL and TL regimes.

Methodology

Two series-connected single-diode models (SDMs) form the 2T tandem, with each SDM cast in explicit voltage form via the Lambert W function to enable direct current-mismatch analysis. Temperature dependence follows De Soto formulations, Varshni model for Si bandgap and linear $E_g(T) = 1.55 + 4 \times 10^{-4} \cdot (T - 300)$ eV for perovskite, while resistances are treated as temperature-independent; the model is validated against measured Si I-V data (10–80°C, 200–1000 W/m²). Nominal temperature coefficients $k_{isc,Si} = 0.4314$ %/K and $k_{isc,pero} = -0.053$ %/K are swept at $\times 1/\times 1.5/\times 2$ and $\times 1/\times 2/\times 4$ respectively, with all results normalized to STC (25°C, 1000 W/m²).

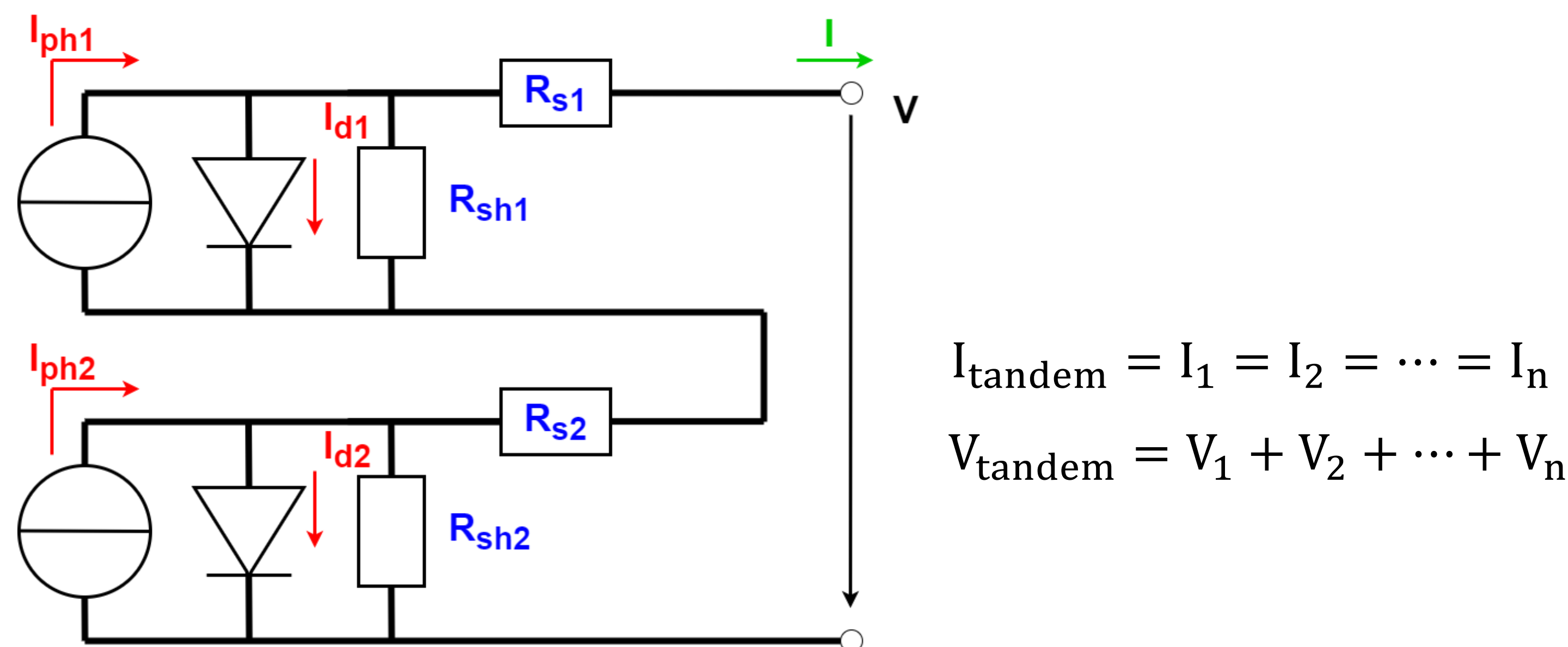


Fig. 1.: Two single-diode equivalents connected in series

Results

In BL operation, the rising silicon short-circuit current ($k_{isc,Si} > 0$) partially offsets the declining open-circuit voltage (V_{oc}), producing a P_{max} peak above STC near 70°C at nominal ($\times 1$) and above 80°C at $\times 2$. The gain ranges from +3.0% ($\times 1$, slope +0.089%/°C) to +19.6% ($\times 2$, slope +0.414%/°C) at peak, while below STC the BL configuration degrades from -2.4% to -9.1% at 10°C. In the TL configuration, varying $k_{isc,Si}$ has negligible effect: the 80°C loss shifts only from -16.2% to -14.9% across the full $\times 1$ – $\times 2$ range.

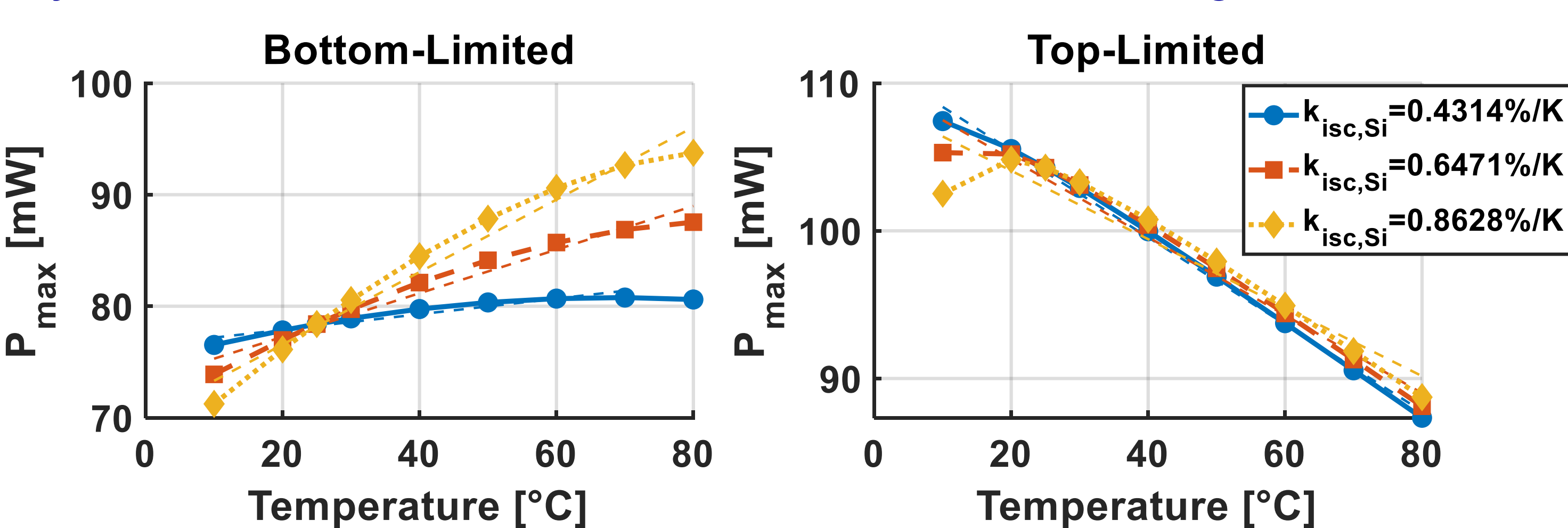


Fig. 2.: Effect of Si temperature coefficient on efficiency

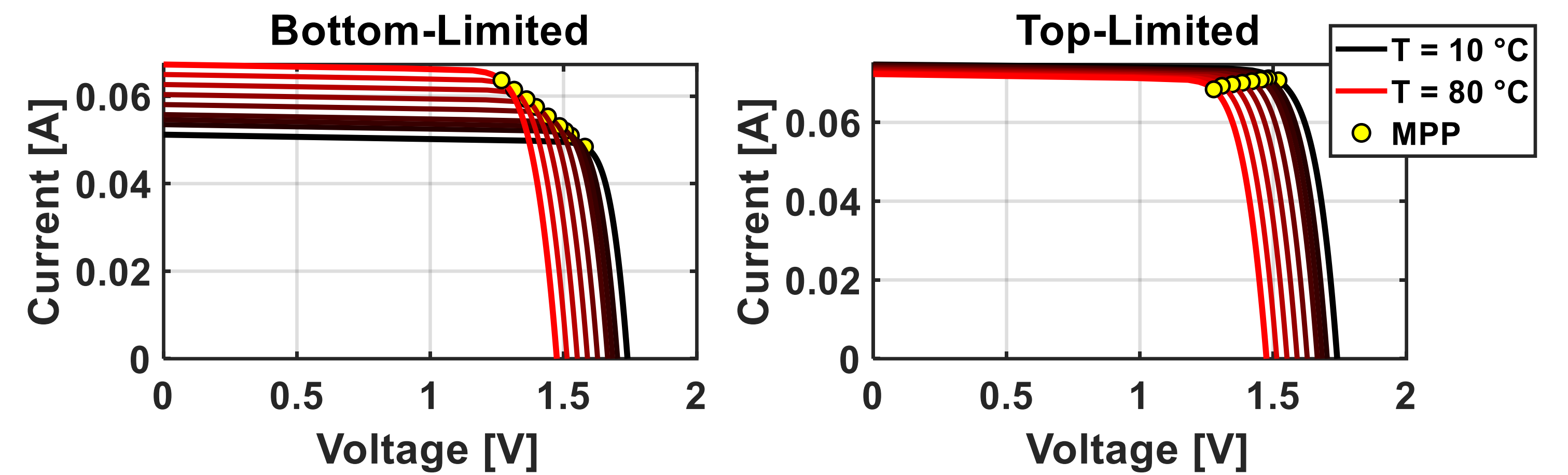


Fig. 3.: BL I-V characteristics ; $k_{isc,Si} = 0.4314$ %/K

In the top-limited (TL) configuration, both short-circuit current and open-circuit voltage decrease with rising temperature ($k_{isc,pero} < 0$), producing a strictly monotonic P_{max} decline -16.2% at 80°C ($\times 1$), widening to -18.4% ($\times 2$) and -23.0% ($\times 4$), while at 10°C a gain of +3.0% to +4.2% is recovered. In the BL configuration, varying $k_{isc,pero}$ is essentially irrelevant the P_{max} peak of +2.4% to +3.0% consistently appears between 60 and 70°C regardless of the perovskite temperature coefficient.

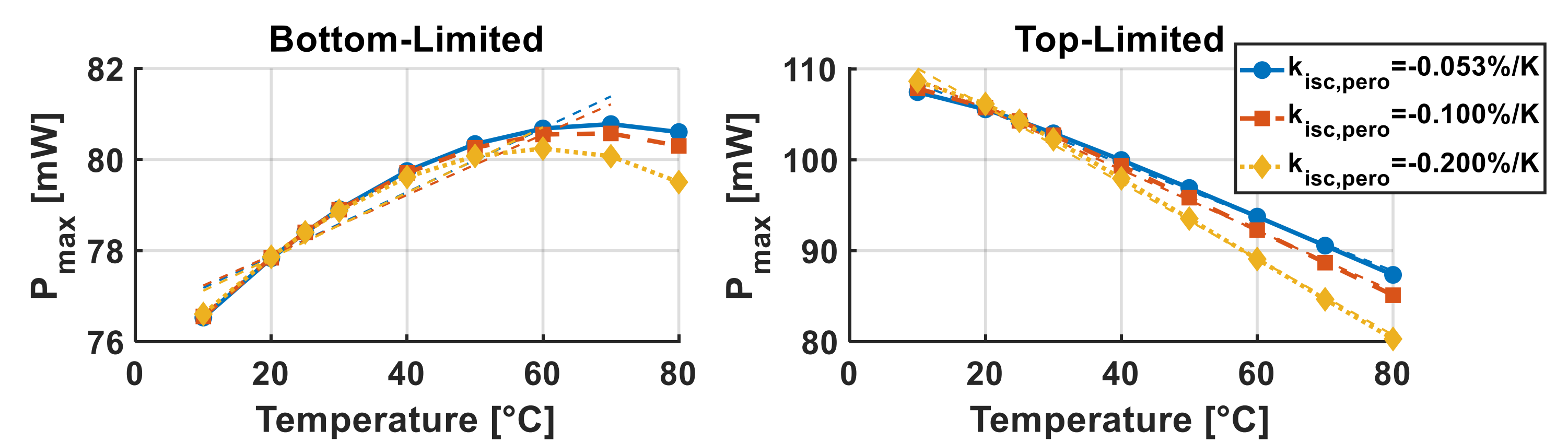


Fig. 4: Effect of perovskite temperature coefficient on efficiency

Near 60–70°C the two architectures diverge sharply: BL peaks at +3.0% above STC while TL has already dropped to -10 to -13%, a gap that widens at 80°C (+2.8% vs. -16.2%) and reverses at 10°C (-2.4% vs. +3.0%). BL behavior is driven by $k_{isc,Si}$ doubling it shifts the 80°C P_{max} gain from +2.8% to +19.6%, whereas TL behavior is controlled by $k_{isc,pero}$, demonstrating that the limiting sub-cell's temperature coefficient dictates the full tandem's thermal response.

Table 1.: BL vs TL P_{max} comparison (nominal k values, STC-normalized)

T[°C]	BL Isc [%]	BL Pmpp [%]	TL Isc [%]	TL Pmpp [%]
10	-6.30	-2.39	+0.25	+3.02
20	-2.10	-0.73	+0.26	+1.21
25	0.00	0.00	0.00	0.00
30	+2.10	+0.65	-0.27	-1.32
40	+6.29	+1.72	-0.80	-4.13
50	+10.49	+2.47	-1.35	-7.08
60	+14.68	+2.91	-1.90	-10.10
70	+18.87	+3.03	-2.45	-13.16
80	+23.06	+2.81	-3.00	-16.24

Conclusions

Temperature dependence of the performance in 2T perovskite/Si tandem solar cells is governed by the temperature behavior of the current limiting sub-cell and especially the temperature dependence of its photocurrent. In BL configuration, the Si I_{sc} rises +23% from STC to 80°C, more than compensating the V_{oc} drop and producing a net P_{max} peak, while in TL configuration the perovskite I_{sc} falls -3%, compounding the voltage loss into a monotonic decline. These results might suggest that different climatic conditions could require different cell setups, e. g. BL tandems being preferable for hot climates and TL tandems better suited to moderate and cold conditions.