Overview of Research and Teaching Accomplishments

Dr. Peter Bermel (pbermel@purdue.edu) leads the Energy and Nanophotonics research group at Purdue University and is a PI for the Bay Area Photovoltaic Consortium. A recipient of an NSF CAREER award, he is also a Purdue IMPACT Faculty Fellow, an NSF Graduate Research Fellow, an MIT Compton Fellow, a Winston Churchill Foundation Scholar, and an Associate Editor for the OSA journal, *Optics Express*.

His research focuses on improving the performance of photovoltaic, thermophotovoltaic, and nonlinear systems using the principles of nanophotonics, with particular focus on light trapping in photovoltaics, selective thermal emission in thermophotovoltaics, and photon recycling for photovoltaic, thermophotovoltaic, and lighting applications. Key enabling techniques for his work include electromagnetic and electronic theory, modeling, simulation, fabrication, and characterization. Dr. Bermel is widely published in scientific peer-reviewed journals, and has been cited over 3,700 times. His work has also been a recurring topic in publications geared towards the general public. His specific research accomplishments include the following:

Light trapping in photovoltaics: At MIT, Dr. Bermel led two key efforts that paved the way for current research on light trapping in photovoltaics. First, in collaboration with Dr. Steven Johnson of MIT, he co-developed a new finite-difference time domain code for Maxwell's equation, known as Meep, which offers the ability to obtain accurate results with a relatively coarse grid [1,2]; it has been downloaded and cited over 1000 times. Second, he led one of the early investigations of novel light-trapping structures in photovoltaics [3,4]. His work leveraged Meep, with cross-checking and validation by S-matrix and eigenmode solver codes, and relatively quickly translated into an experimental demonstration of increased light-trapping from a periodically-textured distributed Bragg reflector [5].

Helping to advance photovoltaic light trapping in several ways since arriving at Purdue, Dr. Bermel first collaborated with Prof. Minghao Qi to build an inverted opal photonic crystal to provide light trapping on the back of a commercial solar cell [6] (the increase in absorption, quantified as the light-generated current was demonstrated to be 31%, while the efficiency, measured through electrical testing, increased by 10%), then developed new modeling techniques to quantify sources of useful and parasitic absorption in complex 3D geometries, including periodic [7], plasmonic [8], and metasurface-based structures [9] which are now being used to design cutting-edge light trapping structures for perovskite/silicon tandems capable of efficiencies over 25% [10]. His work demonstrating the potential importance of introducing periodic light-trapping structures for photovoltaic design optimization has greatly impacted the field.

Thermophotovoltaic selective surfaces: Another major direction of Dr. Bermel's research has been in developing selective solar absorbers and thermal emitters for thermophotovoltaics (TPV). TPV works much like photovoltaics (PV) except that it uses a relatively high-temperature heat source to generate thermal radiation (in lieu of solar radiation). This thermal radiation then illuminates a photovoltaic cell, much like in standard flat-plate solar modules, but can operate at night and in other conditions where typical solar power may not work. During his time at MIT, Dr. Bermel developed a comprehensive modeling framework to predict TPV system performance [11], a framework that subsequently allowed him to design and predict selective solar absorbers for high-performance solar TPV using angular- and wavelength-selection to reduce parasitic thermal emission [12,13].

Also since arriving at Purdue, Dr. Bermel has continued his collaboration with MIT by modeling TPV performance for the design of various experiments. This has resulted in the successful fabrication of a 2D photonic crystal selective emitter made from tungsten that can exceed 1000 °C with low mid-infrared emission [14] as well as the design of a silicon/silicon dioxide 1D stack that can exceed 800 °C when integrated with a selective catalytic burner to use hydrocarbon fuels as the heat source. This carries potential applications in mobile power generation [15].

Photon recycling: A major theme of Dr. Bermel's current research is using sophisticated physics-based, self-consistent optoelectronic design, optimized via direct modeling of system-level performance. He first engaged in this effort by showing that, under ideal circumstances, external photon recycling alone in TPV can give more than 50% heat-to-electricity conversion [11]. He continues to work toward developing an integrated, self-consistent modeling approach for optical and electronic transport, which underlie photon recycling [16], that allows his group to show that the true efficiencies of nanowire solar cells are well below the interpretation of prior researchers [17]. These optical design principles carry across different fields in designing and building a high-efficiency incandescent lighting system which uses filters transparent in the visible, yet highly reflective in the infrared, to recycle light back to a high-temperature emitter thus tripling the overall system efficiency [18].

Teaching Contributions: Leveraging the methodology and key findings of his research, Dr. Bermel developed courses to disseminate this information to new researchers at Purdue and collaborating institutions. He began by developing a pair of advanced courses on the Numerical Modeling of Electro-optic Energy Systems, which taught key simulation approaches, appropriate methods of use, and interpretation of the results. Dr. Bermel has also turned this into a nanoHUB-U course, attracting over 400 students, and will be leveraged into an edX course, with anticipated enrollment of over 1000 students. Dr. Bermel has taught several undergraduate courses in electrical engineering—covering key topics such as linear circuits, semiconductor device fundamentals, and electro- and fiber-optic systems—and received strong teaching evaluations, particularly in the most recent two academic years.

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