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Spectral Management for Renewable Energy Conversion

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Solar energy is abundant. While the Earth is bathed in 130000TW of solar energy, our total energy usage amounts to about 20TW, just 0.015%. However, this energy is delivered as broadband radiation. Our photoelectric energy conversion devices are mostly designed to perform efficiently for a single wavelength, near the bandgap in the case of a semiconductor material. To make solar energy harvesting more efficient, it is desirable to spectrally manage sunlight.

This special section of the *Journal of Photonics for Energy* on spectral management for renewable energy conversion focuses on ways to adapt the incoming solar spectrum to better match the energy threshold of primary photovoltaic devices.

There are two primary routes towards this goal — joining the energy of two incoming photons together using triplet-triplet annihilation in organic molecules, or splitting the energy of incoming photons in two using the conjugate process, singlet fission. The former may also be achieved without emitting a photon from the generated excited state, but rather harvesting excited electrons in mesoscopic semiconductors.

In this special section, Pedrini and Monguzzi review the recent advances in the application of triplet-triplet annihilation-based photon upconversion systems to solar technologies. In this vein, Heinrich et al. report multiple-expanded porphyrins to absorb a 142-nm bandwidth in the deep red of the solar spectrum, upconverting this to the yellow part of the spectrum (560 nm) through triplet-triplet annihilation in rubrene. With the desire to move upconversion away from liquids and into the solid state comes the need to invoke migration of triplet excitons, rather than the molecules themselves. On this theme, Ogawa et al. have demonstrated mixed porphyrin/acene crystals grown under kinetically controlled conditions to enhance an upconversion system.

Zhou et al. have been advancing solar cells that directly use the energy in the excited singlet state that results from triplet-triplet annihilation. By extracting the excited state energy directly rather than requiring photon emission, one can circumvent the need for having high quantum yield emitters. They report on the influence of meta- and para-phosphonated diphenylanthracene on photon upconversion in self-assembled bilayers. Changing tack, there is increasing interest in harnessing singlet fission to perform photon splitting to downconverter solar energy. However, few materials are known to undergo singlet fission, due to the unusual arrangement of energy levels. Here, Pun et al. report on whether TIPS-anthracene is a singlet fission or triplet-triplet annihilation material.

While singlet fission research shows the potential for developing high-efficiency solar cells, we must compare the cost efficiency of these approaches with the market-leading silicon technology. Even better, what if we could use singlet fission to enhance silicon solar cells? In their contribution, Tabernig et al. demonstrate how excitons generated by singlet fission may be harvested in silicon solar cells via a quantum dot intermediate. By enhancing an existing technology, their work provides a pathway for spectral management to compete with current solar cell technologies.

Ultimately, one imagines the case where both up- and downconversion act in concert. How much of an advantage would this give? And what are the optimal semiconductor bandgaps to

couple to such a system? Tayebjee et al. report modeling of combining up- and downconversion to bring about the ultimate solar energy harvesting device.

Timothy Schmidt is professor of chemistry at UNSW Sydney. He graduated from The University of Sydney and obtained his PhD from The University of Cambridge. Previous appointments include The University of Sydney, CSIRO Australia, and the University of Basel. His research group studies molecular spectroscopy, both in the condensed and gas phase, with applications ranging from astrophysics to renewable energy. He is a chief investigator of the ARC Centre of Excellence in Exciton Science.

Rowan W. MacQueen is a physics graduate from The University of Sydney, where he obtained his PhD in chemistry. He undertook postdoctoral research at UNSW Sydney as a fellow of the Australian Renewable Energy Agency and is presently a fellow at the Helmholtz Zentrum Berlin for Materials and Energy. His research focuses on excitonic applications for renewable energy.

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Felix N. Castellano is Goodnight Innovation Distinguished Professor of Chemistry at North Carolina State University and was previously the director of the Center for Photochemical Sciences at Bowling Green State University. His research focuses on metalorganic chromophore photophysics and energy transfer, photochemical upconversion phenomena, and solar fuels photocatalysis.