

Efficient Energy Conversion – From Understanding to Application: Organic Photovoltaics and Solid State Lighting

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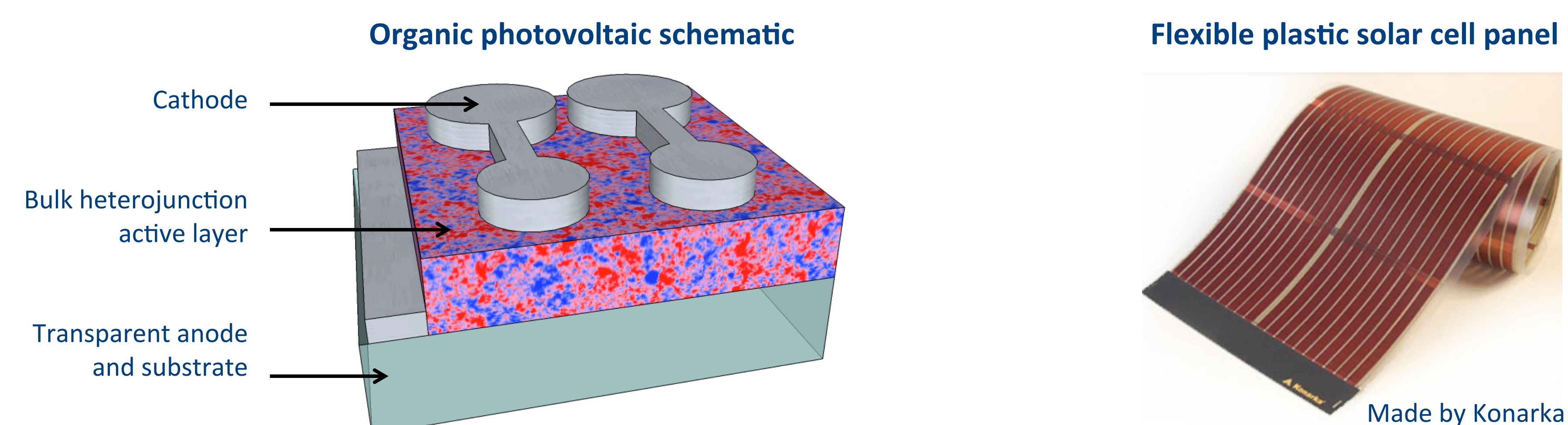
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Light Electricity

Organic photovoltaics for conversion of sunlight

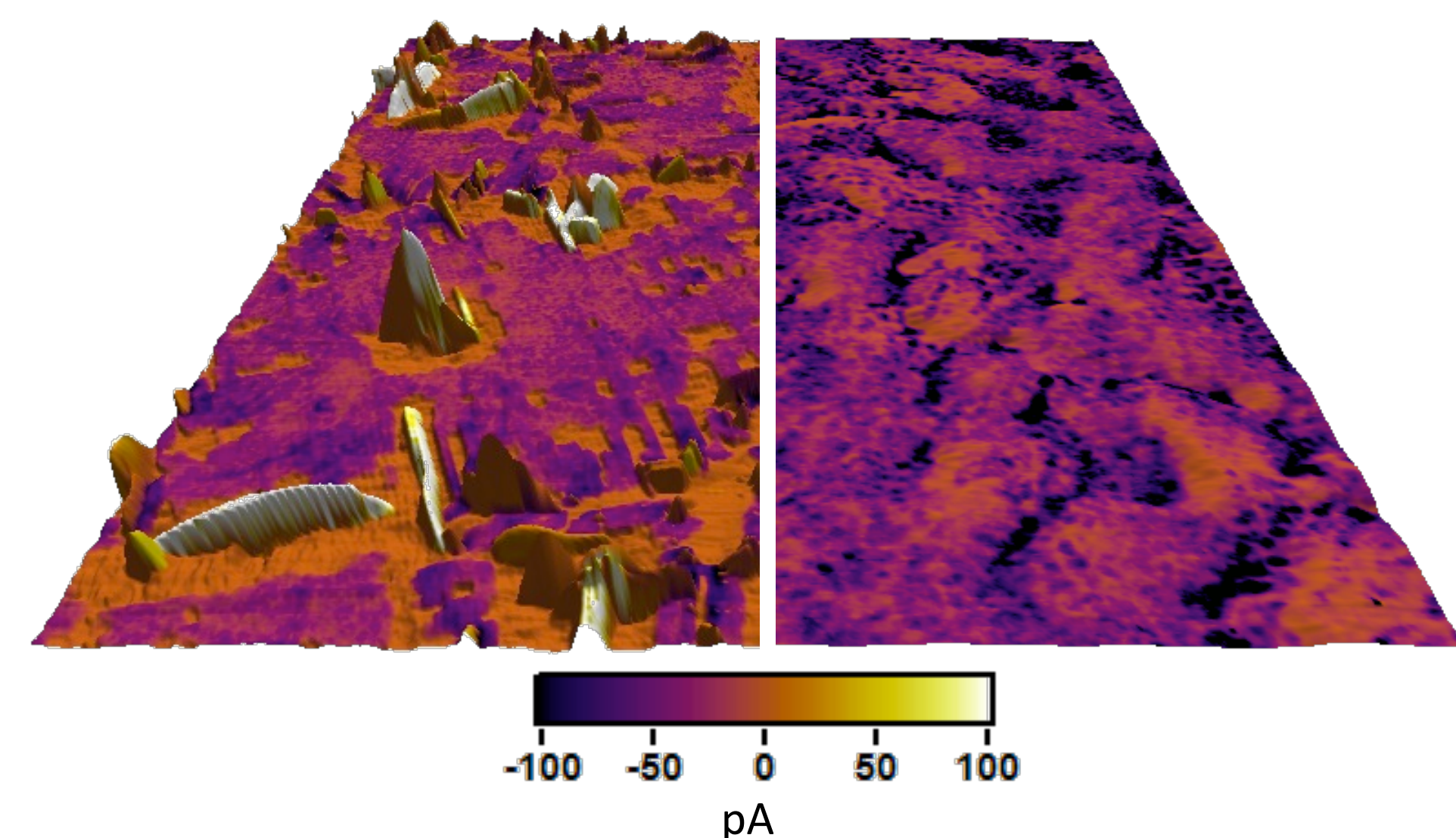
The past decade has witnessed an unprecedented surge of interest in renewable energy technologies. In particular, organic photovoltaics (OPVs) are highly regarded as a next-generation green energy source. OPVs utilize earth-abundant, carbon based molecules to absorb radiation from sunlight and convert photons into useful electrical current. In contrast to traditional silicon solar cells, OPVs are associated with less expensive manufacturing costs because they can be solution processed at room temperature and printed onto flexible plastic substrates. *Organic photovoltaics offer a low cost, lightweight and flexible, renewable energy alternative for our increasing energy demands.*



Higher device efficiencies will allow organic photovoltaics to become a viable option for large-scale power generation. Energy conversion processes in OPVs occur within the “active layer”, about 100 nm thick, made up of a network of donor and acceptor materials sandwiched between two electrodes. Probing devices on the nanoscale is, therefore, necessary in order to understand the processes that affect OPV efficiency. *Through gaining an understanding of these processes, we can develop new active layer materials and new synthesis routes that promote high efficiency and high stability organic photovoltaics.*

Nanoscale morphology of OPV devices

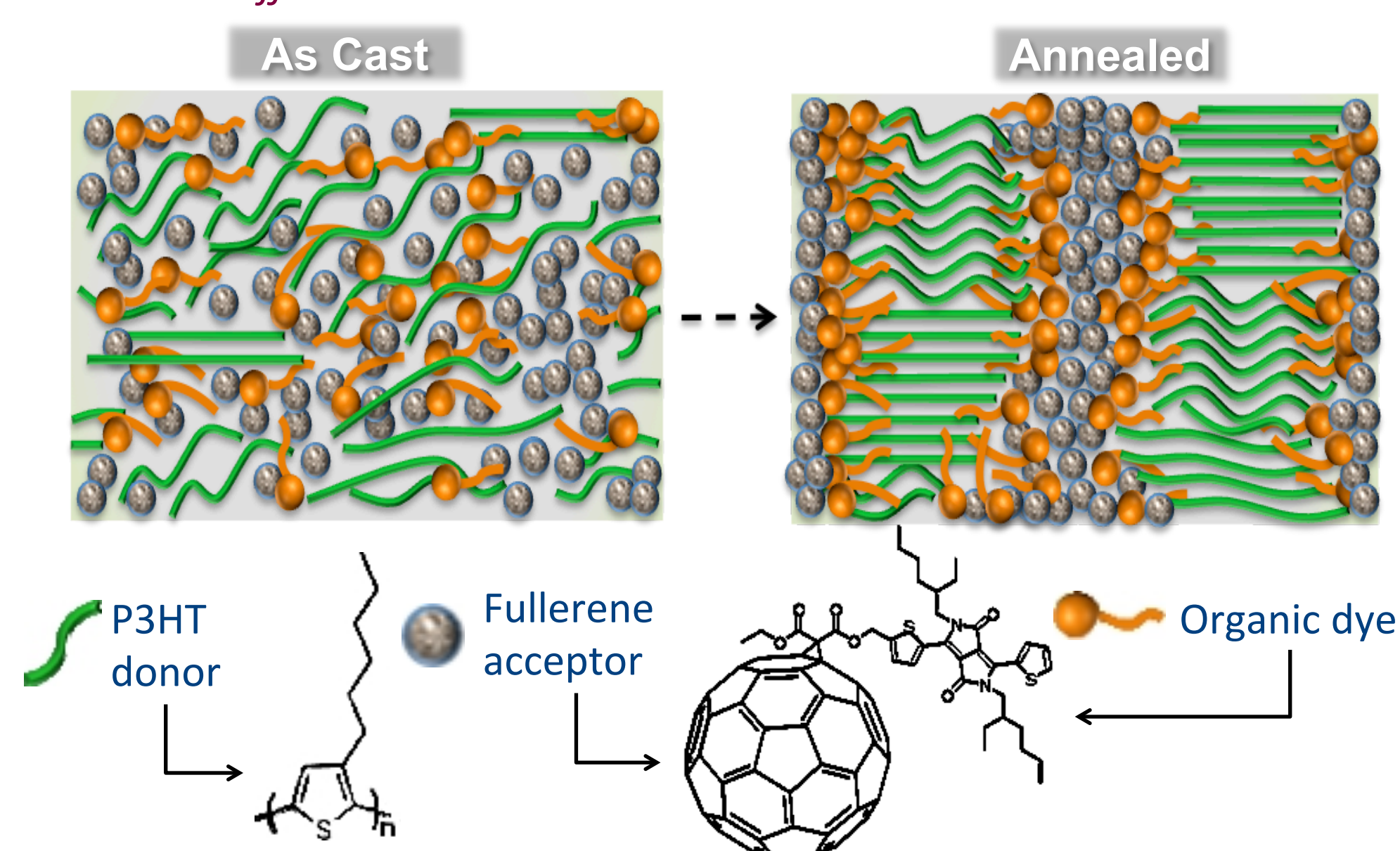
The efficiency of organic photovoltaic devices is critically dependent on the nanoscale structure—property relationships of the active material. Studying these relationships can help us understand the processes that affect efficiency. We study these relationships via photoconductive atomic force microscopy (pc-AFM). *Pc-AFM can be used as a nanoscale analog to bulk measurements, in which we shine light on a device and measure the current, resolving nanoscale morphological features.*



Morphology images above overlaid with photocurrent data for two similar solar cell systems, differing only by the molecular structure of the acceptor material, shows the sample on the right has a much smoother surface with only slight texturing. This favorable morphology shows a more homogeneous and negative photocurrent, leading to higher device performance. *We use this information, which is inaccessible in bulk measurements, to design systems that have more favorable nanoscale features and thus, obtain more efficient solar cells.*

New routes to OPV “active layer” materials

Most high-performance OPVs are fashioned using bulk heterojunction (BHJ) semiconducting active layers. BHJs are fabricated via the simultaneous solution deposition of a fullerene (electron acceptor) and a conjugated polymer (electron donor). While the simplicity of this method is economically attractive, it yields architectures with acceptor and donor molecules kinetically trapped in non ideal morphologies. *Imperfect microstructures facilitate parasitic recombination events that lower power conversion efficiencies.*

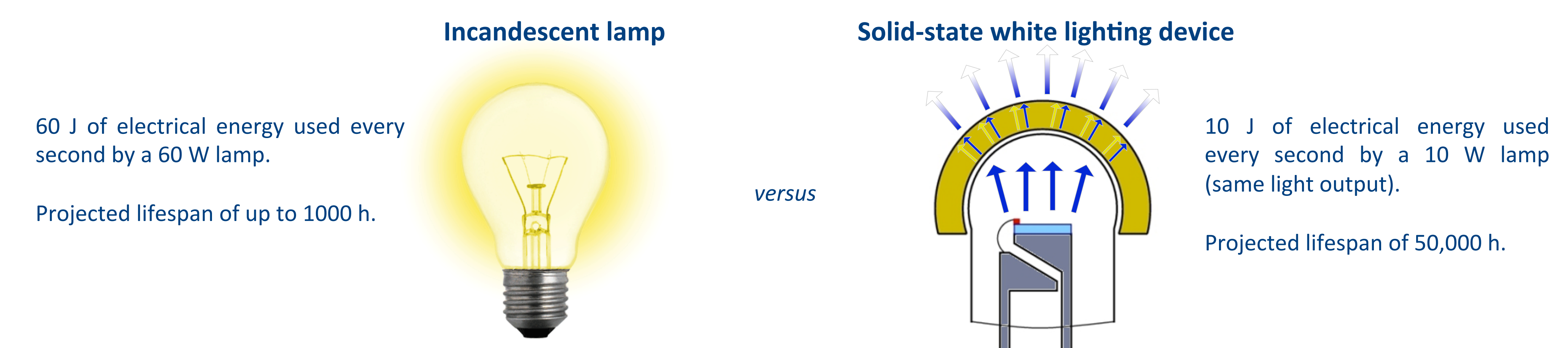


We have developed a series of fullerene-dye adducts. The addition of an organic dye enhances the capacity to harvest visible light by allowing for absorption of photons that are inaccessible to the polymer alone. These materials are additionally designed to increase thermodynamic control over bulk architectures by facilitating mixing between donor and acceptor components. *Incorporation of the fullerene-dye adducts improves control of bulk morphology, enhances light absorption, and leads to higher efficiency organic solar cells.*

Electricity Light

Solid-state white lighting

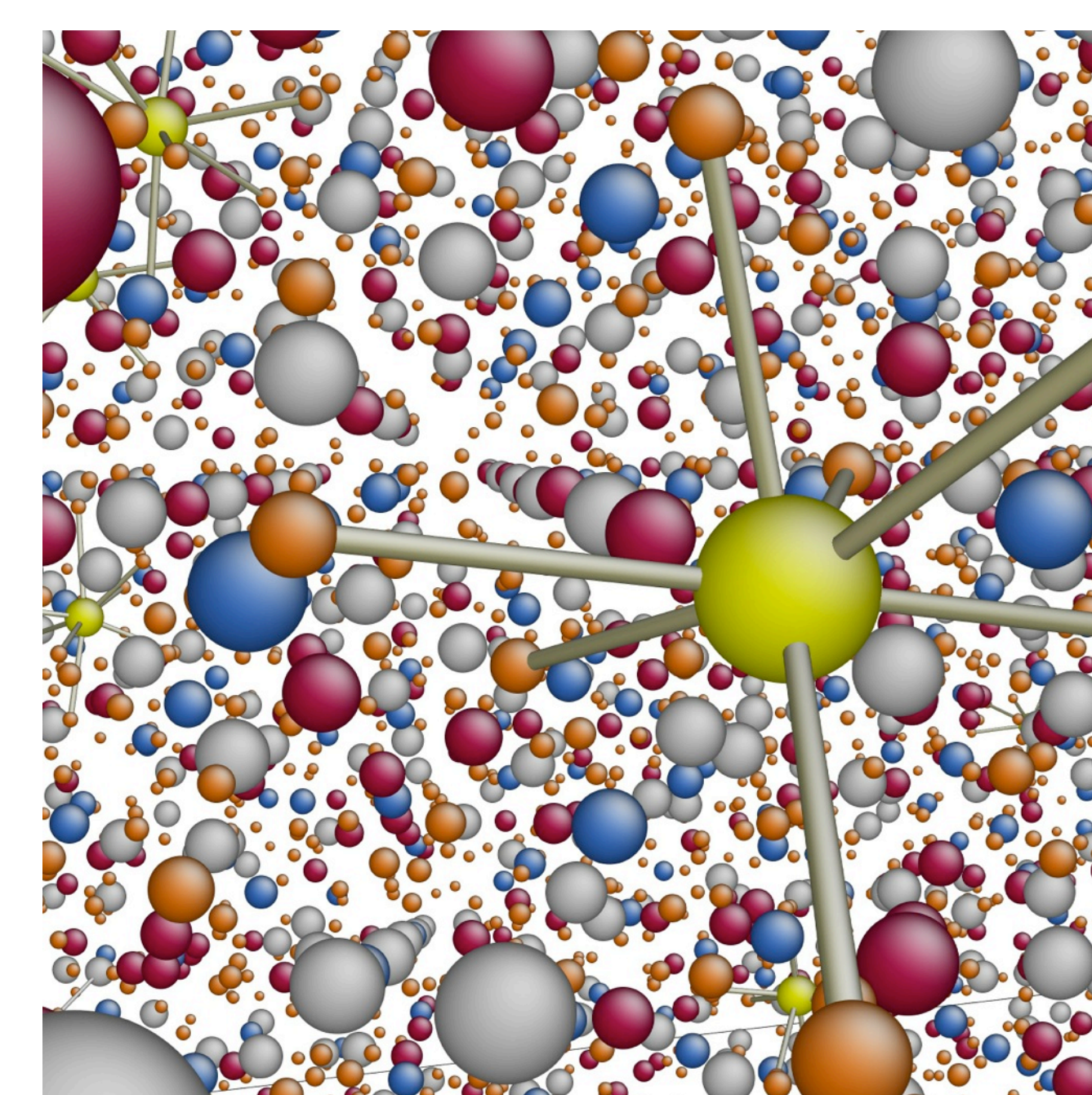
Solid-state white lighting devices comprising a light emitting diode (LED) and a phosphor offer an efficient, clean, and long-lived strategy for converting electrical energy into light. (InGa)N LEDs emit blue light, some of which is absorbed by the cerium-doped yttrium aluminum garnet ($Y_3Al_5O_{12}:Ce^{3+}$) phosphor and re-emitted as yellow light. *This combination of blue and yellow light appears white to the human eye.* These solid-state devices offer many benefits over incandescent and fluorescent light sources.



Higher phosphor efficiencies will lead to higher device efficiencies and a lower energy demand. Going forward, the thermal and chemical stability of phosphors must also be increased. Improvements in color temperature and color rendering can be realized by tuning the emission color of phosphors. This would allow for efficient white light generation for a number of different applications, ranging from home and office use to those which require more stringent lighting requirements, such as museum displays and movie production. *We aim to study these phosphors in an effort to better understand structure—property—composition relationships and to then apply this knowledge to the development of new highly efficient and stable phosphors with optimal color characteristics for solid-state white lighting.*

The local structure of Ce^{3+} in $Y_{3-x}Ce_xAl_5O_{12}$

The optical properties of phosphors are critically dependent on the activator ion (Ce^{3+} , Eu^{2+} , etc.) which is lightly doped into a crystalline lattice (e.g. $Y_3Al_5O_{12}$, abbreviated YAG). *Understanding the environment of the activator in the crystal structure is crucial.*

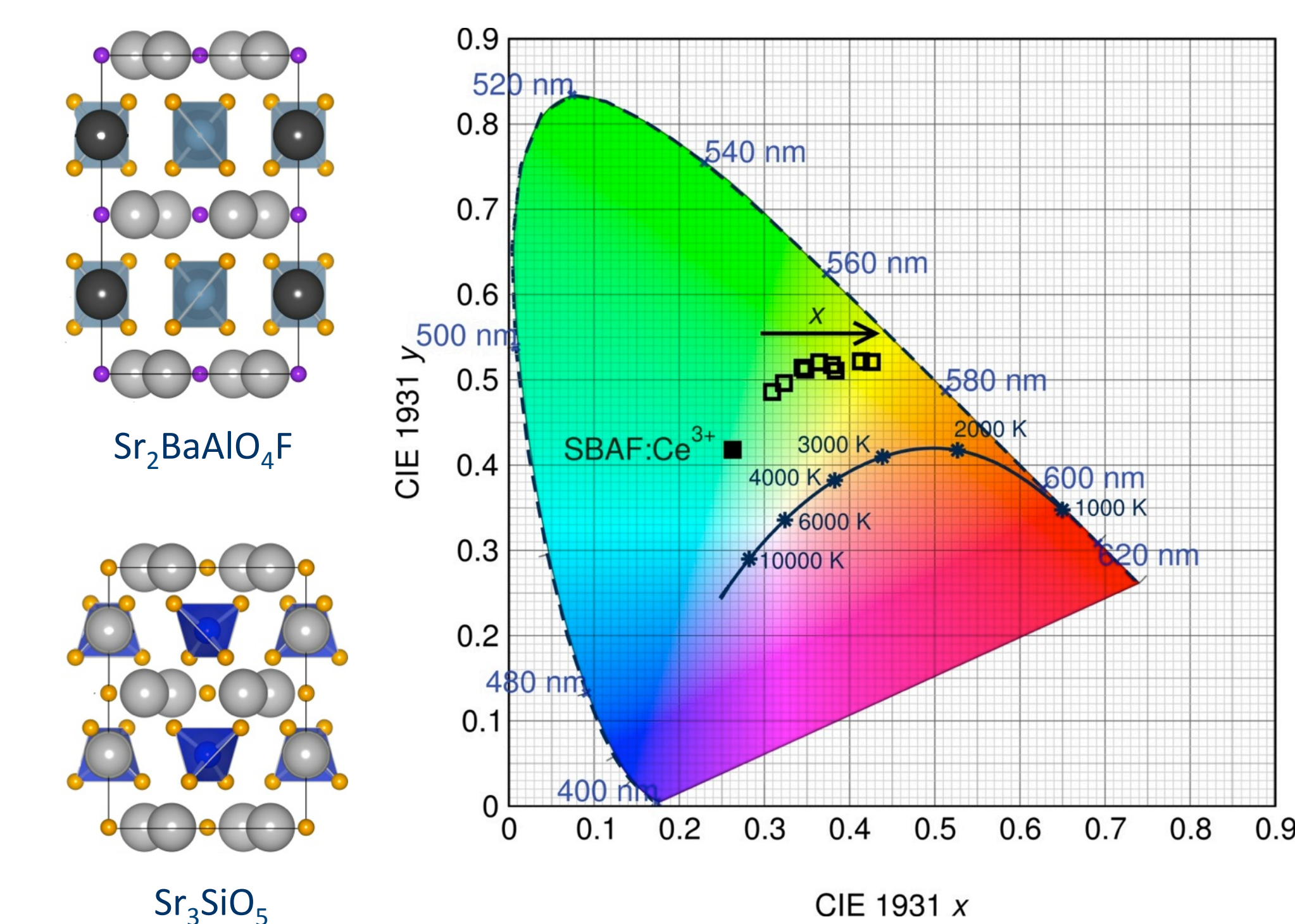


A view of the local structure of a Ce^{3+} atom (yellow sphere), obtained from appropriate experimental data.

We use state-of-the-art experimental methods (solid-state NMR, XANES/EXAFS, synchrotron X-ray and neutron scattering) and computational methods such as Reverse Monte Carlo (RMC) simulations of total neutron scattering, to elucidate the local structure and long-range order of phosphor materials.

New phosphor systems: $Sr_2Ba(AlO_4F)_{1-x}(SiO_5)_x:Ce^{3+}$

Applying the knowledge obtained through understanding the structure—property—composition relationships in phosphors, we can engineer new materials systems.



Photoluminescence data shows that with near-UV excitation, the maximum emission wavelength of the phosphor can be tuned from green to yellow. The combination of near-UV light with this green-yellow emission results in a promising solid state white lighting device with optimal color properties. *The new oxyfluoride solid-solution phosphor, made of two nearly isostructural phosphor hosts, Sr_2BaAlO_4F and Sr_3SiO_5 , results in a highly efficient phosphor system with optimal properties for solid-state white lighting, such as excellent thermal stability and easily tunable emission color.*