STABILIZATION OF ORGANIC ELECTRONIC MATERIALS AND DEVICES

This focus issue of the Journal of Materials Research contains peer reviewed articles that were accepted in response to a call for manuscripts

The path to ubiquitous organic electronics hinges on its stability

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In the year 2004, a revealing review by Stephen Forrest pointed to how organic electronics could shake up the conventional semiconductor industry by exploring the fact that organic semiconductors, in principle, could be processed on inexpensive plastic substrates of virtually any shape from solution or gas phase using high throughput methods.[1] One of the key challenges identified was the successful translation from the proof-of-concept using lab-scale approaches to large-area appliances. This would require a high degree of innovation to achieve ultra low-cost fabrication methodologies, compatible with industrial standards. Since then, the processing of organic semiconductors through printing and coating techniques to realize life size device fabrication has developed rapidly, to the extent that organic light emitting diodes (OLED), organic field effect transistors (OFET), and organic photovoltaics (OPV) advanced from a lab curiosity to commercialized mainstream technologies, mainly in the form of displays and, partially, solar modules.

Today, organic printed electronics are evolving towards smart, highly functional sensors, monitoring temperature, pressure, optical signals, and even physiological parameters. An extension of this development is the emerging interest in the integration of organic semiconductors into imperceptible electronics, soft machines, and detectors of neurological activity.[2] This is possible because organic devices can now be processed onto ultrathin (~1μm), ultra-flexible and stretchable substrates, allowing electronics to seemingly conform to three-dimensional shapes and biological tissue.[3] These are obviously very exciting developments, where interfacing organic electronics with biological material brings about its own technological challenges.

Still, a common, often underestimated, problem for early and advanced applications of organic electronics is the device stability with respect to environmental contaminants – mainly oxygen and moisture – light, and mechanical stress. From the more established organic electronics technologies such as OLED and OPV, it is well known that packaging costs typically dominate the overall production cost because the performance of these types of devices quickly deteriorates when the permeation of moisture and oxygen exceeds 10^{-6} g/m-2/day and 10^{-3} cm3/m2/day/bar, respectively.[4] To date, long operation times rely on costly, high barrier materials. This imposes significant economic burdens on the costs of a final product and limits the ubiquitous adoption of organic electronics. Thus, in order to take full advantage of the low-cost factor of mass-printed organic electronics it is critically important to adopt inexpensive packaging materials with limited oxygen and moisture barrier properties, similar to what is used in the food industry. Some of the emanating technologies described previously may even preclude the use of any barrier. Consequently, conceptually new strategies are necessary for the stabilization of organic electronic materials and devices. This was the driving challenge to be addressed in this Focus Issue.

The reasons for the instability of organic electronics are truly manifold and often system specific. The latter adds additional complexity and makes a universal solution unlikely. Importantly, identifying the underlying degradation mechanism is a tedious, yet essential, process towards a complete understanding and problem solving. This is reflected in the present Focus Issue, which explores an interesting combination of ideas, covering material strategies, device engineering, characterization techniques, and engineering of barriers, while envisioning future applications. For instance, the group of Jean Manca analyzed the requirements for a successful implementation of organic solar cells for space application during a stratospheric balloon flight. OPV has been long foreseen as a very interesting technology for space applications due to its very high power output per unit weight. Yet, this is the first study of its kind. Closely related, and in order to probe the ability of OPV to withstand large temperature fluctuations, which could be

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critical for space applications, Lee et al. demonstrate robust performance of devices that are subject to thermal cycling between -100 °C and 80 °C. High temperatures, in particular, tend to be detrimental as they may degrade various parts of a full device, including contacts, interfaces and active semiconductor. In this context, Hoppe et al. describe a simple, yet very effective method, for selectively probing the effect of temperature on interfaces by measuring charge transport in organic diodes. The advantage of this device layout is that it allows very systematic permutations and clear conclusions. Holdcroft et al., on the other hand, demonstrate how chemical side chain engineering can be employed to suppress changes in the sensitive morphology of polymer-fullerene blends subject to elevated temperatures. Significantly, the side chains of PTB7 derivatives are rendered cross-linkable without affecting the initial power conversion efficiency, leading to thermally stable polymer solar cells. The stability of organic solar cells is notably a topic of increasing concern, also because the power conversion efficiency in the lab is quickly approaching 15%, while progress in device stability under realistic conditions is not following at the same pace. It is thus critically important to combine efforts. This is the case for the interlaboratory study by Galagan et al., in which more than 20 labs fabricated, degraded, measured and shared the data for PCDTBT-based organic solar cells with different device geometries. Given the need for large sample volumes to achieve conclusive results, these studies are of extreme value but difficult to execute, requiring an immense collaborative effort and scrutiny.

A fundamental study of the photooxidation of semiconducting polymers and fullerenes and its implication on the performance of organic solar cells is undertaken by Scharber et al. and Wantz et al., respectively. Both studies showcase the power of electron spin resonance (ESR) spectroscopy to analyze spin sensitive degradation products. While Scharber et al. track radical polymer species in a variety of prototypical semiconducting polymers, Wantz et al. show in particular that oxidized fullerene species may play a crucial role in the degradation mechanism of photovoltaic polymer-fullerene blends, a scenario that was believed to be exclusively related to polymer degradation. Finally, Egelhaaf et al. and Steinmann et al. look into barrier layers from a mechanistic and technological point of view, respectively. Egelhaaf et al. present a study on the fundamental protective limitations of polymer barriers towards reactive oxygen species, while Steinmann et al. provide a global perspective on the state of the art of thin-film encapsulation in organic electronics with emphasis on low-cost packaging. The latter brings back the need for organic electronics to find creative ways to become cost competitive.

A recent analysis estimates the consumer market for organic semiconductor appliances to grow by ~140% within the next 10 years.[5] It is easy to imagine that this value could potentially be significantly higher, if organic electronic devices could be rendered environmentally stable using widely available and inexpensive packaging technology. We are optimistic that this focus issue provides inspiration in the right direction.

ON THE COVER:

Artistic depiction of the use of plastic solar cells in balloons for space applications.

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