Energising Energy

Fascinating World of Invisible Polymers

While emerging polymer-based technologies in energy harvesting, conversion and storage must be viewed as platform technologies with diverse end-applications, polymers are increasingly becoming invisible as they become embedded components of many advanced devices and systems, opines Dr. S. Sivaram.

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Polymers were the product of post-war renaissance in the chemical industry driven by the promise of inexpensive petroleum derived feedstocks. The fifties and sixties saw the introduction of many polymers that changed the face of human civilisation. From early curiosities, polymers became an indispensable part of our daily living and so ubiquitous that we no longer realise how dependant we are on polymer materials! The industry grew from zero to present capacities of close to three hundred million tonnes in about sixty years, the fastest ever growth of any industry in the post-industrialised world.

Polymers - The Embedded Components in Advanced Systems

In the early years, advances in polymer science led to materials and objects that you could see, touch and feel; however, in the twenty first century, polymers are increasingly becoming invisible as they become embedded components of many advanced devices and systems. These include energy harvesting, conversion and storage devices, micro-electronics,

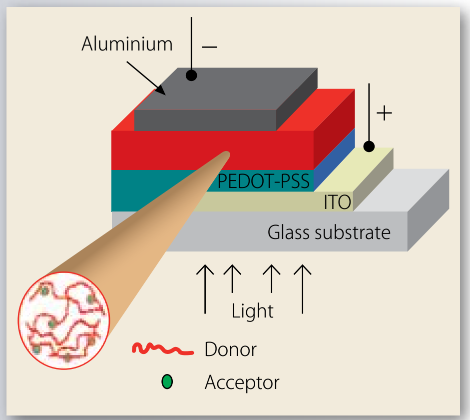

Figure 1: Hierarchical structure of an OPV.

medicine / therapeutics / diagnostics, air and water purification devices, formulated products such as adhesives, coatings, lubricants, cosmetics, personal care products, construction chemicals, oil and fuel additives, among others. Polymers were valued for their structural properties in the first wave of its growth; as they enter the second wave of applications, polymers will be valued for both, structural and functional properties. Therefore, endowing polymers with a diversity of specific functional properties will be one of the overarching themes of polymer science and technology in the years to come.

One of the key areas of functional polymer applications is in the area of energy harvesting, storage and conversion. Emerging science and technology of polymer applications in this area will disrupt conventional technologies and will provide humankind with new and more sustainable options of energy sources for everyday life. These include flexible organic photovoltaics (OPV) for converting solar energy to electricity, more efficient lighting devices, polymer-based anodes, cathodes, separators and solid electrolytes for safer and more efficient energy storage devices and selective proton transport membranes for efficient fuel cells that convert hydrogen to electricity.

The Big Question

The question that is becoming increasingly important is whether there is another way to harvest the energy of the sun apart from using silicon. In spite of rapid growth of silicon-based photovoltaics in the last twenty years, it should be noted that there are many problems with this technology[1]. Solar photovoltaics manufacturing processes involve converting quartz to metallurgical grade silicon and then to polysilicon ingots that are sliced to form wafers. This process is energy intensive, has poor atom economy, generates by-products that are not easy to dispose off, uses chemicals and reagents that are either toxic or have ozone depleting properties and emits humongous amount of carbon dioxide. In fact, it takes an average of six years of operation for a solar photovoltaic facility to just recover the energy that was spent in creating the silicon panels in the first place! It is, therefore, ironic that we consider silicon photovoltaics as a clean and sustainable form of energy! Additionally, the current 'top-down' technology of fabrication of silicon wafers from ingots is incapable of achieving the scale of operation that is needed to replace even 30% of the current energy needs of the world. Clearly, there is a technology gap.

The Big Question, Answered

It is believed that organic solar cells can bridge this gap[2,3]. The process is a 'bottoms-up' approach, namely, to create energy harvesting systems from molecules to polymers and finally to a device, using a continuous processing technique. The technology is likely to be clean, uses earth abundant materials, light in weight, has low energy intensity for manufacturing, can harvest electrical energy out of diffuse lights and is scalable. They are easy to fabricate using technologies already in commercial use (roll-to-roll printing, inkjet printing)[4], provide unlimited design freedom and can be readily placed on roofs, windows, walls and fabrics.

OPV devices are complex hierarchical structures consisting of a stack of fourteen layers of which atleast four are polymers that are the active functional materials. The basic science behind such polymers was described by Alan Heeger (Nobel Prize in Chemistry, 2000) in 1992[5,6].

OPVs have a certified efficiency of conversion of sunlight to electricity of about 11.5% in small area

Figure 2: Printed OPV devices[3].
Courtesy : Chemistry World, RSC

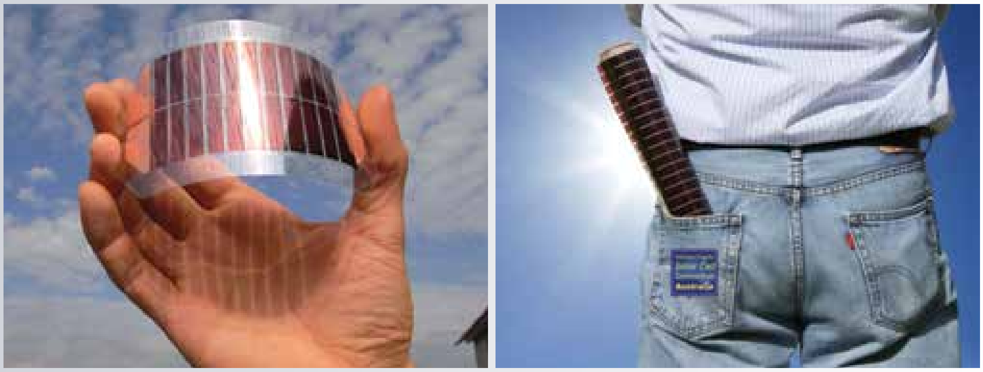

Figure 3: Flexible and rollable OPV devices.

devices. The most advanced technologies to date have an energy conversion efficiency of 2 - 3% in large area devices with a lifetime of about 2000 hours. Printing rates are around 1 metre per minute[7]. The current maximum achievable capacity for roll-to-roll printing is about 10,000 to 20,000 m^2 per year[8]. There is a need to scale up the printing technologies to 1 million m^2 per year. More material innovations are needed to enhance power conversion efficiency and device lifetimes.

Emerging polymer-based technologies in energy harvesting, conversion and storage must be viewed as platform technologies with diverse end-applications. Many questions are still unanswered with regards to these technologies. These are, inter alia, whether they are mere academic curiosities; when can we expect large scale manufacturing; what are the technology challenges; what applications will drive their demand; how relevant are they for the Indian environment; do they have a place in the legacy energy infrastructure, such as grid or distributed power?

In future articles in this space, we will address some of these questions and also explore in greater depth, the fascinating world of invisible polymers.

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