Yet more opportunities for organic semiconductors

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From 'Radio frequency identification' (RFID) tags to OLED displays and photovoltaic cells, organic semiconductors' high potential is widely recognised. A Marie Curie project has set out to bring potential innovation to the next level by using nucleation agent additives to better control the physical properties of these systems.

Organic polymer semiconductors are often regarded as high-potential materials by the EU's most innovative industrial sectors. Thanks to their excellent performance in terms of electrical conductivity, thermal stability, compatibility with mechanically flexible substrates, low-cost manufacturing, and easy integration with chemical and biological functionalities, these materials have been on a roll lately. Today, they are mostly known for their promising applications in the development of improved solar cells and flexible displays.

To take these materials to the next level and better face international competition, however, a better control of their physical organisation is required. It is currently impossible, for example, to control the crystallisation of even the simplest 'plastic'—PE—which otherwise would come out as a much better material than the brittle but commonly used 'polystyrene' (PS). Such control would enable the industry to change at will the physical appearance of an enhanced PE with a high mechanical strength, at a low fabrication cost.

With this objective in mind, the EU-funded CONDPOLYBLENDORD (Controlling the Order of Functional Polymers and their Corresponding

Blends) project has been using nucleation agent additives to control system ordering within conducting polymers and their corresponding blends. While small quantities of additives have been used for decades to manipulate the solid-state structure and properties of materials, their application to organic polymer semiconductors would open the way to many innovations in the sector.

The CONDPOLYBLENDORD was completed in late February. In this exclusive interview with the *research*eu* magazine, Neil Treat elaborates on his findings.

You claim to pursue the holy grail for the polymer community. How exactly?

CONDPOLYBLENDORD utilised the well-known concept of additives to address one of the great challenges in organic semiconductors—controlling their physical organisation. With this project, we wanted to relate molecular order and conformational arrangements to organic conjugate matter with electronic, magnetic and optical phenomena, and aim at developing understanding similar to the polymer mechanics field, where such knowledge led to the development of ultra-high strength polymer fibres, for use in bullet-proof gear as well as superb medical instruments.

What led you to do research in this area?

I became interested in polymers as a first year undergraduate student. I remember making the connection that the polymer systems being researched in my lab would be used to improve life-saving pharmaceuticals. From then on, I never wanted my research to be disconnected or isolated; I felt most inspired when at the forefront of my area of expertise—analysing, questioning and improving technology. My goal as a research scientist became to apply the science that is my passion to the problems and needs of people.

This defining realisation led me to do a Ph.D. at the University of California Santa Barbara, researching a class of solar cells that used polymers as active components. These systems have the potential for cost-effective production over large areas. During my tenure, I was invited to spend two months in the group of Prof. Natalie Stingelin at Imperial College London. Natalie and I began to look into an as yet unexplored idea for the organic electronic community: how to use nucleating agents to influence their structure and electronic properties. Fortunately, we found that this approach was both straightforward and powerful and that it could impact society by enabling more cost-effective production of renewable energy sources. As a result of this experience, I began to pursue opportunities to further develop this disruptive technology in the field of organic electronics.

How does your approach differ from current uses of additives?

The approach advanced by CONDPOLYBLENDORD applies a strategy widely exploited in classical polymer systems to the new material systems that are organic semiconductors. This approach involves the addition of high surface area additives, which increase the volume of nucleation sites within the host material, and, as a result, control the latter's crystallite size. Thus, due to their simplicity and versatility, our findings have begun to catalyse further studies in organic semiconductors carried out by device engineers (e.g. developing processing protocols) and physicists (e.g. understanding microstructure/charge transport relationships). Other potential applications within this area include the use of nucleation agents to control the phase morphologies of active layers in organic photovoltaic cells, where a fine distribution of the active components is believed to be beneficial. In principle, nucleation agents control the size of the crystalline domains in such materials, which enable exploitation of these additives for the production of photonics structures, and also more fundamental studies including elucidation of the influence of grain boundaries on charge transport in organic semiconductors.

How close are you to project completion?

CONDPOLYBLENDORD was completed at the end of February and we have achieved the objectives that were laid out at the beginning of the project. The findings from the project will be widely applicable to other functional systems (e.g. ferroelectrics, magnetic organics, nanomaterials, etc.) and it is our hope that our work will stimulate other groups to pursue this strategy.

What kind of windows of opportunity do your new nucleating agents open for industry in Europe?

CONDPOLYBLENDORD has truly underlined the importance of converging research, technology and innovation to further assist in the transformation of the polymer industry from commodities towards life-changing products while actively integrating them into the EU's PV sector. I aimed to contribute to the fundamental knowledge of semiconducting polymers and their corresponding blends by controlling the morphology within these systems through the use of nucleating agents—an approach that had never been investigated and utilised in semiconducting polymers and their corresponding blends before.

Controlling the nano-morphology of conducting polymers and their blends is still essential to enable further development in the field of organic electronics. Thus CONDPOLYBLENDORD was designed to significantly contribute to the European organic electronic research and industry sector by advancing the understanding of how to control the morphology of polymer-fullerene blends. I also attempted to harness rich, interdisciplinary expertise in chemistry, engineering and physics, which enabled me to gain a better understanding of the requirements for nucleation and allowed me to design new materials that, eventually, may lead to the development of new opportunities that make straightforward, large-area specialty products possible and, thus, will strengthen Europe's long-standing position in state-of-the-art manufacturing.

When do you expect your research to impact the market?

Products comprising organic semiconductors such as 'Organic light emitting diodes' (OLEDs) are already being used in our everyday lives, for instance in mobile devices. CONDPOLYBLENDORD focuses on the fundamental aspects of how to control the crystallisation of this class of functional materials. We believe that our findings will contribute to facilitating further technology developments. It is our hope that nucleating agents will improve the commercial viability of other material systems by addressing issues like batch-to-batch reproducibility.

What are the next steps for the project, and do you have any follow-up plans after its end?

Through the Centre of Plastic Electronics at Imperial College London, we will continue to use nucleating agents as a strategy to control the crystallisation and microstructure formation within emerging technologies such as perovskite photovoltaic cells.

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