Development of a colour-sensitive inkjet-printed pixelated artificial retina model and its study via an optoelectronic device.

Around 300 million people worldwide are visually impaired. Retinitis Pigmentosa (RP) and Age-related Macular Degeneration (AMD), involving deterioration of retinal photoreceptors-cells, are the leading causes of partial or total loss of vision. In the human eye, the retina contains several layers of cells including rods and cones photoreceptors that convert light into electrical signals and are responsible for night and colour vision respectively. With the development of biomedical engineering in the last decades, retinal prostheses, designed to partially restore vision, have seen progress. However, those based on conventional silicon, metallic, or rigid electrodes possess poor flexibility and biocompatibility.

In recent years, photosensitive organic electronic materials have been shown to be a very promising tool, even transplanted in vivo, for transducing light stimuli to non-functioning retinas. The materials are mechanical flexible so applicable to flexible and conformal substrates and can be deposited through inks. Up to now, the spectral responsivity was considered individually for one polymer semiconductor at a time in artificial retina applications. However, to contemplate colour vision, pixelation of different polymers that are photosensitive to different parts of the visible spectrum (colour sensitivity), mimicking those of the photoreceptors, is necessary.

A multidisciplinary international team with researchers from four research institutes has published the results of their project in an article in *Scientific Reports*, the open access journal from Nature Publishing Group, which highlights the progress made in advancing these goals.

The team members are from University of Rome Tor Vergata (Department of Electronic Engineering and Department of Biomedicine and Prevention), University of Surrey (Department of Electrical and Electronic Engineering, Faculty of Engineering and Physical Sciences, Advanced Technology Institute, Guildford, UK), Istituto di Struttura della Materia (CNR-ISM, Rome, Italy), Cicci Research srl. (Grosseto, Italy), and EMBL (European Molecular Biology Laboratory, Epigenetics and Neurobiology Unit, Monterotondo, Italy).

They demonstrate the design and fabrication of a colour-sensitive model of a pixelated artificial retina where each polymer dot was deposited by inkjet-printing (Figure 1). Three types of polymer semiconductors, with spectral absorbance curves emulating those of rods, and of cones which provide colour sensitivity, were deposited in a concentric layout simplifying the anatomical human retinal scheme.

The team verified that the phototransduction process from the artificial retina to a biological electrolyte solution imitating extracellular fluids found in our tissues produced electrical signals compatible with those found in retinas through a novel closed sandwich-type optoelectronic device (Figure 2). The bio-hybrid device, which combines techniques used in electrophysiology, organic photovoltaics and dye-sensitized solar cells, presents some advantages compared to conventional electrophysiological investigative systems: it is compact, easy-to-handle, transportable, with controllable size and requires a small amount of bio-electrolyte thus permitting use of tools typically found in an electronic-engineering/physics/chemistry laboratory. Photosensing through three-colour pixelation allowed incoming light to be resolved both spectrally and spatially. The biocompatibility of each type of photosensitive polymer was also demonstrated.

The number of pixels of the artificial retina model with distinct absorption spectra, mimicking the chromatic sensitivity of photoreceptors in the eye and interfaced with a physiological medium was 42100, the density of the artificial photoreceptors was ~11000 pixels/cm^2 and the corresponding spatial resolution was 267 dpi (dots per inch), with pixel diameters of 95 micrometres comparable to that of a human hair (Figure 3). Future studies should compare and investigate the interaction of the artificial retina model with biological ones. Printing technologies enable placement of different materials in the locations of choice. In view of a future based on personalized medicine, and with the development of higher resolution techniques (i.e. ≤ 10 micrometres which is the diameter of human retinal photoreceptors), one could think of first imaging an individual retina and then printing the pixels so as to spatially reproduce their location.

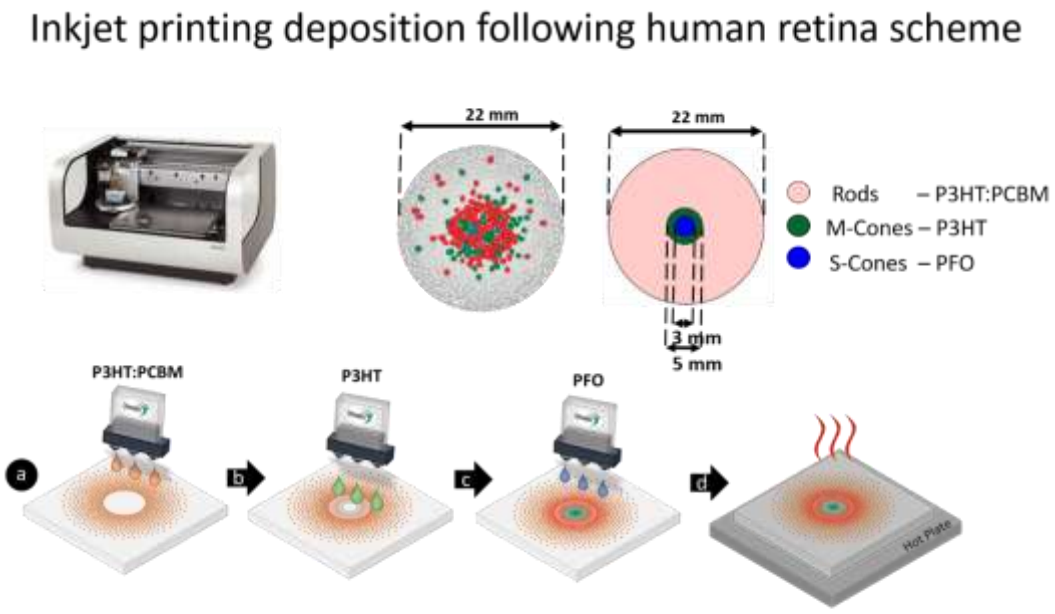

Figure 1: Design and fabrication of a colour-sensitive model of a pixelated artificial retina via inkjet printing.

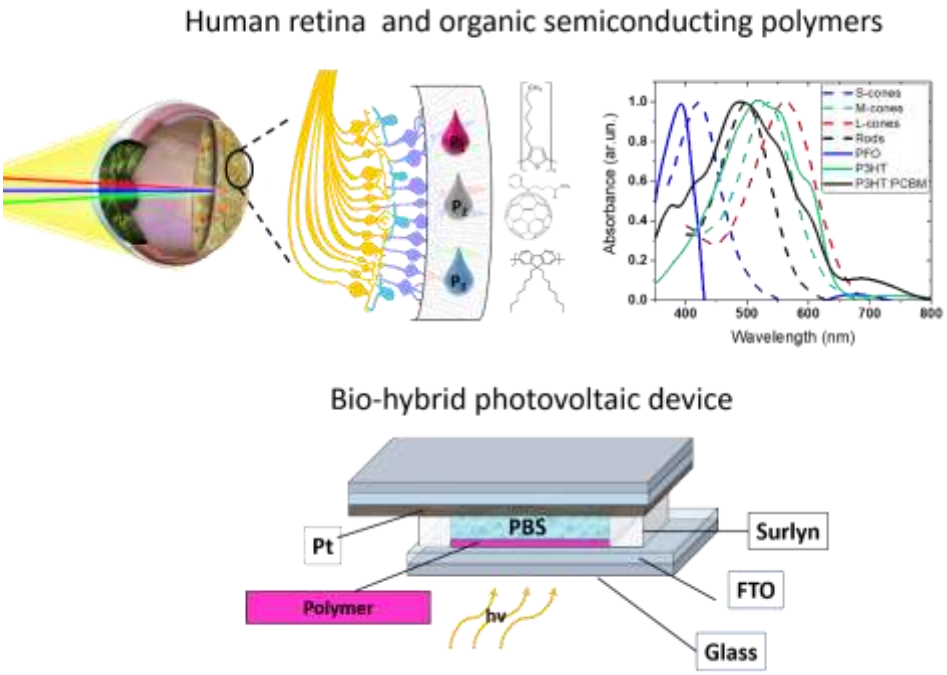

Figure 2: Human retina, organic semiconducting polymers and bio-hybrid photovoltaic device architecture.

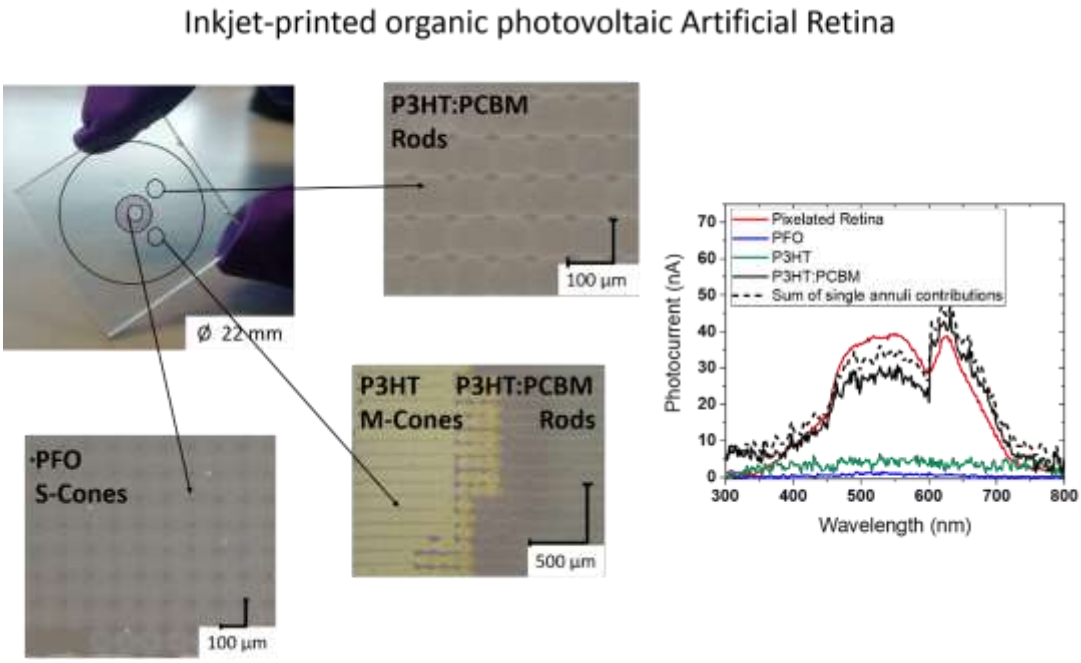

Figure 3: Microscopy images of the inkjet-printed Artificial Retina and its spectral response.

The results are published in Scientific Reports (open access):

"Colour-sensitive conjugated polymer inkjet-printed pixelated artificial retina model studied via a bio-hybrid photovoltaic device." Manuela Ciocca, Pavlos Giannakou, Paolo Mariani, Lucio Cinà,

Aldo Di Carlo, Mehmet O. Tas, Hiroki Asari, Serena Marcozzi, Antonella Camaioni, Maxim Shkunov, Thomas M.Brown and can be read at the following link: https://rdcu.be/cbQ6g

About the Department of Electronic Engineering, University of Rome – Tor Vergata

The Department of Electronic Engineering was founded in 1983 and now counts about 150 people, including faculty, staff, and cooperating personnel. The research described here was mainly conducted at the Centre for Hybrid and Organic Solar Energy (CHOSE) which was founded in 2006 as a result of the aim of the Lazio Region and the University of Rome Tor Vergata to create a centre of excellence in the field of next-generation photovoltaics. The lab consists of a more than 400 square meter laboratory that houses equipment for the fabrication and characterization of photosensitive optoelectronic devices. More than 25-30 researchers work at CHOSE including graduate students, postdocs and staff. CHOSE takes part in many collaborations at the regional, national and international level.

Source: Centre for Hybrid and Organic Solar Energy (CHOSE), http://www.chose.uniroma2.it/en/

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About the Department of Biomedicine and Prevention University of Rome – Tor Vergata

The shared mission of the biological, medical, surgical, and public health disciplines pursued under the auspices of the Department of Biomedicine and Prevention is to study new prevention methods and procedures through biomedical research as well as regenerative medicine by using biomaterials and stem cells. The Department also investigates new risk factors, biomarkers, in vitro and in vivo experimental models for the study of processes that regulate embryonic development and tissue homeostasis, and techniques for both the prevention and treatment of common and rare diseases.

https://en.uniroma2.it/academics/schools-and-departments/school-of-medicine-and-surgery/department-of-biomedicine-and-prevention

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About the Department of Electrical and Electronic Engineering, Faculty of Engineering and Physical Sciences, Advanced Technology Institute, University of Surrey, Guildford, UK

The Advanced Technology Institute (ATI) is one of the University of Surrey's world-leading research centres. ATI researcher fields span in the areas of quantum information, nanotechnology, energy, microwave engineering, and advanced materials. The ATI houses 160 researchers made up of engineers, physicists, materials scientists, biologists and chemists, approximately half of which are PhD students, allowing it to pursue truly multidisciplinary research.

https://www.surrey.ac.uk/advanced-technology-institute

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About the Istituto di Struttura della Materia, CNR-ISM

The Institute performs cutting-edge research in an interdisciplinary field between physics, chemistry and materials science. Its activities find applications in areas such as energy, environment, biological systems, electronic and magnetic devices, and cultural heritage. The institute's activities range from theoretical modelling to development of prototypal devices. This is achieved via the study of the processes, the preparation and functionalization of materials, and the characterization of their structural and electronic properties with novel instrumentation and methodologies.

https://www.cnr.it/en/institute/087

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About Cicci Research Srl.

Cicci Research is a start up company established in 2016 from a research activity with the Centre for Hybrid and Organic Solar Energy (CHOSE http://www.chose.uniroma2.it/) of the University of Rome "Tor Vergata"; the core activities are characterization tools (Arkeo platform) for optoelectronic devices and related post-processing and fully automated coater (Charon platform). Cicci Research instruments are reported on more than 50 scientific publications https://scholar.google.com/scholar?q=%22cicci+research%22. Annually, Cicci and CHOSE organize the International School on Hybrid and Organic Photovoltaics (ISOPHOS http://www.chose.uniroma2.it/ISOPHOS-2019/), an event that brings together researchers and directors of R&D centres.

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About the EMBL (European Molecular Biology Laboratory, Epigenetics and Neurobiology Unit – Asari group)

Founded in 1974, EMBL is Europe's flagship laboratory for the life sciences – an intergovernmental organisation with more than 1,700 employees from more than 80 countries, operating across six sites in Europe: Heidelberg (headquarters), Barcelona, Hamburg, Grenoble, Hinxton, and Rome. The EMBL Rome studies varied mammalian physiological phenomena from a molecular perspective in the context of the whole organism with a very strong emphasis on Neurobiology and Epigenetics and their interface. The Asari group combines experimental and computational approaches to study the principles and the function of neuronal circuits, specifically focusing on the early visual system of mice.

https://www.embl.org/asari/

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