Application in Bioelectronics Open Workshop

23rd July 2025

Centro Singular de Investigación en Química Biológica y Materiales Moleculares (CIQUS), Spain

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Wednesday 23rd July ⇒ Open Talks

Applications in Bioelectronics Workshop

CIQUS, Campus Vida, Santiago de Compostela University

9.15 – 9.30 Presentation

9.30 - 10.15 Dr. Jaime Martín Pérez, Centro de Investigacións Navais e Industriais, CITENI, Ferrol, A Coruña, Spain. *Title:* ***Understanding structural aspects or organic photovoltaic materials*** ***(***presentation + Q&A)

10.15 – 11.00 Prof. Jose Carlos Rodriguez-Cabello, Bioforge group, Universidad de Valladolid and CIBER-BBN, Spain. *Title:* ***Engineering Complex Coacervation from IDPPs: Toward Functional Synthetic Organelle-Like Structures*** (presentation + Q&A)

11.00 – 11.30 Coffee break

11:30– 12:00 Prof. Aitziber L. Cortajarena, CIC biomaGUNE, Spain. *Title:* ***Conductive protein-based biomaterials.*** *Presentation of eProt project* (presentation + Q&A)

12.00 – 12.45 Dr. Antonio Domínguez, Instituto de Microelectrónica de Sevilla, IMSE-CNM - Seville Institute of Microelectronics, Spain. *Title:* ***Bioelectronics: Challenges Beyond the Circuit*** (presentation + Q&A)

12.45 – 13.30 General discussion. Future Applications in Bioelectronics: Challenges and Prospects

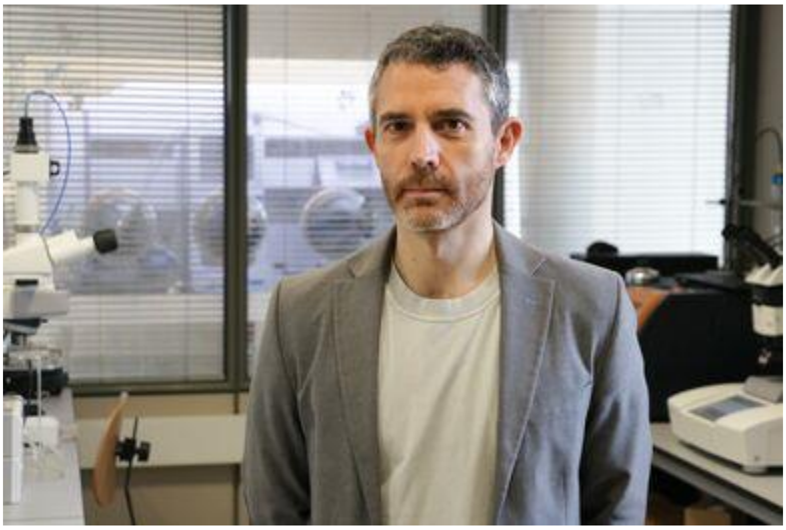
UNDERSTANDING STRUCTURAL ASPECTS OF ORGANIC PHOTOVOLTAIC MATERIALS

Dr. Jaime Martin Pérez

Centro de Investigacións Navais e Industriais, CITENI

Abstract

The majority of efficient organic solar cells consist of a polymeric donor and a small-molecule acceptor blended in a so-called bulk heterojunction architecture. The functionality of organic solar cells depends on the solid-state microstructure of donor and acceptor domains, in addition to the nanomorphology of the bend. In this presentation, I will discuss our recent findings on this subject. The following argument will be put forward: that the microstructure of high-performing donor semiconducting polymers does not conform to the traditional structural models developed for polymers, i.e. the amorphous and semi-crystalline models, nor with established polymeric solid mesophases. This argument will be supported by an examination of the structural aspects of the aforementioned polymers. Furthermore, the discussion will extend to the question of whether these materials exhibit an amorphous phase, as is the case with "regular" polymers. The subsequent discussion will address the topic of polymorphism in non-fullerene acceptor compounds. It will be shown that these compounds exhibit not only effective performance in solar cells, but also high electron mobility, which renders them promising candidates for use in electronic applications. At a higher length scale, the discussion will focus on the observation that donor:acceptor compounds are, to a certain extent, finely intermixed in solar cells. I will present a methodology based on ultrafast calorimetry that allows for the first time to determine the composition of these intermixed domains. Finally, the impact of the crystallinity of donors and acceptors, as well as the domain composition of blends, on the device operation will be discussed.



Short Bio: Jaime Martín Pérez

Jaime Martín is a *Oportunius* Research Professor at Universidade da Coruña (Ferrol), conducting research in the field of functional polymer materials. Within this, his current main interest is on the morphology, structure and dynamics of conjugated polymers and how these are connected with optoelectronic properties. He also holds a visiting position at BERC POLYMAT in San Sebastian.

Jaime received his BSc in Chemistry from UPV/EHU (San Sebastián) and his PhD from the Institute of Polymer Science and Technology (ICTP-CSIC) in Madrid under the supervision of Prof. C. Mijangos. After a 3-year postdoc in the group led by Prof. M. Martín-González at Institute for Microelectronics (IMM-CSIC), he joined Prof. Natalie Stingelin´s team at Imperial College London (UK). In 2015, he was awarded with a Marie Sklodowska-Curie Independent Fellowship and continued at Imperial College London two more years. In 2017, he secured a Gipuzkoa Fellowship and moved to POLYMAT BERC in San Sebastián, Spain. In 2018 he became a Ramón y Cajal Fellow and an Ikerbasque Research Fellow in the Department of Polymer Science and Technology of the UPV/EHU in San Sebastián. In 2020, he moved his Ramón y Cajal Fellow to the University of A Coruña (UDC).

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Engineering Complex Coacervation from IDPPs: Toward Functional Synthetic Organelle-Like Structures.

José Carlos Rodríguez-Cabello

University of Valladolid, Bioforge Lab, LaDIS, CIBER-BBN

Key notes:
Biomolecular condensates; Liquid-Liquid phase separation (LLPS); Elastin-like recombinamers; synthetic biology

Biomolecular condensates are unique structures that form in living cells through liquid-liquid phase separation (LLPS), driven primarily by intrinsically disordered proteins (IDPs) [1]. These proteins regulate biological functions by reversibly compartmentalizing molecules in response to stimuli. Synthetic condensate engineering aims to develop novel biomolecular condensates by understanding how amino acid sequences influence the mechanical properties and assembly of these IDPs. To achieve this, intrinsically disordered protein polymers (IDPPs) with a lower critical solution temperature (LCST) are often employed [2].

In this study, we focus on the formation of synthetic condensates using elastin-like recombinamers (ELRs) and examine the forces driving their coacervation, which include both simple coacervation (hydrophobic interactions) and complex coacervation (electrostatic interactions) at inter- and intramolecular levels. An IDPPs library, based on repeats of motifs found in the intrinsically disordered regions of tropoelastin, was recombinantly produced [3]. It includes two monoblocks with highly charged domains (one enriched in Glu, negatively charged, and the other in Lys, positively charged), a diblock combining these two monoblocks, and two hydrophobic control constructs containing VPGVG domains of different lengths. The latter three ELRs retained the elastin-like phase behavior, undergoing a reversible inverse temperature transition (ITT) above a characteristic transition temperature (T_t) and exhibiting random coiled coils and β-turn conformations similar to tropoelastin[4]. By contrast, the two highly charged monoblocks did not coacervate on their own.

However, mixing these charged monoblocks resulted in complex coacervation. As the molar ratio approached charge neutrality, the inverse transition temperatures decreased, and the random coil conformation shifted to include more β-turn structures, as confirmed by differential scanning calorimetry, ITC, circular dichroism, and molecular dynamics. The combined electrostatic and hydrophobic interactions produced higher-order conformations. Furthermore, the diblock system formed a more ordered structure with a lower Tt than the simple monoblock mixture.

We visualized these coacervation processes through two approaches: (1) in bulk solution and (2) in protocell systems confined within microfluidic devices. Optical and confocal microscopy showed how tuning IDPP chains affects the formation of different coacervates and revealed the critical role of inter- and intramolecular interactions in achieving successful coacervation. These imaging techniques also provided detailed insights into the dynamic behavior of the forming structures, underscoring the intricate balance of interactions required for coacervation.

Overall, our results highlight the interplay of self-organizing forces in creating complex hierarchical assemblies from IDPs. By fine-tuning inter- and intramolecular electrostatic interactions, we can govern the formation and maturation of protein condensates. These findings deepen our understanding of the self-organizing nature of biological macromolecules and LLPS, ultimately facilitating the design of complex organelle-like structures for diverse applications with significant implications in synthetic biology [1,5,6].

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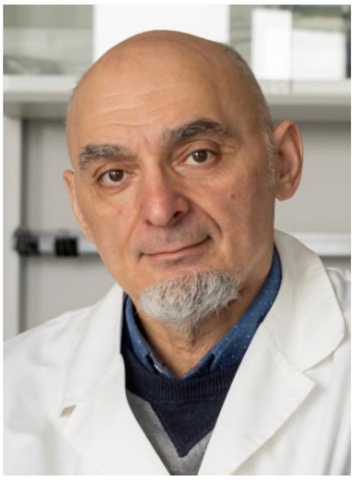

Short Bio: José Carlos Rodríguez Cabello

Dr. Rodríguez-Cabello is a full professor at the Dept. of Condensed Matter Physics of the University of Valladolid (UVa) Spain. During his career he has been teaching courses related to physics of polymers and biomaterials science in both undergraduate and graduate levels. In 1997, he founded BIOFORGE in the UVa, which nowadays is an internationally recognized and word leading group in the field of recombinamers. His current research interests include the development of biofunctional, smart and customized protein polymers towards obtaining advanced biomedical devices.

Prof. Rodríguez-Cabello is author of 152 papers in peer-reviewed journals, 13 book chapters, 350+ communications in international conferences and 9 patents as senior inventor. He has been invited to review manuscripts from different international journals and to routinely evaluate projects from numerous private and state funding agencies. Prof. Rodríguez-Cabello supervised 20 MSc, 23 PhD students, and 7 post-doctoral fellows. He has been part of a series of scientific societies and editorial boards of international journals. He has been coordinating or involved in many National and European research projects (managing 8+ million € for the last 10 years) and participated in the organization of scientific events in the area of polymer/materials science and biomaterials/tissue engineering. He has been member of scientific committees, organizing committees, referee and chairman in different international meetings. He has been invited to present 38 invited/keynote/plenary talks in international conferences including SIBB, World Polymer Congress, TERMIS, ESB, CESB, PEPMAT, LIAC or European Elastin Meeting.

More information: https://bioforge.uva.es/people/jose-carlos-rodriguez-cabello/

Conductive protein-based biomaterials

Prof. Aitziber Cortajarena,

Scientific Director, CIC biomaGUNE, Spain

Abstract

e-Prot project vision encompasses the rational design of efficient conductive protein systems (e-Ps), and the fabrication of all-protein based conductive structures and materials, targeting a **radical change** in design of **green electronic** and energy storage devices.

This breakthrough relies on **a multidisciplinary scientific approach** that includes a profound understanding of protein building blocks; biomolecular design principles and state-of-the-art synthetic biology, and chemical tools, to systematically fabricate new protein materials. At the same time cutting-edge characterization techniques and computational models will provide an unprecedented fundamental understanding of protein conduction thus building a solid foundation for their technological implementation.

e-Prot **proposes the first proof of concept of the envisioned technology in two key applications, printed flexible electronics and supercapacitors, which require optimized electronic and ionic conductivity, respectively**.

Specifically, e-Prot will focus on the optimization, through protein engineering, of a robust protein scaffold, the modular consensus tetratricopeptide repeat (CTPR), a short 34-residue helix-turn-helix motif that forms helical arrays of 3-20 repeats. This robust protein scaffold will remain intact aiming at improving their conductivity, while allowing the control of the stability and properties of the final materials.

These all-protein based printable circuits and energy storage units represent disruptive technological platforms to enable integrated devices for complex bioelectronic designs based on a single, versatile, and inherently biocompatible material. Furthermore, the selected applications, and specifically their final integration into wearable bioelectronics, represent fields in which the development of **naturally compatible and sustainable materials addresses an imminent future need for bioelectronic wearable devices.**

Short Bio: Aitziber L. Cortajarena

Dr. Aitziber L. Cortajarena is Ikerbasque Research Professor and Principal Investigator at CIC biomaGUNE since 2016.. During 2021 she was Scientific Vice-Director of CIC biomaGUNE. Dr. Aitziber L. Cortajarena is the Scientific Director of the Center for Cooperative Research in Biomaterials - CIC biomaGUNE since 2022.

Dr. Cortajarena earned her Ph.D. in Biochemistry from the Universidad del País Vasco in 2002. Then, she worked as a Postdoctoral Fellow at Yale University (USA) on protein design, structure, and function. In 2006, she was Visiting Scientist at the Weizmann Institute, Israel. Then, continued her work at Yale University, as an Associate Research Scientist. In 2010, she joined IMDEA Nanociencia (Madrid) where she developed her independent research group on bionanotechnology, before moving to CIC biomaGUNE in 2016. In addition to leading several European projects, including an ERC Consolidator Grant and an ERC Proof of Concept, she was awarded by Ikerbasque in 2019 in recognition of her professional career as a researcher and for her scientific contributions.

More info: https://www.cicbiomagune.es/org/people-detail?group=42443&id=37405

Bioelectronics: Challenges Beyond the Circuit

Antonio Dominguez-Alfaro [a]

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The bioelectronics of tomorrow envisions ambitious challenges, including tissue-integrated biohybrid implants, long-term stable brain-machine interfaces, skin-integrated electronics, and neuromorphic organic circuits designed for ultra-low power consumption. Currently, Poly 3,4-(ethylene dioxythiophene) (PEDOT) doped with polystyrene sulfonate (PSS) is considered the gold standard material in bioelectronics when interfacing with the tissue, mainly due to its mix in-electronic conduction, volumetric capacitance, 2D solution-processability and commercial availability. However, some fundamental properties remain, particularly with respect to material characteristics such as tridimensionality, bio-functionality, swelling control, charge transport, and long-term stability under electrochemical conditions.

The development of new materials to create the next generation of electroceuticals, implantable or wearable electronics requires the introduction of novel features and innovative processes, such as 3D printing, controlled biological properties (e.g., more biologically compatible dopants), and rationally designed materials with mixed conduction mechanisms.

This presentation outlines our strategy for developing bioelectronic devices, highlighting the transformative impact of material synthesis and design, manufacturing, and innovations in final integration to shape the future of bioelectronics.

References

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Short Bio: Antonio Dominguez-Alfaro

Antonio Domínguez-Alfaro, one of the postdoctoral researchers at IMSE (Instituto de Microelectrónica de Sevilla (IMSE-CNM - Seville Institute of Microelectronics), has been awarded the prestigious and highly competitive national research fellowship **"Ramón y Cajal".**

Antonio graduated in Industrial and Chemical Engineering from the University of Huelva. He completed his PhD through a collaborative program between the research institutes **POLYMAT** and **CIC biomaGUNE** in San Sebastián, working at the intersection of tissue engineering and materials science. In 2021, he earned his PhD in Applied Chemistry and Polymeric Materials from the University of the Basque Country.

He then carried out a postdoctoral stay in the Laboratory of Biomolecular Nanotechnology led by Aitziber L. Cortajarena, focusing on the use of recombinant proteins for transient electronics. That same year, he was awarded the Margarita Salas Fellowship, which enabled him to join the prestigious laboratory of George Malliaras at the University of Cambridge, where he worked on the development of innovative materials for bioelectronics. There, he was hired as a Research Associate until November 2024, at which point he joined the Neuromorphic Group at IMSE with a Momentum Fellowship. His research focuses on the integration of microelectronics, advanced packaging, and printed electronics for backend-of-line (BEOL) processing of CMOS chips.

Despite his early-stage research career, Antonio already has an **h-index of 22** and over **1,200 citations**. His incorporation brings significant value to IMSE, making full use of our new cleanroom facilities and opening new lines of research that complement our traditional activities in micro/nanochip design, further raising the scientific standards of the institute.

At IMSE, we would like to congratulate him on this outstanding recognition and express our pride in having researchers of such high caliber on our team. The awarding of the Ramón y Cajal fellowship not only represents a significant boost to Antonio Domínguez-Alfaro's research career, but also reinforces IMSE's commitment to scientific excellence and talent recruitment.