BOOK OF ABSTRACTS

NANOWORKSHOP
2025

12TH INTERNATIONAL WORKSHOP
ON FUNCTIONAL NANOCOMPOSITES

GOBIERNO DE ESPAÑA

MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

Universidad Internacional de Andalucía

Instituto de Ciencia de los Materiales de Sevilla

icmm
Instituto de Ciencia de Materiales de Madrid

ASEVA
Asociación Española del Vacío y sus Aplicaciones

CONFERENCE CHAIRS

- Ana Borrás (Spanish National Research Council, Sevilla, Spain)
- Lidia Martínez (Spanish National Research Council, Madrid, Spain)
- Alexander Vahl (Kiel University, Kiel, Germany)

LOCAL COMMITTEE

- Carmen López Santos (Universidad de Sevilla, Spain)
- Juan R. Sánchez Valencia (CSIC, Sevilla, Spain)
- Nerea de Tena (CSIC, Sevilla, Spain)
- Director of UNIA LA Rábida (La Rábida, Huelva, Spain)

CONFERENCE OFFICE

- Analía Pérez SImini (ASEVA)

INTERNATIONAL ORGANIZING COMMITTEE

- Stephan Barcikowski (University of Duisburg-Essen, Essen, Germany)
- Hynek Biederman (Charles University, Prague, Czech Republic)
- Marcela Bilek (University of Sydney, Sydney, Australia)
- Walter Caseri (ETH Zürich, Zürich, Switzerland)
- Andrey Choukourov (Charles University, Prague, Czech Republic)
- Mady Elbahri (Aalto University, Helsinki, Finland)
- Franz Faupel (Kiel University, Kiel, Germany)
- Maarit Karpinnen (Aalto University, Helsinki, Finland)
- Antonella Milella (University of Bari Aldo Moro, Bari, Italy)
- Devesh Kumar Avasthi (UPES Dehradun, India)
- Kremena Makasheva (Laboratoire Plasma et Conversion d'Énergie (LAPLACE), Toulouse, France)
- Stephanos Konstantinidis (University of Mons, Belgium)
- Paolo Milani (University of Milan, Milan, Italy)
- Minoru Mizuhata (Kobe University, Kobe , Japan)
- Peter Müller-Buschbaum (TU Munich, Munich, Germany)
- Stephan Roth (DESY, Hamburg, Germany)
- Rony Snyders (University of Mons, Mons, Belgium)
- Andrea Tao (University of California, USA)
- Yogesh K. Vijay (Amity University, Noida, India)

INVITED TALKS

- Dr. Francesca Borghi, Department of Physics, University of Milano, Italy.
- Dr. Daniil Nikitin, Charles University, Prague, Czech Republic.
- Dr. Alberto Palmero, Institute of Materials Science of Seville (CSIC – Univ. Seville), Spain.
- Dr. Elvira Paz, International Iberian Nanotechnology Laboratory (INL), Portugal.
- Dr. Ing. Stefan Schröder, Faculty of Engineering, Kiel University, Germany.
- Dr. Pablo Ares, Instituto de Fisica de Materia Condensada, Universidad Autonoma de Madrid, Spain.

Contributions

Invited Talks..05

Borghi, Francesca. "Reprogrammable and adaptive self-assemble materials for edge data processing"..........05

Schröder, Stefan. "Tailored Polymer Thin Films enabled by Initiated Chemical Vapor Deposition - Fundamentals to Functional Applications"..........06

Ares, Pablo "Advances in fundamentals ElectroMagnetic propertiesof 2D materials: piezoelectricity, ferroelectricity, and magnetic shielding"..........07

Paz, Elvira "Use of artificial intelligence with magnetic sensors for preventive manteinance" 08

Palmero, Alberto "Fundamental and Applications of porous Nanocolumnar Thin Films Grown at Oblique Angles"..........09

Nikitin, Daniil "Advancing Resistive Switching with Nanofluid Engineering: Opportunities and Challenges"..........10

Oral Contributions..11

Aballe, Lucia "Operando experiments at the ALBA synchrotron: the power of x-rays to reveal processes"..........11

Aballe, Lucía "RIANA - Research Infrastructure Access in NAnoscience & nanotechnology"..........12

Angurel, Luis "Control of laser-induced periodic nanostructures to improve electrical and superconducting thin film properties"..........13

Aparicio, Francisco "Piezo-Phototronic ZnO/Spiro-OMeTAD devices via Plasma and Vacuum Processing"..........14

Barranco, Angel "Conformal deposition of aerogel-like functional oxide films by remote plasma deposition and processing"..........15

Biederman, Hynek "Formation of Cu3N nanoparticles using gas aggregation based on cylindrical magnetron"..........16

Budagosky, Jorge "Multiscale modelling the working mechanisms of triboelectric nanogenerators for drop energy harvesting"..........17

Choukourov, Andrei " Plasma Polymer Nanoparticles in Tandem with Boron as Nanofuels for Laser-Driven Proton-Boron Fusion "..........18

Čurda, Pavel "Boosting Nanoparticle Yield: Enhanced Atom-to-Nanoparticle Conversion in Gas Aggregation"..........19

Del Sole, Regina "Atomic Layer Deposition of ZnO on Fullerene Powder: A Comparative Study of Thermal and Plasma-Enhanced Processes for a Photoactive Nanocomposite for Water Remediation..........20

Di Novo, Nicolo Giuseppe "Tuning wetting and triboelectricity: bioinspired dew-TENGs"..........21

Fortio Godinho, Vanda Cristina "Flexible piezoelectric nanogenerators based on aligned and hierarchical ZnO nanorods "..........22

Grammatikopoulos, Panagiotis "Molecular Dynamics Study of Support-Induced Strain Engineering in Anchored Nanoparticles"...23

Hari Krishna, Mishra "Ultrasensitive multifunctional nanosensing of ferroelectric van der Waals monoelemental tellurium coupling with ferroelectric polymer"..........24

Hegemann, Dirk "Enhanced Surface Functionality by Nanoporous Plasma Coatings "..........25

Huttel, Yves "Fine tuning wettability through multiscale structures based on ion beam microtexturization, nanocolumns and nanoparticles"..........26

Kaur, Ramanpreet"Gas-Phase Synthesis of Ag Nanoparticles for Integration into Nanocapacitors and Operando Electron Holography Analysis"..........27

Konstantinidis, Stephanos "Towards VO_2-based high-tunability optical platforms"..........28

Koshy, Abel George "Plasma polymerized polyimide films for the development of electrochemical sensors"..........29

López, Mª Carmen "Anti-fogging and anti-icing transparent glass surfaces by laser treatment and fluorine-based functionalization"..........30

Makasheva, Kremena"Interdisciplinary approach to tackle the nucleation and growth of large carbon molecules and mixed metal-carbon nanoparticles driven by organometallic clusters"..........31

Navascues, Paula "Plasma-engineered Nanocomposites for Controlled Radical Chemistry"..........32

Núñez Galvez, Fernando "Plasma-enable nanomaterials and thin films for Drop-TENGs"..........33

Ruiz Gómez, Sandra "Operando correlative microscopy for advanced magnetic nanostructures"..........34

Sánchez Valencia, Juan Ramón "Glancing Angle Deposition of halide perovskites"..........35

Solař, Pavel "Improved continuous feeding evaporator system for gasification of polymers for use in a gas aggregation source"......36

Strunskus, Thomas "Effects on Early-Stage Noble Metal Growth on Polymer Substrates deposited by Magnetron Sputtering"........37

Toro, Jose Angel "Non-exchange bias in binary soft-hard nanoparticle composites"....38

Vahl, Alexander "High-Resolution Plasma Printing at Atmospheric-Pressure for Microfluidics, Microfabrication and Emerging Electronics"....39

Poster Section....40

P1. Acosta Rivera, Maria Hiedra "Low temperature production of VO2 Crystalline Domains in thin films for thermochromic applications by magnetron sputtering at oblique geometries....41

P2. Arslonova, Shirin "Development of 3D Printable Lead-Free Polymer Composites with Nanosized Fillers for Radiation Shielding"....42

P3. Czermak Álvarez, Triana "DCM-based Organic Nanometric Thin Films with Tailored Dielectric Properties by Remote Plasma Assisted Vacuum Deposition"....43

P4. Del Moral, Jaime "Enhanced acoustic de-icing through thin film technology: exploring the link between acoustic waves and surface properties for energy-efficient ice protection"....44

P5. Del Sole, Regina "Atomic Layer Deposition of ZnO on Fullerene Powder: A Comparative Study of Thermal and Plasma-Enhanced Processes for a Photoactive Nanocomposite" 45

P6. Delgado Álvarez, Juan "EHierarchical SiO2 nanostructures confinement mediated molecular dipoles of poly(vinylidene fluoride): Enhancing piezo and pyroelectric performances"....46

P7. Ferreira de Sousa Junior, José Transparent Pt nanonetworks for the mitigation of spacecraft charging issues in photovoltaic solar arrays" 47

P8. GAO, Yan "A Robust Alginate Hydrogel Interface via Cryogelation for Highly Reversible and Dendrite-Free Zinc Anodes....48

P9. Garcia Casas "Stretchable skin-like 3D nanostructured hybrid piezo-triboelectric nanogenerators"....49

P10. Garrido Segovia, María ."Sputter-deposited gold–iron nanostructures for magnetoplasmonic applications"....50

P11. Jumilla Núñez, Darío' "Towards Sustanaible Energy harvesting: vertically aligned BaTiO3 Nanowires for flexible piezoelectric nanogenerators" 51

P12. Lotito, Sara "Atomic Layer Deposition of ZnO on Chitosan Sponges: toward engineered nanocomposites for water remediation technologies"....52

P13. Lotito, Sara "Benzothiadiazole-based polymeric S-scheme homojunction for photoelectrochemical ORR"....53

P14. Moreno, Gloria Patricia "Vacuum-Deposited Adamantane-Based Plasma Polymers as Multifunctional Triboelectric Films".....54

P15. Nuñez Galvez, Fernando "Highly Tunable and Conformal Graphene Nanowalls on Nanostructured Scaffolds for Triboelectric and Moisture-Driven Energy Harvesting"....55

P16. Núñez Galvez, Fernando "SLIPS-TENGs: triboelectric nanogenerators with liquid infused porous surfaces as highly slippery drop energy arvesters"....56

P17.Saintilme, Gladel "Controlling the Size and Surface Chemistry of Nickel Nanoparticles via a Modified Polyol Method"....57

P18. Skorvankova, Katerina ."Plasma polymer nanoparticles from evaporated PLA precursor"....58

Reprogrammable and adaptive self-assembled materials for edge data processing

Francesca Borghi[1]

[1]*University of Milan, Physics Department and CIMaINa, via Celoria 16, 20133 Milano, Italy*

The brain's ability to perform efficient and fault-tolerant data processing is strongly related to its peculiar interconnected adaptive architecture, based on redundant neural circuits interacting at different scales. In such a system, individual neurons contribute little on their own; it is the collective activity of the population that matters. Part of the difficulty in understanding population coding is that neurons are noisy, which means that the same pattern of activity never occurs twice, even when the same stimulus is presented.[1] In this context, correlation and simultaneity within spiking activity of different neurons, as also synchronous population firing,[2] may play a crucial role in decreasing/increasing the amount of information that is decoded, in a non-trivial way.[1]

By emulating brain's processing and learning mechanisms, computing technologies strive to achieve higher levels of energy efficiency and computational performance.[3] Although efforts to address neuromorphic solutions through hardware based on top-down CMOS-based technologies have obtained interesting results in terms of energy efficiency improvement, the replication of brain's self-assembled and redundant architecture is not considered in the roadmaps of data processing electronics.

In materia computing has been proposed as competitive and alternative strategy, exploiting the complexity and collective phenomena originating from various classes of physical substrates, to perform unconventional data processing.[4] The leveraging of self-assembled systems with nonlinear dynamics has already been demonstrated as a possible unconventional strategy for energy efficient data processing tasks, relying on the emerging behavior of stochastic network activity.[4,5] However, the proper encoding of the stimulus and the decoding of information in the response of such systems remain a challenge, in particular for all those systems based on the stochastic activity of the network.

Here I will present and discuss results obtained on the spatial and temporal dynamics of resistive switching (RS) activity in metallic cluster-assembled networks, employed for neuromorphic data processing, and characterized by a combined approach based on micro-thermography and electrical measurements. Cluster-assembled films produced by Supersonic Cluster Beam Deposition (SCBD)[6] have been widely studied from both experimental and theoretical perspectives, as resistive switching systems that can be used for data processing tasks.[3,7–10] The main mechanism at the nanoscale which causes the reversible changes in electric conductivity (10% to 10^5% from its initial value) is the stochastic reorganization of the grain boundaries in local active sites of the nanogranular matrix of cluster-assembled thin films.[11,12]

The description and the understanding of the dynamics of local active sites, leading at a larger scale to the emerging electrical behavior of the network, will be discussed. The control obtained over the adaptive reorganization of the network, from the nano to the macroscale, will be proposed as an effective strategy to control the reversible connectivity and the tunable correlation and synchronicity between the activities in micrometric active sites, which drive RS behavior at the macroscale. This control allows the programmability of these systems, used as reversible electronic switches and reconfigurable nonlinear threshold logic gates (TLGs),[13] implemented on both hard[7] and soft substrates[14] as complete functional systems for Boolean function classification tasks.[15] We also demonstrated the potentiality of the use of these cluster-assembled systems to classify neuronal traces with high accuracy and in real-time, requiring limited datasets for training and memory storage, and offering greater interpretability and accuracy compared to artificial neural networks.[16]

We propose hardware implementation of self-assembled neuromorphic materials, featuring controlled and reversible connectivity and memory mechanisms, to develop novel hybrid, reprogrammable electronic architectures for data processing in edge systems that interact efficiently with their environment.

Keywords: *cluster-assembled materials, resistive switching, reconfigurable nonlinear threshold logic gates, neuromorphic computing, time-series classification*

References:

1. B. B. Averbeck, P. E. Latham, A. Pouget, *Nat. Rev. Neurosci.* **2006**, *7*, 358.
2. M. B. Feller, *Neuron* **1999**, *22*, 653.
3. F. Borghi, T. R. Nieus, D. E. Galli, P. Milani, *Front. Neurosci.* **2024**, *18*.
4. H. Jaeger, *Neuromorphic Comput. Eng.* **2021**, *1*, 012002.
5. A. Vahl, G. Milano, Z. Kuncic, S. A. Brown, P. Milani, *J. Phys. Appl. Phys.* **2024**, *57*, 503001.
6. K. Wegner, P. Piseri, H. V. Tafreshi, P. Milani, *J. Phys. Appl. Phys.* **2006**, *39*, R439.
7. G. Martini, M. Mirigliano, B. Paroli, P. Milani, *Jpn. J. Appl. Phys.* **2022**, *61*, SM0801.
8. S. Radice, F. Profumo, F. Borghi, A. Falqui, P. Milani, *Adv. Electron. Mater.* **2024**, *n/a*, 2400434.
9. G. Nadalini, F. Borghi, T. Košutová, A. Falqui, N. Ludwig, P. Milani, *Sci. Rep.* **2023**, *13*, 19713.
10. F. Profumo, F. Borghi, A. Falqui, P. Milani, *J. Phys. Appl. Phys.* **2023**, *56*, 355301.
11. M. Mirigliano, P. Milani, *Adv. Phys. X* **2021**, *6*, 1908847.
12. A. Casu, A. Chiodoni, Y. P. Ivanov, G. Divitini, P. Milani, A. Falqui, *ACS Appl. Nano Mater.* **2024**, *7*, 7203.
13. B. Paroli, F. Borghi, M. A. C. Potenza, P. Milani, *The receptron is a nonlinear threshold logic gate with intrinsic multi-dimensional selective capabilities for analog inputs*, arXiv, **2025**.
14. G. Nadalini, A. Dallinger, D. Sottocorno, F. Greco, F. Borghi, P. Milani, *Adv. Electron. Mater. n/a*, 2400717.
15. B. Paroli, G. Martini, M. A. C. Potenza, M. Siano, M. Mirigliano, P. Milani, *Neural Netw.* **2023**, *166*, 634.
16. F. Profumo, F. Borghi, T. Angì, M. Maschietto, S. Vassanelli, P. Milani, *Adv. Intell. Syst.* **2025**, 2401150.

Tailored Polymer Thin Films enabled by Initiated Chemical Vapor Deposition - Fundamentals to Functional Applications

Stefan Schröder[1,2,3]

[1]Department of Materials Science, Chair for Multicomponent Materials, Kiel University, 24143 Kiel, Germany
[2]Department of Materials Science, Chair for Composite Materials, Kiel University, 24143 Kiel, Germany

[3]Kiel Nano, Surface and Interface Science (KiNSIS), Kiel University, 24118 Kiel, Germany

Functional polymer thin films are of great interest in vast application fields ranging from electronic devices to biomedical interfaces. Device miniaturization and the consequent need for new polymer films on the nanoscale demand precise thickness control and defect free films. Solvent-free initiated chemical vapor deposition (iCVD) meets these demands, because it circumvents de-wetting and surface tension effects encountered in conventional solution-based polymer thin film fabrication. The process provides conformal polymer coatings on the nanoscale on large-area substrates as well as complex geometries. In addition, it enables deposition on delicate substrates like flexible organic substrates, copy paper and biomedical patches at room temperature. This talk demonstrates the versatility of the iCVD process and highlights recent results from fundamental studies based on density functional theory (DFT) on the underlying reaction processes up to the application of iCVD films in sensors, biomedicine and electronic devices as well as fabrication of functional nanocomposites.

Keywords: *Polymer thin films, Chemical vapor deposition, Nanoscale, Organic surfaces, Nanocomposites*

Advances in fundamental ElectroMagnetic properties of 2D materials: piezoelectricity, ferroelectricity, and magnetic shielding

Pablo Ares[1,2]

[1]*Departamento de Física de la Materia Condensada, Universidad Autónoma de Madrid, E-28049 Madrid, Spain*

[2]*Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, E-28049 Madrid, Spain*

The wide variety of properties of 2D materials offers exciting possibilities for integration into nanoscale devices. Much work has been done to understand their fundamental properties, a crucial aspect for future applications. However, there is a lack of knowledge about the fundamental electrical and magnetic properties of the most common 2D materials. In this talk, I will present several studies on these properties, performed using advanced atomic force microscopy (AFM) measurements.

First, I will briefly present our results on 2D hexagonal boron nitride (hBN). Its covalent bonds are highly polar, raising the possibility of different polarizations in the correct crystal configurations. I will describe the observation of in-plane piezoelectricity for monolayer (one atom thick) hBN [1], a property that does not exist for bilayer or bulk systems. Next, I will report on the occurrence of spontaneous out-of-plane polarization and ferroelectric-like behavior at anomalously stacked hBN interfaces [2].

In the last part of the talk, I will present our recent results on how graphene, graphene oxide (GO), and MoS_2 interact with magnetic fields generated by underlying magnetic nanostructures. We find that graphene exhibits a weak but measurable overall screening effect (~ 0.5% per layer), while GO and MoS_2 show negligible interaction with the magnetic field [3]. This suggests that few layer graphene (FLG) could be used for controlled magnetic field modulation, whereas GO and MoS_2 provide minimal interference with magnetic functionalities. It is important to note that the screening produced by FLG should be considered when calculating the effective applied magnetic field when using this material to make electrodes.

All these results highlight the potential of 2D materials for precise control of device properties. For example, the development of piezoelectric actuators, ferroelectric memories, devices with self-powering potential, or effective protection while minimally affecting the underlying magnetic functionalities, which is important in spintronics, data storage, and other nanodevices, where precise tuning of electromagnetic interactions is crucial.

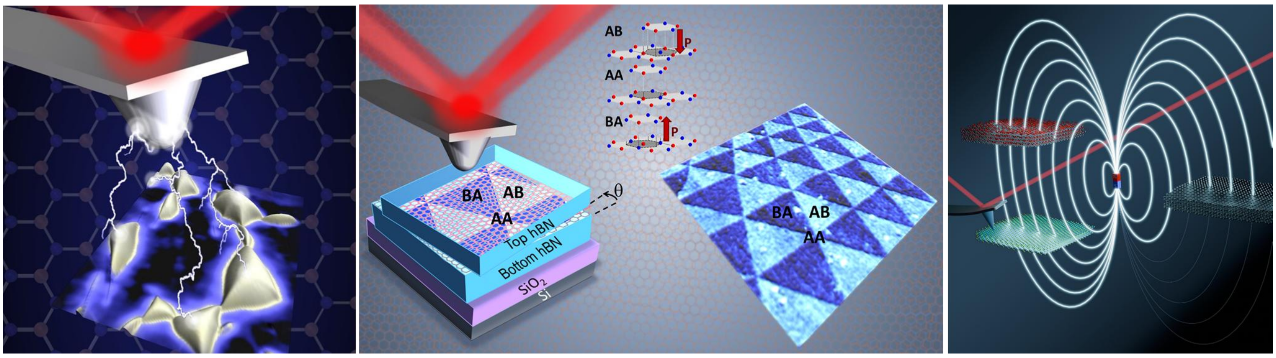

Fig. 1. Schematics of 2D materials piezoelectricity, ferroelectricity, and magnetic field screening probed by atomic force microscopy

Keywords: *2D materials, atomic force microscopy, piezoelectricity, ferroelectricity, magnetic field screening*

References:

1. P. Ares et al., Adv. Mater. **32**, 1905504 (2020).
2. C. R. Woods et al., Nat. Commun. **12**, 347 (2021).
3. D. A. Aldave et al., Adv. Electron. Mater. **11**, 2400607 (2025).

Acknowledgements: Spanish Ministry of Science, Innovation and Universities & the State Research Agency, Ministry of Universities and the European Union-Next Generation, Fundación Max Mazin, Comunidad de Madrid, European Research Council.

Magnetic sensors based on magnetic tunnel junctions (MTJ) used for predictive maintenance

Elvira Paz[1], **Artem Talantsev**[1], **André Araújo**[1], **Tim Böhnert**[1], **Ensieh Iranmehr**[1], **Ricardo Ferreira**[1]

[1]*INL – International Iberian Nanotechnology Laboratory, Braga, Portugal*

Magnetic sensors are widely used in our daily lives [1], resulting in a significant amount of research on improving their performance. They can be used non-invasively for condition monitoring and predictive maintenance of the equipment on a production plant, that is crucial to detect anomalies in the equipment's behaviour before it fails [2][3], so they can save money by having a cheaper repair and not stopping the production line.

Current challenges include sensitivity improvement, increased thermal stability for working under harsh conditions [4], and dimensional reduction while maintaining high performance to achieve better spatial resolution and power reduction [5][6]. For sensors based on magnetic tunnel junctions (MTJ), the signal to noise ratio depends on the volume of the sensing layer. In theory, the larger and thicker the sensing layer is, the lower the noise of the sensor. In reality a trade-off has to be met [7].

The field sensors need to have a linear response with the field. The most common approach to linearize the MTJ signal is by introducing shape anisotropy, whereby the shortest dimension exceeds a few micrometers. In this work, the linear response is achieved in continuous thin films, allowing the patterning of large area sensors to decrease the noise. Here, we will introduce two distinct strategies to control the sensing range of an MTJ circumventing the use of shape anisotropy.

One way is to softly pin the sensing layer of the MTJ with a antiferromagnet (AFM), tuned to have a blocking temperature lower than the AFM of the fixed layer. Afterwards a multi-step magnetic annealing is employed [8]. We show an area increase from 10^3 to 10^4 μm^2, with a good linear response.

The second strategy uses a thick layer of an amorphous ferromagnetic material as a sensing layer. Amorphous materials have shown very soft magnetic characteristics in layers with thicknesses up to few hundreds of nanometers [7] and delivered competitive noise levels as the sensing layer of an MTJ [9]. We will show that a single magnetic annealing step is sufficient to linearize.

In the end, we control the linear range from 3 to 54 mT, which determines the sensitivity and the field operation window. We do so without affecting the tunnel magnetoresistance or the coercive field, thus widening the applications of these sensors.
Integrating the sensors with a microcontroller and an electronic circuit to condition and digitize the sensor's signal we developed a portable device that can be used in a lot of different places.

Here we are going to present how we fabricate and optimized the magnetic sensors based on magnetic tunnel junction (MTJ). And their use in measuring the characteristic signal of an equipment enables advanced machine learning techniques to automatically identify the characteristic signal and detect deviations that may indicate potential faults or failures, [8], supporting predictive maintenance.

Keywords: *spintronics, magnetic tunnel junction, magnetic sensors, machine learning, predictive maintenance*

References:

[1] X. Liu, K. H. Lam, K. Zhu, et al., IEEE Trans. Magn. 55 (2019) 0800222
[8] E. Iranmehr et al., IEEE Sensors Journal, 2023, 23, 11, 11992 - 12007
[9] R. Ferreira, T. Bohnert, and E. Paz, "Method and system for non-invasive vibration-based condition monitoring of a MachinE," WIPO Patent
WO2 021 220 162, Apr. 2020/04/27.
[4] P. D. R Araujo, R. Macedo, E. Paz, et al., Nanotechnology 34 (2023) 435502
[5] E. Raymenants, O. Bultynck, D. Wan, et al., Nat. Electron. 4 (2021) 392–398
[6] K. Wu, M. C. J. Cheeran, J. P. Wang, et al., ACS Appl. Nano Mater. 3 (2020) 9560–9580
[7] M. Oogane, K. Fujiwara, A. Kanno, et al., Appl. Phys. Express 14 (2021) 123002
[8] E. Paz, R. Ferreira, P. P. Freitas, IEEE Trans. on Mag. 52 (2016) 4002104
[9] M. Rasly, T. Nakatani, J. Li, et al. J. Phys. D: Appl. Phys. 54 (2021) 095002

Acknowledgements: *The work is supported by the projects NeWeSt - New generation of cyberphysical Weighing Systems, with the reference nº POCI-01-0247-FEDER-069716, co-funded by COMPETE 2020 - Operational Programme for Competitiveness and Internationalisation under the PORTUGAL 2020 Partnership Agreement, through the European Regional Development Fund (ERDF), and Horizon Europe SWAN-on-chip (101070287)*

Fundamentals and Applications of Porous Nanocolumnar Thin Films Grown at Oblique Angles

Alberto Palmero

1
Institute of Materials Science of Seville (CSIC-US). Americo Vespucio Avenue 49, 41092 Seville, Spain

Porous thin films are being extensively studied due to their outstanding morphological features and properties in comparison with their compact counterparts. They may present singular structural properties such as a high specific surface, low density or may contain an accessible/occluded pore network, among other features, that make them suitable for a broad set of applications [1]. In this presentation, an up to date description of the fundamentals and nanostructuration possibilities of these films when using Physical Vapor Deposition techniques, such as Magnetron Sputtering or e-beam evaporation, when using the so-called Oblique or Glancing Angle Deposition configuration will be shown. Different types of available porous structures will be shown (see figure 1a-c for some examples), such as compact (with or without embedded nanopores), nanocolumnar arrays that may be randomly scattered or that follow certain geometrical patterns or even sponge-like formations, depending on the experimental conditions [2]. Different examples of applications based on these type of films will be shown for the development of sensors, e.g. of cholesterol or glucose, or of implants, in which the film surface energy can be tailored to allow the growth of living cells while inhibiting bacterial proliferation (see figure 1d-e) [3]. Moreover, the application of these porous films for the development of smart windows will be also presented, where the existence of an accesible porous structure is key for the low temperature processing the the coatings and to achieve an optimum optical and electrical response (see figure 1f) [4].

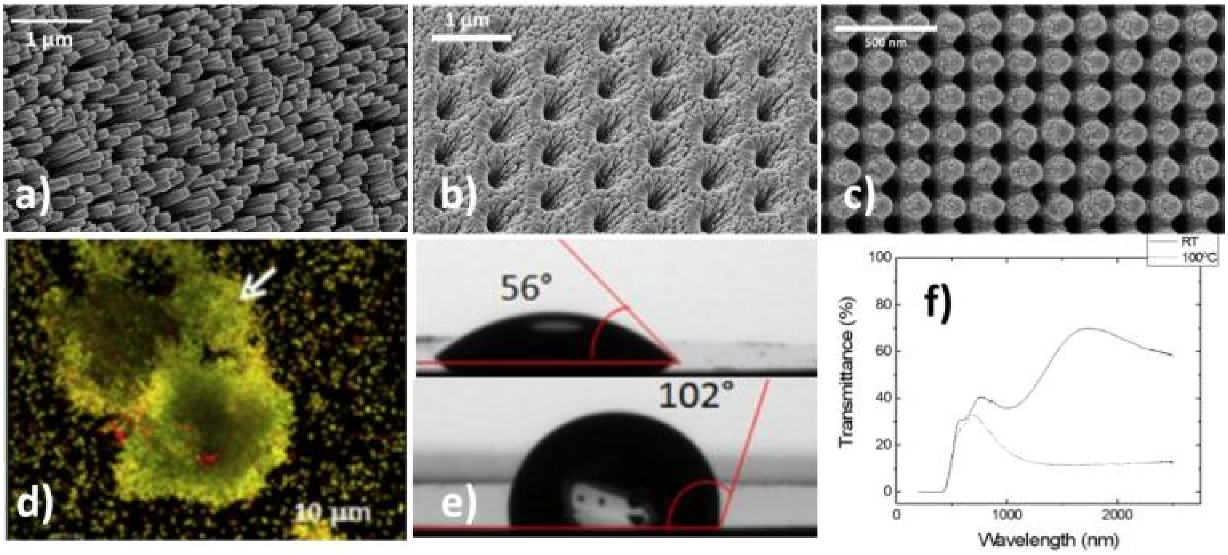

Fig. 1. Top view SEM image of a thin film formed by randomly scattered nanocolumns (a), well-ordered hole structure (b) and well-ordered nanopillar array (c). Illustration of a biofilm growing on a nanocolumnar Ti surface (d). Different water contact angles depending on the film nanostructure(e). Illustration of the optical changes experienced by a thermochromic porous VO2 thin film produced at low temperatures

Keywords: Physical Vapor Deposition, Oblique Angle Deposition, Porous Thin Films, Smart Windows, Implants, Sensors.

References:

[1] A. Barranco, A. Borras, A.R. Gonzalez-Elipe and A. Palmero. Progress in Materials Science 76, 59 (2016)

[2] S. Muñoz-Piña, A.M. Alcaide, B. Limones-Ahijon, M. Oliva-Ramírez, V. Rico, G. Alcalá, M.U. Gonzalez, J.M. García-Martín, R. Alvarez, D.Wang, P. Schaaf, A. R. Gonzalez-Elipe, A. Palmero. Surface&Coatings Technology 4336, 128293 (2022)

[3] I. Izquierdo-Barba, J. M. García-Martín, R. Álvarez, A. Palmero, J. Esteban, C. Pérez-Jorge, D. Arcos, M.Vallet-Regí. Acta Biomaterialia 15, 28 (2015)

[4] M.H. Acosta-Rivera, V. Rico, F.J. Ferrer, T.C. Rojas, R. Alvarez, N. Martin, A.R. Gonzalez-Elipe, A. Palmero. Submitted for publication.

Acknowledgements:

The authors acknowledge the projects PID2020-112620GB-I00 funded by MCIN/AEI/10.13039/ 501100011033 and the intramural project 202560E034 funded by the Spanish Council of Research. We thank the projects PID2022-143120OB-I00, TED2021-130916B-I00 funded by MCIN/AEI/10.13039/501100011033/FEDER, UE and by "ERDF (FEDER) A way of making Europe". We thank the financial support from the CSIC Interdisciplinary Thematic Platforms (PTI +) "Sustainable Plastics towards a Circular Economy" (PTI-Susplast +) and "Transición Energética Sostenible" (PTI- TRANSENER+) SOUNDofICE H2020-FETOPEN-2018-2019-2020-01 call GA no: 899352.

Advancing Resistive Switching with Nanofluid Engineering: Opportunities and Challenges

Daniil Nikitin[1], Kateryna Biliak[1], Mariia Protsak[1], Blessing Adejube[2], Suren Ali-Ogly[1], Kateřina Škorvanková[1], Veronika Červenková[1], Ronaldo Katuta[1], Marco Tosca[1], Jan Hanuš[1], Zulfiya Černochová[3], Peter Černoch[3], Petr Štěpánek[3], Oleksandr Boiko[4], Paulina Szymoniak[5], Andreas Schönhals[5], Franz Faupel[2], Hynek Biederman[1], Alexander Vahl[2, 6], and Andrei Choukourov[1]

1 Faculty of Mathematics and Physics, Department of Macromolecular Physics, Charles University V Holešovičkách 2, Prague, 18000, Czech Republic
2 Chair for Multicomponent Materials, Department of Material Science, Kiel University, Kaiserstraße 2, Kiel, D-24143, Germany
3 Institute of Macromolecular Chemistry CAS, Heyrovského nám. 2, Prague, 16206, Czech Republic
4 Lublin University of Technology, Department of Electrical Engineering and Superconductivity Technologies, 38A Nadbystrzycka St., 20-618 Lublin, Poland
5 Bundesanstalt für Materialforschung und -prüfung (BAM), Unter den Eichen 87, 12205 Berlin, Germany
6 Leibniz Institute for Plasma Science and Technology, Felix-Hausdorff-Str. 2, 17489 Greifswald, Germany

The increasing demand for higher computation speed and reduced power consumption in artificial intelligence systems is driving the search for alternative computing paradigms beyond the traditional von Neumann architecture. Inspiration comes from biology, where neural systems efficiently perform complex tasks with minimal energy consumption. As a result, the field of neuromorphic engineering has been rapidly advancing over the past decade. Most neuromorphic computing systems rely on crossbar arrays of memristors – devices that adjust their conductivity in response to external stimuli (such as an electric field), mimicking synapses. However, their operating principles and organization differ significantly from the self-organized, three-dimensional nature of biological counterparts. Additionally, the top-down fabrication of these devices is highly complex and technologically demanding. Consequently, researchers continue to explore alternative approaches.

Percolated systems composed of nanowires and nanoparticles (NPs), fabricated via bottom-up deposition approaches, have gained attention due to their simple manufacturing process and strong resemblance to complex neural networks [1]. Networks formed by Sn, Au, Mo, and Ag NPs exhibit dynamic spiking behaviour, akin to neuronal avalanches, enabling the information processing in a neuromorphic manner. A notable example is the Receptron, a device that leverages these emergent properties to perform classification tasks efficiently. However, despite these advantages, such systems struggle to fully replicate the intricate structure of biological neural networks, particularly their ability to form long-range, three-dimensional (3D) connections, which are crucial for advanced cognitive functions.

Recently, there has been growing interest in the development of wetware neuromorphic systems [2]. Most efforts focus on liquid memristors, where reversible conductivity changes result from the migration of oppositely charged ions within electrolytes between two reservoirs separated by an ultrasmall channel. This mechanism closely mimics the potentiation and depression of biological synapses, and the power consumption of such devices is approaching the biological level. However, the miniaturization of liquid memristors and their integration into larger computing assemblies remain significant technological challenges. To address this, our group proposes combining a fluid environment with resistive switching in nanoparticle-based percolated systems, aiming to fabricate reconfigurable architectures capable of forming long-range connections between electrodes [3]. As a model system, we selected nanofluids produced by direct deposition of gas-aggregated silver nanoparticles (Ag NPs) into liquid polyethylene glycol (PEG).

The formation of the long-range connections between the electrodes in nanofluids is essential for the resistive switching. They grow by self-organization of the negatively charged Ag NPs migrating toward the positively biased electrode, which is driven by electrophoresis. These connections could potentially be formed in the 3D arrangement. The kinetics of growth depend on the viscosity of PEG, determining the electrophoretic mobility of NPs. The fitting of the current-time (I-t) characteristic recorded during the formation step can be used to determine the initial electrophysical parameters of nanofluids, such as base resistance, capacitance components and temporal constants of their charging.

Following the formation of conductive paths, resistive switching behaviour is characterized through a series of current-voltage (I–V) sweeps. Three distinct conductive states are identified. In the high-resistance state (HRS), the resistance exceeds 10^5 Ω, corresponding to a configuration where the distance between individual nanoparticles (NPs) is larger than their diameter. The low-resistance state (LRS) exhibits Ohmic behaviour with $R < 10^3$ Ω, indicating the presence of at least one continuous metallic path bridging the electrodes. Additionally, an intermediate transition resistance state is observed within the range 10^3 Ω $< R < 10^5$ Ω, attributed to space-charge-limited conduction and electric-field-driven tunnelling, depending on the NP spacing. This was confirmed through fitting of the resistance-voltage (R–V) characteristics. The occurrence and stability of these states are governed by nanoconfinement effects, which are, in turn, influenced by the length of macromolecular chains in PEG.

Environmental conditions and temperature are additional key factors affecting resistive switching in nanofluids. Evacuation (removal of ambient gases) and thermal treatment were found to significantly influence both the distribution of resistance states and the threshold voltage required to initiate switching.

Keywords: neuromorphic engineering, nanofluid, electroforming, resistive switching, conductivity mechanism

References:

1. Vahl et al., *Journal of Physics D: Applied Physics* **69** (2023).
2. Nikitin et al., *Recent Patents on Nanotechnology* **19** (2025).
3. Nikitin et al., *Advanced Functional Materials* **34** (2024).

Acknowledgements: The work was supported via the grant GACR 23–06925S from the Czech Science Foundation. D.N., K.B., and M.P. also acknowledge the Czech-German Mobility grant number 8J23DE016 from the Ministry of Education, Youth and Sports. A.V., B.A., and F.F. acknowledge funding by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – Project-ID 434434223 – SFB 1461. A.V. and B.A. also acknowledge German Academic Exchange Service (DAAD) - Project-ID: 57654440.

Operando experiments at the ALBA synchrotron: the power of x-rays to reveal processes

Lucía Aballe

[1]*ALBA Synchrotron Light Facility, Cerdanyola del Vallés, Spain*

Synchrotron radiation is a key tool for advanced material characterization and is available to the scientific community at user facilities through open calls where proposals are evaluated based on scientific merit. The Spanish synchrotron, ALBA [1], has 13 operating beamlines plus one in construction and three more starting the design phase. In the beamlines, state of the spectroscopy, scattering, diffraction and imaging in different environments and photon energy ranges (from infrared to hard x-rays) are used for fundamental and applied research in fields from life sciences to material sciences or cultural heritage.

The high brilliance of synchrotron light makes it ideal to perform experiments in situ and operando during relevant processes such as chemical reactions, phase transitions, sample growth, thermal treatment or electrochemical cycles. The operando methodology provides concurrent and pertinent data on both the structure/composition of a system and its performance under actual working conditions, which is crucial to understand its dynamic behaviour. The reaction pathways and intermediates, the role of the environment, and synergistic effects between different components are a few of the questions which can rarely be answered without operando or at least in situ experiments. Furthermore, understanding and optimizing complex systems usually requires correlative or multimodal approaches combined with simulations and advanced data analysis.

I will present the operando capabilities of the ALBA beamlines and selected examples from different scientific fields where in situ or operando characterization has been key to understand complex challenges, from magnetization dynamics to heterogeneous catalysis or battery cycling. I will also briefly introduce the new In situ Correlative facility for Advanced Energy Materials [2] and the opportunities it will bring for the user community in order to trigger discussions about future experiments and collaborations.

Keywords: *x-ray spectroscopy, x-ray diffraction, x-ray imaging, nanomaterials, operando*

References:

1. https://www.cells.es/n
2. Part of the Advanced eMaterials project within the Planes Complementarios programme, funded by the Ministry of Science and Innovation and the Generalitat de Catalunya, with the support of NextGeneration EU funds.

Acknowledgements:

This contribution is based on the hard work of all ALBA staff and our collaborators.

RIANA - Research Infrastructure Access in NAnoscience & nanotechnology

Lucía Aballe[1], Núria Valls[1], Michael Stueckelberger[2]

on behalf of the RIANA project team
1ALBA Synchrotron Light Facility, Cerdanyola del Vallés, Spain
2Deutsches Elektronen Synchrotron DESY, X Ray Nanoscience and X Ray Optics, Hamburg, Germany

RIANA is a Horizon-Europe-funded project to assist research in nanoscience and nanotechnology [1]. Coordinated by DESY, the project runs from March 2024 for 4 years.

The project supports the entire chain of processes in nanoscience research and technology, from simulation and synthesis to processing, characterization and analysis.

We support curiosity-driven research in nanoscience with open research questions for long-term impact and challenge-driven research in nanotechnology with targeted research questions for short- and mid-term impact.

At the core of the RIANA consortium is the ARIE (Analytical Research Infrastructures in Europe, arie-eu.org) network, which comprises European analytical networks with a focus on large scale research infrastructures:

- League of European Accelerator-based Photon Sources (LEAPS) [2].
- Integrated Initiative of European Laser Research Infrastructures (LaserLab Europe) [3].
- European Distributed REsearch Infrastructure for Advanced Electron Microscopy (e-DREAM) [4].
- Research and Development with Ion Beams – Advancing Technology in Europe (RADIATE) [5].
- League of Advanced European Neutron Sources (LENS) [6].
- Academic nanofabrication centers EuroNanoLab [7].
- European Soft Matter Infrastructure (EUSMI) [8].
- Jülich Supercomputing Centre (JSC) [9].

Keywords: *transnational access, research infrastructure, nanofabrication, multimodal characterization*

References:

[1] https://riana-project.eu/
[2] https://www.leaps-initiative.eu/
[3] https://laserlab-europe.eu/
[4] https://e-dream-eu.org/
[5] https://www.ionbeamcenters.eu/
[6] https://lens-initiative.org/
[7] https://euronanolab.eu/euronanolab-overview/
[8] https://eusmi-h2020.eu/
[9] https://www.fz-juelich.de/en/ias/jsc

Acknowledgements:

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101130652.

Control of laser-induced periodic nanostructures to improve electrical and superconducting thin film properties

L.A. Angurel[1], A. Frechilla[1], J. Frechilla[1], S. Martín[1], L. Porta-Velilla[1], E. Martínez[1], A. Badía-Majós[1], G.F. de la Fuente[1], N. Lejeune[2], E. Fourneau[2], A.V. Silhanek[2], J. Bonse[3], J. del Moral[4], V. López-Flores[4], F. Nuñez[4], C. López-Santos[4], A.R. González-Elipe[4], A. Borrás[4]

[1]Instituto de Nanociencia y Materiales de Aragón (CSIC-Universidad de Zaragoza), Zaragoza, Spain, [2]Experimental Physics of Nanostructured Materials, Q-MAT, CESAM, University de Liège, Liège, Belgium, [3]Bundesanstalt für Materialforschung und –prüfung (BAM), Berlin, Germany, [4]Instituto de Ciencia de Materiales de Sevilla (CSIC-Universidad de Sevilla), Sevilla, Spain

When a thin film is irradiated with a fs laser radiation, its surface can be nanopatterned via generation of well-ordered nanostructures. These are known as Laser-Induced Periodic Surface Structures (LIPSS, ripples). This effect has been applied to achieve performance improvements in a wide range of thin films by inducing chemical, structural and physical modifications [1-5]. Application of convenient laser processing parameters enables control of LIPSS periodicity, orientation and order.

In this work, surface treatments have been applied to induce controlled nanostructures on Nb and ITO thin films. In the first case, these nanostructures have been used to enhance their superconducting properties, observing that in some ranges of temperatures and magnetic fields, the samples that have been irradiated with a 343 nm UV 238-fs laser exhibit an improvement in properties. By controlling the laser processing parameters, it is possible to obtain surface nanostructures with a high level of anisotropy, which is also transferred to the superconducting properties. Control of the laser beam fluence and scanning parameters facilitates the generation of a surface nanostructure without compromising the thin film, as observed using electron and atomic force microscopies. Physical properties, evaluated using magnetometry and magneto-optical microscopy have confirmed that the critical current density values can duplicate in comparison with the behaviour of the non-textured samples. This anisotropy on the surface nanostructures can also be used to define directional flux penetration and with an adequate selection of the nanostructure domains it is possible to define the geometry of magnetic flux penetration on the sample. Several laser-patterned geometries have been characterized showing the relevance of the boundaries between different nanostructure domains. In this communication we will present some examples of different geometries showing the potentiality and versatility of this technology for controlling how the magnetic field penetrates in the superconducting thin film.

In the case of the ITO thin film samples, fs laser irradiation has been used to machine microcircuits with different geometries. The Gaussian energy distribution on the laser beam generates LIPSS-based nanostructures at the edges of the micromachined electrical paths. Similar phenomena have also been observed in the Nb thin films in cases where the designed geometry of the Nb layer requires complete removal within specific areas. The influence of these laser-affected regions on the electrical properties of the ITO path has been evaluated using 515 nm and 343 nm laser sources. Depending on the orientation of the laser polarization, ripples can be generated parallel or perpendicular to the direction of the electrical path. UV fs-laser irradiation yields more pronounced transitions between non-textured and textured regions and narrower LIPSS zones, whereas the use of a green fs-laser wavelength results in smoother transitions and wider textured regions. The contribution of these nanotextured regions to the overall electrical resistance of the electrical path has been established. It was found that the electrical resistance of the micromachined paths are mainly determined by the non-textured region and that, only when the width of the micromachined region is completely nanotextured, these LIPSS control the path's resistance of the electrical circuit.

In conclusion, we present herein the opportunities that fs laser irradiation opens for the control of functional thin film properties and, consequently, for the design of electric and superconducting microcircuits for different application.

Keywords: *LIPSS, ITO, Nb, thin films, fs laser processing*

References*:*

1. J. Bonse, J. Krüger, *Applied Physics A* **129** (2023) 14.
2. X. Chen, T. Huang, R. Li, Y. Lin, J. Yang, W. Li, W. Yu, *ACS Appl. Electron. Mater* **5** (2023) 3316–3323.
3. V. Lapidas, et al., ACS Applied Materials and Interfaces **17** (2025) 16122–16131.
4. A. Badía-Majós, et al., *Applied Surface Science* **649** (2024) 159164.
5. E. Martínez, et al., *Applied Surface Science* **679** (2025) 161214.

Acknowledgements:

The authors are grateful for funding from the European Commission EU H2020 program under grant agreement 899352 (FETOPEN-01-2018-2019-2020 – SOUNDofICE), from the Spanish MCIN/AEI/10.13039/501100011033 and ERDF (FEDER) A way of making Europe, Fondos Next generation EU and Plan de Recuperación, Transformación y Resiliencia (projects TED2021-130916B-I00 and PID2023-146041OB-C21) from the Government of Aragon (Research Group T54_23R). The authors also thank the use of the Servicio General de Apoyo a la Investigación – SAI and the Spanish National Facility ELECMI ICTS, node "Laboratorio de Microscopías Avanzadas (LMA)" at Universidad de Zaragoza.

Piezo-Phototronic ZnO/Spiro-OMeTAD devices via Plasma and Vacuum Processing

Gloria P. Moreno[1], **Francisco J. Aparicio***[1], **Xabier García-Casas**[1], **Hari Krishna Mishra**[1], **Jaime Del Moral**[1], **Juan R. Sanchez-Valencia**[1], **Angel Barranco**[1], **Ana Borras***[1].

Correspondence to fjaparicio@icmse.csic.es and anaisabel.borras@icmse.csic.es

Nanotechnology on Surfaces and Plasma Group (CSIC-US), Materials Science Institute of Seville (CSIC – US),
Americo Vespucio 49, 41092 Seville, Spain

Piezophototronic devices represent a cutting-edge class of multifunctional systems that integrate piezoelectric, photonic, and electronic properties to enable enhanced control over charge carrier generation, transport, and separation. In particular, the piezopotential generated within piezoelectric semiconductors under mechanical strain contributes to the overall built-in potential developed at the interface of semiconductor junctions, affecting the band bending. This provides an additional route for the **mechanical actuation over different types of optoelectronic processes,** such as light emission, detection, and energy conversion, with high sensitivity and precision. Thus, the advantageous coupling between piezoelectric and optoelectronic properties provided by some piezoelectric semiconductors, such as ZnO, opens new avenues for developing flexible electronics, energy-harvesting technologies, and **advanced self-powered sensors,** particularly in environments where mechanical stimuli and optical signals coexist.

Plasma and vacuum deposition methods are solvent-free fabrication technologies extensively utilised for large-scale manufacturing in microelectronics and optoelectronics. We have adopted plasma-enhanced chemical vapour deposition (PECVD) techniques for the nanoengineering of ZnO thin films and nanoarchitectures, enabling applications in nanogenerators [1][2], sensors [3], and photonics [6]. Additionally, we have demonstrated the vacuum deposition of high-purity, highly crystalline p-type Spiro-OMeTAD semiconductor with a compact thin film structure that enhances the environmental stability and performance of perovskite solar cells [7]. This study presents a combined fabrication approach for flexible, self-powered piezo-phototronic devices, integrating polycrystalline, texturised ZnO nanocolumns synthesised via PECVD with a vacuum-deposited Spiro-OMeTAD layer forming a piezophototronic system. Our goal is to highlight the advantages of plasma and vacuum technologies in optimising the interface between these materials and the high compatibility with flexible substrates.

To ensure reliable mechanical deformation, we employed a four-point bending setup [6]. Our self-powered piezo-phototronic devices achieved a photocurrent of 1.15 μA/cm² with a competitive responsivity of 3.2 mA/W, providing a tuning range of ca. 20 % under soft mechanical deformation of 0.2 % longitudinal strain.

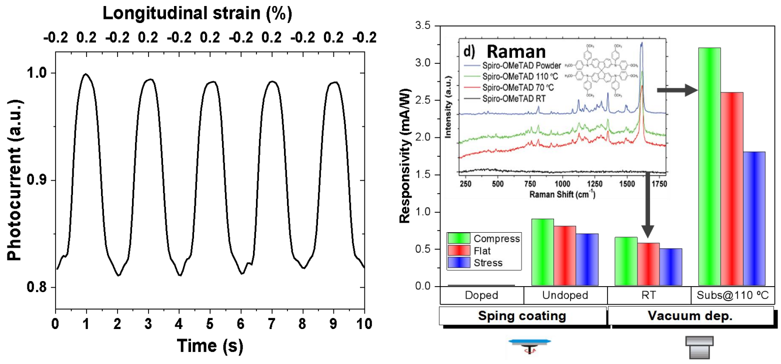

Fig. 1. Left modulation of the generated photocurrent under mechanical actuation. Photosensor responsivity for different fabrication methods.

Keywords*: Piezo-Phototronic ZnO, Spiro-OMeTAD Self Self-powered sensors*

References:

1. Nanoworkshop et al., *Nanoworkshop Materials* **2** (2025).
1. X. Garcia-Casas et al., *Nano Energy* **91** (2022), 106673.
2. X. Garcia-Casas et al., *Nano Energy* **114** (2023), 108686.
3. J.R. Sanchez-Valencia et al., *J. Phys. Chem. C* **118** (2014), 9852.
4. M. Macias-Montero et al., *Adv. Funct. Mater.* **23** (2013), 5981.
5. A. Barranco et al., *Adv. Enery Mater.* **10** (2020) 1901524.
6. Hao li, et al. *Nano Research* **17** (2024), 5317.

Acknowledgements:

EU-H2020 program under agreement 851929 (ERC Starting Grant 3DScavengers) and agreement 958174 (M-ERA.NET ANGSTROM)
AEI-MICINN (PID2022-143120OB-I00, TED2021-130916B-I00 and PCI2024-153451) funded by MCIN/AEI/10.13039/501100011033 and by "ERDF (FEDER)" A way of making Europe, Fondos NextgenerationEU and Plan de Recuperación, Transformación y Resiliencia".
AEI-MIU (FPU19/01864). G.P Moreno and X. Garcia-Casas respectively thank the AEI for the PID2019-110430GB-C21 and FPU19/01864 contracts.

Conformal deposition of aerogel-like functional oxide films by remote plasma deposition and processing

Gloria P. Martínez, Jose Obrero, J. Ferreira de Souza, Triana Czermak, Lidia Contreras, Francisco J. Aparicio, Juan R. Sánchez-Valencia, Ana Borrás, Angel Barranco*

P Nanotechnology on Surfaces and Plasma Laboratory. Materials Science Institute of Seville (CSIC-US) c/Américo

Vespucio 49, 41092, Sevilla, Spain.

*Corresponding Author: angel.barranco@csic.es

Developing new fabrication methods for nanostructural control is crucial for synthesizing rationally designed materials with enhanced properties.[1] In this context, plasma-activated deposition methods have evolved over the last decade, shifting from a focus on compact thin films to enabling the controlled deposition of nanoscale materials, including nanoporous layers, low-dimensional carbon structures, and complex one-dimensional nanostructures.[2,3] The advantages of these vacuum–plasma methods lie in their straightforward scalability, low deposition temperatures, compatibility with a wide variety of substrates, and high precision in the control of material composition (including doping), as well as in morphological characteristics such as microstructure, texture, and alignment.[2,3] However, a critical bottleneck in applying such techniques to the deposition of nanoscale materials is the limited availability of volatile metalorganic and metal halide precursors.

Although many examples exist of porous oxide synthesis by plasma-enhanced CVD,[4,5] the fabrication of ultraporous layers, such as aerogels, has remained limited primarily to wet-chemistry-based methods.

This work establishes the foundation for a vacuum- and plasma-assisted methodology to fabricate nanostructuredmetal oxide layers with controlled microstructure using solid metal precursors, such as phthalocyanines and porphyrins.[6–8] By combining remote plasma synthesis with plasma processing of the growing films at low or room temperature,[9,10] we have deposited conformal, aerogel-like functional films of a wide variety of oxides. These films are directly applicable in optics, photonics, and optoelectronics.

The most notable strengths of this method include its broad generality in terms of material composition, crystallinity, and microstructure, as well as its mild temperature and energy requirements. Additionally, it offers straightforward compatibility with processable substrates and device architectures. Examples of antireflective coatings, omniphobic surfaces, photoelectrodes for perovskite solar cells, and thermochromic coatings will be presented, demonstrating the potential of this novel, plasma-based approach for direct industrial-scale implementation.

References

[1] N. Baig, et al., Mater. Adv. 2 (2021) 1821.
[2] N. K. Kaushik, et al., Nanomaterials 9 (2019) 98.
[3] R. M. Sankaran, Plasma Processing of Nanomaterials, CRC Press, (2017).
[4] P. Romero-Gómez J. Phys. Chem C 114, 2010, 20932.
[5] A. N. Filippin et al ACS Applied Materials & Interfaces 12 (2020) 50721.
[6] J. M. Obrero, et al., Front. Chem. 8 (2020) DOI 10.3389/fchem.2020.00520.
[7] M. Alcaire, et al., Plasma Process. Polym. 13 (2016) 287.
[8] A. N. Filippin, et al., Adv. Mater. Interfaces 4 (2017) 1601233.
[9] J. Obrero et al. ACS Appl. Mater. Interfaces (2024). DOI: 10.1021/acsami.4c00555
[10] J. Obrero et al. arXiv:2504.08133 (2025)

Acknowledgments: We thank the project PID2019-110430GB-C21, TED2021-130916B-I00 and PCI2024-153451 funded by CIN/AEI/10.13039/501100011033 and by "ERDF (FEDER) A way of making Europe, Fondos NextgenerationEU and Plan de Recuperación, Transformación y Resiliencia. The project leading to this communication has also received funding from the EU H2020 program under grant agreement 851929 (ERCStarting Grant 3DScavengers) and M-ERA.NET 3 (Ref. 958174).

Formation of Cu_3N nanoparticles using gas aggregation based on cylindrical magnetron

**Daniil Nikitin, Veronika Cervenkova, Jan Hanus, Ronaldo Katuta, Pavel Mares, Jiri Vyskocil, Mirek Cieslar,
Lucie Bajtosova, Milan Dopita, Terka Kosutova, Andrei Choukourov,
Hynek Biederman[1]**

[1]*Charles University, Faculty of Mathematics and Physics, Department of Macromolecular Physics, V Holesovickach 2,
180 00 Prague 8, Czech Republic*
**Corresponding Author: bieder@kmf.troja.mff.cuni.cz*

Refractory metal nitrides in the form of nanostructures have been in the center of attention because of their potential applications such as plasmonic, photocatalysis and etc. However, also other metal nitrides are now days considered. Among them, copper nitride (Cu_3N) prepared by wet chemical procedures has been investigated in the form of thin films [1] and nanoparticles (NPs) [2]. Cu_3N has relatively narrow band gap (1.2 eV – 2 eV) and possesses efficient formation of electron – hole pairs. This makes Cu_3N interesting for various applications, namely in optics and photocatalysis.

In this contribution, a very clean process is presented - so called gas aggregation using sputtering based on a cylindrical magnetron. Gas aggregation cluster source (GAS) was originally introduced by Haberland et al. [3] in 1991 using a planar magnetron for sputtering. This design possesses certain weaknesses, such as low usage of the target material, low efficiency of the nucleation/growth of NPs because of the out-diffusion of atomic metal from the growth region, uncontrollable redeposition on the target surface and escape to the walls. In recent years, new experimental design was presented- post (cylindrical) magnetron with a rotating magnetic circuit. This cylindrical magnetron was positioned “in line” i.e. parallel to the gas axis. Magnetic circuit created the two elliptical plasma zones with associated erosion zones that were on opposite sides of the magnetron cylindrical target. Rotation of these zones enabled better usage of the target material. Cu NPs creation and deposition have been investigated. Highest values of deposition rate of around 19 mg/h were reached [4].

In this contribution, post(cylindrical) magnetron was equipped with a new design of magnetic circuit consisting of a closed loop endless arch [5] and was placed perpendicularly to the GAS axis. This perpendicular arrangement is preferential as it gives a narrower size distribution of NPs than in the co-axial case. Different mixtures of Ar and N_2 have been used to vary the chemical composition of resulting NPs. Also, the influence of the gas mixture pressure on resulting NPs has been studied. It has been found that the deposition in pure N_2 results in cubic-shaped Cu_3N nanoparticles. They are thermally stable until 200 °C under the ambient atmosphere, transforming to CuO at higher temperatures. Further perspectives of gas-aggregated Cu_3N NPs are outlined.

Keywords: *gas aggregation, magnetron, sputtering*

References:

1. Aihua Jiang, Meng Qi, Jianrong Xiao,Journal of Materials Science & Technology 34 (2018) 1467–1473
2. P.Parades, E. Rauwel and P. Rauwel, Nanomaterials 2022, 12, 2218
3. H. Haberland, M. Karrais, M. Mall, Y. Thurner, J. Vac. Sci.Technol., A 1992, 10, 3266.

Multiscale modelling the working mechanisms of triboelectric nanogenerators for drop energy harvesting

J. A. Budagosky Marcilla [1, 2], **X García-Casas** [2], **F. Nuñez-Galvez** [1, 2], **J. R. Sánchez-Valencia** [2], **A. Borrás** [2]

[1]Departamento de Física Aplicada I, Escuela Politécnica Superior, Universidad de Sevilla - Seville (Spain),

[2]Nanotechnology on Surfaces and Plasma Laboratory, Materials Science Institute of Seville (CSIC-US) (Spain).

Extracting energy from low-frequency liquid flows is a comparatively new idea when placed alongside the well-established fields of solar and wind power. Today, it stands as a key research focus in exploiting the potential of water as a clean, renewable energy resource. In this context, triboelectric nanogenerators (TENGs) have emerged as very promising players in this field. Yet, even with substantial research investment, droplet energy harvesters still struggle with limited output. This limitation arises primarily from challenges in finding materials that feature the ideal combination of triboelectric and wetting properties, as well as from device architectures that are not optimized to fully convert the kinetic energy of impacting droplets. To overcome these obstacles, it is essential to simulate every stage of the energy collection process, since each phase contributes critical elements necessary for capturing the energy stored in the droplets. As part of a broader effort to develop a TENG that can directly extract electrical energy from high-density droplets in one step, we have introduced a simplified model. Our approach relies on two key factors: the intrinsic conductivity of the droplet and the instantaneous electrical capacitance that arises from the rapid contact between the droplets and the active electrode area of the device. We have implemented this model using finite element simulations in the COMSOL Multiphysics environment. The simulation results offer valuable insights into the behavior of liquid-solid triboelectric nanogenerators and clarify how the pre-charging effect of the triboelectric surface influences the timing and dynamics of the energy conversion process.

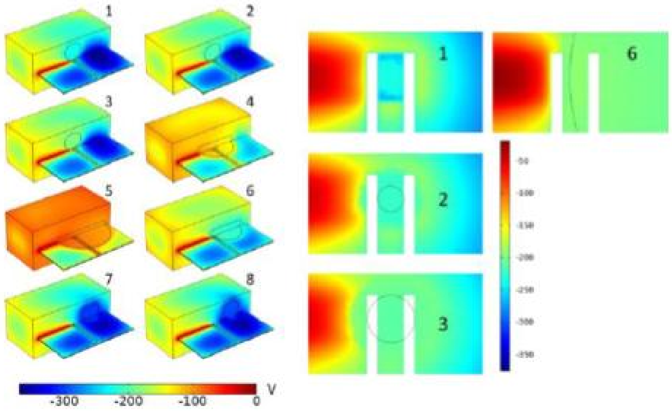

Fig. 1. Snapshots of the simulated electrostatic potential distribution (in V) at different instants during the spreading and recoiling stages of the drop. The PFA Surface has parasitic surface charges distributed uniformly throughout, and the density of negative charges is higher in the middle of the top electrodes.

Keywords*: Energy harvester, Nanogenerator, Liquid-solid electrification.*

Acknowledgements: The authors thank the projects PID2022-143120OB-I00 and TED2021-130916B-I00 funded by MCIN/AEI/10.13039/501100011033 and by "ERDF (FEDER)" A way of making Europe, Fondos NextgenerationEU and Plan de Recuperación, Transformación y Resiliencia". J. R. S.-V. thank the AEI-MICINN through the Ramon y Cajal Spanish National program and also the University of Seville through the VI PPIT-US program. C.L.S. thanks the University of Seville through the VI PPIT-US and "Ramon y Cajal" program funded by MCIN/AEI/10.13039/501100011033. JB thank the University of Seville through the VII PPIT-US program. XGC acknowledges the FPU program under the grant number FPU19/01864. FNG acknowledges the "VII Plan Propio de Investigación y Transferencia" of the Universidad de Sevilla. The project leading to this article has received funding from the EU H2020 program under grant agreement 851929 (ERC Starting Grant 3DScavengers).

Plasma Polymer Nanoparticles in Tandem with Boron as Nanofuels for Laser-Driven Proton-Boron Fusion

Marco Tosca[1,2], Mariia Protsak[1], Daniil Nikitin[1], Kateryna Biliak[1], Jan Hanuš[1], Veronika Červenková[1], Ronaldo Katuta[1], Jakub Čížek[1], Daniel Molloy[3], Marco Borghesi[3], Eric Hirschmann[4], Jaakko Julin[5], Lorenzo Giuffrida[2], Daniele Margarone[2], Andrei Choukourov[1]

1Faculty of Mathematics and Physics, Charles University, V Holešovičkách 2, 180 00, Prague, Czech Republic
2ELI Beamlines Facility, the Extreme Light Infrastructure ERIC, Dolni Brezany, Czech Republic
3Centre for Light-Matter Interactions, School of Maths and Physics, Queen’s University Belfast, UK
4Institute of Radiation Physics, Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Bautzner Landstr. 400, 01328 Dresden, Germany
5University of Jyväskylä, Department of Physics, Jyväskylä, Finland

Materials rich in hydrogen and boron have been considered attractive fuels for laser-driven proton-boron (pB) fusion since 2005 [1]. In this process, a high energy laser pulse irradiates the material to ionize atoms and accelerate protons to energies sufficient for fusion with B nuclei, producing energetic alpha-particles without creating neutrons, thus without radioactive activation or waste [2]. Alpha-particles can then be used in various applications, including sustainable electricity generation, space propulsion, radiobiology, and cancer treatment. Several experiments have been performed in recent years using macroscopic materials, such as boron nitride (BN) as a source of boron, and polymers as a source of hydrogen. The major drawback of these experiments is that the yield of alpha particles is strongly limited by low energy absorption by the target surface. This problem can be mitigated using nanostructured and/or porous materials, since structures smaller than the wavelength of the incident laser (< 1 micrometer) could facilitate absorption of the laser energy.

Performing plasma polymerization of hydrocarbon precursors (hexane, cyclohexane, and benzene) in a gas aggregation cluster source at different rf powers, we prepared porous, dendrite-structured, micrometer-thick layers of plasma polymerized hydrocarbon nanoparticles (ppC:H NPs) of the size ranging from tens to hundreds of nanometers. Variable-energy positron annihilation spectroscopy and N_2 sorption analysis found the multiscale porosity in these coatings, which was given by free volumes in the plasma polymer matrix (with characteristic diameter of 0.4 - 0.7 nm) and interparticle voids (10 - 100 nm). Elastic recoil detection analysis revealed that ppC:H NPs lose half the amount of precursor hydrogen, with hexane showing the highest retention. We used ppC:H NPs from hexane and optionally overcoated them with sputtered boron. Using the TARANIS laser system (10 J per 800 fs pulse, 2×10^{19} W/cm^2), the pB fusion was successfully initiated to produce energetic alpha-particle fluxes competitive with the best results obtained so far.

Keywords: *nanoparticles, plasma polymer, nanocomposites*

References:
[1] V.S. Belyaev et al., Phys. Rev. E, 2005, 72, 026406.
[2] M.L.E. Oliphant, E. Rutherford, Proc. R. Soc. London Ser. A, 1933, 141, 259.

Acknowledgements: *This work was supported via the grant GAČR 24-11398S from the Czech Science Foundation.*

Boosting Nanoparticle Yield: Enhanced Atom-to-Nanoparticle Conversion in Gas Aggregation

<u>Pavel Curda,</u> Alexej Horak, Abel Koshy, Petr Sezemsky, Vitezslav Stranak

University of South Bohemia, Faculty of Science, Branisovska 1760, 37005 Ceske Budejovice, Czech Republic

Gas-phase synthesis of nanoparticles via magnetron sputtering is a promising method for producing ligand-free nanostructures with high purity, controlled size, and tuneable properties. However, a fundamental bottleneck in this approach lies in the low atom-to-nanoparticle conversion efficiency, which limits production yield and scalability. This work investigates two interconnected aspects of this challenge: the early-stage nucleation mechanism driven by atomic dimers, and the optimization of plasma discharge parameters to enhance nanoparticle growth.

We first focus on the role of dimer species such as Cu_2^+, $ArCu^+$, and Ar_2^+ in the initial stages of nanoparticle formation. Energy-resolved mass spectrometry was employed to probe the plasma species in a magnetron aggregation system operated under both direct current (DC) and pulsed conditions. The results indicate that sputtered Cu_2^+ dimers—originating from the target and carrying higher kinetic energy consistent with the Thompson energy distribution—serve as critical cluster nuclei. These dimers initiate nucleation more effectively than gas-phase-formed $ArCu^+$, although both contribute to nanoparticle formation. The population of dimers correlates strongly with the nanoparticle mass deposited on the substrate, highlighting their relevance to overall growth dynamics. The generality of this mechanism was supported by comparable trends observed in systems using silver targets.

In the second part of the study, we demonstrate how pulsed magnetron sputtering can be tuned to significantly improve nanoparticle formation efficiency. By adjusting pulse duration and repetition frequency, we achieve an **order-of-magnitude enhancement** in nanoparticle yield without increasing material consumption or overall power input. This is attributed to improved control over plasma density, sputtering kinetics, and aggregation conditions.

Together, these findings contribute to a deeper understanding of gas-phase nucleation mechanisms and offer a practical strategy for boosting production efficiency. The results are broadly relevant to the scalable synthesis of functional nanoparticles for applications in catalysis, plasmonic sensing, and nanomedicine.

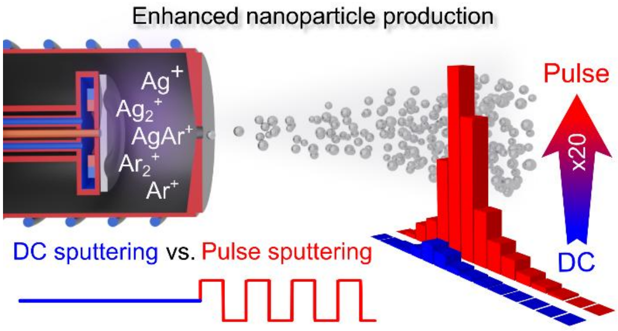

Fig. 1. Representative scheme of enhancing mechanisms for increased efficiency of atom-to-nanoparticle gas conversion.

Keywords: *Nanoparticle synthesis, Nanoparticle yield enhancement, Gas aggregation, Atom-to-nanoparticle conversion, Pulsed magnetron sputtering*

Acknowledgements: The research was financially supported by the Czech Science Foundation through the project GACR 21-05030K, and by National Centre of Competence (TACR) under project NCK TN02000069/007.

Atomic Layer Deposition of ZnO on Laser Induced Graphene: a Photoactive Nanocomposite for Water Remediation

Regina Del Sole[1], Fabio Palumbo[4], Antonella Milella[1], Alexander Dallinger[2], Francesco Greco[3, 2], Sreenadh Thaikkattu Sankaran[3], Paola Parlanti[5], Mauro Gemmi[5], Francesco Fracassi[1,4], Anna Maria Coclite[2]

1 Università degli Studi di Bari Aldo Moro, Department of Chemistry, Bari, Italy
2 Graz University of Technology, Institute of Solid State Physics, Graz, Steiermark, Austria
3 Center for Micro-BioRobotics @SSSA, Istituto Italiano di Tecnologia, Pontedera, Italy
4 CNR-NANOTEC, Istituto di Nanotecnologia, sez. Bari, Bari, Italy
5 Center for Materials Interfaces @SSSA, Istituto Italiano di Tecnologia, Pontedera, Italy

Metal oxide–carbon nanocomposites have garnered significant attention over the past decades due to their superior properties, which often surpass those of the individual components. Among metal oxides, interest around zinc oxide (ZnO) has blossomed owing to its antifouling and antibacterial activity. Furthermore, it is widely recognized for being low-cost, environmentally safe, and biocompatible. As an n-type semiconductor, ZnO exhibits excellent photosensitivity, with a wide band gap of 3.37 eV that enables strong absorption in the UV region, making it suitable for photocatalytic applications. However, a key limitation of ZnO lies in its fast electron–hole recombination, which significantly hampers its photocatalytic efficiency. To address this drawback, ZnO–carbon nanomaterial (CNM) nanocomposites have been extensively explored in the literature as an effective strategy to enhance charge separation and improve performance in various photocatalytic processes, including wastewater treatment, degradation of organic pollutants, and antimicrobial applications. Among carbon-based nanomaterials, a particularly innovative and promising candidate is Laser-Induced Graphene (LIG), first reported by Lin et al. in 2014 [1]. LIG offers a unique combination of properties that make it especially attractive for the development of photoactive nanocomposites: it acts as an efficient electron sink, enhancing charge separation, and serves as a 3D porous solid support with high surface area, which promotes the adsorption of pollutants and facilitates photocatalytic degradation. Additionally, using LIG as a support enables easy recovery and recycling of the photocatalyst when coupled with ZnO nanoparticles, thus providing a sustainable and scalable platform for environmental applications.

Keeping this background as a starting point, we addressed the thermal Atomic Layer Deposition of ZnO on LIG obtained from polyimide substrates. Two morphologically distinct LIG substrates were used, one that consisted of a thinner layer with smaller pores and a second one, thicker with larger pores.

XPS analyses indicate that the ALD technique allows to grow ZnO stoichiometrically on the chosen substrates. Moreover, SEM and EDX show that ZnO is deposited down to the bottom of the pores of the material, guaranteeing an increasing coverage with increasing number of deposition cycles and preserving the initial 3D structure. The crystallinity of the deposited ZnO is also proven via XRD analysis. The photocatalytic activity of the ZnO/LIG nanocomposites has been evaluated by monitoring the discoloration of a 10^{-5} M methylene blue (MB) solution upon UV irradiation ($\lambda = 365$ nm) over a time span of 120 min. Results indicate that the photocatalytic performance of the nanocomposites increases with the ZnO deposition time. For nanocomposites showing the higher ZnO coverage degree, after 120 min of irradiation a net MB photodegradation percentage of 71 ± 4 % and 69 ± 4 % is reached respectively for the less porous and more porous substrate. Conversely, the MB adsorption percentage of the samples decreases upon ZnO deposition, due to the reduced accessible porosity and the hydrophobicity of the nanocomposites, confirmed by WCA measurements.

The approach used for the fabrication of these solid-supported nanocomposites is straightforward and constitutes a promising strategy for the development of efficient, environmentally sustainable photoactive materials.

Keywords: *Atomic Layer Deposition, Photocatalysis, Laser Induced Graphene, ZnO, Nanocomposites*

References:

1. Lin et al., *Nature Communications, **5** (2014)*
2. Dallinger et al., *ACS Appl Nano Mater.* **6**(18):16201-16211 (2023)
3. Tesfahunegn, et al., *Nanomaterials*, 2023, 13, 947

Tuning wetting and triboelectricity: bioinspired dew-TENGs

Nicolò Giuseppe Di Novo,[1] **Fernando Núñez Gálvez,**[1,2] **Jaime del Moral,**[1] **Victor Joaquin Rico-Gavira,**[1] **Luis Angurel,**[3] **Joaquín Rivera-Sahún,**[3] **Carmen Lopez Santos,**[1,2] **Juan Ramón Sánchez Valencia,**[1] **and Ana Borrás**[1]

[1]Nanotechnology on Surfaces and Plasma Lab, Materials Science Institute of Seville (CSIC-US), c/ Américo Vespucio 49, 41092 Seville, Spain

[2]Departamento de Física Aplicada I, Escuela Politécnica Superior, Universidad de Sevilla, Seville 41011, Spain

[3]Instituto de Nanociencia y Materiales de Aragón (INMA), CSIC-Universidad de Zaragoza, 50018 Zaragoza, Spain

nicolo.dinovo@icmse.csic.es

The growing interest in IoT technologies—such as sensors for environmental and agricultural monitoring or communication systems in off-grid areas—requires non-conventional, environmentally friendly energy sources. Water, in the form of droplets or vapor, represents a largely untapped source of ambient energy. In recent years, triboelectric nanogenerators that harvest energy from rain (TENGs) [1], moisture (MEGs) [2], or evaporation [3] have gained significant attention, yet dew remains relatively unexplored. Dew droplets can form on surfaces for several hours a day in specific environments and tend to accumulate in certain areas due to Laplace pressure-driven capillary flows, as observed in the spines of the Old Man cactus, which feature microgrooves [4].

By combining these capillary flows with triboelectric materials, it is possible to generate usable electrical current. In this study, we present a novel investigation focused on designing surface micro- and nanostructures, along with tailored surface chemistry, to guide charged dew droplets through microchannels into a reservoir, thereby inducing an ionic current. To fabricate the devices, we employed a combination of techniques including spin coating, nanostructuring (SiO_2 nanotubes via plasma-enhanced chemical vapor deposition using a soft-template method with H_2Pc as the organic precursor) [5], femtolaser microtexturing, fluorosilane grafting, and electrodes deposition on glass or PET substrates (Fig. 1). We report and discuss the performance of these surfaces under dew-forming conditions, along with preliminary results on electrical power generation, with an emphasis on the mechanisms, future optimization and potential applications.

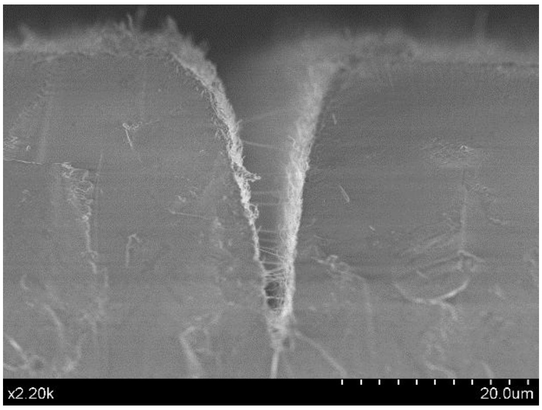

Fig. 1. SEM image of femto-laser textured microgrooves on glass, covered by SiO_2 nanotubes.

Keywords: *Dew, capillary flow, TENGs, femto-laser, PECVD*

References:
1. Ali Ghaffarinejad et al., Device, 2025.
2. Jin Tan et al., Nature communication, 2022.
3. Van-Duong Dao et al., Nano Energy, 2021.
4. Kundanati et al., Physics of Fluids, 2022.
5. Filippin et al., Nano Energy, 2019.

Acknowledgements:
We thank the EUH2020 program under grant agreement 3Dscavengers Starting Grant 851929 and TED2021-130916B-I00 funded by MCIN/AEI/10.13039/501100011033.

Flexible piezoelectric nanogenerators based on aligned and hierarchical ZnO nanorods

Melania Sánchez, Vanda Godinho*, Xabier García-Casas, Juan Delgado, Darío Jumilla, Hari Krisha Mishra, Angel Barranco, Juan Ramon Sánchez-Valencia, Ana Borras.

[1]*Instituto de Ciencia de Materiales de Sevilla (CSIC-US) C/Américo Vespucio 49, Seville E-41092, Spain*

**Corresponding author email: godinho@icmse.csic.es*

Hydrothermal synthesis of ZnO nanorods [1] has attracted attention over the last years for the fabrication of piezoelectric nanogenerators [2-4]. This is a simple cost-effective, template-less and surfactant-free aqueous method, consisting normally of two steps: the growth of a seed layer followed by the hydrothermal synthesis of the ZnO nanorods array. It is a procedure that takes place at moderate temperatures [1], enabling the fabrication of ZnO devices on flexible polymeric substrates.

It has been reported that the thickness, roughness and crystallinity of the seed layer has a strong effect on the ZnO nanorod's growth morphology and crystallinity and thus their properties [4]. In this work, we investigate the influence of seed layers produced by 3 different deposition methods: Spin-coating, Atomic layer Deposition (ALD) and Plasma-enhanced Chemical Vapor Deposition (PECVD). The different types of seed layers conduct to the growth of single-crystalline nanorods with different preferential orientations as revealed by TEM and XRD results. As described in Figure 1 a), the nanorods grow vertically aligned in the case of spin-coating and ALD seed layers. PECVD-seeded nanorods instead are not perfectly vertically aligned and show different aspect ratios from the base to the tip of the nanorods. The influence of the different morphology and crystalline orientation on the piezoelectric properties by PFM of the fabricated nanorods is reported. These nanorods were also incorporation as active layer in piezoelectric nanogenerators as the ones in Figure 1b). The nanogenerators were tested in cantilever mode and a higher Voc was observed under the same experimental conditions for ALD seeded nanorods.

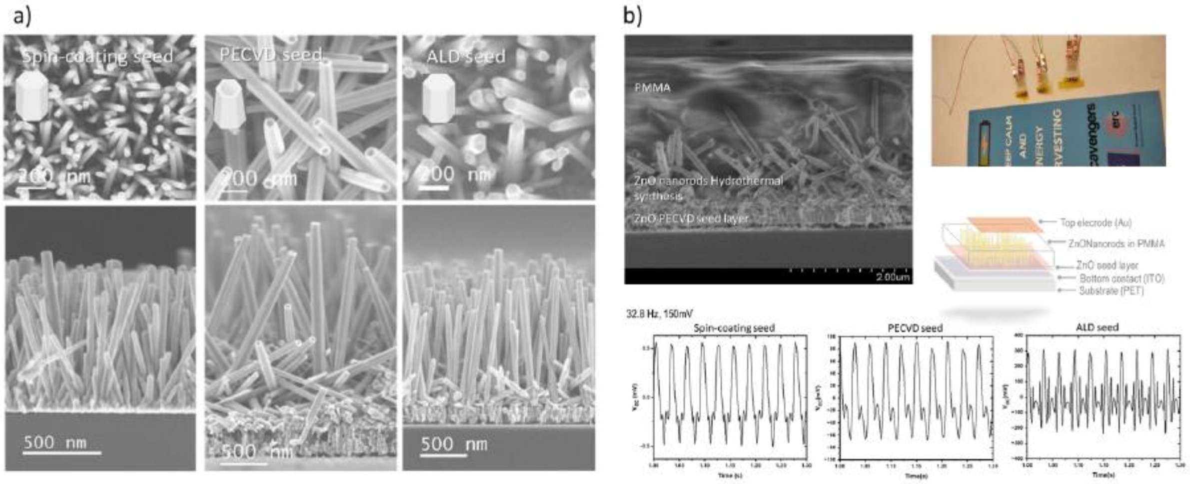

Fig. 1. a) Morphology of hydrothermally grown ZnO nanorods from different seed layers, b) Schequematics and cross-sectional view of the devices and piezoelectric response of nanogenerators fabricated with nanorods grown from different seed layers.

Keywords: *Nanogenerators, Piezoelectric response, interfaces effect, hydrothermal growth.*

References:

1. Vayssieres, L., Growth of Arrayed Nanorods and Nanowires of ZnO from Aqueous Solutions. 2003. 15(5): p. 464-466.
2. He, Q., et al., P–N junction-based ZnO wearable textile nanogenerator for biomechanical energy harvesting. Nano Energy, 2021. 85: p. 105938.
3. Lim, Y.P., et al., Modulating ZnO Growth Structures for Maximum Power Output of Hybrid Piezo/Triboelectric Nanogenerator. 2022. 32(46): p. 2206750.
4. Le, A.T., M. Ahmadipour, and S.-Y. Pung, A review on ZnO-based piezoelectric nanogenerators: Synthesis, characterization techniques, performance enhancement and applications. Journal of Alloys and Compounds, 2020. 844: p. 156172.

Acknowledgements:

Projects PID2022-143120OB-I00, TED2021-130916B-I00, and PCI2024-153451 funded by MCIN/AEI/10.13039/501100011033 and by "ERDF (FEDER), A way of making Europe", Fondos NextgenerationEU and "Plan de Recuperación, Transformación y Resiliencia". Darío Jumilla acknowledges the FPU doctoral contract, AEI-MIU (FPU20/02994)
Project ANGSTROM was selected in the Joint Transnational Call 2023 of M-ERA.NET 3, which is an EU-funded network of about 49 funding organisations (Horizon 2020 grant agreement No 958174).
The project leading to this article has received funding from the EU H2020 program under grant agreement 851929 (ERC Starting Grant 3DScavengers).

Molecular Dynamics Study of Support-Induced Strain Engineering in Anchored Nanoparticles

Yue Wang[1], Zibo Chen[1], Joseph Kioseoglou[2], Panagiotis Grammatikopoulos[1,3,4]

1Materials Science and Engineering, Guangdong Technion – Israel Institute of Technology, Shantou, Guangdong 515063, China
2School of Physics, Department of Condensed Matter and Materials Physics, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece
3Guangdong Provincial Key Laboratory of Materials and Technologies for Energy Conversion, Guangdong Technion – Israel Institute of Technology, Shantou, Guangdong 515063, China
4Instituto Regional de Investigación Científica Aplicada (IRICA) and Departamento de Física, Universidad de Castilla-La Mancha, 13071, Ciudad Real, Spain

Alloy NPs can be described in terms of their physical ordering (size, shape, crystallinity, etc.) and their chemical ordering; namely, the pattern in which the different elements are arranged. There are three main parameters that determine whether a stable structure of an alloy NP falls into a mixing or a non-mixing class [1]: (i) the enthalpy of mixing; (ii) surface energy differences between various elements; and (iii) strain energy considerations. If all parameters work together, identifying chemical order is straightforward. However, they often compete with each other, making the prediction of the final arrangement of atoms challenging; it is difficult to anticipate which parameter is dominant for every individual nanoalloy, especially since their influence changes with NP size.

Of all three parameters, strain energy is the only one that can be manipulated. Therefore, the key scientific question of this work is: can we strain-engineer the chemical order of alloy NPs for specific applications?

To this day, the equilibrium structures of multi-elemental NPs have been investigated thoroughly, but always with the implicit assumption that the particles are in vacuum [1]. For clusters in vacuum the strain energy parameter is usually less important than the other two; however, for NPs strongly bound on supports it can become dominant. Indeed, gas-phase deposited clusters can bind strongly on supports, thus introducing strain to their own lattice [3]; a portion of them (all, if small enough) can become epitaxially aligned with the support even if their lattice-constant mismatch is significant. So far, this has been demonstrated only for monometallic NPs.

This work combines these two considerations, i.e., investigate supported alloy NPs, revealing design opportunities which, to this day, have been hiding in plain sight. We propose a strain-engineering method to control atomic arrangement by anchoring bimetallic clusters to flexible supports and use atomistic computer simulations to provide initial proof-of-concept validation of our proposal.

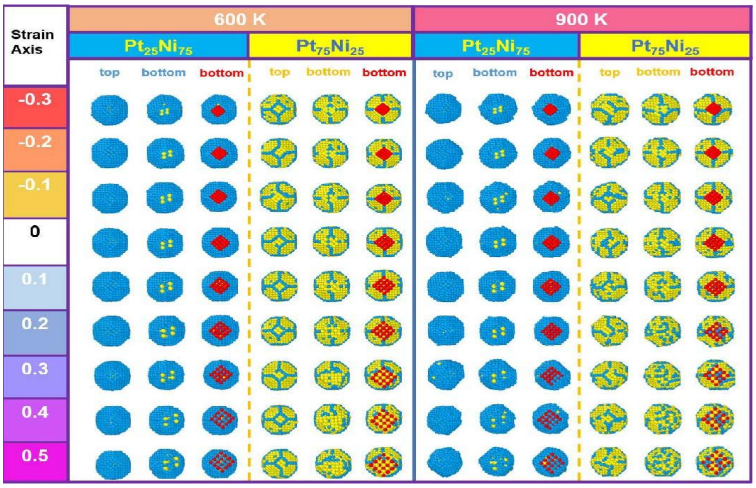

Fig. 1. collection of snapshots for equilibrated 586-atom NiPt nanoalloys under a complete straining routine (including the equilibrium structures prior to straining). For each group of NiPt nanoalloys with a specified temperature and composition, three columns of snapshots are presented along the strain axis: the leftmost column shows a top viewpoint, the middle corresponds to a bottom viewpoint; the third column shows the same bottom viewpoint but with marking fixed atoms (at the bottom layer) in red, to highlight the leaching atoms.

Keywords*: nanoalloys, molecular dynamics, Metropolis Monte Carlo, strain engineering, cluster-support interaction*

References:

1. Ferrando, R.; Jellinek, J.; Johnston, R. L. Nanoalloys: From Theory to Applications of Alloy Clusters and Nanoparticles. *Chem Rev.* **108(3)** 845 (2006).
2. Yeadon, M.; Ghaly, M.; Yang, R. S.; Averback, R. S.; Gibson, J. M. “Contact epitaxy” observed in supported nanoparticles. *Appl. Phys. Lett.* **73(22)** 3208 (1998).

Acknowledgements: *Work performed at GTIIT was supported by funding from the Guangdong Technion Israel Institute of Technology and Guangdong Provincial Key Laboratory of Materials and Technologies for Energy Conversion, MATEC (No. MATEC2022KF001).*

Ultrasensitive multifunctional nanosensing of ferroelectric van der Waals monoelemental tellurium coupling with ferroelectric polymer

<u>Hari Krishna Mishra</u>,* Ana Borras

Speaker Email ID: <u>hari.krishna@icmse.csic.es</u>

Nanotechnology on Surfaces and Plasma Laboratory, Materials Science Institute of Seville, CSIC-US, Avd. Americo Vespucio 49, 41092, Seville, Spain

The next-generation intelligent sensing demands advanced materials with enhanced sensitivity and multifunctionality for diverse applications, including wearable electronics, biomedical devices, and environmental monitoring.[1] In this regard, we present an innovative approach to realise ultrasensitive multifunctional nanosensing through the synergistic coupling of ferroelectric van der Waals (vdW) monoelemental tellurium (Te) with a ferroelectric polymer poly(vinylidene fluoride) (PVDF). The non-centrosymmetric crystal structure and anisotropic properties of Te nanorods have demonstrated interesting piezo and pyroelectric properties in response to mechanical and thermal stimuli, respectively.[2] Notably, due to the quantum mechanical approach, Born effective charges and in-plane piezoelectricity significantly enhanced the pyroelectric response of Te. [2,3] Furthermore, we demonstrated the rational design and fabrication of a composite nanosensor for multifunctional properties where the unique ferroelectric properties and high chirality of 2D Te are integrated with the robust mechanical flexibility and strong ferroelectric polarization of a PVDF polymer matrix. As a proof-of-concept, the fabricated flexible hybrid piezoelectric and pyroelectric nanogenerator (HyNG) promises an excellent electrical output performance as ~ 7.5 V and ~ 4 μA of open circuit voltage (V_{OC}) and short circuit current (I_{SC}) under a continuous imparted mechanical force of 12 N. HyNG also exhibits superior output performance of power density (~ 4.5 μW/cm^2) and pressure sensitivity of 148 mV/kPa, which demonstrate the capability to convert very small amount of pressure into electricity. The performance is further verified by the vital signals of human eye blinking and several physiological signals, to harvest untapped mechanical vibration. In addition to that, we have also recorded the excellent pyroelectric response of HyNG with a pyroelectric coefficient of ~ 60 μC.m^{-2}.K^{-1}, under periodic temperature oscillation, i.e., ΔT ~ 7 K. Therefore, due to the intrinsic piezoelectricity and pyroelectricity of both constituents, this novel hybrid architecture aims to unlock unprecedented sensing capabilities at the nanoscale. This work highlights a promising pathway for developing high-performance, integrated nanosensing platforms with broad implications for future smart systems requiring simultaneous and ultrasensitive detection of mechanical stress and thermal variations.

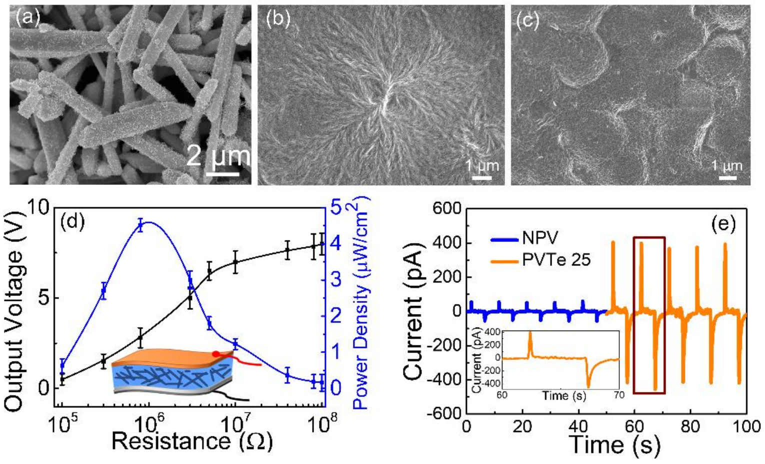

Fig. 1. (a) Surface morphology of synthesized Te nanorods. (b) Fibril structure formation in the PVDF thin film. (c) Nucleation of the spherulitic structure for the β-phase of PVDF. (d) Power density and (e) pyroelectric response, illustrating the output performance of the HyNG.

Keywords: Piezoelectricity, Pyroelectricity, Tellurium, PVDF, Nanogenerators, Energy Harvesting

References:

1. H. K.Mishra et al., Revisiting of δ−PVDF nanoparticles via phase separation with giant piezoelectric response for the realization of self-powered biomedical sensors, Nano Energy **95**, 107052 (2022).
2. H.K. Mishra, A. Jain, D. Saini, B. Mondal, C. Bera, S. Ram, and D. Mandal, Ultrahigh pyroelectricity in monoelemental two-dimensional tellurium. Phys. Rev. B 111, 155436 (2025).
3. J. Jiang, L. Zhang, C. Ming, H. Zhou et al., Giant pyroelectricity in nanomembranes, Nature 607, 480 (2022).

Acknowledgements: The authors thank the projects PID2022-143120OB-I00, TED2021-130916B-I00, and PCI2024-153451 funded by MCIN/AEI/10.13039/501100011033 and by "ERDF (FEDER)" A way of making Europe, Fondos NextgenerationEU and Plan de Recuperación, Transformación y Resiliencia". Project ANGSTROM was selected in the Joint Transnational Call 2023 of M-ERA.NET 3, which is an EU-funded network of about 49 funding organisations (Horizon 2020 grant agreement No 958174). The project leading to this article has received funding from the EU H2020 program under grant agreement 851929 (ERC Starting Grant 3DScavengers).

Enhanced Surface Functionality by Nanoporous Plasma Coatings

Dirk Hegemann[1], Luka Hansen[2], Michał Gora[1], Jan Benedikt[2], Paula Navascués[1]

[1]Empa, St.Gallen Switzerland [2]Institute of Experimental and Applied Physics, Kiel University, Kiel, Germany

Nanoporous films with porosities of 10-30 vol% and pore sizes around one nanometre or below offer various interesting effects. Besides a reduced refractive index – as used for *low k* dielectrics – ultrathin nanoporous films also yield enhanced surface functionalities due to the penetration and interaction with fluids. Diffusion properties of small molecules are controlled while larger molecules are blocked, molecules can orient within nanochannels, adsorption/desorption can be tuned by enhanced surface areas, and nm-range interaction forces are affected [1-3].
Here, a method is presented to deposit nanoporous coatings based on a defined interplay of plasma deposition and etching processes, avoiding heating of the substrate [4]. In particular, the plasma-surface interaction with energetic ions is limited on purpose, while plasma chemical deposition and etching processes are advanced based on a novel method named "Near-Surface Plasma Chemistry" (NPC) [5]. A polymeric mesh with large open space is placed about 2 mm above the substrate, i.e. immersed in the plasma sheath of a low-pressure RF capacitively-coupled plasma, to filter out part of the ion flux. For example, organosilicon coatings can be deposited from HMDSO plasmas yielding a defined Si–O–Si cage structure, where residual hydrocarbons are removed by Ar/O_2 plasma etching. At low ion bombardment highly stable nanoporous coatings are produced comprising interconnected nanopores with a porous volume up to 30%.

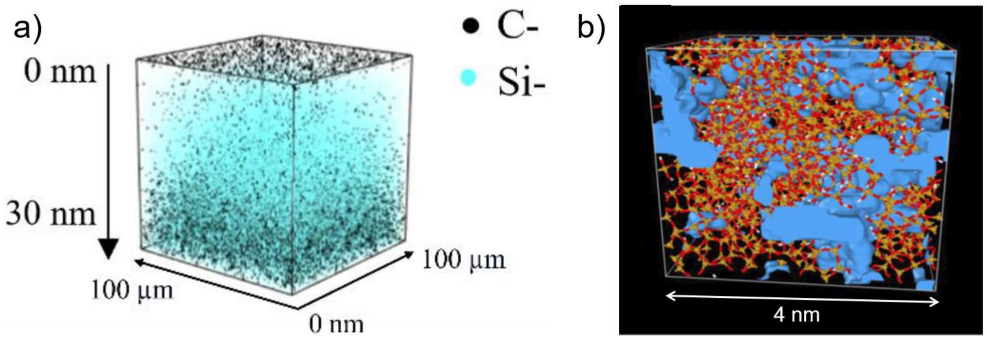

Fig. 1. a) Depletion of hydrocarbons up to about 20 nm in depth by plasma etching (ToF-SIMS), b) illustration of nanopore size and distribution (blue-coloured voids) within Si–O–Si cage structures (MD simulation)

The Ion Energy Distribution Function is measured by Mass Spectrometry. Porosity is analysed by ellipsometry and Rutherford Backscattering Spectrometry, while the film structure and penetration of fluids such as water and hydrogels is characterized by FTIR, ToF-SIMS and Neutron Reflectometry. The obtained nanoporous plasma coatings enabling enhanced surface functionality are applied for various fields: i) reduced protein adsorption affected by water structuring, ii) cell attachment on nanocomposite films, iii) antimicrobial efficacy combined with catalytic active metal oxide supports (metal/polymer nanocomposite), iv) liquid-infused surfaces, v) CO_2 sorption for direct air capture.

Keywords:
plasma chemistry
plasma-surface interaction
plasma deposition
plasma etching

References:

1. D. Hegemann, *Thin Solid Films* **581** (2015) 2–6.
2. E. Bülbül et al., *Surf. Interfaces* **23** (2021) 100922.
3. M. Gora et al., *Appl. Surf. Sci.* (2025) 163776.
4. T. Gergs et al., *Plasma Process Polym.* 2022 **19** (2022), e2200049.
5. P. Navascues et al., *Nanomaterials* **14** (2024) 195.

Acknowledgements*:*

The Swiss National Science Foundation (SNSF, grants no. 200021_169180, no. 200021_204111 and COST 2022, no. 213368) and the German Research Foundation (DFG, project no. 530936824) are acknowledged for funding parts of this work.

Fine tuning wettability through multiscale structures based on ion beam microtexturization, nanocolumns and nanoparticles

Y. Huttel[1], M. Garrido-Segovia[2,3], J. M. García-Martín[2], M. A. García[1,4], R. Gago[1], L. Martínez[1]

1Instituto de Ciencia de Materiales de Madrid (ICMM), CSIC, Madrid, Spain.
2Instituto de Micro y Nanotecnología (IMN), CSIC, Tres Cantos (Madrid), Spain.
3Departamento de Física de Materiales, Universidad Complutense de Madrid (UCM), 28040, Madrid, Spain.
4Instituto de Física, Universidad Nacional Autónoma de México (UNAM), Ciudad de México, México.

Wettability of surfaces is a continuously growing field were surfaces with special characteristics are of significant interest from environmental and economical points of view, as they can present properties like self-cleaning of solar panels. While chemical modifications of surfaces are popular to modify the wettability of the surfaces, less is known about the physical effect of morphological changes on the wettability. Here we present a multiscale approach that combines the use of templates by surface microtexturization of titanium (Ti) substrates together with the subsequent deposition of Ti nanocolumnar coatings and the final decoration with Ti nanoparticles (NPs).

We will first briefly present the (ultra-)high vacuum physical methods used to induce ripples on Ti substrates by ion beam sputtering (IBS) [1], the growth of tilted nanocolumn arrays by Glancing Angle Deposition (GLAD) [2-3] and NPs fabricated by means of an Ion Cluster Source (ICS) [4], highlighting the control over chemical composition, shape and dimensions of the fabricated nanostructures at each step. Later, we will present some examples where the proposed multiscale approach leads to synergic effects on the wettability by following the evolution of the contact angle at the different stages and with the progressive surface coverage with NPs.

Keywords: Wettability, Microtexturization, Titanium, Nanocolumns, Nanoparticles.

References:

1. M. A. Garcia et al., Surf. Coat. Tech. 458, 129363 (2023).
2. R. Álvarez et al., Nanomaterials 9, 1217 (2019).
3. J. M. García-Martín et al., Appl. Phys. Lett. 97,173103 (2010).
4. "Gas Phase Synthesis of Nanoparticles", Wiley-VCH Verlag GmbH, 2017, Ed. Y. Huttel.

Acknowledgements:

Financial support of the Spanish Ministry of Science and Innovation to grant PID2021-126524NB-I00 funded by MCIN/AEI/10.13039/501100011033 and by “ERDF A way of making Europe” is acknowledged. Financial support is also acknowledged through project TED2021-129876B-I00, financed by MCIN/AEI/10.13039/501100011033 and the European Union “NextGenerationEU”/PRTR”.

Gas-Phase Synthesis of Ag Nanoparticles for Integration into Nanocapacitors and Operando Electron Holography Analysis

Ramanpreet Kaur[1,a], Salomé Trillot[1,b], Caroline Bonafos[1], Kremena Makasheva[2], Martin Hytch[1], Christophe Gatel[1] and Patrizio Benzo[1]

[1]*CEMES-CNRS and Université de Toulouse, 29 rue J. Marvig, 31055 Toulouse, France*

[2]*LAPLACE, Université de Toulouse; INPT, CNRS; 118 route de Narbonne, F-31062 Toulouse cedex 9, France*

[a]***ramanpreet.kaur@cemes.fr***

[b]***salome.trillot@cemes.fr***

Nanocapacitors are essential components for power distribution networks and memory devices in microelectronic industries, as they provide ultrahigh power density and ultra-fast charge/discharge rates. They are thus widely used in DC/AC convertors, field-effect transistors, flash memory, and dynamic random-access memory (DRAM). However, charge traps in the insulating layer impact the device's performance by modifying its capacitance, threshold voltage, and frequency response. The understanding of charge transport mechanisms in such hybrid conductive-insulating systems is fundamental for the advancement of microelectronic systems. Despite their critical role, understanding charge dynamics remains a significant challenge as the majority of electrical characterisations are based on indirect measurements which can only measure the global response and lack in spatial resolution to probe the distribution of charge traps at nanometer scale [1-2].

The aim of this work is to fabricate model nanocapacitors with metal nanoparticles (NPs) embedded within the dielectric layer, achieving precise control over their size, density, and spatial distribution relative to the electrodes. These NPs will act as charge traps to precisely control the properties of the nanocapacitors. To investigate their role, *operando* electron holography will be used for mapping charge distribution within the device. This powerful transmission electron microscopy (TEM) technique enables real-time visualization of charge distribution during device operation, which will provide deeper insights of charge-trapping phenomena and electric field behavior at the nanoscale.

We focus on Ag nanoparticles (AgNPs) synthesized in the gas phase by magnetron sputtering [3], followed by size selection using a quadrupole mass filter (QMF) before deposition onto a substrate. This original synthesis technique enables independent control of both the size distribution (ranging from 0.5 to 15 nm) and the density of the AgNPs by tuning the synthesis conditions. To improve the efficiency of the process, the deposition parameters must be optimized in order to maximize the nucleation rate. Here, we will discuss the effect of different deposition parameters such as aggregation length, deposition time and effect of introducing oxygen (O_2) [4] into the aggregation chamber on the nucleation and growth of AgNPs. The resulting nanoparticles are analysed using advanced transmission electron microscopy (TEM) techniques to obtain the structural properties such as size, surface density, crystalline structure, and morphology down to the atomic scale. These structural properties are directly correlated with the specific synthesis parameters. These findings will provide crucial insights about the nucleation and growth mechanisms of AgNPs for their ultimate integration into microelectronic device applications.

Keywords: *metal NPs embedded nanocapacitor, gas-phase synthesis, Ag nanoparticles, nucleation and growth mechanism*

References

[1] C. Gatel , R. Serra, K. Gruel , A.Masseboeuf , L. Chapuis, R. Cours, L. Zhang , B.Warot-Fonrose, and M. J. Hÿtch, *Physical Review Letters,* **129**, 137701 (2022)

[2] B. Jolayemi, G. Buvat, P. Roussel, and C. Lethien, *Batteries*, **10**, 317 (2024)

[3] Y. Huttel, *Gas-Phase Synthesis of Nanoparticles*, (Wiley-VCH, 2017)

[4] S. Trillot, P. Benzo, S. Barre, N. Tarrat, M. Benoit, K. Makasheva, and C. Bonafos, *Nanoscale* – under review

Towards VO_2-based high-tunability optical platforms.

G. Savorianakis[1][2], C. Rousseau[3], Y. Battie[4], A. En Naciri[4], N. Martin[5], B. Maes[3], M. Voué[2], S. Konstantinidis[1].

[1] Plasma-Surface Interaction Chemistry, University of Mons, Belgium
[2] Physics of Materials and Optics Group, University of Mons, Belgium
[3] Micro- and Nanophotonic Materials Group, University of Mons, Belgium
[4] Laboratoire de chimie et physique – Approche multi-échelle des milieux complexes, University of Lorraine, France
[5] FEMTO-ST, University of Bourgogne Franche-Comté, France

The aim of this work is to develop optical platforms that exploits the Metal-Insulator Transition (MIT) of monoclinic vanadium dioxide (VO_2) to achieve a tunable optical response.

Initially, we successfully synthesized thermochromic VO_2 thin films using reactive magnetron sputtering whose thermochromic properties were characterized through optical transmission and resistivity measurements as a function of temperature [1].

We then conducted experimental research by combining VO_2 films with gold nanoparticles (AuNPs) to achieve tunable plasmonic signals in response to temperature change. We demonstrated the successful grafting of AuNPs onto the VO_2 film surface thanks to molecular linkers and optimized functionalization protocol. A noticeable shift in the plasmonic peak wavelength was observed as a function of temperature for two different platforms: one with NPs positioned on top of the VO_2 film and another with NPs embedded within the film. The grafting of AuNPs onto VO_2 films resulted in a shift in the plasmonic peak wavelength with temperature, enhanced resistivity, transmission drops, and a reduction of the critical MIT temperature by 5 °C. Embedding NPs within the VO_2 matrix further reduced the critical transition temperature to 35 °C, making it promising for smart window applications. Regarding the plasmonic wavelength, COMSOL simulations allowed us to study and understand the influence of NP penetration inside the VO_2 matrix on plasmonic modulation with temperature [2].

In a separate approach, by combining Glancing Angle Deposition (GLAD) with reactive magnetron sputtering, we successfully synthesized thermochromic VO_2 nanostructures including tilted nanocolumns and helices,. Ellipsometry analyses revealed that the optical properties show a significant anisotropy with sample rotation. Transmission analyses highlighted improved visible and infrared modulation compared to “dense” films, reinforcing their suitability for smart windows [1, 3].

This work paves the way for thin-film materials with high optical tunability and enhanced performance, potentially applicable in color displays, anti-counterfeiting, optoelectronic chips, and energy-saving smart windows.

Keywords: *VO_2, thermochromism, reactive magnetron sputtering, plasmonics, GLAD.*

References:

[1] Savorianakis, Konstantinidis et al, J. Appl. Phys., 129(18), 185306 (2021).
[2] Savorianakis, Konstantinidis et al. Adv. Mater. Interfaces, 2400172 (2024).
[3] Savorianakis, Konstantinidis et al, Surf. Coat. Technol., 502, 131938 (2025).

Plasma polymerized polyimide films for the development of electrochemical sensors

Abel George Koshy[1], Franciszek Skiba[2], Robert Bogdanowicz[2], Vítězslav Straňák[1]

1Department of Physics, Faculty of Science, University of South Bohemia, Branišovská 31, 370 05 České Budějovice, Czech Republic
2Department of Metrology and Optoelectronics, Faculty of Electronics, Telecommunications, and Informatics, Gdańsk University of Technology, 11/12 Narutowicza St., 80-233 Gdańsk Poland

The demand for advanced chemical and biosensing platforms has driven the development of tailored nanostructured surfaces and functional thin films capable of selective and sensitive interaction with a wide range of target analytes, including biomolecules, explosives, and chemical warfare agents. Among various surface engineering methods, low-temperature plasma processes have emerged as powerful tools for nano-engineering and precise surface functionalization. In this work, we report the development of a novel, flexible electrochemical sensor based on laser-induced graphene (LIG) fabricated on plasma-polymerized polyimide films.

The fabrication process begins with the deposition of thin polyimide films via magnetron sputtering, a Physical Vapor Deposition (PVD) technique known for its ability to control film thickness, uniformity, and chemical composition with high precision. The deposited films serve as the precursor layer for laser-induced graphene formation, a single-step, maskless technique performed under ambient conditions [1]. The laser photolysis process converts the polymeric surface into a porous, three-dimensional graphene-like structure, leveraging the localized thermal and photochemical effects of laser irradiation. This approach offers several key advantages over conventional graphene synthesis methods: it is scalable, solvent-free, cost-effective, and compatible with flexible substrates [2].

Structural and chemical characterization of the resulting LIG was carried out using Fourier-Transform Infrared Spectroscopy (FTIR), Raman spectroscopy, and Scanning Electron Microscopy (SEM). These analyses confirmed successful graphitization of the polyimide surface and a well-developed porous morphology. The developed sensor platform utilizes voltammetric techniques for analyte detection and is specifically designed for the identification of nitroaromatic explosives such as 2,4,6-trinitrotoluene (TNT) and 2,4-dinitrotoluene (DNT), as well as other chemical warfare agents in complex sample matrices.

The enhancement of the properties of deposited polyimide films by employement of catalysis or co-sputtering of metal nanoparticles is an approach of interest. It is believed that the incorporation of metal nanoparticles helps in improving electrical, catalytic and electrochemical properties of the LIG treated polyimide films.

Overall, this work highlights the integration of magnetron-sputtered polyimide films with laser-induced graphene conversion as a promising strategy for the fabrication of next-generation, flexible sensing devices. The combination of plasma-assisted thin-film engineering with laser-based nanostructuring provides a versatile and efficient route toward the development of advanced electrochemical sensors for environmental monitoring, security, and defense applications.

Keywords*:* Laser-Induced Graphene, electrochemical sensors, plasma polymer

References:

1. Lin, J., et al., *Nature Communications*, **5**, **5714** (2014)
2. Huang, L., et al., *Nano-Micro Letters*, **12**, **1–17** (2020)

Anti-fogging and anti-icing transparent glass surfaces by laser treatment and fluorine-based functionalization

Laura Montes-Montañez[1], Fernando Núñez-Gálvez[1,4], Melania Sánchez-Villa[1], Luis A. Angurel[2], Heli Koivuluoto[3], German F. de la Fuente[2], Victor Trillaud,[4] Philippe Steyer,[4] Karine Masenelli-Varlot,[4] Agustín R. González-Elipe[1], Ana Borrás[1], Víctor Rico[1], Carmen López-Santos[1,5]

1.- Institute of Materials Science of Seville (US-CSIC) Americo Vespucio 49, Seville, 41092 Spain
2.- Institute of Nanoscience and Materials of Aragón (UNIZAR-CSIC) María de Luna 3, Zaragoza, 50018 Spain
3.- Materials Science and Environmental Engineering, FI-33014 Tampere, Finland
4.- Univ Lyon, INSA Lyon, Université Claude Bernard Lyon 1, CNRS, MATEIS, UMR5510, Villeurbanne, 69621, France
5.- Departamento de Física Aplicada I, Escuela Politécnica Superior, Universidad de Sevilla, Virgen de Africa Seville, 41011 Spain

Glass surfaces used in outdoor technologies often suffer from fogging, ice accumulation, and surface fouling, significantly limiting their optical performance and durability, especially in architectural glazing, photovoltaic modules, and exposed optical or sensing devices. Glass surfaces inherently exhibit partial hydrophilicity. Therefore, the precise modulation of wetting behavior in transparent substrates has emerged as a critical research area with broad industrial relevance.

Traditional approaches for modifying surface wettability—such as functional coatings or microscale texturing—often incur detrimental effects on optical properties, including scattering-induced losses and reduced transmittance. Consequently, achieving a stable, highly water-repellent (superhydrophobic) response while preserving the inherent optical clarity of glass remains a central challenge in surface science and materials engineering. This objective becomes even more demanding in operational scenarios characterized by severe environmental conditions, such as sub-zero temperatures and high ambient humidity.

We report a novel surface-engineering method that imparts robust superhydrophobic, anti-fogging, and anti-icing functionalities to borosilicate glass without sacrificing transparency. Our strategy combines femtosecond UV laser patterning—tuned for precise surface morphology control—with low-energy chemical functionalization using fluorinated compounds. The resulting microstructured patterned surfaces exhibit high optical transmittance, exceptional water repellency, and strong environmental durability. Systematic parametrization of the ultrafast laser treatment was performed on borosilicate glass, whereby variables such as pattern geometry, scanning repetitions, and motif dimensions were finely adjusted. This enabled controlled manipulation of the surface topography at the micro- and nano- scales, quantitatively described through metrics such as laser-modified area fraction and root-mean-square roughness. The resulting hierarchical surfaces were specifically designed to host low-surface-energy fluorinated molecules, which further ensured water repellence while preserving visible-light transmittance.

Anti-fogging behavior was confirmed via ESEM imaging under condensation conditions, while ice adhesion and freezing delay tests demonstrated significantly improved anti-icing properties, which remained stable across five freeze–thaw cycles. The modified glass surface also showed resistance to biofouling agents.

This approach opens new pathways for integrating passive environmental resistance into optical systems, with potential applications in smart windows, solar panels, autonomous sensors, and microfluidics.

Keywords: transparent surfaces, superhydrophobic, anti-fogging, femtosecond laser, anti-icing

References:

1. Nanoworkshop et al., *Nanoworkshop Materials* **2** (2025).

Acknowledgements:
EU-H2020 program under agreement 899352 (FETOPEN-01-2018-2019-2020 – SOUNDofICE).

AEI-MICINN (PID2022-143120OB-I00 and TED2021-130916B-I00) funded by MCIN/AEI/10.13039/501100011033 and by “ERDF (FEDER)” A way of making Europe, Fondos NextgenerationEU and Plan de Recuperación, Transformación y Resiliencia”.

Interdisciplinary approach to tackle the nucleation and growth of large carbon molecules and mixed metal-carbon nanoparticles driven by organometallic clusters

Rémi Bérard[1,2], Christine Joblin[2], Sandra Wiersma[2], Hassan Sabbah[2], Camille Alauzet[3], Aude Simon[3], Fernand Spiegelman[3], and Kremena Makasheva[1]

1Laboratoire plasma et conversion d'énergie (LAPLACE), CNRS, INPT, Université de Toulouse, France
2Institut de recherche en astrophysique et planétologie (IRAP), CNRS, CNES, Université de Toulouse, France
3Laboratoire de chimie et physique quantiques (LCPQ), Institut FeRMI, CNRS, Université de Toulouse, France

The ANR GROWNANO is motivated by the need to understand the formation of carbonaceous/organosilicon dust in the presence of metal atoms (Fe, Ag, Ti, Al, Mg) with expected impact in the field of astrophysics and that of new materials for nanoelectronics. Astrochemical models currently do not take into account the role of metals in the nucleation and growth of carbonaceous dust. GROWNANO investigates the role of organometallic complexes and nanoclusters in these processes (Figure 1). These studies also provide useful guidelines for a better control of nanoparticle synthesis.

GROWNANO makes use of complementary reactors. The laser vaporization (LVAP) reactor on the PIRENEA 2 setup at IRAP allows us to investigate the first steps of nucleation and growth whereas the formation of the nanoparticles in the plasma gas phase is studied using the Plasma reactor at LAPLACE, which brings physical and chemical complexity with respect to LVAP. A variety of *in-situ* and *ex-situ* analytical methods are used to characterize the materials synthesized in the two reactors [1, 2]. In addition, a computational reactor investigates reaction dynamics and makes the bridge between the two size scales by using DFT methods for small species and approximated DFTB methods for larger ones [3]. Current challenges and results of this collaborative interdisciplinary work will be presented.

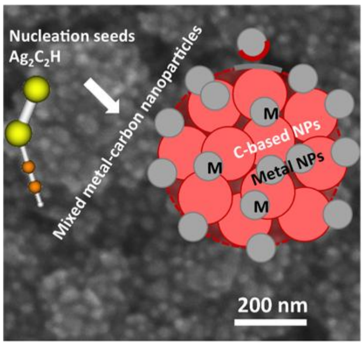

Fig. 1. The different scales explored in the ANR GROWNANO project.

Keywords: carbon/metal nanoparticles, nucleation and growth, nanostructured thin layers, DFT computational methods

References:

1. R. Bérard, K. Makasheva, H. Sabbah, A. Simon, D. Nunez Reyes, F. Mastrorocco, K. Demyk, C. Joblin, "Impact of metals on (star)dust chemistry: a laboratory astrophysics approach," *Front. Astron. Space Sci.* **8** 654879 (2021).
2. R. Bérard, V. Garofano, C. Joblin, L. Stafford, and K. Makasheva, "Layer-by-layer structured nanocomposite deposits from plasma-synthesized organosilicon nanoparticles and organosilicon nanoparticles decorated with Ag nanoparticles by taking advantage of cyclic nanoparticle formation in Ar/HMDSO reactive plasmas," *Frontiers in Nanotechnology* **6** 1337571 (2024).
3. C. Alauzet, F. Spiegelman, A. Simon "Modeling silver clusters-hydrocarbon interactions: a challenge for SCC-DFTB," *Comput. Theor. Chem.* **1239** 114744 (2024).

Acknowledgements:

This work was supported by the French ''Agence Nationale de la Recherche'', project ANR GROWNANO (ANR-21-CE29-0001).

Plasma-engineered Nanocomposites for Controlled Radical Chemistry

Paula Navascués[1], **Julia Morini**[1], **Emmanuel Chabal**[1], **Flaela Kalemi**[1], **Giacomo Reina**[2], **Dirk Hegemann**[1]

1 Laboratory for Advanced Fibers, Plasma & Coating group, Empa, St. Gallen, Switzerland
2 Laboratory for Nanomaterials in Health, Nano-Inter-Cell group, Empa, St. Gallen, Switzerland

Functional nanocomposites based on catalytic metal oxide thin films and plasma polymer coatings represent a promising platform for the controlled generation and delivery of reactive oxygen species (ROS). When properly coupled with a secondary semiconductor, titanium oxide-based (TiOx) thin films exhibit light absorption in the visible range and reduced recombination of charge carriers, allowing ROS generation even in the dark for limited periods of time [1]. Low-pressure plasma technology enables the effective fabrication and functionalization of catalytically active metal oxide thin films.

In this study, we explore various combinations of AgOx-doped TiOx thin films for ROS production. By modifying the material's nanostructure, both the type and rate of ROS produced can be controlled. This fine-tuning of catalytic activity allows for the specific selection of nanomaterials for diverse applications, ranging from therapy (e.g., antimicrobial biomaterials) to sustainability (e.g., water purification from emerging contaminants). The catalytic thin films can be further functionalized by plasma polymerization, enabling radical chemistry while preventing direct oxidation at the catalyst surface. The deposition of ultra-thin plasma polymer films, particularly nanoporous SiOx-like layers, allows additional control over ROS delivery. Recent results from our group demonstrate that the conversion of superoxide ($O_2^{-\bullet}$) to singlet oxygen ($^1O_2$) can be selectively modulated by adjusting the thickness of the functional layers [2] (see Fig. 1a).

Depending on the target application, precise doses and concentrations of ROS are required. For therapeutic uses, such as the treatment of skin infections, a controlled and stable ROS dose is necessary to eliminate bacteria without harming skin cells. Conversely, the degradation of emerging contaminants in water, such as dyes, pharmaceuticals, or surfactants, demands higher ROS levels, with short-lived species like hydroxyl radicals playing a crucial role. Plasma technology enables the fine-tuning of nanomaterials to address these diverse challenges by precisely controlling ROS production and delivery.

Finally, although catalytic metal oxides exhibit excellent performance after fabrication, they tend to lose activity during use and storage, and existing reactivation methods often fail to restore their full functionality. Atmospheric-pressure plasma (APP) treatment offers a novel and feasible approach to recover high activity levels (see Fig. 1b). The oxidizing species generated by plasma discharges in air restore the desired oxidized states on the nanomaterial surface. This treatment also reinstates a more porous nanostructure, restoring the catalytically active sites for ROS production.

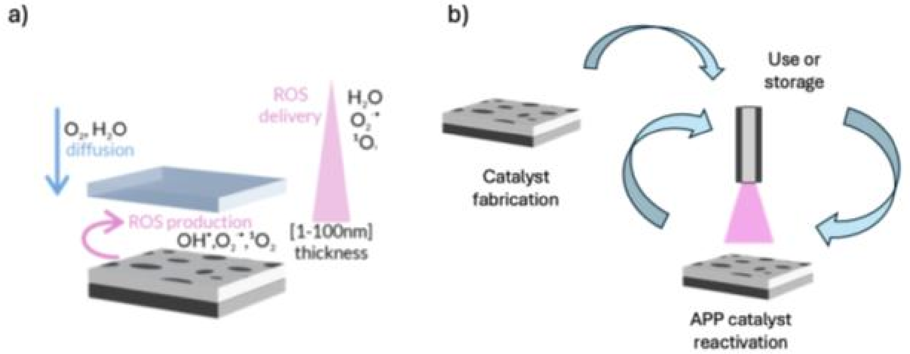

Fig. 1. a) Plasma-engineered nanocomposites (functionalized metal oxide thin films) for controlled ROS production and delivery. (b) Atmospheric-pressure plasma (APP) treatment reactivates catalytic materials after use or storage, allowing their long-term use.

Keywords:
plasma deposition
reactive oxygen species
plasma polymer films
thin films
radical chemistry

References:
[1] D. Hegemann et al. Plasma Process Polym. 19:e2100246 (2022).
[2] P. Navascués et al., Under review in *Small* (2025).

Acknowledgements: We acknowledge funding by the Swiss National Science Foundation (SNSF, COST 2022, grant number 213368), by the European Union's Horizon-Europe Framework Programme (EU-NOVA project, grant number 101058554), and by the Swiss State Secretariat for Education, Research and Innovation (SERI) and the UK Research and Innovation (UKRI) (grant numbers 10042534 and 10055606),

Plasma-enable nanomaterials and thin films for Drop-TENGs

Fernando Núñez-Gálvez[1,2], Xabier García-Casas[2], Jorge Budagosky[1,2], Vanda Godinho[2], Juan Ramón Sánchez-Valencia[2], Ángel Barranco[1], Carmen Lopez-Santos[1,2]and Ana Borras[2]

[1]*Departamento de Física Aplicada I, Escuela Politécnica Superior, Universidad de Sevilla*

[2]*Nanotechnology on Surfaces and Plasma Lab, Institute of Materials Science of Seville (CSIC-US)*

*fngalvez@us.es *fernando.ngalvez@icmse.csic.es

The harvesting of renewable energy has become an important topic in the last few decades in the context of growing energy demands. [1] Water-droplet triboelectric nanogenerators (WD-TENGs) are promising candidates to harness the kinetic energy of raindrop impact as the emerging drop energy harvesting methodology. Solid-liquid contact electrification produces a charge transfer process which generates an output signal that can be harvested. [2] This mechanism is improved with a nanostructured device with high surface area in comparison with a thin film reference. For that purpose, the design of the multilayer systems as well as the triboelectric surface material are the main keys to optimize the conversion efficiency. PDMS, a hydrophobic transparent elastomeric silicone-based polymer is one of the most used triboelectric layers. This work proposes the use of three-dimensional surface nanostructuration of TiO_2 nanotubes and nanotrees produced by soft-template method [3] assisted by vacuum and plasma techniques (PECVD, Plasma Enhanced Chemical Vapor Deposition) as porous and flexible hierarchical scaffold embedded in the triboelectric layer. The D-TENG architecture was inspired by the top-bottom asymmetric electrodes proposed by Z. Wang et al in reference [4]. This nanostructured system preserves the transparency and pursues to promote a more stable, robust and durable drop energy harvester under continuous raindrop actions or water flows in addition of a higher surface area and changes in permittivity. The final device shows a highly transparency (reaching up to the 80% in visible region) making it compatible with solar and photovoltaic technology. Scaffold is embedded in a 10µm PDMS matrix serving as triboelectric layer by spin-coating method generating up to 100V open circuit voltage and up to 5,1% of efficiency in comparison with the kinetic energy of a raindrop. For instance, polymers such as PDMS show a loss of efficiency and malfunction after exposure to ultraviolet light and other atmospheric phenomena. A step forward was achieved by replacing these polymers with Teflon-like plasma polymers (CFx) with high triboelectric capacity and conformal coating. These can be combined with third-generation solar cells, such as those based on halide perovskite, to create hybrid solar-rain panels that capture residual energy regardless of weather conditions.

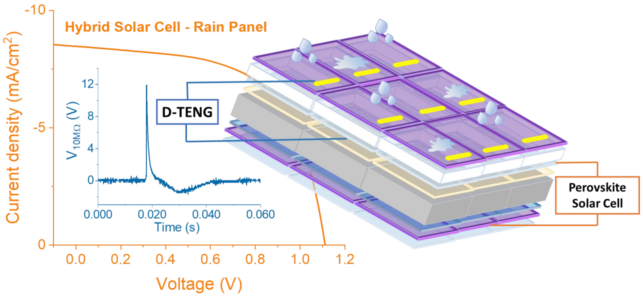

Fig. 1. Hybrid solar panel overview.

Keywords: WD-TENG, PDMS, PECVD, rain panel, CFx.

References:

[1] Q. Shi *et al.*, «Triboelectric single-electrode-output control interface using patterned grid electrode», *Nano Energy*, vol. 60, pp. 545-556, jun. 2019, doi: 10.1016/j.nanoen.2019.03.090.

[2] Z.-H. Lin, G. Cheng, L. Lin, S. Lee, y Z. L. Wang, «Water-Solid Surface Contact Electrification and its Use for Harvesting Liquid-Wave Energy», *Angew. Chem. Int. Ed.*, vol. 52, n.o 48, pp. 12545-12549, nov. 2013, doi: 10.1002/anie.201307249.

[3] X. García-Casas *et al.*, «Plasma engineering of microstructured piezo – Triboelectric hybrid nanogenerators for wide bandwidth vibration energy harvesting», *Nano Energy*, vol. 91, p. 106673, ene. 2022, doi: 10.1016/j.nanoen.2021.106673.

[4] W. Xu *et al.*, «A droplet-based electricity generator with high instantaneous power density», *Nature*, vol. 578, n.o 7795, Art. n.o 7795, feb. 2020, doi: 10.1038/s41586-020-1985-6.

Acknowledgements:

We thank the projects PID2022-143120OB-I00, TED2021-130916B-I00 and PCI2024-153451 funded by MCIN/AEI/10.13039/501100011033 and by “ERDF(FEDER) A way of making Europe, Fondos NextgenerationEU and Plan de Recuperación, Transformación y Resiliencia”, by the “EuropeanUnion", roject ANGSTROM was selected in the Joint Transnational Call 2023 of M-ERA.NET 3, which is an EU-funded network of about 49 funding organisations (Horizon 2020 grant agreement No 958174). the EUH2020 program under grant agreement 3Dscavengers Starting Grant 851929. FNG and CLS thanks to the “VII Plan Propio de Investigación y Transferencia” of the Universidad de Sevilla.

Operando correlative microscopy for advanced magnetic nanostructures

Sandra Ruiz Gómez[1*], **Claudia Fernandez-Gonzalez**[1], **Ana Arché-Núñez**[1], **Andrea Sorrentino**[1], **M. Waqas Khaliq**[1], **Michael Foerster**[1], **Miguel Angel Niño**[1], **Núria Bagués**[1] **and Lucía Aballe**[1]

[1] ALBA Synchrotron Light Source, CELLS, Cerdanyola del Vallès, 08290, Barcelona, Spain

**sruiz@cells.es*

The characterization of magnetic textures at the nanoscale, along with their dynamic properties [1,2,3], has become increasingly reliant on polarized soft X-rays due to their unique capability to provide element-resolved magnetic domain maps and tomograms with spatial resolution down to a few 10 nm.

A comprehensive understanding of the dynamic behaviour of magnetization in nanostructures often requires complementary techniques, such as transmission electron microscopy (TEM), to correlate magnetic properties with crystallographic and chemical structures. To address this, operando-compatible sample environments and advanced data analysis are essential for true multi-modal and multi-length-scale characterization of magnetic materials. While (S)TEM techniques offer unparalleled spatial resolution and a diverse range of contrast mechanisms, X-ray-based methods provide highly specific chemical, electronic, magnetic and orbital information with high efficiency. This allows the study of larger fields of view, thicker samples, and faster dynamic processes.

In this presentation, I will show how a correlative approach that combines X-ray microscopies, transmission electron microscopy, and scanning probe microscopy enables the full characterization of the morphology, chemical composition, crystal structure, and three-dimensional (3D) magnetic configuration of nanostructures [4,5]. Our approach demonstrates that integrating multiple imaging techniques is key to understand the coupling among different properties in complex nanostructures.

Keywords: *Correlative imaging, 3D magnetism, Nanostructures, X-ray microscopy*

References:

1. Gianluca Gubbiotti et al 2025 J. Phys.: Condens. Matter 37 143502
2. D V Christensen et al 2024 J. Phys. Mater. 7 032501
3. M. W. Khaliq et al. Ultramicroscopy 250 (2023) 113757
4. S. Ruiz -Gomez et al. Nanoscale 12 (2020) 17880
5. S. Ruiz- Gomez et al. arXiv: 2404.06042. (2024)

Glancing Angle Deposition of halide perovskites

Javier Castillo-Seoane[1], Juan Delgado-Alvarez[1], Lidia Contreras-Bernal[1,2], Jose M. Obrero-Perez[1], Xabier García-Casas[1], Francisco J. Aparicio[1], T. Cristina Rojas[1], Ana Borrás[1], Ángel Barranco[1],* Juan Ramon Sanchez-Valencia[1]*

1 Institute of Materials Science of Seville (Spanish National Research Council, CSIC), Seville (Spain)
2 Dpto. Ingeniería y Ciencia de los Materiales y del Transporte. University of Seville Seville (Spain)

Polarisers are ubiquitous components in modern optoelectronic devices, including displays and photographic cameras. However, achieving efficient control of light polarisation remains an unsolved challenge. The main drawback of the existing display technologies lies in the substantial optical losses due to the use of polarisers for generating polarised light. In this context, halide perovskite (HP) nanostructures offer a promising solution owing to their tunable optical properties, including adjustable bandgap, photoluminescence, and efficient light emission with minimal non-radiative recombination.[1–3] Their outstanding electrical properties have elevated hybrid perovskites as the material of choice in photovoltaics and optoelectronics. Among the different HP nanostructures, nanowires and nanorods have lately arisen as key players in controlling light polarisation for lighting or detector applications.

In this work,[4] we propose applying an evolved version of the vacuum technique, Glancing Angle Deposition (GLAD), as an advanced alternative to synthesising anisotropic-supported OMHP nanostructures. Our approach is a two-step fabrication procedure consisting of the room temperature deposition of PbI_2 at glancing angles, followed by deposition of CH_3NH_3I at normal incidence (0º). As a result, highly anisotropic perovskite nanostructures resembling "nanowalls" have been fabricated. Such alignment degree endows the samples with anisotropic optical properties such as UV-visible absorption and photoluminescence. Moreover, their implementation in n-i-p solar cells can be used to develop self-powered polarisation-sensitive photodetectors along the visible range. Thus, the use of Glancing Angle Deposition yields HP nanostructures with high anisotropy, controlled microstructure, and thickness, demonstrating potential for scalable, large-area fabrication. This technique is fully compatible with microelectronic and optoelectronic processing methods, including CMOS and roll-to-roll technologies, which opens the path towards developing tunable anisotropic optoelectronic devices based on halide perovskites.

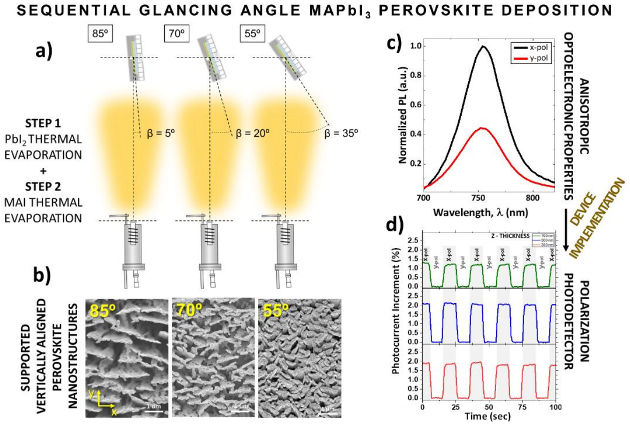

Fig. 1. a) Glancing Angle Deposition of PbI_2 at different deposition angles (step 1). The transformation to perovskite is achieved by MAI sublimation onto the PbI_2 nanostructures (step 2). b) Top-view SEM images of GLAD perovskite films deposited at different angles. Photoluminescence emission polarised spectra along the x- and y-polarisation exciting with unpolarized light at 600 nm. Photocurrent increment response recorded by changing between x- (higher photocurrents) and y-polarisation (lower photocurrent) every 10 seconds for devices implementing MAPI NWs of 350 (red), 500 (blue) and 700 nm (green) thickness

Keywords: *organometal-halide perovskites, Glancing Angle Deposition (GLAD), anisotropic nanostructures, photoluminescence polarisation, self-powered polarisation photodetector*

References:

1. Wang, H.-P. *et al.* Low-Dimensional Metal Halide Perovskite Photodetectors. *Advanced Materials* **33**, 2003309 (2021).
2. Zhang, C. *et al.* Metal Halide Perovskite Nanorods: Shape Matters. *Advanced Materials* **32**, 2002736 (2020).
3. Zhang, D. *et al.* Metal Halide Perovskite Nanowires: Synthesis, Integration, Properties, and Applications in Optoelectronics. *Advanced Energy Materials* **13**, 2201735 (2023).
4. Castillo-Seoane, J. *et al.* Highly Anisotropic Organometal Halide Perovskite Nanowalls Grown by Glancing-Angle Deposition. *Advanced Materials* **34**, 2107739 (2022).

Acknowledgements:

Projects PID2022-143120OB-I00, TED2021-130916B-I00, and PCI2024-153451 funded by MCIN/AEI/10.13039/501100011033 and by "ERDF (FEDER), A way of making Europe", Fondos NextgenerationEU and "Plan de Recuperación, Transformación y Resiliencia". Project ANGSTROM was selected in the Joint Transnational Call 2023 of M-ERA.NET 3, which is an EU-funded network of about 49 funding organisations (Horizon 2020 grant agreement No 958174).
The project leading to this article has received funding from the EU H2020 program under grant agreement 851929 (ERC Starting Grant 3DScavengers).

Improved continuous feeding evaporator system for gasification of polymers for use in a gas aggregation source

Pavel Solař[1], Kateřina Škorvánková[1], Zdeněk Krtouš[1], Jaroslav Kousal[1]

[1]*Charles University, Faculty of Mathematics and Physics, Department of Macromolecular Physics*

Vacuum thermal degradation of polymers is a process in which polymeric materials undergo chemical breakdown when exposed to elevated temperatures in a vacuum environment. Unlike thermal degradation in atmospheric conditions, vacuum conditions significantly alter the degradation pathways by minimizing oxidative reactions and enhancing the removal of volatile degradation products [1].

This method was investigated for several decades [2],[3] but similarly to evaporation of metals the process was principally a batch method. Although sufficient for some types of processes, batch method is cumbersome to prepare and to conduct. Also, unlike metals, organic compounds tend to degrade at high temperatures over time and therefore the material at the beginning of the evaporation is different to the material at the end. To solve both problems, we have sought to make it a continuous process. Using the technology of now rapidly developing 3D printers we are continuously feeding the polymeric filament into the evaporator [4]. Therefore, there is always only a small amount of precursor to be evaporated and the rest is not heated and does not degrade.

This is especially important when we want to use the evaporator in a gas aggregation source, where stabilized amount of input material – chemically unchanged over time – is crucial for successful and stable formation of the nanoparticles.

Keywords: Gas aggregation nanoparticle source, Vacuum thermal degradation, Plasma polymer, Nanoparticles

References:
[1] C.L. Beyler et al., in SFPE Handb. Fire Prot. Eng. (2002), pp. 110–131.
[2] A. Choukourov et al., The Journal of Physical Chemistry B 113 (2009) 2984.
[3] A. Choukourov et al., Vacuum 80 (2006) 923.
[4] J. KOUSAL et al., in NANOCON Conf. Proc. - Int. Conf. Nanomater. (2022), pp. 261–266.

Acknowledgements: *This work was supported by the grant GACR 25-15644S from the Grant Agency of the Czech Republic.*

Effects on Early-Stage Noble Metal Growth on Polymer Substrates deposited by Magnetron Sputtering

Kristian A. Reck[1], Yusuf Bulut[2,3], Stefan Schröder[1,4], Ruoxuan Qi[3], Xiaojing Ci[3], Thomas Strunskus[1,5], Peter Müller-Buschbaum[3], Stephan V. Roth[2,6], Tayebeh Ameri[4,5], Alexander Vahl[1,5,7], and Franz Faupel[1,5]

[1] Chair for Multicomponent Materials, Department of Materials Science, Kiel University, Kaiserstr. 2, 24143 Kiel,Germany
[2] Deutsches Elektronen-Synchrotron DESY, Notkestr. 85, 22607 Hamburg, Germany
[3] Technical University of Munich, TUM School of Natural Sciences, Department of Physics, Chair for Functional Materials, James-Franck-Str. 1, 85748 Garching, Germany
[4] Chair for Composite Materials, Department of Materials Science, Kiel University, Kaiserstr. 2, 24143 Kiel, Germany
[5] Kiel Nano, Surface, and Interface Science, KiNSIS, Kiel University, Christian-Albrechts Platz 4, 24118 Kiel, Germany
[6] KTH Royal Institute of Technology, Department of Fibre and Polymer Technology, Teknikringen 56-58, 100 44 Stockholm, Sweden
[7] Leibniz Institute for Plasma Science and Technology, Felix-Hausdorff-Str. 2, 17489 Greifswald, Germany

The controlled deposition of ultra-thin metal films is critical for advancing applications in flexible electronics, sensors, and optoelectronic devices. In particular, noble metals such as silver (Ag), gold (Au), and copper (Cu) offer unique advantages due to their outstanding electrical conductivity, optical properties, and chemical stability. Therefore, the early-stage growth of Ag, Au, and Cu thin films on five different polymers—polystyrene (PS), poly(methyl methacrylate) (PMMA), polytetrafluoroethylene (PTFE), ethylene glycol dimethacrylate (EGDMA), and tetravinyltetramethylcyclotetrasiloxane (PV4D4)—using both direct current magnetron sputtering (DCMS) and high-power impulse magnetron sputtering (HiPIMS).

Scanning electron microscopy (SEM) and in-situ grazing-incidence small-angle X-ray scattering (GISAXS) are utilized to analyze morphological features such as island formation, cluster density, and surface coverage [1]. Electrical properties are evaluated via sheet resistance measurements. The results demonstrate that HiPIMS significantly improves surface coverage and reduces electrical resistance for Ag and Au films compared to DCMS, while exhibiting a higher density of clusters [2,3]. Among the substrates, PS promotes high surface coverage, whereas PTFE consistently yields the lowest, underscoring the influence of polymer surface energy on nucleation and growth dynamics.

By comparing deposition techniques and material combinations, it is revealed that film morphology and functional properties can be finely tuned through process parameters alone—without the need for additional layers or surface modifications.

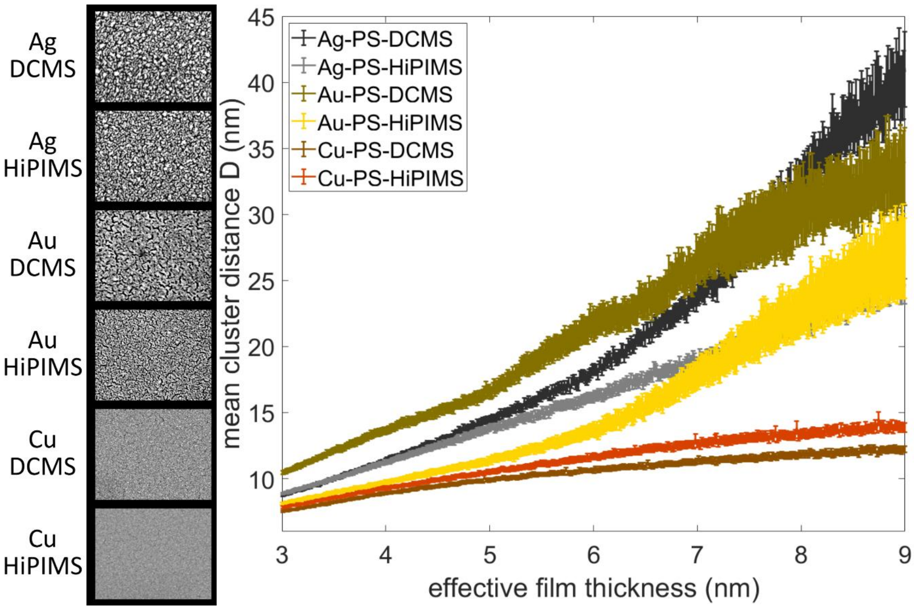

Fig. 1. SEM images of Ag, Au, and Cu deposited by DCMS and HiPIMS on PS with an effective film thickness of 8 nm and in-situ evolution of the mean cluster distance of respective depositions derived from GISAXS.

Keywords: early growth, HiPIMS, noble metals, polymer substrate, GISAXS

References:

1. Schwartzkopf, Matthias, et al. "Real-time monitoring of morphology and optical properties during sputter deposition for tailoring metal–polymer interfaces." ACS applied materials & interfaces 7.24 (2015): 13547-13556
2. Reck, Kristian A., et al. "Early-stage silver growth during sputter deposition on SiO2 and polystyrene–Comparison of biased DC magnetron sputtering, high-power impulse magnetron sputtering (HiPIMS) and bipolar HiPIMS." Applied Surface Science (2024): 160392.
3. Bulut, Yusuf, et al. "Investigating Gold Deposition with High-Power Impulse Magnetron Sputtering and Direct-Current Magnetron Sputtering on Polystyrene, Poly-4-vinylpyridine, and Polystyrene Sulfonic Acid." Langmuir 40.43 (2024): 22591-22601.

Non-exchange bias in binary soft-hard nanoparticle composites

R. López Martin[1], P. Maltoni[2], P. S. Normile[1], M. Vasilakaki[3], S. S. Lee[4], K. N. Trohidou[3], B. Santos Burgos[1], D. Peddis[5], R. Mathieu[2], J. Nogués[6], J. A. De Toro[1]

[1]Universidad de Castilla-La Mancha, 13071 Ciudad Real, Spain; [2]Uppsala University, 751 03 Uppsala, Sweden; [3]NCSR "Demokritos", 153 10 Agia Paraskevi, Attiki, Greece; [4] The Nanos, 138669 Singapore, Singapore; [5]Università di Genova, 1-16146 Genova, Italy; Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC, Barcelona, Spain

Exchange bias has been extensively studied both in exchange-coupled thin films [1] and both single-phase [2] and multiphase nanoparticle systems. However, the role of non-exchange mechanisms in the overall hysteresis loop bias are far from being understood. Here, dense soft-hard binary nanoparticle composites are used as a novel tool not only to unravel the effect of dipolar interactions on the hysteresis loop shift, but as a new strategy to enhance the bias of any magnet exhibiting an asymmetric magnetization reversal. Densely-packed uniform mixtures of equally sized, 6.8 nm, soft maghemite nanoparticles (no bias – symmetric reversal) and hard cobalt-doped maghemite nanoparticles (large exchange bias – asymmetric reversal) exhibit a hummingbird-like loop, typical of weakly coupled systems [3], due to the very different magnetic anisotropy of the constituent nanoparticles. For certain fractions of soft particles, the loop shift of the composite can be significantly larger than the exchange-bias field of the hard particles in the mixture. Simple calculations indicate how this emerging phenomenon is mainly driven by the asymmetric reversal of the hard loop and how it can be further enhanced by optimizing the parameters of the hard particles (coercivity and loop asymmetry) [4].

In addition, the existence of a dipolar-induced loop shift ("dipolar bias") is demonstrated both experimentally and theoretically, where, for example, a bias is induced in the initially unbiased soft nanoparticles due to the dipolar interaction with the exchange-biased hard nanoparticles. These results open novel approaches to tune loop shifts in magnetic hybrid systems beyond interface exchange coupling.

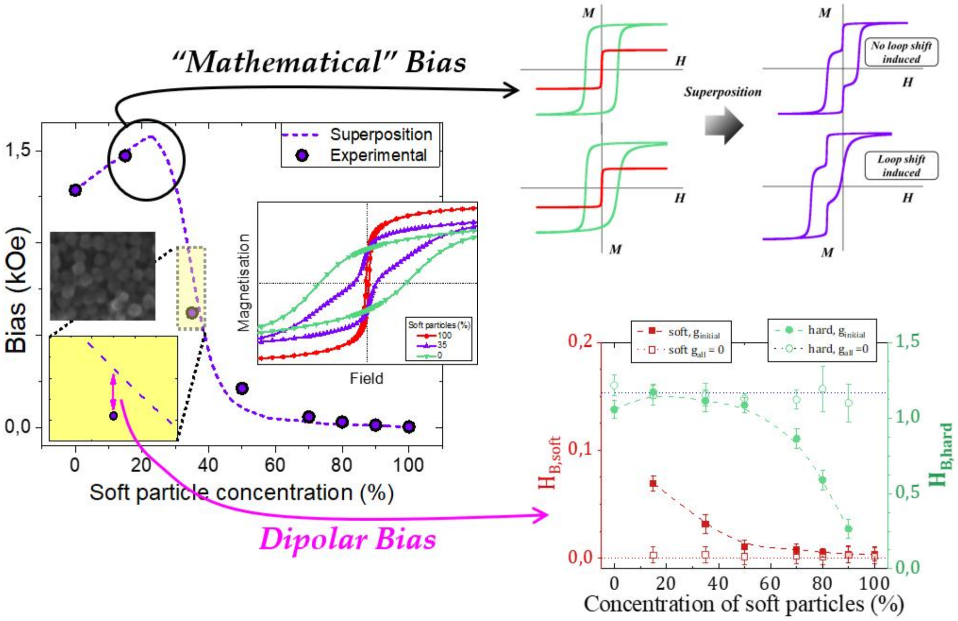

Fig. 1. Left: bias field of the binary compacts (such as the example in the inserted TEM picture) and those obtained in superpositions of the soft and hard components. The main inset shows the hysteresis loops measured for the soft and hard particles (labelled as 100 and 0%, respectively), and the 35% soft binary compact. Top right: schematic explanation of bias generation by simply adding soft and asymmetric hard loops. Bottom right: Monte Carlo simulations showing the "dipolar transference" of bias from hard to soft particle in dense assemblies, which causes the discrepancy highlighted in the yellow insert of the left panel.

Keywords: magnetic nanoparticles, composites, exchange bias.

References:

[1] J. Nogués et al., *Phys. Rep.*, **2005**, *422*, 65–117.
[2] B. Muzzi et al., *Small Methods,* **2023,** 2300647.
[3] E. H. Sánchez et al., *Chem. Mater.*, **2020**, *32*, 969-981.
[4] P. Maltoni et al., *Adv. Comp. & Hyb. Mater.*, **2024**, *7*, 182.

Acknowledgements: *Funding from the Agencia Estatal de Investigación (grant PID2022–142267NB-I00) and from the Junta de Castilla-La Mancha (grant SBPLY/21/180501/000226).*

High-Resolution Plasma Printing at Atmospheric-Pressure for Microfluidics, Microfabrication and Emerging Electronics

Laura-Barillas-Mora[1], David Rettke[1], Monique Levien[1], Adrian Lopez Vasquez[1], Nadia Mora-Barrantes[1], Jens Zöllner-Krumme[1], Alexander Vahl[1,2]

1 Leibniz Institute for Plasma Science and Technology, Greifswald, Germany
2 Department for Materials Science – Chair for Multicomponent Materials & Composite Materials, Kiel University, Kiel, Germany

Plasma technology applying low temperature plasmas, both at low pressure and atmospheric conditions, offers a wide range of approaches for material synthesis and surface modification. Plasma printing using locally confined atmospheric pressure plasmas gained considerable interest in the last decade(s) due to its capability of local surface treatment and rapid prototyping, opening up particular application potential in microfluidics, biosensing, microfabrication and emerging electronics. To date, common plasma printing approaches face challenges to reduce the lateral extension of the processing area, to expand the range of processable materials (polymers, metals, composites) and the range of attainable surface modifications (activation, deposition, sintering, etching) using a single type of plasma source.

This contribution presents the recent developments on plasma printing sources and showcases use cases of Surface Atmospheric Pressure Plasma Printing (SurfAP3®) technology at INP. Employing different atmospheric-pressure plasma jet-based (APPJ) devices and in particular, MicroPulsar, a state-of-the-art microplasma source, spatially confined surface treatments with line widths as small as 35 µm can be realized. The high reactivity obtained with MicroPulsar, allows for plasma polymerization of both liquid- and gas-phase precursors on a broad range of substrates and enables processing of microscopic features sizes at fast processing speeds [1,2]. It will be showcased how unlike other microplasma sources, it is possible to treat conductive and non-conductive substrates and samples, including liquids, as no counter or ground electrode is needed to generate the plasma discharge. In general, INP's APPJs also permit the synthesis of hydrogels [3] and NP-based composites, such as plasma polymer thin films with embedded gold nanoparticles or MXenes.

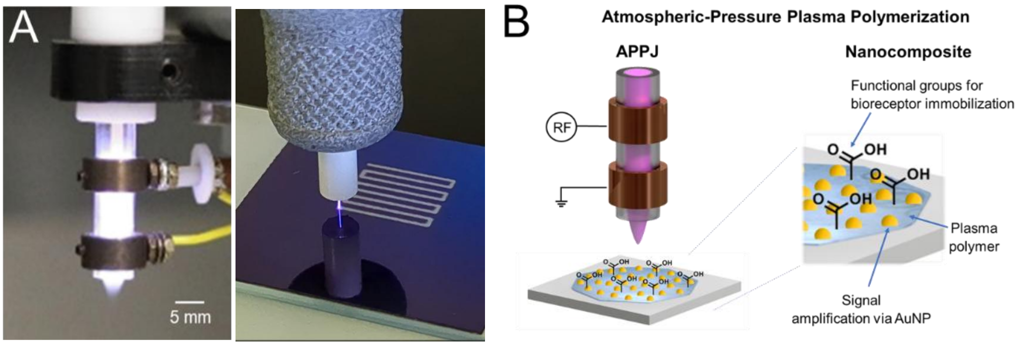

Fig. 1. (A) Atmospheric pressure plasma sources such as atmospheric pressure plasma jet (left, APPJ) and MicroPulsar (right), enable local surface modification and the preparation of a plasma-polymer Au NP nanocomposites (B)

Keywords: *Microfluidics, Microfabrication, Plasmapolymerization, Maskless Patterning, Nanocomposites*

References:

1. L. Barillas et al., Plasma printing - direct local patterning with functional polymer coatings for biosensing and microfluidics applications. *Microelectronic Engineering* **233**, 111431 (2020).
2. L. Barillas, SurfAP3®: A flexible plasma printing technology for micrometric surface treatment in biomedical applications and microfabrication. *Science Talks* **9**, 100315 (2024).
3. M. Levien et al., Direct grafting of microwrinkled hydrogels by atmospheric-pressure plasma polymerization: Going simple and environmentally friendly. *European Polymer Journal* **198**, 112413 (2023).

Acknowledgements:

The work was in parts supported via Federal Ministry of Education and Research (BMBF) – Project Mikro-APPS – 03DPS1272.

POSTER SECTION

Low temperature production of VO2 Crystalline Domains in thin films for thermochromic applications by magnetron sputtering at oblique geometries

H. Acosta-Rivera[1], F.J. Ferrer[2], R. Alvarez[1,3], T.C. Rojas[1], V. Rico[1], N. Martin[4], A.R. Gonzalez-Elipe[1], A. Palmero[1*]

1 Instituto de Ciencia de Materiales de Sevilla (CSIC-Universidad de Sevilla). Américo Vespucio 49, E-41092 Seville, Spain
2 Centro Nacional de Acelerador, CSIC-Universidad de Sevilla, Seville, Spain
3 Departamento de FAMN, Universidad de Sevilla, Aptdo 1065, E-41012, Spain
4 SUPMICROTECH, CNRS, Institut FEMTO-ST, F-25000 Besançon Cedex, France

An innovative low-temperature processing method has been developed to synthesize monoclinic VO_2 thin films with thermochromic properties [1-2]. It is based on the growth of highly porous and amorphous nanocolumnar VOx thin films by the magnetron sputtering technique at oblique angles, followed by subsequent oxidation at temperatures below 300 °C. The incorporation of oxygen into the film throughout the whole pore structure causes an important structural shift defined by i) an increase of volume and the progressive occlusion of the pores and ii) the formation of VO_2 crystalline domains in its monoclinic form in the material along with the V_2O_5 and V_3O_7 crystalline phases. It is demonstrated that these structural changes are hastructure, as well as the particular oxidation temperature. The metal-insulator transition has been characterized by analysing the optical and electrical properties of these films at temperatures around the transition value, revealing the high efficiency of the proposed methodology to produce crystalline VO_2 in comparison with other approaches that requires temperatures well above 500ºC (see Figure 1).

Keywords: Thermochromic thin films, Porous thin films, Magnetron sputtering, Oblique angle deposition, Nanocolumns.

References:

[1] Alcaide AM, Regodon G, Ferrer FJ, Rico V, Alvarez R, Rojas TC, González-Elipe AR, Palmero A. Low temperature nucleation of thermochromic VO_2 crystal domains in nanocolumnar porous thin films. Nanotechnology 34
2023) 255702 Nanoworkshop et al., *Nanoworkshop Materials* **2** (2025).
[2] Acosta-Rivera H, , Ferrer FJ, Alvarez R, Rojas TC, Rico V, Martin N, González-Elipe AR, Palmero A. Low Temperature Crystallization of VO_2 Crystalline Domains in Porous Nanocolumnar V-O Thin Films for Thermochromic Applications. Submitted for publication.

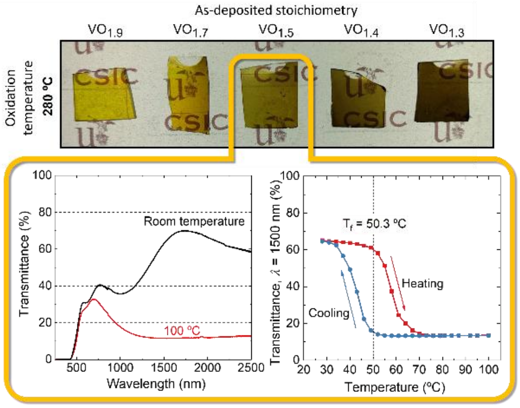

Figure 1. Image of a set of nanocolumnar films with different as-deposited O/V ratios after undergoing an oxidation process at a temperature of 280ºC (top). Optical transmittance spectra of the central film at room temperature and 100ºC (left). Hysteresis loop corresponding to the changes in transmittance measured at a wavelength of 1500 nm as a function of temperature after a single heating/cooling cycle from 25ºC to 100ºC and back.

Acknowledgements: The authors acknowledge the projects PID2020-112620GB-I00 and PID2021- 123879OB-C21 funded by MCIN/AEI/10.13039/501100011033, and the intramural project 202560E034 funded by the Spanish Council of Research. We thank the projects 494 PID2022-143120OB-I00, TED2021-130916B-I00 funded by MCIN/AEI/10.13039/501100011033/FEDER, UE and by “ERDF (FEDER) A way of making Europe”. We thank the financial support from the CSIC Interdisciplinar Thematic Platforms (PTI +) “Sustainable Plastics towards a Circular Economy” (PTI-Susplast +) and “Transición Energética Sostenible” (PTI-TRANSENER+) SOUNDofICE H2020-FETOPEN-2018-2019- 2020-01 call GA nº: 899352.

Development of 3D Printable Lead-Free Polymer Composites with Nanosized Fillers for Radiation Shielding

<u>Shirin Arslonova</u>[1], **Diana Adliene**[1]

[1]*Kaunas University of Technology, Studentu g. 50, Kaunas, Lithuania*

The growing demand for lightweight, lead-free radiation shielding has led to the development of polymer composites reinforced with high-Z nanoparticles [1]. This study focuses on polymer composites that demonstrate efficient photon attenuation while maintaining extrudability and 3D printability, allowing reliable fabrication of customized shielding components. Composites were prepared by reinforcing Acrylonitrile Butadiene Styrene (ABS) with various nanosized metal and metal oxide (M/MO) fillers, including tungsten (W), tungsten carbide (WC), tungsten boride (WB), bismuth (Bi), and bismuth oxide (Bi_2O_3). Filaments were extruded using a 3DEVO Filament Precision 350 extruder (3devo B.V., Netherlands), and test samples were printed with an M300 3D printer (Zortrax S.A., Poland), ensuring precise geometrical control using additive manufacturing technology. Photon attenuation was evaluated irradiating samples with 120 keV photons in a GULMAY D3225 X-ray therapy machine (Gulmay Ltd., UK), and using a Piranha MULTI X-ray meter (RTI Electronics AB, Sweden).
The experimental results (Fig.1) revealed a significant improvement in photon attenuation in composites reinforced with M/MO nanoparticles as compared with pure polymer.

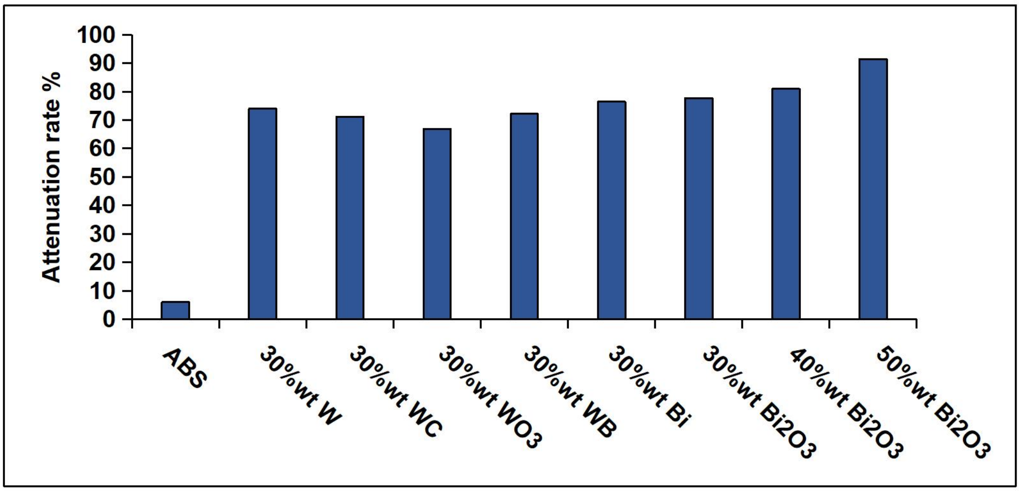

Figure 1. Photon attenuation of ABS composites reinforced with different M/MO nanosized fillers

Among the tested fillers, polymers with bismuth oxide (Bi_2O_3) showed the highest shielding performance, with up to 91.2% attenuation at 50 wt% of fillers concentration, but it posed noticeable challenges during extrusion and 3D printing of samples due to poor flowability. In contrast, composites with 30–40 wt% Bi_2O_3 maintained attenuation rates between ~61% and 81% while offering better printability. Fillers such as tungsten oxide (WO_3) and tungsten boride (WB) provided a favorable balance between attenuation and processability, making them suitable for additive manufacturing. These findings demonstrate the potential of nanoparticle-reinforced, lead-free polymer composites as efficient and customizable materials for radiation shielding applications.

Keywords: radiation shielding, Nanoparticle-reinforced composites, 3D printing.

References:

1. M. Elsafi, M. A. El-Nahal, M. I. Sayyed, I. H. Saleh, and M. I. Abbas, *“Novel 3-D printed radiation shielding materials embedded with bulk and nanoparticles of bismuth,”* *Scientific Reports*, vol. 12, Art. no. 12467, (2022).

DCM-based Organic Nanometric Thin Films with Tailored Dielectric Properties by Remote Plasma Assisted Vacuum Deposition

Triana Czermak Álvarez[1], Juan Ramón Sánchez Valencia[1], Ana Borrás[1], Carmen López Santos[1, 2], Francisco J. Aparicio[1], Ángel Barranco[1]

Correspondence to fjaparicio@icmse.csic.es and angel.barranco@csic.es

1 Nanotechnology on Surfaces and Plasma Lab, Institute of Materials Science of Seville, c/ Américo Vespucio 49, 41092, Seville, Spain
2 Department of Applied Physics I, Escuela Politécnica Superior, University of Seville, c/ Virgen de África 7, 41011, Seville, Spain

Organic dielectric materials with both high permittivity and dielectric strength, are highly desirable for their implementation as gate dielectrics into flexible organic field-effect transistors (OFETs). Achieving optimal performance requires precise control over dielectric properties, including relative permittivity and dielectric strength, as well as morphological characteristics such as surface topography and thickness

Plasma deposition and treatment methods are well-established techniques in different industrial sectors, including mass-scale manufacturing in microelectronics and large-area roll-to-roll processing of flexible and wearable materials. Amongst other advantages, the plasma synthesis of organic coatings, known as plasma polymerization, is a consolidated method for growing compact, uniform, and pinhole-free coatings. These coatings typically exhibit a smooth and ultra-flat topography (surface roughness at the nanometric scale) and offer precise control over the coating thickness (ranging from a few nanometres to the micrometre). This communication shows the fabrication of high-k organic thin films for gate dielectric applications using a remote plasma-assisted vacuum deposition (RPAVD) technique.[1] This method relies on the vacuum sublimation of functional molecules within the afterglow region of a remote plasma discharge, providing precise control over the fragmentation and poly-recombination processes involved in plasma polymerization processes. Advancements in this technique have enabled the synthesis of plasma-polymer-like thin films that maintain, at some extend, the molecular structure and integrity of complex precursor molecules, benefiting applications such as photonics[2], sensing[3], lasing[4], antimicrobial surfaces[5], conformal protective coatings[6], and strain engineering of 2D semiconductors[7]. Furthermore, it is a room-temperature and solvent-free procedure compatible with a wide range of flexible and delicate substrates (paper, textiles, and others)[2], and the conformal growth over complex nanoarchitectures. In this work, the development of organic coatings with tailored permittivity is addressed by using a high dipole moment dye (DCM (4-(dicyano-methylene)-2-methyl-6-(4-dimethylamin-styryl)-4H-pyran) a polymerization precursor. As a result, ultra-flat (RMS roughness < 1 nm) organic thin films (thickness down to few nm) with controlled relative permittivity (ε_r = 3.5 to ca. 7.5) are synthesized. Furthermore, dielectric breakdown results confirm the high dielectric strength with breakdown fields of up to 5 MV/cm. The influence of integer dye molecules on the optical properties, specifically the refractive index of the films, was examined and correlated with the observed evolution in permittivity.

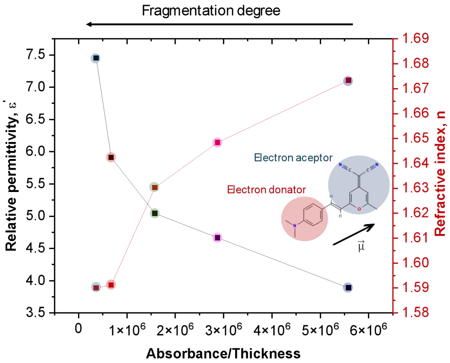

Fig. 1. Variation in relative permittivity and refractive index vs the thickness normalized absorbance.

Keywords: *RPAVD, high-k organic dielectrics, OFET, flexible electronics.*

References:

1. A. Barranco et al., Langmuir 22 (2006), 6719.
2. F.J. Aparicio, et al., Adv. Mater. 23 (2011) 761.
3. F.J. Aparicio et al., Sens, Actuators, B: Chem. 228 (2016), 649.
4. M. Alcaire et al., ACS Appl. Mater. Interfaces 3 (2017), 8948.
5. A. Mora-Boza et al. Front. Chem. Science and Engineering 13 (2019), 330.
6. M. Alcaire et al., Adv. Funct. Mater. 29 (2019), 1903535.
7. F. Carrascoso et al., npj 2D Mater. Appl. 7 (2023).

Acknowledgements: EU-H2020 program under agreements 851929 (ERC Starting Grant 3DScavengers) and 899352 (FETOPEN-01-2018-2019-2020 – SOUNDofICE).
AEI-MICINN (PID2022-143120OB-I00, TED2021-130916B-I00 and PCI2024-153451) funded by MCIN/AEI/10.13039/501100011033 and by "ERDF (FEDER)" A way of making Europe, Fondos NextgenerationEU and Plan de Recuperación, Transformación y Resiliencia.

Enhanced acoustic de-icing through thin film technology: exploring the link between acoustic waves and surface properties for energy-efficient ice protection.

Jaime del Moral[1], Stefan Jacob[2,3], Laura Montes[1], Victor Rico[1], Juan R. Sanchez-Valencia [1], Carmen López-Santos[1], Agustín R. González-Elipe[1], Ana Borrás[1]

1Nanotechnology on Surfaces and Plasma, Instituto de Ciencia Materiales de Sevilla (ICMSE), Sevilla, Spain
2 SAWLab Saxony, Leibniz IFW Dresden, Dresden, Germany
3Junior Research Group Infrasound, Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany

Ice accretion on materials relevant to industrial applications impacts our daily lives and poses critical challenges in transportation, renewable energy, and telecommunications. Conventional methods that rely on the Joule effect are insufficient, primarily due to significant losses associated with heat scattering. Recently, using bulk and surface acoustic waves (AWs) has emerged as one of the most promising solutions to these problems. This approach also benefits from synergies with advanced passive anti-icing and multifunctional surfaces. Acoustic waves serve as energy carriers, directing power precisely to where it is needed—specifically, at the ice particles and the ice-substrate interface. These waves can travel along targeted surfaces and dissipate energy only when they encounter ice interfaces. While these phenomena have been described in terms of acoustic wave modes following a phenomenological approach[1-3], there is still a lack of exploration about the influence of the surface properties on the acoustic de-icing mechanisms. Previous research has demonstrated the potential to combine standing acoustic waves with thin film technology to reduce energy consumption. In this study, we aim to further investigate this concept by providing a detailed fundamental description of the de-icing process using standing thickness shear mode acoustic waves (TSM-AW) and the role of these thin films in it. Depending on the wettability properties of the films, the ice interface can be modified to weaken its adherence to the surface. Additionally, these films can promote interfacial cracking, significantly reducing the power required for deicing while their mechanical properties allow for efficient transmission of acoustic waves from the substrate to the ice with minimal losses. The generation of TSM-AW is performed on a chip made of LiNbO3 128ºY-X cut crystal plate of 0.5 mm thickness, which is activated by two planar electrodes in a lateral field excitation (LFE) arrangement, generating ultrasonic waves at a frequency of 3.5 MHz. These crystals have been coated by three different surface modification approaches: diamond-like coating (DLC), ZnO nanowires, and fluorinated polymers (CFx). The DLC and CFx films were deposited using Plasma Enhanced Chemical Vapor Deposition (PECVD). The ZnO nanowires were formed through a soft-template method that involved the growth of supported Organic Nanowires (ONWs) followed by the conformal deposition of ZnO polycrystalline shells via PECVD. While the DLC and CFx coatings have partially hydrophobic and hydrophilic surfaces, the ZnO nanowires can be UV-activated, allowing them to transition from a superhydrophobic state to a superhydrophilic state. These coatings play a twofold role: they reduce the interaction between ice and the substrate while also protecting the piezoelectric substrate.

The acoustic and wetting characteristics of the LiNbO3 film devices were assessed using a vector network analyzer (VNA) and water contact angle measurements, respectively. Subsequently, a thorough experimental analysis was conducted on these devices with various types of ice inside a cold chamber. Initial results from in-situ observations of the de-icing mechanism in an Environmental Scanning Electron Microscope (ESEM) are included to examine the interaction between the coatings and the ice at a microscopic level. This study is complemented by simulations using finite element modeling (FEM) to clarify how acoustic waves are transmitted through both the crystal and the thin film, and how they dissipate into the ice particles.

Keywords: *de-icing, acoustic waves, plasma nanostructures, DLC,* CF_x

References:

[1] S. Jacob et al., “Surface Acoustic Waves Equip Materials with Active De-Icing Functionality: Unravelled Glaze Ice De-Icing Mechanisms and Application to Centimeter-Scale Transparent Surfaces,” Adv Mater Technol, vol. 8, no. 16, Aug. 2023, doi: 10.1002/admt.202300263.

[2] S. Pandey et al., “Mechanisms of De-icing by Surface Rayleigh and Plate Lamb Acoustic Waves,” Adv Eng Mater, no. 3401820, Dec. 2024, doi: 10.1002/adem.202401820.

[3] A. Karimzadeh et al., “Harnessing a Vibroacoustic Mode for Enabling Smart Functions on Surface Acoustic Wave Devices - Application to Icing Monitoring and Deicing,” Adv Mater Technol, vol. 9, no. 8, Apr. 2024, doi: 10.1002/admt.202301749.

[4] J. Moral et al., “A holistic solution to icing by acoustic waves: de-icing , active anti- icing , and sensing with piezoelectric crystals,” pp. 1–20. doi: 10.1002/adfm.202209421

Acknowledgements:
The authors are grateful for funding from the European Commission through the SOUND of ICE project (H2020-FETOPEN-2018-2019-2020-01)

Atomic Layer Deposition of ZnO on Fullerene Powder: A Comparative Study of Thermal and Plasma-Enhanced Processes for a Photoactive Nanocomposite

Regina Del Sole 1 , Antonella Milella 1,2 , Francesco Fracassi 1,2 , Paola Parlanti 3 , Mauro Gemmi 3 , Anna Maria Coclite 4,5 , Fabio Palumbo 2

1 Università degli Studi di Bari Aldo Moro, Dipartimento di Chimica, via Orabona 4, 70125, Bari (ITALY)
2 CNR-Istituto di Nanotecnologia, Unità di Bari, Consiglio Nazionale delle Ricerche, c/o Dipartimento di Chimica, Università degli Studi di Bari Aldo Moro, via Orabona 4, 70125, Bari (ITALY)
3 Center for Materials Interfaces, Electron Crystallography, Istituto Italiano di Tecnologia, Pontedera (ITALY)
4 Institute of Solid State Physics, NAWI Graz, Graz University of Technology, Petersgasse 16, 8010 Graz (AUSTRIA)
5 Università degli Studi di Bari Aldo Moro, Dipartimento di Fisica, via Orabona 4, 70125, Bari (ITALY)

Among n-type semiconductors, ZnO stands out for its low cost, environmental friendliness, and biocompatibility, as well as its remarkable photosensitivity, attributed to its wide band gap (3.37 eV), which enables strong absorption in the UV region. Nevertheless, its photocatalytic performance is hindered by the rapid recombination of photogenerated electron–hole pairs. To address this drawback, recent research has been increasingly focused on ZnO/carbon nanomaterial-based nanocomposites. Among the other carbon-based nanomaterials, fullerene (C_{60}) can serve as an effective co-catalyst within these systems, thanks to its high work function (4.70 eV), which facilitates the transfer of photoexcited electrons to its energy levels, thereby prolonging the lifetime of charge carriers.

In our work, Thermal Atomic Layer Deposition (t-ALD) and Plasma-Enhanced Atomic Layer Deposition (PE-ALD) are performed in a fixed bed reactor in order to accomplish a controlled and conformal deposition of ZnO on fullerene powder. The so obtained powders were thoroughly characterized from the chemical and morphological point of view, to underscore the influence of the applied technique on the characteristics of the resulting material.

Going into detail, XRD and XPS analyses prove the crystallinity and the stoichiometric growth of ZnO, respectively. SEM analysis reveals the conformality of the coating not only on the surface of the powder grains but even on the walls of the pores of the material. In the case of PE-ALD, ZnO is found only on the walls of the most superficial pores, while thermal ALD allows the successful coverage also of deeper ones. The photocatalytic activity of the ZnO/C 60 nanocomposites obtained at 400 cycles by thermal and PE-ALD has been assessed through monitoring the discoloration of a 10 -5 M methylene blue solution upon UV irradiation over 180 min. Results indicate that the photocatalytic performance of the thermal coated C 60 was higher than the one obtained by PE-ALD (54±12% vs 33±10 %, respectively), in accordance with the higher amount of ZnO retrieved on thermal ALD treated samples. However, the deposition of ZnO was not uniform on the whole batch of powder treated, thus leading to a high relative error on the MB degradation percentage.

Both fabrication strategies employed for obtaining these powder nanocomposites are straightforward and effective,representing a promising avenue for the development of high-performance, environmentally sustainable photoactive materials. Further enhancement of the deposition process—and consequently of the materials' photocatalyticperformance—could be achieved through the optimized design of a reactor specifically tailored for powder-based systems, which would be object of future studies.

Keywords: Atomic Layer Deposition, ZnO, Fullerene, Photocatalysis, Nanocomposite

Acknowledgements: The author Regina Del Sole thanks the PRIN 2022 PNRR project DEvising soLar-driven catalysis at Perovskites Heterogeneous Interfaces for hydrogen evolution (DELPHI) (Project code: P2022W9773; CUP: H53D23007810001)

Hierarchical SiO_2 nanostructures confinement mediated molecular dipoles of poly(vinylidene fluoride): Enhancing piezo and pyroelectric performances

Juan Delgado-Alvarez,[1] **Hari Krishna Mishra,**[1]* **Francisco J. Aparicio,**[1] **Xabier García-Casas,**[1] **Angel Barranco,**[1] **Juan R. Sanchez-Valencia,**[1] **Victor Lopez-Flores,**[1,2]* **Ana Borras**[1]

[1]Nanotechnology on Surfaces and Plasma Laboratory, Materials Science Institute of Seville, CSIC-US, Avd. Americo Vespucio 49, 41092, Seville, Spain
[2]Departamento de Física Aplicada I, Escuela Politécnica Superior, Universidad de Sevilla, Virgen de Africa, 41011, Seville, Spain

Presenter and correspondence: juan.delgado@icmse.csic.es

The escalating global demand for sustainable and miniaturized electronic devices necessitates advancements in energy harvesting technologies.[1] Of particular interests, poly(vinylidene fluoride) (PVDF) stands out as a promising material for flexible and biocompatible devices due to its excellent piezo- and pyroelectric properties.[2] However, its energy output is often limited by the crystallization into non-electroactive phases. In this context, we report on the development of a novel flexible piezo/pyro-electric nanogenerator (PPNG) that significantly enhances energy harvesting capabilities by combining a uniform film of PVDF infiltrated over vertically supported SiO_2 nanowires (NWs). The fabrication process employs a low-temperature, multi-step method, beginning with the soft-template growth of SiO_2 NWs on a flexible substrate, followed by PVDF thin film (TF) infiltration. Plasma-assisted synthesis enables precise vertical alignment of the SiO_2 NWs, allowing fine control over the surface microstructure, density, and thickness of the confined nanostructures. This engineered architecture fosters the formation of the electroactive β- and γ-phases in the PVDF matrix, crucial for improved electrical output. Electrical poling further enhances performance by aligning the molecular dipoles of PVDF macromolecular chain, promoting a more ordered and responsive electroactive phase.

As a proof-of-concept, the fabricated PPNG demonstrated remarkable improvements in output performance compared to bare PVDF thin film counterparts. The instantaneous piezoelectric output power density exhibited ~ 9-fold amplification, reaching ~10.8 $\mu W/m^2$ compared to ~1.2 $\mu W/m^2$ for bare PVDF TF-based PPNG. Similarly, the pyroelectric coefficient (p) showed a 4-fold superior performance, increasing from ~0.35 $\mu C/m^2.K$ for bare PVDF TF to ~1.40 $\mu C/m^2.K$ for the NWs-based PPNG at a ΔT of 22 K.[3] This enhanced performance is attributed to the synergistic interplay of several factors: the high aspect ratio and stiffness of the SiO_2 NWs acting as effective stress concentrators, and the strong interfacial interactions (hydrogen bonding and electrostatic interactions) promoting the nucleation and growth of polar phases during nanoconfinement and subsequent electrical poling. Therefore, the engineered SiO_2 NWs@PVDF system offers a promising pathway towards multisource energy harvesting. These substantially improved piezoelectric and pyroelectric performances, coupled with the mild conditions employed for device fabrication and poling, open new avenues for applications in self-powered devices, wearable technologies, and sustainable energy solutions. This work provides a versatile platform for developing high-performance energy harvesters by exploiting the synergistic interplay between ferroelectric polymers and rationally designed 1D vertical SiO_2 nanostructures.

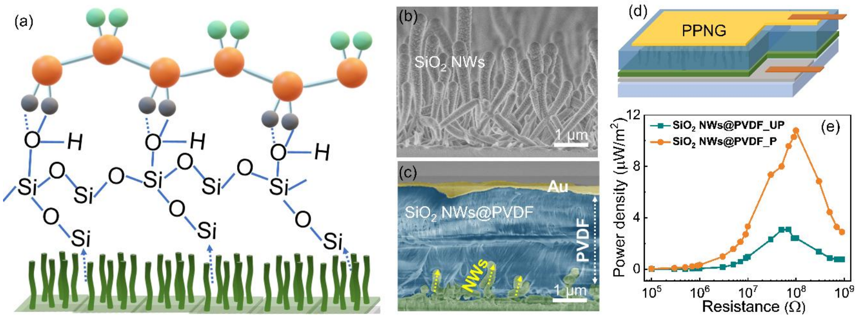

Fig. 1. (a) Schematic interaction of PVDF dipoles with SiO2 nanostructures, (b) vertical growth of SiO2 NWs (c) nanoconfinement of NWs with PVDF thin film (d, e) fabricated nanogenerator and corresponding power output.

Keywords: *Plasma Enhanced Chemical Vapor Deposition (PECVD), Nanogenerator, Piezo/pyroelectricity, PVDF, Energy harvesting*

References:

[1]. X. García-Casas et al., Plasma engineering of microstructured piezo–Triboelectric hybrid nanogenerators for wide bandwidth vibration energy harvesting, *Nano Energy* **91**, 106673 (2022).
[2]. H. K.Mishra et al., Revisiting of δ−PVDF nanoparticles via phase separation with giant piezoelectric response for the realization of self-powered biomedical sensors, Nano Energy 95, 107052 (2022).
[3]. J. Delgado-Alvarez et al., Unlocking the hybrid piezo and pyroelectric nanogenerators performance by SiO_2 nanowires confinement in poly(vinylidene fluoride), arXiv, *https://doi.org/10.48550/arXiv.2506.01580.*

Acknowledgements:

The authors thank the projects PID2022-143120OB-I00, TED2021-130916B-I00, and PCI2024-153451 funded by MCIN/AEI/10.13039/501100011033 and by "ERDF (FEDER)" A way of making Europe, Fondos NextgenerationEU and Plan de Recuperación, Transformación y Resiliencia". Project ANGSTROM was selected in the Joint Transnational Call 2023 of M-ERA.NET 3, which is an EU-funded network of about 49 funding organisations (Horizon 2020 grant agreement No 958174). The project leading to this article has received funding from the EU H2020 program under grant agreement 851929 (ERC Starting Grant 3DScavengers).

Transparent Pt nanonetworks for the mitigation of spacecraft charging issues in photovoltaic solar arrays

Jose Ferreira de Sousa Junior[1], Noel Orozco[1], Francisco J. Aparicio*[1], Miguel Ramiro[2], Isabel Montero[3], Beatriz Sarrion[4], Maria Alcaire[1], Ismael Sanchez[2], Angel Yedra[5], Carla Ortiz[5], Gregoire Deprez[6], Fredrik Leffe Johansson[6], Fabrice Cipriani[6], Ana Borras[1], J.R. Sanchez-Valencia[1], and Angel Barranco*[1]

**Correspondence to fjaparicio@icmse.csic.es and angel.barranco@csic.es*

1Nanotechnology on Surfaces and Plasma Laboratory, Materials Science Institute of Seville (CSIC-US), Seville, Spain
2DHV Technology, Av. Juan López de Peñalver, 21, Campanillas, 29590 Malaga, Spain
3 Instituto de Ciencia de Materiales de Madrid (CSIC), Sor Juana Ines de la Cruz, 3. Cantoblanco (Madrid), Spain.
4Alter Technology TÜV NORD, C. Tomás Alva Edison, Seville, Spain.
5Centro Tecnológico CTC, C. Isabel Torres, Santander, Spain
6European Space Agency, ESA-ESTEC, Noordwijk, The Netherlands

Spacecraft charging is a well-documented phenomenon resulting from the interaction between space vehicles and the surrounding space environment, including plasma, solar radiation, and high-energy particles. This interaction leads to the accumulation of electrical charge on spacecraft surfaces, particularly on non-conductive materials such as photovoltaic cover glasses, which can lead to catastrophic electrostatic discharge (ESD) events. Therefore, spacecraft charging is the **root cause of critical failures** that threaten the structural integrity and operational lifespan **of spacecraft systems** (e.g. solar arrays).

Under the **ESA contract Ref. 40001139513/22/NL/CRS**, this research aims to address the spacecraft charging problem by developing **innovative Pt-based transparent nanocoatings**. These coatings are composed of percolated platinum-based nanonetworks fabricated using advanced plasma processing techniques.

The fabrication process integrates two key steps consecutively carried out in a single plasma reactor: the remote plasma-assisted vacuum deposition (RPAVD) of a hybrid platinum plasma-polymer nanocomposite, followed by room-temperature plasma etching of the deposited layer.[1]-[3] This entirely vacuum-based method leverages **plasma processing techniques** similar to other plasma and vacuum deposition processes **widely used in industrial applications**, such as the large-area production of **optical coatings for photovoltaics applications**. This illustrates the scalability of the technique to both large-area substrates (up to several square meters) and high-volume production of microelectronic and optoelectronic components.

Previous studies have demonstrated the successful development of solar cell photoelectrodes using nanoporous TiO_2 coatings[2] and nanostructured Pt electrodes[3] fabricated through RPAVD and mild-temperature plasma etching (~120°C). Building on this foundation, the current work extends the approach to produce **highly transparent and conductive nanoporous** coatings at **room temperature**. These coatings, featuring laterally **interconnected Pt nanonetworks**, achieve solar transmittance levels above 85% while maintaining low sheet resistance.

To evaluate their suitability for spacecraft charging mitigation, sheet resistance measurements were performed under vacuum at various temperatures. These were complemented by **advanced assessments** of secondary electron emission yield and vacuum ultraviolet (VUV) photoemission. The resulting data were used in simulations with SPENVIS' EQUIPOT and SPIS-6 tools to model **surface charging** and potential behaviour in different **orbital environments**. Simulations confirm that the developed **Pt-nanonetwork coatings offer effective protection against spacecraft charging**, making them a promising solution for enhancing the durability and performance of photovoltaic solar arrays in space.

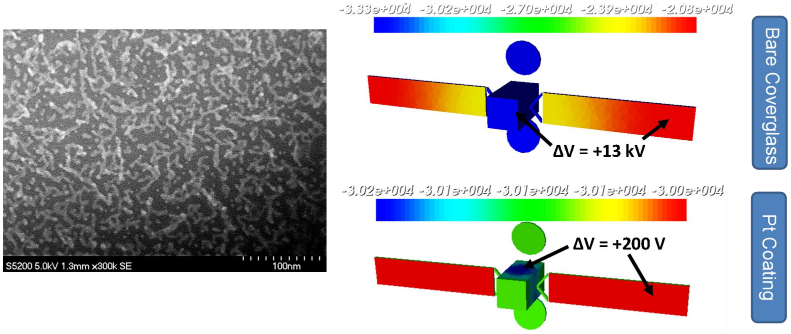

Fig. 1. Left: SEM image of the Pt interconnected nanostructures. Right: Simulated potential on bare and Pt-coated nanostructures

Keywords: Metal nanonetworks, transparent conductive coatings, plasma fabrication, spacecraft charging. ESD protections

References:

1. J. M. Obrero et al. Front. Chem. **8** (2020), 520.
2. J. M Obrero et al. ACS Appl. Mater. Interfaces **16** (2024), 39745.
3. A.N. Fillipin et al. Adv. Mater. Interfaces **4** (2017), 1601233.

Acknowledgements: European Space Agency (ESA) contract number 40001139513/22/NL/CRS "Charging effects mitigation using innovative materials"

A Robust Alginate Hydrogel Interface via Cryogelation for Highly Reversible and Dendrite-Free Zinc Anodes

Yan Gao,[1] **Dino Tonti**[1]

[1]Institut de Ciència de Materials de Barcelona (ICMAB), CSIC, Campus UAB, 08193 Bellaterra, Spain

Aqueous zinc-ion batteries are plagued by dendrite growth and side reactions on the zinc anode.[1] To address this, we report a robust alginate hydrogel protective layer fabricated via a unique cryogelation and in situ ionic cross-linking process.[2] This method involves coating an alginate precursor on the zinc surface, followed by freeze-thaw cycles where ice crystals act as templates to form a porous polymer architecture. Subsequent immersion in a $ZnSO_4$ solution introduces Zn^{2+} ions, which cross-link the alginate chains, significantly enhancing the gel's mechanical integrity. Benefiting from this cryo-structured porous network that homogenizes Zn^{2+} flux and physically suppresses dendrites, the protected anode exhibits a dramatically extended lifespan of 261 hours at 5 mA/cm². This is a stark contrast to the bare zinc anode, which fails after only 35 hours. Our work presents a facile yet effective cryogelation strategy to engineer stable interfaces for high-performance zinc anodes.

Keywords: *Zinc metal anode; Aqueous zinc-ion batteries; Hydrogel interface; Cryogelation; Dendrite suppression*

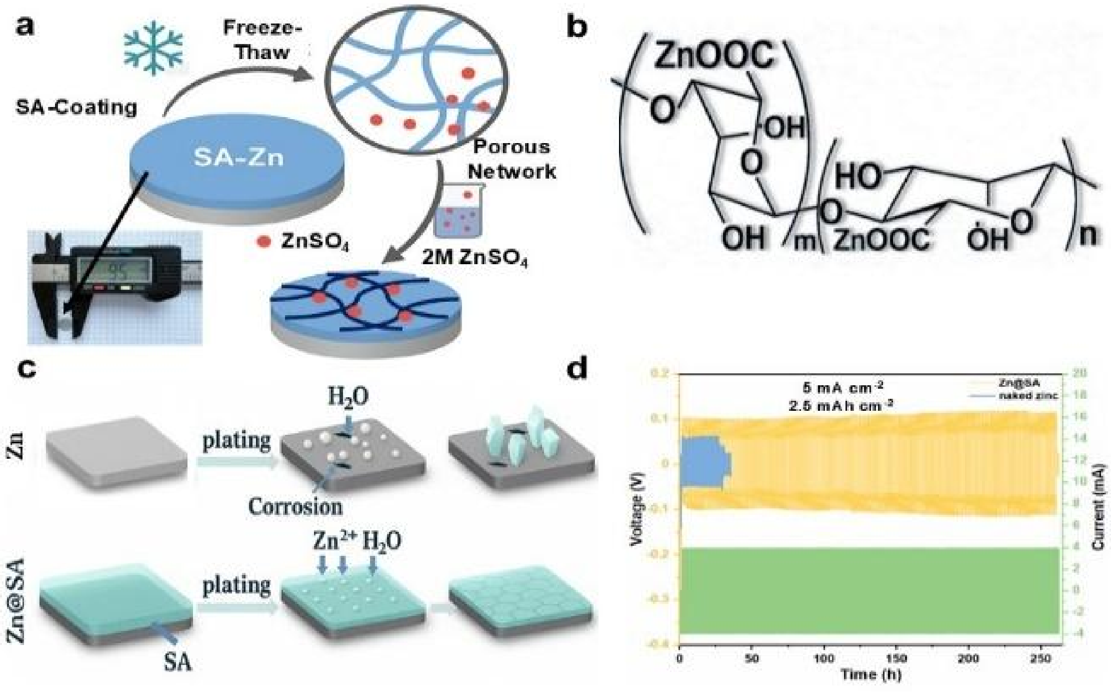

Fig. 1. (a) Schematic illustration of the fabrication process of the cryo-structured SA hydrogel, highlighting the formation of a porous network via freeze-thawing and subsequent Zn^{2+} cross-linking. (b) Schematic illustration of the molecular bonding in the gel formed after soaking the SA solution in 2 M $ZnSO_4$ solution. (c) Comparison of the Zn deposition behavior on a bare Zn anode versus the protected Zn@SA anode, which promotes uniform Zn^{2+} flux and dendrite-free deposition. (d) Galvanostatic cycling performance of symmetric cells assembled with the SA-hydrogel-coated Zn anode (Zn@SA) and the bare Zn anode at a current density of 5 mA/cm² and an areal capacity of 2.5 mAh/cm².

References:

(1) Liu, H.; Li, Z.; Sui, B.; Bao, Q.; Wang, P.; Gong, Z.; Zhang, Y.; Wu, Y.; Shi, F.; Zhou, M.; Zhu, K. Calcium Alginate Hydrogel Coating Comprehensively Optimizes Zn Deposition Behavior of Aqueous Zinc-Ion Batteries Anode. Ind. Eng. Chem. Res. 2024, 63 (31), 13611–13622.

(2) Hong, L.; Wu, X.; Liu, Y.; Yu, C.; Liu, Y.; Sun, K.; Shen, C.; Huang, W.; Zhou, Y.; Chen, J.; Wang, K. Self-Adapting and Self-Healing Hydrogel Interface with Fast Zn2+ Transport Kinetics for Highly Reversible Zn Anodes. Adv. Funct. Mater. 2023, 33 (29), 2300952.

Stretchable skin-like 3D nanostructured hybrid piezo-triboelectric nanogenerators

Xabier García-Casas[1], **Alberto Peinador-Veiga**[1], **Melania Sánchez-Villa**,[1] **Hari Krishna Mishra**,[1] **Lidia Contreras-Bernal**[1,2], **Juan R. Sanchez-Valencia**,[1] **Ángel Barranco**[1], **Vanda Godinho**[1], **Ana Borrás**[1]

[1]Nanotechnology on Surfaces and Plasma laboratory, ICMS Material Science Institute of Seville (CSIC-US), C/Americo Vespucio 49, 41092 Seville, Spain

[2]Dep. de Ingeniería y Ciencia de los Materiales y del Transporte, Universidad de Sevilla, C/ Camino Descubrimientos s/n, 41092 Seville, Spain

Triboelectric nanogenerators (TENGs) have gained significant attention over the past decade as an effective solution for harvesting kinetic energy to power devices of various scales. These devices include compact, lightweight, and wireless technologies designed for the Internet of Things (IoT) and Wireless Sensor Networks, as well as energy conversion from natural sources. In this communication we focus on the design and optimization of self-powered triboelectric nanosensors for their implementation into wearable devices for the detection of low and medium biomechanic vibrations. For this purpose, it is critical to develop triboelectric architectures on flexible and stretchable substrates able to respond to low amplitude vibrations with high durability and flexibility. With such an aim, we have advance into the nanoscale modification of stretchable triboelectric matrixes by integrating core@shell and piezoelectric one-dimensional (1D) nanowires and three-dimensional (3D) nanotrees with core-shell morphologies [1, 2] as shown in Figure 1. Based on vacuum and plasma-assisted depositions, zinc oxide (ZnO) has been utilized as its functional piezoelectric material. Polydimethylsiloxane (PDMS) has been implemented as both substrate and triboelectric polymer due to its soft, mechanically durable, flexible, and stretchable character. A protocol has been developed to conformally or fully embed the 3D microstructures into the PDMS matrix. Surface plasma treatments and plasma-assisted perfluorinated grafting on PDMS surfaces have been employed to enhance the TENG voltage output while also improving long-term reproducibility and durability, even in moist conditions.

This work presents both the characterization of devices and the fabrication steps for manufacturing fully stretchable, flexible, and highly sensitive triboelectric nanogenerators. These generators can be used as self-powered sensors for detecting vibrations and movements such as hand movement recognition or recognition of talking, coughing, and swallowing.

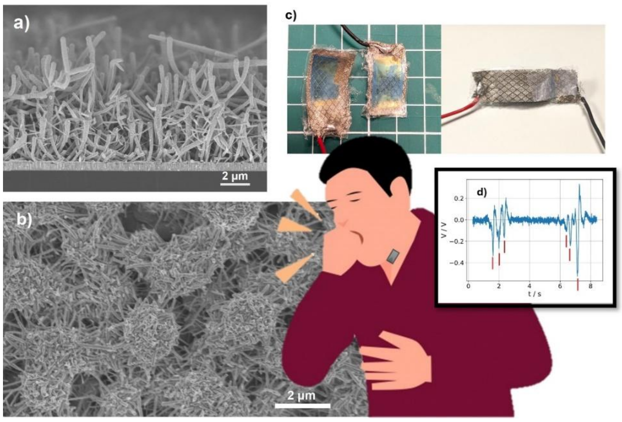

Fig. 1. a) Cross-sectional SEM micrograph of 3D functional piezoelectric nanotrees. b) Top view micrograph of PDMS drop-casted microstructures. c) Photograph of flexible and stretchable devices. d) Electrical output signal under cough activation.

The development of the flexible and stretchable triboelectric nanogenerators could lead to advanced healthcare monitoring systems that integrate with the human body, enabling continuous health tracking and real-time data collection on vital signs and physical activity without the need for external power sources or bulky equipment. Furthermore, their ability to harness energy from everyday movements opens up possibilities for wearable technology, making it easier for patients and practitioners to adopt these innovations.

Keywords: Flexible electronics, TENG, self-powered sensors, 3D core@shell nanostructures, plasma assisted deposition

References:

1. Filippin et al., *Nano Energy* **58**, 476-483 (2019).
1. Garcia-Casas et al., *Nano Energy* **91**, 106673 (2020).

Acknowledgements: The authors thank the projects PID2022-143120OB-I00, TED2021-130916B-I00, and PCI2024-153451 funded by MCIN/AEI/10.13039/501100011033 and by "ERDF (FEDER)" A way of making Europe, Fondos NextgenerationEU and Plan de Recuperación, Transformación y Resiliencia". Project ANGSTROM was selected in the Joint Transnational Call 2023 of M-ERA.NET 3, which is an EU-funded network of about 49 funding organisations (Horizon 2020 grant agreement No 958174). The project leading to this article has received funding from the EU H2020 program under grant agreement 851929 (ERC Starting Grant 3DScavengers).

Sputter-deposited gold–iron nanostructures for magnetoplasmonic applications

María Garrido-Segovia 1,2 , María Ujué González 2 , Ana Espinosa 3 , Elena Navarro 1,4 and José Miguel García-Martín 2

1 Depto. Física de Materiales, Universidad Complutense de Madrid (UCM), 28040, Madrid, Spain.
2 Instituto de Micro y Nanotecnología (IMN), CSIC, 28760, Tres Cantos, Spain.
3 Instituto de Ciencia de Materiales de Madrid (ICMM), CSIC, 28049, Madrid, Spain.
4 Instituto de Magnetismo Aplicado (IMA-UCM-ADIF), 28230, Madrid, Spain.

Magnetron sputtering (MS), known for its scalability and versatility, is a widely used technique for the fabrication of thin films, both at the industrial and at the academic levels. Its compatibility with glancing angle deposition (GLAD) makes it interesting for the production of nanostructured surfaces. When sputtering is combined with GLAD, nanocolumnar films (NCs) are grown by taking advantage of the shadowing effect generated during atomic deposition at grazing incidence. This results in highly anisotropic and porous films [1]. Among the materials used in MS-GLAD, Fe-based NCs have attracted attention due to their varying magnetic properties, which strongly depend on the morphology and orientation of the columns that are due to the deposition geometry and conditions [2,3]. On the other hand, Au NCs have been of extensive interest because of their optical properties, particularly the presence of localized surface plasmon resonances (LSPR) [4,5]. In this work, it is shown the integration of both magnetic and plasmonic properties in a single structure, that is, the combination of Au and Fe NCs to produce magnetoplasmonic nanostructures.

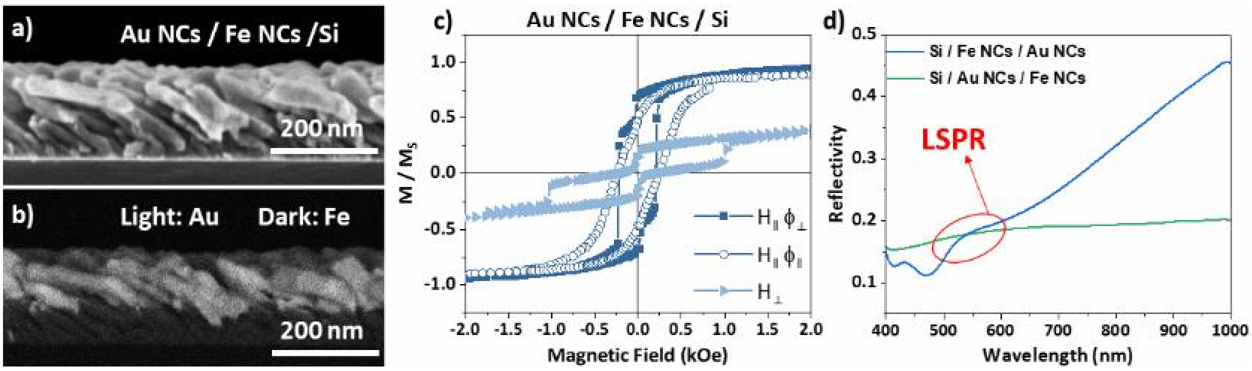

Fig. 1. Cross-sectional SEM images of (a) scattered electrons and (b) backscattered electrons of Au NCs above Fe NCs. (c) Hysteresis loops in plane and out-of-plane of Au NCs above Fe NCs. (d) Reflectivity of both Au NCs above Fe NCs and Fe NCs above Au NCs.

In this study, two different bimetallic structures of gold and iron NCs have been fabricated using GLAD sputtering. The two types of samples fabricated are bi-layers consisting of: 1- gold NCs layer at the bottom of iron NCs layer, and 2- the opposite configuration, i.e., iron NCs layer at the bottom of gold NCs layer. Growth parameters remained the same in bothsamples. Samples were morphologically characterized by means of scanning electron microscopy (SEM), where backscattered electrons distinguish between the different materials used. The crystalline and electronic structures were evaluated via X-ray diffraction (XRD). The reflectivity of these films−and the resonance plasmons were examined using a home-made reflectivity system, and their magnetic properties were analysed using a vibrating sample magnetometer (VSM).
The findings highlight the potential of these nanostructures for applications in sensing technologies, as well as in magnetic and photothermal therapies for cancer treatment.

Keywords: magnetron sputtering, nanocolumns, magnetoplasmonic, photothermal therapies

References:

1. R. Álvarez et al., Nanotechnology 24(4), 045604 (2013).
2. E. Navarro et al., Nanomaterials 12(7), 1186 (2022).
3. M. Garrido-Segovia et al., (2023). Engineered Fe-Based Nanocolumnar Films. In Advanced Study Institute on NATO ASI on Quantum Nano-Photonics (pp. 27-45). Dordrecht: Springer Netherlands (2024).
4. A. Espinosa et al., Advanced Functional Materials 28(37), 1803660 (2018).
5. R. López-Méndez et al., Advanced Healthcare Materials, 2403799 (2024).

Acknowledgements: This work was supported by Ministerio de Ciencia, Innovación y Universidades (FPU grant (M. G.-S.) and projects PID2021-126524NB-100 and PID2021-127033OB-C21), and CSIC (PIE 20226AT024).

Towards Sustanaible Energy harvesting: vertically aligned BaTiO3 Nanowires for flexible piezoelectric nanogenerators

Darío Jumilla[1], Melania Sanchez-Villa[1], Gloria P. Moreno[1], Hari Krishna Mishra[1], Xabier García-Casas[1], Jorge Gil-Rostra[1], Angel Barranco[1], Juan Ramón Sánchez-Valencia[1], Vanda Godinho[1],* and Ana Borrás[1]

[1]*Instituto de Ciencia de Materiales de Sevilla (CSIC-US) C/Americo Vespucio 49, Seville E-41092, Spain*

**corresponding author email: godinho@icmse.csic.es*

The growing demand for alternative permanent power sources in portable electronic devices presents a key challenge in the advancement of the Internet of Things (IoT). In this context, piezoelectric, triboelectric, and pyroelectric **nanogenerators** have emerged as promising candidates to sustainably **power low-consumption IoT** nodes. These devices can harvest various forms of **ambient energy**- mechanical (e.g., vibrations, movement, pressure changes) and thermal (e.g., temperature fluctuations)- to generate usable electricity. By harvesting these ubiquitous and otherwise wasted energy sources, nanogenerators are establishing a new paradigm for self-powered, battery-free IoT systems, enabling autonomous and maintenance-free operation in distributed environments [1].

In this work, we utilize **lead-free $BaTiO_3$ (BTO)**, a ferroelectric perovskite which has been proven as a **multi-source energy harvesting material** [2-4]. Over the last years, research efforts have been focused on the synthesis of BTO in the form of one-dimensional (1D) nanowires as they present potentially higher power-generating capability and higher energy conversion [5-8]. While most synthesis methods for 1D BTO nanostructures rely on hydrothermal reactions [5-8], we explore an alternative soft-template route. By combining **vacuum and plasma-assisted deposition techniques** [9-11], we achieve the direct growth of **vertically aligned BTO nanowires on mica substrates**. This approach is not only compatible with microelectronic industry standards but also environmentally friendly. The resulting structures exhibit remarkable potential for flexible piezoelectric nanogenerators, with their piezoelectric response being directly influenced by deposition conditions. Our findings contribute to the development of next-generation energy harvesting solutions for sustainable electronics.

Keywords: Piezoelectric, Flexible Nanogenerator, $BaTiO_3$, Nanowires, Plasma Technology

References:

1. Wang, Z. L., et al. *ACS Nano*, 17, 7661 (2023).
2. Zhao, K. et al., *Nano Energy* 71, 104632, (2020).
3. Song, K. et al., *Advanced Materials* 31, **36**, 1902831, (2019)
4. Zhao, K. et al., *Nano Energy*, 77, 105152 (2020)
5. Song, K. et al., *Advanced Materials* 5, **1**, 1800413 (2019)
6. Koka, K. et al., *Energy & Enviromental Science* 7, **1**, 288 (2014)
7. Jian, G. et al., *Journal of Materials Science* 55, **16**, 6903-6914 (2020)
8. Wang, Y. et al., *Journal of Materials Science* 53, **18**, 13081-13089 (2018)
9. Borras, A. et al., *Chemistry of Materials* 20, **24**, 7371-7373, (2008)
10. García-Casas, X. et al., *Nano Energy* 91, 106673, (2022)
11. Borrás. A. et al., *Langmuir* 26, **8**, 5763-5771, (2010)

Acknowledgements:

Projects PID2022-143120OB-I00, TED2021-130916B-I00, and PCI2024-153451 funded by MCIN/AEI/10.13039/ 501100011033 and by "ERDF (FEDER), A way of making Europe", Fondos NextgenerationEU and "Plan de Recuperación, Transformación y Resiliencia". Darío Jumilla acknowledges the FPU doctoral contract, AEI-MIU (FPU20/02994)
Project ANGSTROM was selected in the Joint Transnational Call 2023 of M-ERA.NET 3, which is an EU-funded network of about 49 funding organisations (Horizon 2020 grant agreement No 958174).
The project leading to this article has received funding from the EU H2020 program under grant agreement 851929 (ERC Starting Grant 3DScavengers).

Atomic Layer Deposition of ZnO on Chitosan Sponges: toward engineered nanocomposites for water remediation technologies

Sara Lotito[1,2], Domenico Cignolo[1], Jennifer Gubitosa[1,2], Marinella Striccoli[3], Fabio Palumbo[2], Pinalysa Cosma[1], Paola Fini[3], Vito Rizzi[1], Francesco Fracassi[1], Antonella Milella[1] and Alberto Perrotta[2]

1Dipartimento di Chimica Università degli Studi di Bari “Aldo Moro” Bari 70126, Italy
2CNR NANOTEC – Istituto di Nanotecnologia – Sede Secondaria di Bari c/o Dipartimento di Chimica Università degli Studi di Bari “Aldo Moro” Bari 70126, Italy
3CNR IPCF: Istituto per i Processi Chimico-Fisici – Sede Secondaria di Bari- c/o Dipartimento di Chimica Università degli Studi di Bari “Aldo Moro” Bari 70126, Italy

The disposal of large quantities of undesirable substances, originating from both natural processes and human activities poses serious concern challenging the scientific community in finding effective solutions to enhance water quality. Adsorption process is usually considered particularly effective, especially when using bio-based adsorbents due to their low cost, simplicity of design, and reusability [1]. Chitosan-based adsorbents have been widely used as well as their modification with metal oxides (e.g., Fe_2O_3, ZnO, TiO_2) demonstrated to be promising in treating diverse pollutants given their multifunctionality: enhanced adsorption capacity, photocatalytic and antimicrobial activities [2] . Typically, the fabrication of such hybrid nanocomposites relies on complex and long procedures like physical blending, chemical grafting, and sol-gel methods which can also induce coalescence, aggregation, and potential structural damage to the substrate or support. In this light, atomic layer deposition (ALD) emerges as an outstanding tool for adsorbent and membrane surface engineering due to its processing capabilities, even on complex 3D structures, although there is still a gap in the current literature regarding the nanoengineering of chitosan by this approach. In the work herein proposed, millimeter-thick chitosan-based sponges are engineered with zinc oxide (ZnO) using atomic layer deposition (ALD) to create a multifunctional nanocomposite for the potential application in water remediation and self-regeneration via solid-state photocatalysis (Fig.1) [3].

Initially, non-porous chitosan films served as control samples to study the ZnO growth mechanism and its impact on the biopolymer’s optical and chemical properties. Subsequently, porous chitosan sponges are engineered to further explore the photocatalyst growth and infiltration into the porous matrix. A comprehensive characterization performed via spectroscopic ellipsometry, X-ray photoelectron spectroscopy, UV–vis, photoluminescence, and infrared spectroscopy allowed to investigate the growth mechanism of ZnO within the polymeric matrix as a function of the number of ALD cycles. The ZnO growth extended to several hundred microns within the sponge matrix indicating a reaction-limited growth process.
Covalently bounded ZnO to the chitosan amino groups was found as crucial for the enhanced stability of the sponges. Notably, adsorption tests employing Direct Blue 78 dye demonstrated high removal efficiency, with capacities up to 2000 mg g^{-1}, surpassing pristine chitosan sponges, which degrade in water. Furthermore, ZnO enabled photocatalytic activity as demonstrated by preliminary experiments where Naproxen was successfully degraded.

These results encourage the use of ALD for creating nanoengineered chitosan-based adsorbents for water remediation, providing a novel approach to surface modification that has not been extensively explored. Furthermore, this study paves the way for the development of multifunctional, sustainable materials for environmental applications, combining adsorption and photocatalysis for the effective removal of a wide range of water pollutant.

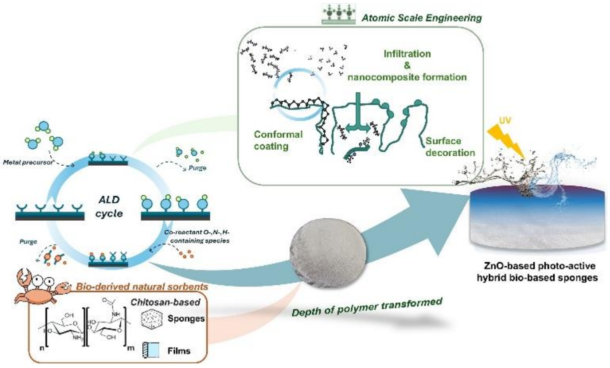

Fig. 1. Chitosan sponges engineered with zinc oxide (ZnO) using atomic layer deposition (ALD) to create a multifunctional nanocomposite. Adapted from ref. [3]

Keywords: Atomic Layer Deposition (ALD), chitosan, photocatalysis, water remediation

References:

1. M.R. Adam et al., *J. Environ. Chem. Eng*., **10** (2022)
2. Gajera et al., *J. Water Process Eng.,* **49** (2022).
3. Lotito et al., *Adv. Mater. Interfaces,* **12** (2025)

Acknowledgements:

This work was supported by the European Union – Next Generation EU, in the framework of the National Recovery and Resilience Plan, Mission 4, Component 2, with the project BECOMEH2 (CUP B53D23027360001). The authors thank Gianni Barucca, Paolo Mengucci and Sapia Murgolo for data collection and insightful discussions. S. Cosmai and D. Benedetti are also acknowledged for their technical support.

Benzothiadiazole-based polymeric S-scheme homojunction for photoelectrochemical ORR

Sara Lotito[1,2], Amr A. Nada [2], Drialys Cardenas Morcoso [2], Rodolphe Mauchauffé [2], Alberto Perrotta [3],

Antonella Milella [1], Nicolas D. Boscher [2]

1 Dipartimento di Chimica, Università degli Studi di Bari “Aldo Moro”, Via Orabona 4, 70125 Bari, Italy
2 Luxembourg Institute of Science and Technology, Advanced Plasma and Vapor Deposition Processes Engineering, L-4362, Esch-sur-Alzette, Luxembourg
3 CNR NANOTEC – c/o Dipartimento di Chimica, Università degli Studi di Bari “Aldo Moro”, Via Orabona 4, 70125 Bari, Italy

Benzothiadiazole-based donor-acceptor (D-A) conjugated polymers attracted great interest in solar-driven processes such as hydrogen peroxide production [1] and sensing of dissolved oxygen based on oxygen reduction reaction (ORR) [2]. This growing interest stems from their intrinsic donor–acceptor character, which induces reduced band gap —a key requirement for efficient light-harvesting— tunable energy levels and high charge mobility, although the strongly bound excitons formed upon light absorption may hamper their photo(electro)catalytic efficiency due to the fast recombination of the carriers. On this ground, the formation of homo- or heterojunctions are usually adopted to promote the dissociation of excitons into free charge carriers, increasing the photocurrent yield.

The simultaneous synthesis, doping and deposition of benzothiadiazole–oligothiophene D–A conjugated polymer thin films was recently achieved from the oxidative chemical vapour deposition (oCVD) from 4,7-dithien-2-yl-2,1,3-benzothiadiazole[3]. oCVD is a versatile deposition technique [4] and emerged as promising to expedite the commercialization process of conjugated polymers in large-scale applications. Given its gas-phase nature, oCVD obviates the need for solubilizing groups as well as the need for orthogonal solvents when fabricating multilayered devices, lowering the complexity of device fabrication.

With these premises, we adopted the oCVD technique for the development of a S-scheme homojunction in benzothiadiazole-based polymeric photocathodes. Accordingly, a bilayer thin film has been prepared by sequentially synthesizing two benzothiadiazole-based polymers, namely pDEDOT-BT and pDTBT, from 4,7-Di(2,3-dihydro-thieno[3,4-b][1,4]dioxin-5-yl)benzo[1,2,5]thiadiazole (DEDOT-BT) and 4,7-dithien-2-yl-2,1,3-benzothiadiazole (DTBT) using triflate salt of iron(III), ($Fe(OTf)_3$), and iron chloride ($FeCl_3$), as oxidants, respectively.

A comprehensive optochemical and morphological characterization outlined the different polymerization extent and the resulting optoelectronic properties of pDEDOT-BT and pDTBT thin films and the band structure of the bilayer thin film was retrieved. A systematic photoelectrochemical characterization was conducted for the bilayer thin film, pDEDOT-BT, and pDTBT layers in both Ar-purged and O_2- saturated solutions under slightly acidic conditions to evidence the beneficial effect of the S-scheme homojunction proposed. Electrochemical impedance spectroscopy results supported the hypothesis that it facilitates the charge separation and transport, as indicated by the lower charge-transfer resistance (57 kOhm cm^2) of the bilayer thin film compared to pDEDOT-BT (179 kOhm cm^2) and pDTBT (131 kOhm cm^2). The bilayer thin film also showed a higher double-layer capacitance, suggesting increased charge accumulation at the electrode–electrolyte interface justifying the higher photoresponse delivered even in the absence of oxygen. Contrarily, pDEDOT-BT and pDTBT showed negligible photo-activity. In the presence of oxygen that acts as electron acceptor, the bilayer thin film achieved a photocurrent density of -250 μA cm^{-2} (0.35 V vs RHE) while pDEDOT-BT and pDTBT barely reached 20-25 μA cm^{-2}. Given the high-lying and strongly reducing LUMO, these results pointed out that the bilayer thin film could be thermodynamically suitable for driving the hydrogen evolution reaction, although oxygen reduction appears to dominate the photocathodic process with the highest photocurrent values reached under O_2-saturated condition. Based on the S-scheme proposed, charge carriers with weaker redox ability likely recombine at the interface, while the photogenerated electrons in pDTBT and holes in pDEDOT-BT are preserved, enhancing charge separation and retaining strong redox potentials for ORR.
A preliminary evaluation of the stability of the system suggested that further efforts are needed to improve long-term durability laying the groundwork for the study of protective layers and the integration of co-catalysts, which may enhance reaction kinetics or potentially shift selectivity toward the hydrogen evolution reaction (HER) over ORR.

This work highlights the potential of oCVD as an effective strategy to fabricate high-performing benzothiadiazole-based photocathodes where the enhanced charge separation and preserved redox activity achieved by S-scheme open new opportunities for their integration in ORR-based photoelectrochemical applications, including hydrogen peroxide production and oxygen-sensing technologies.

Keywords: *oxidative chemical vapor deposition, photoelectrochemistry, conjugated polymers, S-scheme homojunction*

References:

[1]. Gańczarczyk et al, *Adv Mater Interfaces*, vol. 10, no. **21**, (2023)
[2]. Bellani *et al., Adv Funct Mater*, vol. 25, no. **28** (2015)
[3]. Charyton et al., *J Mater Chem C Mater*, vol. 12, no. **30**, (2024)
[4] Wang et al., *Adv. Mater. **29**, (2017)*

Acknowledgements:

This project has received funding from the European Research Council (ERC) under the European Union’s Horizon 2020 research and innovation programme (grant agreement No 865985).

Vacuum-Deposited Adamantane-Based Plasma Polymers as Multifunctional Triboelectric Films for Harvesting Mechanical and Droplet Energy

Gloria P. Moreno[1], Fernando Núñez-Gálvez[1], Xabier García-Casas[1], F.J. Aparicio[1], J.R. Sánchez-Valencia[1], Ángel Barranco*[1], Ana Borras*[1].

**Correspondence to angel.barranco@csic.es and anaisabel.borras@icmse.csic.es*

[1]Nanotechnology on Surfaces and Plasma Laboratory, Materials Science Institute of Seville (CSIC-US), c/ Américo Vespucio 49, 41092 Seville, Spain

Due to the high environmental impact and critical raw materials constraints, the current battery technology is inadequate to meet the growing demand for compact, lightweight, and wearable portable devices. To address this challenge, portable nanogenerators provide a promising solution by scavenging environmental micro-energy at the point of need to power to low-energy wireless devices. This emerging technology is expected to drive the development of disruptive, self-sustained electronic systems. One of the most widely adopted solutions for this working concept are Triboelectric Nanogenerators (TENGs), which efficiently convert low-amplitude and low-frequency mechanical or kinetic stimuli, such as human movement, into electricity. TENGs systems achieve this by combining friction-induced triboelectrification with electrostatic induction. The versatility and simplicity of the TENG architectures and diversity of triboelectric surfaces, without reliance on specific crystalline phases or stoichiometries, make TENG a leading approach for microscale energy harvesting.

Boosting the triboelectric response typically involves a fluorinated surface to improve the friction-induced charge transfer efficiency. In response to the related environmental concerns, we have explored the Remote Plasma Assisted Vacuum Deposition (RPAVD) [2-3] of adamantane (ADA) as a high-performance triboelectric organic material. Adamantane RAPVD coatings are advanced dielectric films originally designed for protective coatings in perovskite solar cells and strain-engineering applications in 2D nanomaterials [4-5]. As a general characteristic, these coatings hydrophobic, non-soluble, and transparent in the UV-VIS-NIR range with a continuous and compact microstructure within an ample thickness range from, few nanometres to several micrometres. On the other hand, the RPAVD synthetic method is industrially scalable and straightforwardly compatible with photolithography and surface functionalization approaches. It is also environmentally friendly, making it a reliable and competitive solution to fluorinated-free thin film triboelectric material.

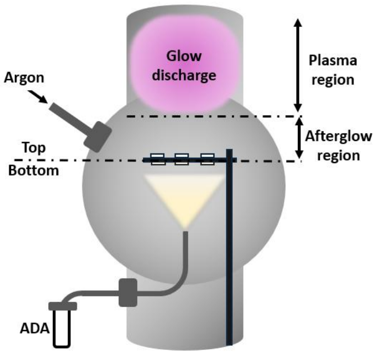

Fig. 1. Schema of the Remote Plasma Assisted Vapor Deposition.

RPAVD provides broad control over the surface composition, topography, and crosslinking degree, which have been recently revealed as key parameters controlling the triboelectrification process (6-8). Thus, in the current work, we have adapted the technique to the development adamantane-based coatings capable of exhibiting both tribopositive and tribonegative character through simple modification of the synthesis conditions and film morphology without additional post-synthesis functionalisation steps. Under mechanical excitation, vertical contact separation TENGs devices consisting of tribonegative and tribopositive ADA RPAVD coatings (2800 and 400 nm of thickness, respectively) are able to generate open-voltage and short-circuit current outputs as high as 88 V/cm^2 and 1.05 µA, providing a maximum power density as high as 2.0 µW/cm^2. Additional examples of using RPAVD ADA films as active components in micropatterned solid-solid and top-bottom drop-TENGs will also be presented.

Keywords: Nanogenerator, Triboelectricity, drop-TENG, plasma polymer.

References:

1. T. Cheng et al., *Nat. Rev. Meth. Primers* **3** (2023), 39.
2. F.J. Aparicio et al., *Advanced Materials* **23** (2011), 761.
3. M. Alcaire el al., *Adv. Funct. Mater* 5 (2019), 1903535.
4. J. Idígoras et al., *ACS Appl. Mater. Interfaces* **10** (2018), 11587.ok
5. F. Carrascoso et al. npj 2D mater. appl. 7,24 (2023)
6. M. Knite et al. *Energy & Environmental Science*. 12, 8 (2019)
7. A. Šutka et al. *Nano Energy*. 104, 107914 (2022)
8. P. Scherrer et al. *ACS Applied Materials & Interfaces*. 13, 37, 44935-44947 (2021)

Acknowledgements: EU-H2020 program under agreement 851929 (ERC Starting Grant 3DScavengers)
AEI-MICINN PID2022-143120OB-I00 AEI-MICINN (PID2022-143120OB-I00, TED2021-130916B-I00 and PCI2024-153451) funded by MCIN/AEI/10.13039/501100011033 and by "ERDF (FEDER)" A way of making Europe, Fondos NextgenerationEU

Highly Tunable and Conformal Graphene Nanowalls on Nanostructured Scaffolds for Triboelectric and Moisture-Driven Energy Harvesting

Fernando Núñez-Gálvez[1,2], Muhammad Hamza[3], Johannes Berndt[3], Juan R. Sánchez-Valencia[2], Carmen Lopez-Santos[1,2], Eva Kovacevic[3] and Ana Borras[2]

1Departamento de Física Aplicada I, Escuela Politécnica Superior, Universidad de Sevilla
2Nanotechnology on Surfaces and Plasma Lab, Institute of Materials Science of Seville (CSIC-US)
3GREMI, Groupe de Recherches sur l'Energétique des Milieux Ionisés (CNRS-Université d'Orléans)

*fngalvez@us.es fernando.ngalvez@icmse.csic.es

To meet the growing energy demands caused by the increasing number of wireless smart devices—many of which are difficult to power using conventional rechargeable batteries—alternative energy solutions are urgently needed. In this context, triboelectric nanogenerators (TENGs) have emerged as a promising technology for harvesting *multisource residual energy*, particularly from sources categorized as "blue energy"—including low-frequency water motions, raindrop impacts, microchannel water flows, and moisture-induced water adsorption over porous nanostructures [1].

To enhance the performance of TENGs and moisture-electric generators (MEGs), the development of tunable hierarchical nanostructures with high surface area is crucial. These structures can function as either fillers in polymer matrices or as scaffolds to improve energy conversion efficiency. Therefore, solventless, clean, controllable, and zero-waste fabrication techniques, such as plasma and vacuum-based methods, are highly desirable. Among these, Plasma Enhanced Chemical Vapor Deposition (PECVD) stands out for its ability to grow a wide range of nanostructured scaffolds composed of metal oxides like TiO_2, SiO_2, or ZnO [2,3], as well as to decorate them with low-dimensional carbon nanostructures (e.g., carbon nanotubes (CNTs), graphene nanowalls (GNWs)) with precise morphological control—even at relatively low processing temperatures (<450 °C) [4,5].

In this work, we report the fabrication of highly conformal, GNW-decorated nanostructures—including nanotubes (NTs), high thickness nanotubes (HT-NTs), and nanostructured trees (Ntrees)—via a multistep PECVD process. The resulting 3D nanostructures exhibit high surface area and exceptional electrical properties. These nanomaterials were thoroughly characterized using SEM, XPS, TEM, NEXAFS, and in-situ Raman spectroscopy [6].

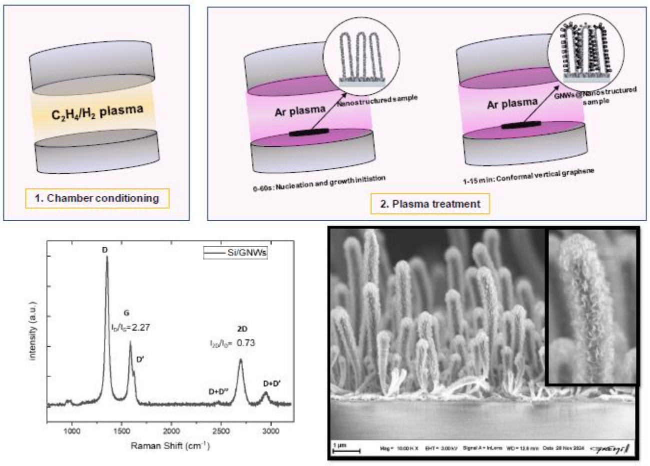

Fig. 1. GNWs@NTs overview

Keywords: graphene, PECVD, conformality, nanostructures, MEGs

References:
1. Borras et al. Nano Energy, 2019
2. Borras et al. Nanoscale 2011.
3. Borras et al. ACS Appl. Mater. Inter. 2020
4. Kovacevic et al. Nano-Micro Letters 2020
5. Kovacevic et al. Nanotechnology 2020
6. Kovacevic et al. Appl. Phys. Lett. 2014

Acknowledgements: We thank the projects PID2019-109603RA-I00, PID2022-143120OB-100, TED2021-130916B-I00 and PID2019-110430GB-C21 funded by MCIN/AEI/10.13039/501100011033 and by "ERDF(FEDER) A way of making Europe, Fondos NextgenerationEU and Plan de Recuperación, Transformación y Resiliencia", by the "EuropeanUnion", the EUH2020 program under grant agreement 3Dscavengers Starting Grant 851929. FNG and CLS thanks to the "VII Plan Propio de Investigación y Transferencia" of the Universidad de Sevilla.

SLIPS-TENGs: triboelectric nanogenerators with liquid infused porous surfaces as highly slippery drop energy harvesters

Fernando Núñez-Gálvez[1,2], **Nicolò di Novo**[2], **Carmen Lopez-Santos**[1,2] **and Ana Borrás**[2]

1Departamento de Física Aplicada I, Escuela Politécnica Superior, Universidad de Sevilla
2Nanotechnology on Surfaces and Plasma Lab, Institute of Materials Science of Seville (CSIC-US)

*fngalvez@us.es fernando.ngalvez@icmse.csic.es

With the growing demand for portable electronic devices, increasing attention has been directed toward harvesting electrical energy from ambient sources. Among these technologies, triboelectric nanogenerators (TENGs) play a critical role in capturing residual energy. [1,2] While most TENGs utilize polymer materials as the triboelectric layer in solid-liquid contact electrification, slippery liquid-infused porous surfaces (SLIPs) offer an alternative by enabling liquid-liquid interactions. SLIPs possess several advantageous properties—including antifouling, anticorrosion, self-lubrication, self-repair, stability, and anti-icing. Notably, their slippery nature creates an ideal environment for the rolling of raindrops, making them suitable for water-droplet-based TENGs operating in harsh environments. [3,4,5]

In our device, ultraporous nanostructured scaffolds of TiO_2 nanotubes are fabricated via plasma-enhanced chemical vapor deposition (PECVD) using a soft-template method with DAAQ or H_2Pc as organic precursors [6]. These scaffolds are subsequently infused with commercial lubricants such as silicone oil or Krytox. This approach yields surfaces with high roughness, large surface area, and hydrophobic characteristics that enhance charge transfer efficiency. Key parameters—including nanotube density, lubricant coverage, and wettability—were systematically investigated. Further characterization involved measuring water contact angles (WCA), tilt angles, and droplet rolling and sliding behavior across various temperatures. Finally, the triboelectric output performance of the device was evaluated and presented.

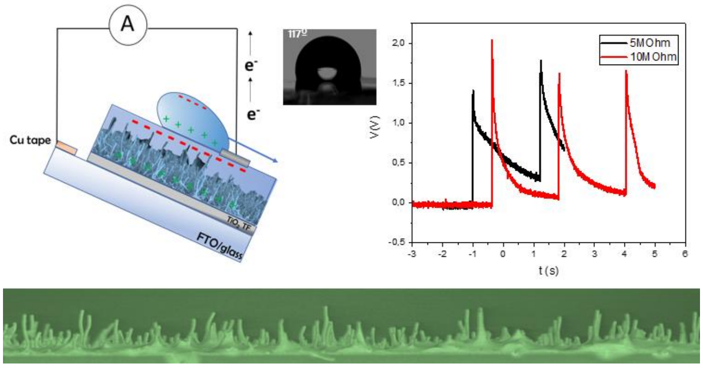

Fig. 1. SLIPS-TENGs overview.

Keywords*: slippery, TENGs, nanogenerators, SLIPS, PECVD*

References:

1. Borras et al. Nano Energy, 2019.
2. Borras et al. ACS Appl. Mater. Inter. 2020.
3. Montes et al. Surfaces and Interfaces, 2024.
4. Aizenberg et al. Nature, 2011.
5. Alcaire et al, Langmuir 2019.
6. Borras et al. Nanoscale 2011.

Acknowledgements:

We thank the projects PID2019-109603RA-I00, PID2022-143120OB-100, TED2021-130916B-I00 and PID2019-110430GB-C21 funded by MCIN/AEI/10.13039/501100011033 and by “ERDF(FEDER) A way of making Europe, Fondos NextgenerationEU and Plan de Recuperación, Transformación y Resiliencia”, by the “EuropeanUnion", the EUH2020 program under grant agreement 3Dscavengers Starting Grant 851929. FNG and CLS thanks to the “VII Plan Propio de Investigación y Transferencia” of the Universidad de Sevilla.

Controlling the Size and Surface Chemistry of Nickel Nanoparticles via a Modified Polyol Method

Gladel Saintilme[1,2], Renjie Wang[1], Xiao Tong[3], Sooyeon Hwang[3], Vivian Merk[1,2*]

[1] Department of Chemistry & Biochemistry, Florida Atlantic University, 777 Glades Road, Boca Raton, FL 33431, United States of America
2 Department of Ocean & Mechanical Engineering, Florida Atlantic University, 777 Glades Road, Boca Raton, FL 33431, United States of America
3 Center for Functional Nanomaterials, Brookhaven National Laboratory, Upton, NY 11973-5000, United States of America

This study presents a detailed exploration of the synthesis, morphological tuning, and physicochemical characterization of nickel nanoparticles (NiNPs) engineered for catalytic applications in freshwater and saltwater media. Using a modified polyol method adapted from Couto *et al.*[1], nanoparticles were synthesized under controlled thermal and chemical conditions with nickel chloride, polyvinylpyrrolidone (PVP) and sodium borohydride in ethylene glycol according to a synthesis protocol. The reaction temperature and reactivity of the reducing agent were found to significantly influence particle size. Fresh $NaBH_4$ enabled rapid burst nucleation, yielding uniform NiNPs in the 5-10 nm size range, as shown in Figure 1 through Transmission Electron Microscopy. Aged reagents led to larger, aggregated structures[2]. Post-synthesis processing included rigorous washing and sonication to minimize residual contaminants and enhance colloidal stability. The morphological and chemical characterization of NiNPs was conducted using transmission electron microscopy (TEM), dynamic light scattering (DLS), energy-dispersive X-ray spectroscopy (EDS), electron energy loss spectroscopy (EELS), and high-angle annular dark field (HAADF) in scanning TEM[3]. We will discuss a variety of surface stabilization approaches, such as carboxymethylcellulose (CMC), which influence particle dispersion, agglomeration behavior, and chemical accessibility. DLS and zeta potential analyses further corroborated the role of surface charge in nanoparticle stability[3]. XPS and EELS helped us quantify the level of surface oxidation occurring at various reaction temperatures, which could potentially affect the catalytic activity of NiNPs. The findings provide a systematic foundation for tailoring nickel nanoparticle synthesis and surface chemistry for various aqueous-phase applications. The work highlights the importance of precursor freshness, surfactant selection, and reaction temperature as controllable levers for engineering size, dispersion, and stability—critical factors for future integration into aqueous-phase systems and nanomaterial-based environmental technologies.

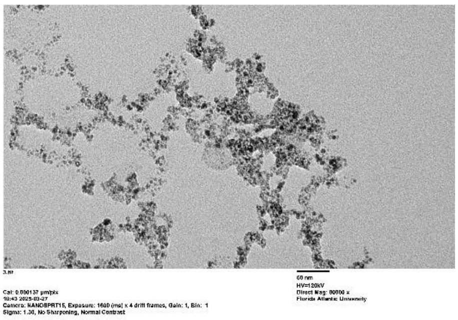

Fig. 1. Nickel nanoparticles averaging between 5-10 nm

Keywords*: Nickel nanoparticles, nanotechnology, polyol method, characterization, surface modification*

References:

1. Couto et al., Nickel nanoparticles obtained by a modified polyol process: synthesis, characterization, and magnetic properties, (2007).

2. Silva et al., Controlled Nickel Nanoparticles: A Review on How Parameters of Synthesis Can Modulate Their Features and Properties, AppliedChem 4(1) (2024) 86–106.

3. Ashraf et al., Effects of size and aggregation of nanoparticles on interfacial properties and tensile strength, Nanoscale Research Letters 13(1) (2018).

Acknowledgements: This research was funded by the U.S. National Science Foundation (grant number 2207642). This research used X-ray Photoelectron Spectroscopy and Electron Energy Loss Spectroscopy at the Center for Functional Nanomaterials (CFN), which is a U.S. Department of Energy Office of Science User Facility, at Brookhaven National Laboratory under Contract No. DE-SC0012704.

Plasma polymer nanoparticles from evaporated PLA precursor

Kateřina Škorvánková[1], Pavel Solař[1], Jaroslav Kousal[1], Zdeněk Krtouš[1]

[1]*Charles University, Faculty of Mathematics and Physics, Department of Macromolecular Physics, V Holesovickach 747/2, 180 00 Prague 8, Czech Republic*

Plasma polymer nanoparticles synthesized via vacuum thermal decomposition of polymers represent a novel class of nanomaterials with unique chemical and structural properties [1]–[7]. In this method, conventional polymers such as polylactic acid (PLA) are thermally decomposed in a vacuum chamber, generating volatile monomeric and oligomeric species, which are subsequently ionized and polymerized in a low-pressure plasma environment.

When used inside a gas aggregation nanoparticle source, the process yields nanoparticles rather than thin films already known from this process. This combined approach leverages the controlled decomposition of solid polymers and the highly reactive nature of plasma to produce nanoscale particles with amorphous, tunable cross-linked structures and adjustable surface functionalities. The process offers solvent-free synthesis of nanoparticles that have tunable structure in between the classical highly crosslinked plasma polymer (with very low retention of the original polymer structure) and the linear, non-crosslinked classical polymer.

Nanoparticles were deposited both under inert (argon) and reactive (argon/nitrogen) atmospheres, with varying plasma power, to investigate the influence of the deposition environment on nanoparticle characteristics.

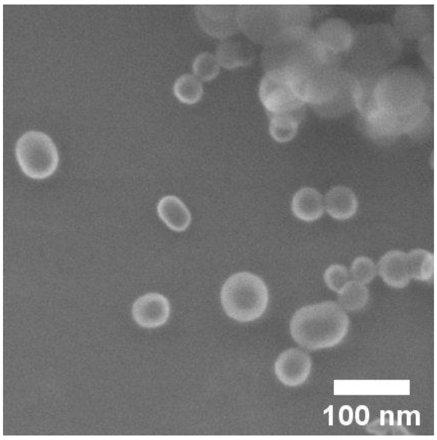

Fig. 1. Example of the plasma polymer nanoparticles from evaporated PLA

Keywords: Gas aggregation nanoparticle source, Vacuum thermal degradation, Plasma polymer, Nanoparticles

References:
[1] J. Kousal et al., in *NANOCON Conf. Proc. - Int. Conf. Nanomater.* (2022), pp. 261–266.
[2] J. Kousal et al., Vacuum 173 (2020) 109062.
[3] J. Kousal et al., in *NANOCON 2017, 9th Int. Conf. Nanomater. - Res. Appl.* (2017), pp. 461–466.
[4] Z. Krtouš et al., Surface and Coatings Technology 421 (2021) 127402.
[5] Z. Krtouš et al., Materials 14 (2021) 459.
[6] A. Choukourov et al., Vacuum 80 (2006) 923.
[7] A. Choukourov et al., Thin Solid Films 565 (2014) 249.

Acknowledgements: This work was supported by the grant GACR 25-15644S from the Grant Agency of the Czech Republic.

Name	Affiliation
Aballe, Lucia	ALBA Synchrotron Light Facility
Acosta Rivera, Maria Hiedra	Institute of Material Science of Seville (CSIC)
Angurel, Luis A	Universidad de Zaragoza - INMA
Aparicio, Francisco J	Materials Science Institute of Seville (CSIC-US)
Ares, Pablo	IFIMAC, Universidad Autónoma de Madrid
Arslonova, Shirin	Kaunas University of Technology
Barranco Quero, Angel	Institute of Material Science of Seville (CSIC)
Biederman, Hynek	Charles University MFF
Borghi, Francesca	Department of Physics, University of Milano
Borras Martos, Ana Isabel	Institute of Material Science of Seville (CSIC)
Budagosky Marcilla, Jorge Alejandro	Institute of Material Science of Seville (CSIC)
Choukourov, Andrei	Charles University, Faculty of Mathematics and Physics
Čurda, Pavel	University of South Bohemia
Czermak Álvarez, Triana	Institute of Material Science of Seville (CSIC)
De Navascues , Paula	Empa, Swiss Federal Laboratories for Materials Science and Technology
de Tena Álvarez, Nerea	Institute of Material Science of Seville (CSIC)
de Toro, José Ángel	University of Castilla-La Mancha
Delgado Álvarez, Juan	Consejo Superior de Investigaciones Científicas
del Moral Jalón, Jaime	CSIC
Del Sole, Regina	Università degli Studi di Bari Aldo Moro
Di Novo, Nicolo' Giuseppe	Nanotechnology on Surfaces and Plasma Lab, Materials Science Institute of Seville
Faupel, Franz	Kiel University
Fortio Godinho, Vanda Cristina	Institute of Material Science of Seville (CSIC)
Gao, Yan	ICMAB-CSIC
García Casas, Xabier	Universidad de Sevilla
Garrido Segovia, María	Instituto de Ciencia de Materiales de Madrid (ICMM-CSIC)
Grammatikopoulos, Panagiotis	Universidad de Castilla-La Mancha
Ferreira de Sousa Junior, Jose	CSIC
Hegemann, Dirk	Empa
Huttel, Yves	Instituto de Ciencia de Materiales de Madrid (CSIC)
Jumilla Núñez, Darío	Institute of Material Science of Seville (CSIC)
Kaur, Ramanpreet	CEMES/CNRS, Université de Toulouse
Konstantinidis, Stephanos	University of Mons
Koshy, Abel George	University of South Bohemia, Czech Republic
Krishna Mishra, Hari	Institute of Material Science of Seville (CSIC)
Kumar Avasthi, Devesh	UPES Dehradun
López Santos, Mª Carmen	Institute of Materials Science of Seville
Lotito, Sara	Università degli Studi di Bari Aldo Moro
Makasheva, Kremena	LAPLACE, CNRS, University of Toulouse
Martínez Orellana, Lidia	ICMM-CSIC
Moreno Martínez, Gloria Patricia	Instituto de Ciencias de los Materiales de Sevilla
Nikitin, Daniil	Charles University
Núñez Gálvez, Fernando	Institute of Material Science of Seville (CSIC)
Palmero, Alberto	Institute of Materials Science of Seville (CSIC – Univ. Seville), Spain.
Paz, Elvira	International Iberian Nanotechnology Laboratory (INL)
Saintilme, Gladel	Florida Atlantic University
Sánchez Valencia, Juan Ramón	Institute of Material Science of Seville (CSIC)

Schröder, Stefan	Faculty of Engineering, Kiel University
Skorvankova, Katerina	Charles University
Solař, Pavel	Charles University MFF KMF
Strunskus, Thomas	Chair for Composite Materials, Kiel University
Ruiz Gómez, Sandra	ALBA Synchrotron
Vahl, Alexander	INP Greifswald