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TÉCNICO LISBOA

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Center of Physics and Engineering of Advanced Materials



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Credits

CeFema Forum Coordination: Teresa Morgado, Diná Afonso and Pedro Sebastião **Graphic Design:** Mário Barros **Photography:** Ana Casimiro

Funded by FCT under the strategic project UID/CTM/04540/2013. **FCT** Fundação para a Ciência e a Tecnologia MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR Instituto Superior Técnico - Universidade de Lisboa (IST - UL), is the largest school of Engineering, Science and Technology in Portugal. Since 1911, IST's mission is providing top quality higher education. It has collaborated with many prestigious RD&I and technology transfer institutions worldwide.

Internationalization has been a key aim with increasing participations in international academic networks (e.g. CLUSTER, TIME, CESAER, MAGALHÃES, EIT-KIC InnoEnergy). IST has participated in Dual Master programmes, and joint PhD programmes with MIT, CMU, UT-Austin, and EPFL and in EC-funded projects, such as: FP7, H2020, Marie Curie Actions, ENERGY, ERA, ERC, EURATOM, LEONARDO DA VINCI, SOCRATES, TEMPUS, LIFE, ALFA, etc.

The Center of Physics and Engineering of Advanced Materials (CeFEMA) is a unique research group of IST, because it congregates theoretical and experimental physicists, materials, chemical, and mechanical engineers, allowing an integrated approach to new materials development, from first principles design and modelling to materials synthesis, testing and application.

CeFEMA's mission consists of advancing materials science and engineering by theoretical and experimental research to the highest international scientific standards; providing advanced education / training of young researchers at high scientific level; promoting knowledge transfer to national / international development; pursuing projects and technology transfer to industry.



Introduction	Research Groups	ТР	CFNMRS	LASP	MNM	MCEP	Contacts

TP Theoretical Physics Group

Research areas

- Search for new phases of matter
- Dense and condensed systems
- Applications of information theory
- Systems far from equilibrium
- Resonances and bound states
- Spintronics
- Differential geometry and applications to physical systems

Goals

Search for new phases of matter, their characterization and potential for new understanding of physical systems and possible interesting applications.

Strengthen existing collaborations with experimental groups and foster new collaborations both inside the Center and with other scientists.

Study of systems far from equilibrium and interrelations between various branches of physics, mathematics and information theory. Presence of non-local extended structures or defects in many of the systems studied that require treatments beyond local field theories.



Magnetization switching times of a macrospin

Introduction	Research Groups	TP	CFNMRS	LASP	MNM	MCEP	Contacts

TP Theoretical Physics Group

Current topics

Study of interactions in magnetism, superconductivity and topological phases in graphene and in novel 2D materials with technological potential.

Structure and decays of exotic odd-even and odd-odd nuclei at the extremes of stability.

Spin dynamics in magnetic nanostructures induced by ultrafast optical injection of charge and magnetic excitations.

Study of non-equilibrium phase transitions and a route to thermalization in strongly interacting systems.

Employment of Resonance-Spectrum Expansion, both for scattering and production processes.

Geometric phases and their connection to physical problems and topology.



Nilsson levels for the protons in 180Ta

Introduction	Research Groups	ТР	CFNMRS	LASP	MNM	MCEP	Contacts

TP Theoretical Physics Group



Energy-momentum of some spin excitations

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Introduction	Research Groups	TP	CFNMRS	LASP	MNM	MCEP	Contacts

CFNMRS <u>Complex Fluids</u>, NMR and Surfaces Group

Research Topics

- Physical properties and applications of soft matter and complex fluids (e.g. liquid crystals (LC), polymers, dendrimers, ionic liquids)
- Optoelectronic devices based in the thin film technology (e.g. TFTs, solar cells)
- Study of low dimensional systems (e.g. 0-, 1- and 2-dimensional structures like WO₃ nanospheres, ZnO nanorods, and GaN/AlGaN superlattices)

Experimental Facilities

- NMR (superconducting magnet 7T; variable field 0-2.4T; fast field cycling 10-4 T – 0.2 T)
- Polarising Optical Microscopy
- Powder X-ray diffraction
- LC cells Electro-Optical characterization
- Atomic Force Microscopy
- Thin film deposition facilities (e.g. plasma-enhanced chemical vapor deposition, RF plasma-enhanced reactive thermal evaporation, hybrid pulsed laser deposition, chemical bath deposition, thermal evaporation)
- Thin film characterization (conductivity and photoconductivity, visible spectroscopy, FTIR, profilometry; Raman; photoluminescence; photocapacitance; microwave reflection; laser interference)



UHV laser deposition chamber

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CFNMRS <u>Complex Fluids</u>, NMR and Surfaces Group

Complex Fluids and NMR

In the field of Liquid Crystals (LC), the research efforts of the group involved most of the LC phases and LC / polymer composite materials. The study of those systems by means of NMR and electro and magneto-optical techniques is important for the understanding of their fundamental properties and technological applications such as electrical controllable transparency windows and display technology with low environmental impact.

lonic liquids are compounds with increasing impact on the development, design and the use in clean technology (e.g. "Green Chemistry", CO_2 harvesting). The main scientific outcomes from the research activities on this topic encompass the description of molecular dynamics, structure and molecular interactions and their influence on macroscopic properties of ionic liquids based systems.



Variable field NMR electromagnet

Introduction	Research Groups	TP	CFNMRS	LASP	MNM	MCEP	Contacts

CFNMRS <u>Complex Fluids</u>, NMR and Surfaces Group

Complex Fluids and NMR

The study of molecular order and dynamics of soft matter systems as base materials for hosting dopants is another key research topic of the group. These advanced composite systems might present a great variety of applications such as pharmaceutical drug carriers, enhanced transport properties in membranes, energy storage, gas absorption, development of fuel cell electrolytes, CO₂ capture, functionalized ionic liquid systems with magnetic and electric controlled properties.

The development of new fast field cycling (FFC) NMR relaxometers with a very large frequency operational range is also a key activity of the group. The expected spin-off of this technology to the industry has been supported by spreading the use of FFC NMR in the study of a diversified set of systems.



X-ray diffractometer's setup detail

Introduction	Research Groups	TP	CFNMRS	LASP	MNM	MCEP	Contacts

CFNMRS Complex Fluids, NMR and Surfaces Group

Thin Films and Surfaces

The AFM characterization of membranes for blood treatment, the tailoring of such membranes to improve hemocompatibility, and the preparation and analysis of biological liquid-crystal photosensitive films is an important research activity of the group.

The study of thin films and low dimensional quantum structures include: the application of new dopant predeposition methods at low temperature for the production of CMOS integrated circuits and for a-Si/c-Si heterojunctions of HIT type; the study and application of transparent conductive oxide (TCOs) thin films in sensors, in particular in photodetectors; the deposition of: (0-D) nanospheres of tungsten and molybdenum oxide, (1-D) nanorods of ZnO and ferroelectric NKN, and (2-D) superlattices of (amorphous) a-Si:H/a-SiC:H and (crystalline) GaN/AlGaN. Higher sensitivity and increased spatial resolution of these structures are important for applications such as medical imaging.



AFM tip's modification setup detail

Introduction	Research Groups	TP	CFNMRS	LASP	MNM	MCEP	Contacts

CFNMRS Complex Fluids, NMR and Surfaces Group

Thin Films and Surfaces

Thin film deposition techniques include chemical vapour (CVD), rf-plasma enhanced reactive thermal deposition evaporation (PERTE), hybrid pulsed laser deposition (PLD), chemical bath deposition (CBD), and thermal evaporation with subsequent electrolytic transport. The characterization of morphological, structural, and optoelectronic properties of the thin films is achieved by means of SEM and XRD, complemented by AFM. Both recombination and transport are studied by photoluminescence and current-voltage characteristics and supported by non-invasive and contactless methods like photocapacitance and transient microwave reflection Materials wide-bandgap ranged from measurements. semiconductors and magnetic films, to thin organic films and biological membranes are also investigated.

On a higher level, the group studies new material systems and process technologies. Examples are the use of copper oxide films in field-effect transistors, the inclusion of ferroelectric thin films for hysteresis and memory effects, the realization of pixel detectors based and zinc oxide thin films, and the fabrication of solar cells using a new doping procedure.



SEM image of a polycrystalline ferroelectric NKN thin film

Introduction	Research Groups	TP	CFNMRS	LASP	MNM	MCEP	Contacts

CFNMRS Complex Fluids, NMR and Surfaces Group



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Laser-Assisted Synthesis and Processing Group

Research Areas

Ultrafast laser materials processing

- Study of self-organised nanostructures created by ultrafast laser processing and their application in medicine, microfluidics and photonics.
- Spin-dependent properties of hybrid heterostructures created in laser patterned thin films.
- Phase transformations due to ultrafast laser irradiation of materials.
- Ultrafast laser ablation for minimally invasive surgery. Effect of ultrafast laser ablation on the viability of biological tissues.

Materials and nanostructures for applications in energy, thermal management and spintronics

- Thermoelectric properties of Si-based heterostructures.
- Study of electrical, magnetic and magnetotransport properties of composite materials for magnetoresistive and spintronic devices.



Ultrafast laser materials processing system details

Introduction	Research Groups	TP	CFNMRS	LASP	MNM	MCEP	Contacts

Laser-Assisted Synthesis and Processing Group

Research Areas

Study of physical and electrochemical properties of SnO²/C nanostructures prepared by pulsed laser deposition.

- Synthesis and characterization of core-shell nanoparticles for fuel cells electrocatalysts.
- Laser processing and synthesis of metallic and composite materials for medical and aerospace applications
- Laser deposition of single crystalline high-temperature materials for the aerospace industry.
- Laser-assisted combinatorial design of metallic alloys and metalmatrix composite systems.

Light detection and ranging (LIDAR) and Laser-induced flourescent - light detection and ranging (LIF-LIDAR) environmental applications.

Materials characterization and testing.

Integriy, reability and failure studies.



Metal 3D printing by laser powder deposition

Introduction	Research Groups	TP	CFNMRS	LASP	MNM	MCEP	Contacts

Laser-Assisted Synthesis and Processing Group

Examples of FCT Projects

BenthicLIF – Estuarine phytobenthic communities studied by laser induced fluorescence. FCT project PTDC/MAR/117929/2010, 2012-2015.

SpinText – Engineering spin textures for magnetoelectronics. FCT Project PTDC/FIS/121588/2010, 2012-2015.

SHELL – Novel Composite Functionalized Shell NanoCatalyst for Fuel Cell Applications, FCT Project PTDC/CTM-ENE/1585/2012, 2013-2015.

Titanate nanotubes photosensitization by narrow bandgap semicondutor nanoparticles. FCT Project PTDC/CTM-NAN/113021/2009, 2011-2014.

TITAN – Novel Titanium alloys for biomedical applications, project FCT PTDC/CTM/098115/2008, 2010-2013.

FSENS – Optofluidic sensor based on 3D micro- and nanomachining with femtosecond lasers. FCT project PTDC/FIS/102127/2008, 2010-2013.

SEMISPIN – High Curie temperature dilute magnetic oxide Semiconductors for application in Spintronics. FCT project PTDC/CTM/101033/2008, 2010-2013.



SEM wires observation showing the friction marks on the wires http://dx.doi.org/10.4028/www.scientific.net/MSF.730-732.325

Introduction	Research Groups	TP	CFNMRS	LASP	MNM	MCEP	Contacts

Laser-Assisted Synthesis and Processing Group

Examples of EU Projects

IMPALA – Intelligent Manufacture from Powder by Advanced Laser Assimilation, FP7-NMP-2007-SME-1, NMP2-SE-2008-214380.

NANOMICRO – Nano/Micro Integration in Micromanufacturing, FP7-NMP-2008-SME-2, FP7-NMP-2008-3.5-1, Project 228815.

DEOSOM – Detection and Evaluation of Oil Spills by Optical Methods, AMPERA ERA-Net project (Accidental Marine Pollution) ERA-AMPERA/0002/2007.

RAMATI – Rapid manufacturing of titanium implants, FP6 STREP Project NMP2-CT-2003-505954.



Femtosecond laser ablation of cortical bone, for orthopaedic surgery applications. Up: Craters produced in static mode with 130 fs (on the left) and 560 fs (on the right), using a 1030 nm laser. Down: Track produced with 25 fs, 775 nm laser (on the left); Volume ablated using a 560 fs, 1030 nm laser (on the right).

Introduction	Research Groups	TP	CFNMRS	LASP	MNM	MCEP	Contacts

Laser-Assisted Synthesis and Processing Group



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Introduction	Research Groups	TP	CFNMRS	LASP	MNM	MCEP	Contacts

MNM

Multiscale Nanostructured Materials Group

Research Areas

- Development, production and characterization of multiscale bulk nanostructured metal and ceramic matrix composites via the powder route and solid/liquid processing for functional and structural performance under extreme conditions.
- Development of new dental materials and characterization of its wear and tribological behaviour.
- Development and characterization of submicron and nanoparticles, and their colloidal suspensions.
- Development and characterization of intermetallic compounds and complex metal phases, their phase transitions and crystalline defects.
- Development of new concrete high strength formulations based on dispersion of submicron carbon materials.
- Mechanical characterization at fine scales.

The group is focused on materials engineered so that multiple length scales are simultaneously explored. The primary activity is centred on multiscale dispersions in bulk nanostructured materials tailored for functional and structural performance under extreme conditions.



Development nanostructured metal ceramic composites by infiltration

Introduction	Research Groups	TP	CFNMRS	LASP	MNM	MCEP	Contacts

MNM

Multiscale Nanostructured Materials Group



Development colloidal suspensions

The Cuo-Tiron system. Zeta potential vs. pH curves for CuO suspensions. (\circ Bare CuO particles; \bullet 0.1 wt % Tiron). Calculated Dissociation vs. pH curve for Tiron presented in gray background ($C_6H_4O^8S_2^{-2}$; $C_6H_3O_8S_2^{-3}$; ---- $C_6H_2O_8S_2^{-4}$. Predominant species in each pH range up to pKa₄ are shown).

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Introduction	Research Groups	TP	CFNMRS	LASP	MNM	MCEP	Contacts

Membrane, Chemical and Electrochemical Processes Group

Research areas

Synthesis and characterization (SEM, TEM, XPS, AFM, ATR-FTIR) of:

- polymeric membranes based on new nanostructured functional materials;
- bio and hemocompatible bi-soft segment polyurea / polyurethane membranes for blood oxygenators and immunoisolation;
- polymeric, mixed matrix and nanocomposite membranes, by tailoring membrane design, morphology and characteristics on a molecular level to enhance mass transport.

Modelling and optimization of flow and mass transfer in plate-andframe and spiral wound modules, artificial organs and microfluidic systems, by using Computer Fluid Dynamics, and experimental techniques of Particle Image Velocimetry and Holographic Interferometry.

Design and optimization of membrane hybrid processes (Ultrafiltration / Nanofiltration / Reverse Osmosis / Electrodialysis) for applications in environment, water, chemicals, medicines, medical devices, food, wine, biorefineries, etc.



EKA Electro Kinetic Analyser

Introduction	Research Groups	TP	CFNMRS	LASP	MNM	MCEP	Contacts

Membrane, Chemical and Electrochemical Processes Group

Research areas

Synthesis, characterization and testing of new materials and electrochemical processes for energy and environmental applications:

- novel materials and technologies for industrial application to environmental friendly energy conversion and storage processes
- (nano)materials for anodes / cathodes in low temperature fuel cells, viz. metal-based nanosized catalysts for borohydride electro-oxidation, three dimensional cathodes for O₂ / H₂O₂ reduction, small-scale borohydride fuel cells and alcohol-fuelled proton exchange membrane fuel cells;
- novel alkaline electrolysers and materials for water electrolysis, viz. functional cathodes for H₂ production;
- lithium batteries with enhanced recyclability and disposable rechargeable Zn / MnO₂ printable batteries on paper.



Rotating Ring Disk Electrode controlled by ALS 2325 bipotentiostat

Introduction	Research Groups	TP	CFNMRS	LASP	MNM	MCEP	Contacts

Membrane, Chemical and Electrochemical Processes Group

Publications

Al Cavaco Morão, AM Brites Alves, MD Afonso, Concentration of clavulanic acid broths: Influence of the membrane surface charge density on NF operation, Journal of Membrane Science, 281 (2006) 417-428. doi:10.1016/j.memsci.2006.04.010

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V Geraldes, AM Brites Alves, Computer program for simulation of mass transport in nanofiltration membranes, Journal of Membrane Science, 321 (2008) 172-182. doi:10.1016/j.memsci.2008.04.054

JA Restolho, A Prates, MN de Pinho, MD Afonso, Sugars and lignosulphonates recovery from eucalyptus spent sulphite liquor by membrane processes, Biomass & Bioenergy, 33(11) (2009) 1558-1566. doi:10.1016/j.biombioe.2009.07.022

C Korzenowskia, M Minhalma, AM Bernardes, JZ Ferreira, MN de Pinho, Nanofiltration for the treatment of coke plant ammoniacal wastewaters, Separation and Purification Technology, 76(3) (2011) 303-307. doi:10.1016/j.seppur.2010.10.020



Nanofiltration / Reverse Osmosis Lab-Unit P-28

Introduction	Research Groups	TP	CFNMRS	LASP	MNM	MCEP	Contacts

Membrane, Chemical and Electrochemical Processes Group

Publications

M Rosa, C Lopes, EP Melo, SK Singh, V Geraldes, MA Rodrigues, *Measuring and modeling hemoglobin aggregation below the freezing temperature*, Journal of Physical Chemistry B, 117(30) (2013) 8939-8946. doi: 10.1021/jp4035369

AS Figueiredo, MG Sánchez-Loredo, A Maurício, MFC Pereira, M Minhalma, MN de Pinho, *Tailoring of structures and permeation properties of asymmetric nanocomposite cellulose acetate/silver membranes*, Journal of Applied Polymer Science, 132 (2015) paper 41796. <u>doi: 10.1002/APP.41796</u>

CAC Sequeira, DMF Santos, PSD Brito, *Electrocatalytic activity of simple and modified Fe-P electrodeposits for hydrogen evolution reaction from alkaline media*, Energy, 36 (2011) 847-853. <u>doi:10.1016/j.energy.2010.12.030</u>

DMF Santos, CAC Sequeira, *Sodium borohydride as a fuel for the future*, Renewable & Sustainable Energy Reviews, 15 (2011) 3980-4001. <u>doi:10.1016/j.rser.2011.07.018</u>

B Šljukic, M Vujkovic, L Amaral, DMF Santos, RP Rocha, CAC Sequeira, JL Figueiredo, *Carbon-supported Mo₂C electrocatalysts for hydrogen evolution reaction*, Journal of Materials Chemistry A, 3 (2015) 15505-15512. <u>doi:</u> 10.1039/c5ta02346g



Electrodialysis bench-scale unit EUR2C-7P18

Introduction	Research Groups	TP	CFNMRS	LASP	MNM	MCEP	Contacts

Membrane, Chemical and Electrochemical Processes Group

Publications

DSP Cardoso, L Amaral, DMF Santos, B Šljukic, CAC Sequeira, D Macciò, A Saccone, *Enhancement of hydrogen evolution in alkaline water electrolysis by using nickel-rare earth alloys*, International Journal of Hydrogen Energy, 40 (2015) 4295-4302. <u>doi:10.1016/j.ijhydene.2015.01.174</u>

DSP Cardoso, S Eugénio, TM Silva, DMF Santos, CAC Sequeira, MF Montemor, Hydrogen evolution on nanostructured Ni-Cu foams, RSC Advances, 5 (2015) 43456-43461. doi: 10.1039/C5RA06517H

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Nanofiltration / Reverse Osmosis LabUnit M20

Introduction	Research Groups	TP	CFNMRS	LASP	MNM	MCEP	Contacts

MCEP Membrane, Chemical and Electrochemical Processes Group

PAR 273A Potentiostat / Galvanostat for electrochemical / impedance studies

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