NanoSecurity & Defense International Conference

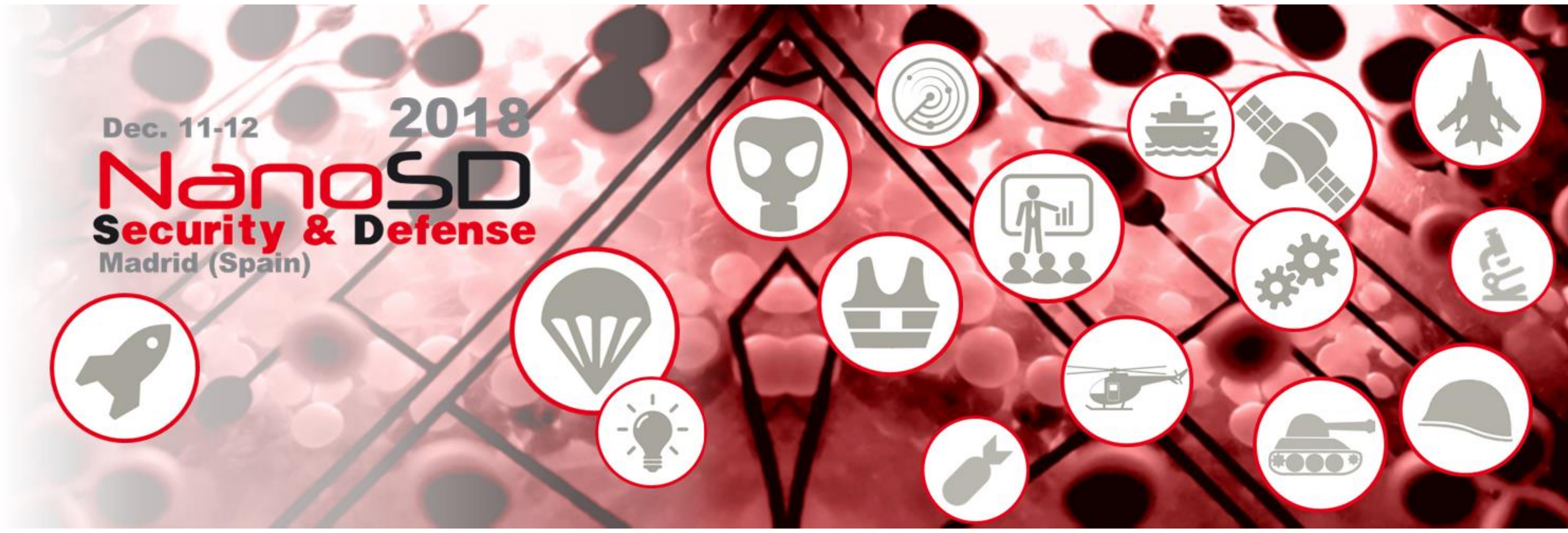
Dec. 11-12 2018

NanoSD

Security & Defense

Madrid (Spain)

Index



Foreword

We take great pleasure in welcoming you to Madrid (Spain) for the 5th edition of the nanoSD International Conference (nanoSD2018).

After several editions organised in Madrid, Avila and Bilbao nanoSD2018 will again provide in Madrid an opportunity to discuss general issues and important impacts of nanotechnology in the development of security and defence. A broad range of defence and security technologies and applications, such as nanostructures, nanosensors, nano energy sources and nanoelectronics which are influencing these days will be discussed.

It is evident that nanotechnology can bring many innovations into the defence world such as new innovate products, materials and power sources. Therefore, nanoSD2018 will present current developments, research findings and relevant information on nanotechnology that will impact the security and defence.
nanoSD is now one of the premier European conferences devoted to Nanotechnology for Security & Defence.

We are indebted to the following Scientific Institutions, Companies and Government Agencies for their financial support: ICEX España Exportación e Inversiones, Centro Superior de Estudios de la Defensa Nacional (CESEDEN) and Universidad Politécnica de Madrid (UPM).

In addition, thanks must be given to the staff of all the organising institutions whose hard work has helped planning this conference.

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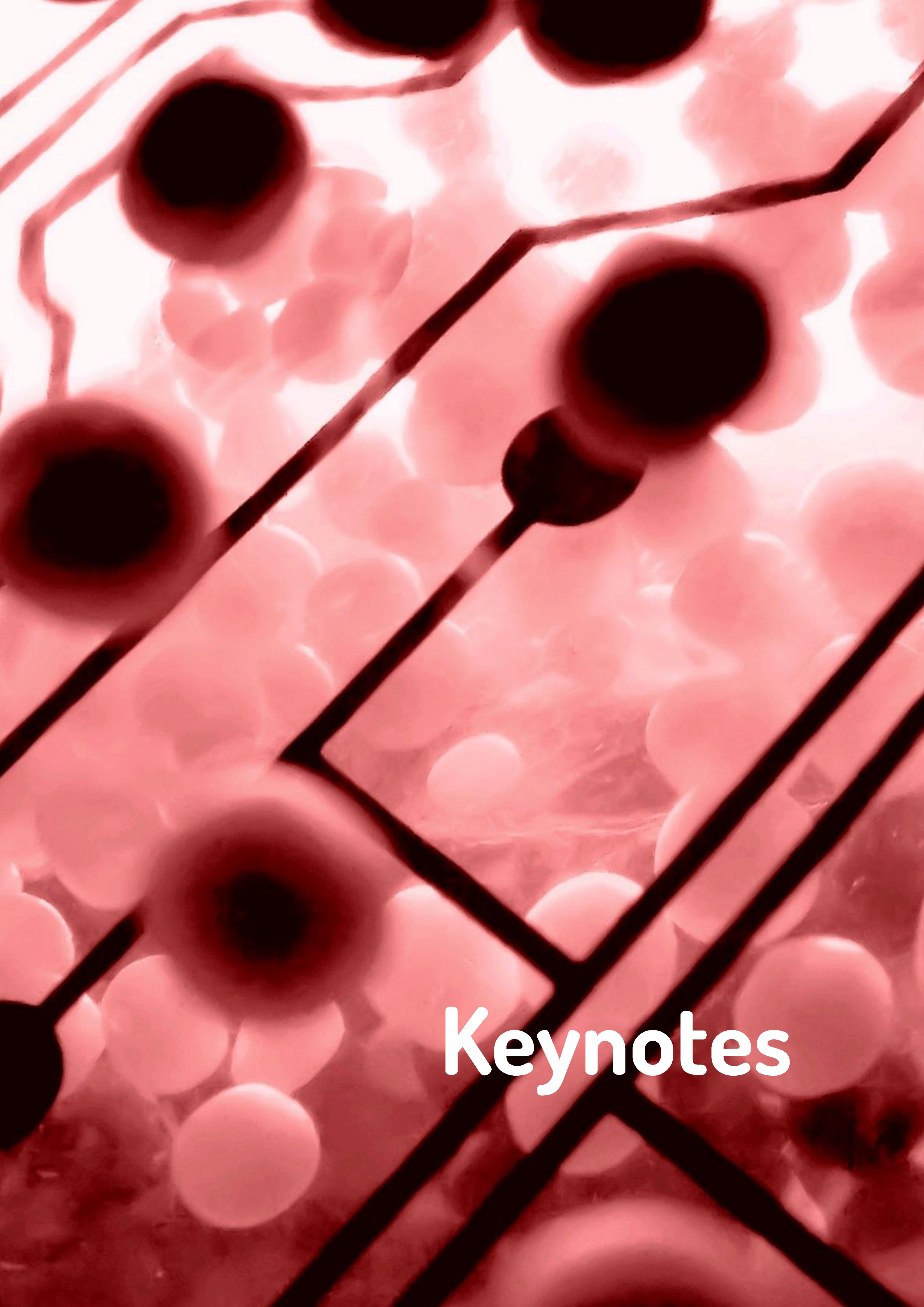

Keynotes

Nanotechnology for Security and Defense. CBRN and Materials Department at INTA-Campus La Marañosa

Ltc. Juan Carlos Cabria Ramos, Paloma Lorenzo Lozano, Inés Peraile Muñoz, Matilde Gil García

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Abstract

Biological warfare agents involve a wide range of risks, since they can be deliberately addressed not only at human population but also at livestock or crops [1], causing effects both on human health (mortality/morbidity/incapacity) and on the economy (failed harvest, death of livestock, health and safety investment) [2]. Therefore, much effort has been devoted to the research, design and development of new technologies for their detection and identification. New low-cost sensor devices that allow their detection and early identification are very significant in the effective fight against these agents. The need to carry out analytical determinations with specific devices, easy to use and low cost has led to the development of immunobiosensors [3]. In the OPTONANOSENS project, national project financed by MINECO-FEDER funds, the main objective is the development of analysis devices based on photonic technology for the early and reliable of identification of biological threats as a consequence of a CBN attack.

In the device nanostructured, supports based on nanofibers (manufactured by TECNALIA) will be used. These nanofibers will be used for the immobilization of specific antibodies. In the immobilization assays BSA as used as a surrogate of biological warfare agent, in particular of protein toxin and a specific antibody against BSA will be used.

Three immobilization methods were assayed: passive adsorption, covalent bond and affinity bond by intermediate proteins, as streptavidin-biotin and chimerical protein A/G.

The results show on the one hand, that the more effective system for being used in a biosensor is the antibody immobilization by A/G protein and on the other hand, nanofibers provide a significant increase of the sensitivity due to their high surface/volume relation offering a greater immunocapture capability. Lastly, this immunocapture system was validated with ricin toxin, that can be used as a biological warfare agent.

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Figures

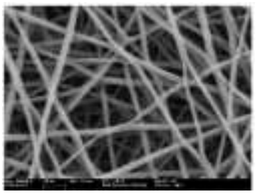

Figure 1: Nanofibers PA6 5% pyridine

Acknowledgements: MINECO / FEDER funds.

Chemically functionalized nanomaterials based sensors and colorimetric papers for the detection of nerve agents

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Organophosphorus compounds represent one of the most important and lethal classes of chemical warfare agents (e.g. Sarin, Soman, Tabun, VX). These agents have been used for terrorist attacks in the past (e.g. 1995 Japanese subway attack). The efficient detection of OPs has recently become an increasingly important research goal to circumvent the drawbacks of commercially available detectors. Nanomaterials based field effect transistors are extremely sensitive towards electrostatic change. Differents strategies have been developed for the detection of organophosphorus compounds (OPs) using nanomaterials based field effect transistors functionalized with a chemical receptor specific to traces of organophosphorus agents.[1-5] We demonstrated new concepts for electrical detection of OPs based on the chemical functionalization of a silicon nanowire field-effect transistor (SiNW-FET) or by the functionalization of the gold electrodes of a carbon nanotubes field effect transistor (CNTFET). The sensors are a very sensitive towards OPs. Their integration into hand held device will be presented. In a second part, efficient colorimetric papers for the detection and the identification of nerve agents will be presented. [6]

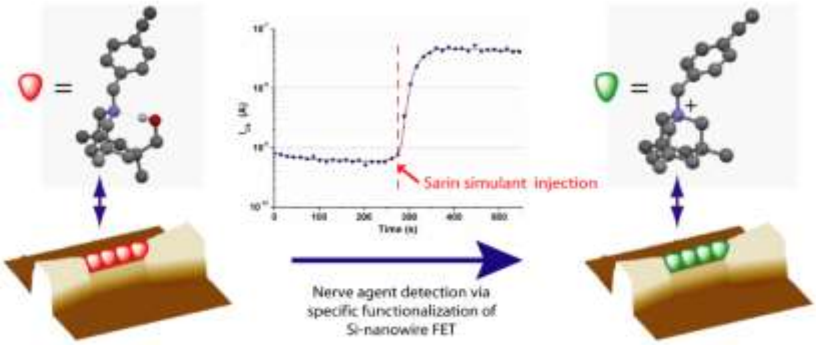

Figure 1: Detection of nerve agents via specific functionalization of nanomaterials based field effect transistors

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Nanofabrication and microscopies based on focused electron / ion beams for applications in nanosafety

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In the present contribution, we will highlight the relevance of focused electron and ion beams for applications in nanosafety. We will first introduce the capabilities of dual beam FIB-SEM (Focused Ion Beam – Scanning Electron Microscope) equipment for nanofabrication and for advanced microscopic characterization of materials and devices, which can be in particular applied to nanosafety. One example of such devices is a gold nanohole array [1], depicted in Figure 1. In this device, the light transmission can be tuned as a function of the wavelength by choosing appropriate dimensions of the holes. This device can be eventually used for label-free detection of toxic molecules absorbing light at wavelengths that coincide with those transmitted by the nanohole array. In the second part of the talk, examples will be provided in which nanoscale imaging with focused electron / ion beams provide useful information on materials relevant for nanosafety, including their nanoscale three dimensional (3D) structural and compositional characterization.

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Figures

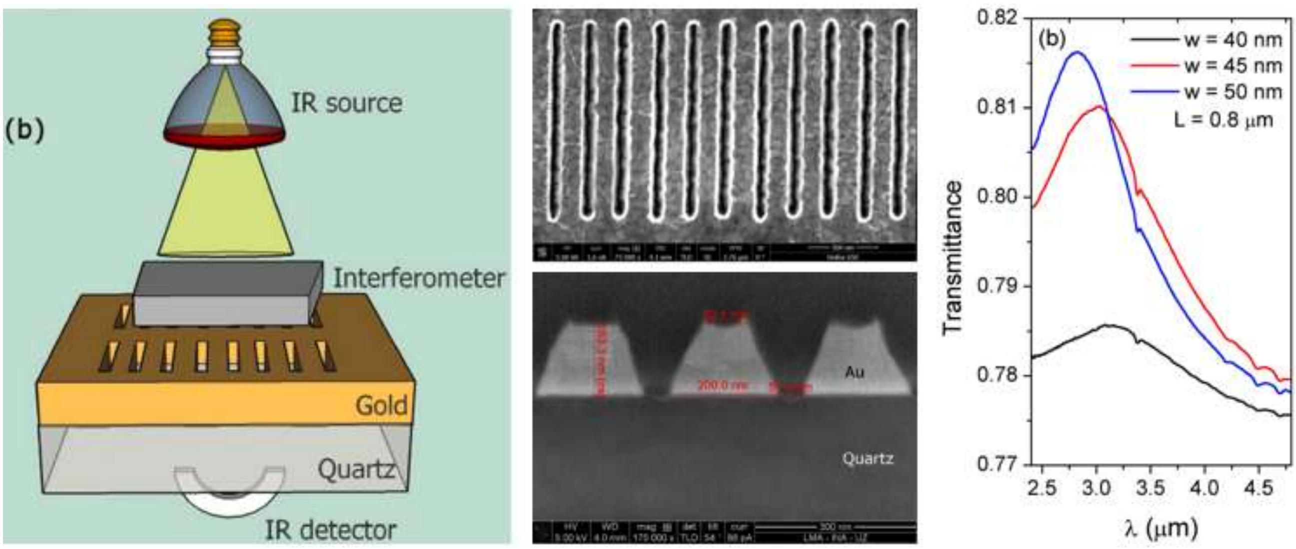

Figure 1: Left: Setup for the measurement of light transmission in the infrared regime **Middle:** Nanofabrication by electron-beam lithography of a gold-based plasmonic device with *Extraordinary Optical Transmission* **Right:** Measurements of the light transmission as a function of its wavelength

Fabrication of ultra-monodisperse colloidal gold nanorods by means of femtosecond laser irradiation

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The optical response of gold nanorods strongly depends on their aspect ratio, defined as the quotient of their length and diameter, which defines the position of its longitudinal localized surface plasmon resonance (LSPR). Besides, in the colloidal synthesis of gold nanorods exists an inherent level of polidispersity in size and shape that affects the aspect ratio of the nanorod dispersion. Then, The polidispersity in terms of aspect ratio greatly affects their optical behaviour by broadening their absorption band and lowering its intensity, which could compromise its feasibility for technological applications that require optimal coupling between the plasmon resonance and the excitation wavelength.

Here, a method based on femtosecond laser irradiation is presented to reduce the aspect ratio polidispersity in a way that the irradiated colloids present an exceptional ultranarrow LSPR, near the theoretical limit. The irradiation regime is characterized by a gentle multishot reduction of the aspect ratio, barely affecting the nanoparticle shape and size [1].

This kind of monodisperse nanoparticles has the potential use for optical data storing applications [2] and for information encryption [3,4].

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Fabrication of nanostructured coatings for energy applications

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Energy production and the combat against climate change are at the centre of our daily concerns and stand for a socioeconomic priority. Nowadays, great efforts are being made to develop different ways of providing clean energy sources to supply our increasing energy demand abating provisions of fossil fuels.

In this work, we are going to focus on the fabrication of nanostructured coatings and its capabilities to contribute to develop "clean" energy sources. Firstly, we are going to present the power of the sputtering technique to fabricate nanostructured coatings with the desired morphology in large area. We are going to show the influence of the sputtering parameters such as working gas pressure, distance between the target and the substrate, substrate temperature, voltage applied to the cathode, angle of incidence of the particle flux and sputtering configuration (DC, HiPIMS) on the morphology of the produce coatings. Then, by combining experimental and multiscale simulations (Density Functional Theory Object Kinetic Monte Carlo and Molecular Dynamics) results, we are going to discuss the capabilities and limitations of nanostructured W to be used as plasma facing material in nuclear fusion reactors, highlighting the role of nanostructurization in the light species (H) behavior [1-5].

Acknowledgments

The work was financed by the M.I.N.E.C.O (Spain) under the project RADIAFUS ENE-2012-39787-CO6, MATFUSLA AIC-A-2011-0718, by the EUROfusion Consortium under the project AWP15-ENR-01/CEA-02 and, by the Comunidad de Madrid (Spain) under the project S2013/MIT-2745.

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NANOBIOSENSORS FOR SAFETY AND SECURITY APPLICATIONS

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There is a high demand to develop innovative and cost effective devices with interest for safety and security applications. The development of such devices is strongly related to new materials and technologies being nanomaterials and nanotechnology of special role. We study how new nanomaterials such as nanoparticles, graphene, nano/micromotors can be integrated in simple sensors thanks to their advantageous properties. Beside plastic platforms physical, chemical and mechanical properties of cellulose in both micro and nanofiber-based networks combined with their abundance in nature or easy to prepare and control procedures are making these materials of great interest while looking for cost-efficient and green alternatives for device production technologies. How to design simple paper-based biosensor architectures? How to tune their analytical performance upon demand? How one can couple nanomaterials such as metallic nanoparticles, quantum dots and even graphene with paper and what is the benefit? How we can make these devices more robust, sensitive and with multiplexing capabilities? Can we bring these low cost and efficient devices to places with low resources, extreme conditions or even at our homes? Which are the perspectives to link these simple platforms and detection technologies with mobile communication? I will try to give responses to these questions through various interesting applications related to bacteria, pesticides and other highly toxic compounds including heavy metals and a highly demanded element such as uranium in waters. The developed devices are based on lateral flow technology and the use of nanoparticles and other nanomaterials as sensitive labels or signal-generation tools.

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[1] Authors, Journal, Issue (Year) page (Calibri 11) Indicate references with sequential numbers within [square brackets].
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[4] Authors, Journal, Issue (Year) page (Calibri 11)

Multiple possibilities of nanoparticulate biomaterials

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Biomaterials have played a central role in human society since the onset of civilization, including security and defense (SD) as a fundamental part of their deployments. Materials such as wood, wool, or cotton, to mention just a few, have been and still are, part of our life styles all over the world. Hence, the incorporation of the nanoscale into materials science could not have taken place without a special attention to biomaterials in the form of nanoparticles, the nanoparticulate biomaterials. Proteins, nucleic acids, sugars, lipids, and other natural products are in the center of the development of nanobiotechnology. Natural nanoparticles, like viruses for instance, are also significant players in the field. Nanomedicine and agri-food, which are life sciences-related applications, are perhaps the most immediate and obvious ones, but SD is not out of nanobiotech. In this presentation an overview of some of the most promising SD nanobiotechnological developments will be considered. These include among others, long-term data storage, energy-generating nanodevices, and optical applications at the nanoscale level. Other possibilities will also be mentioned.

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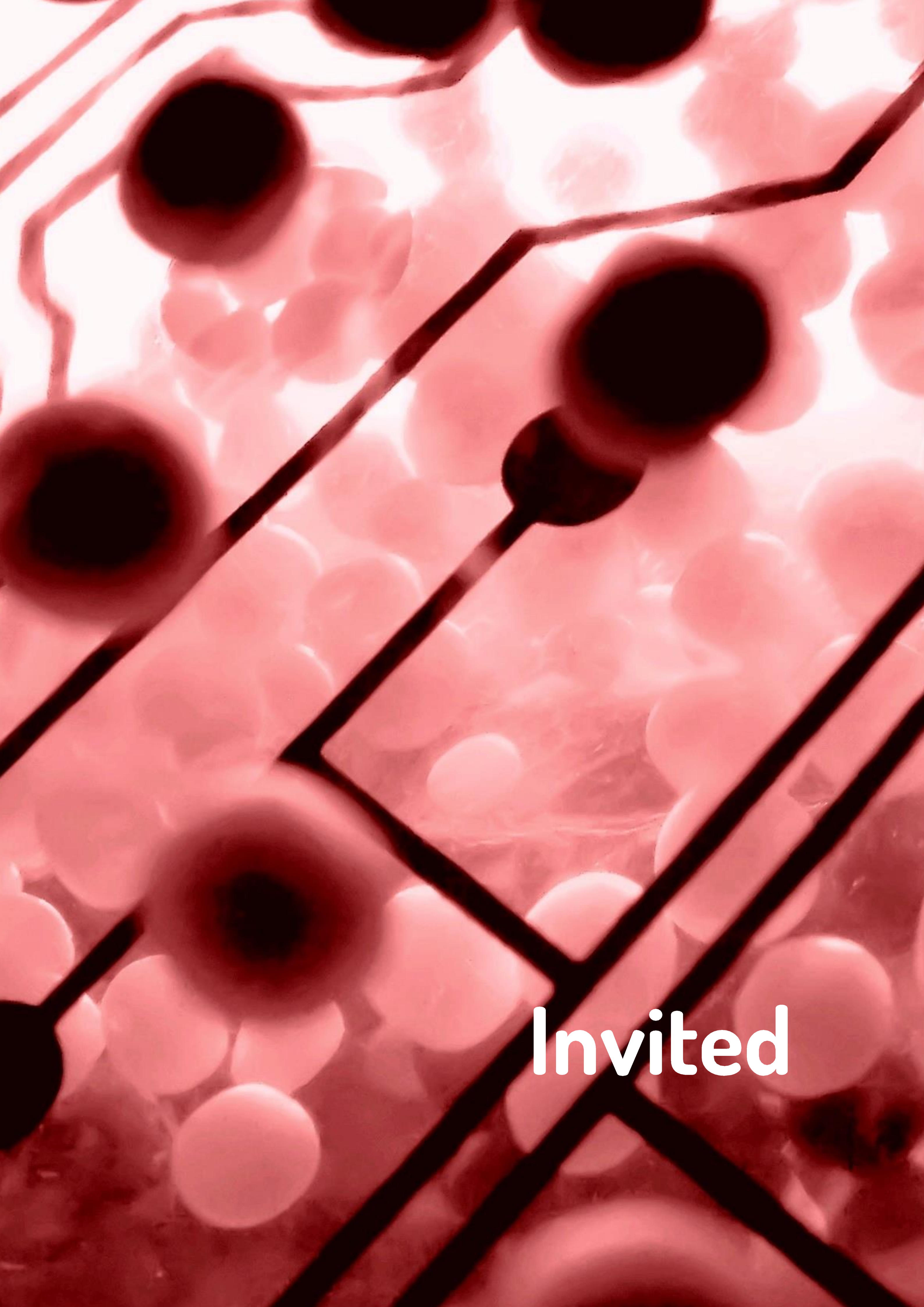

Invited

Shape changes in plasmonic nanostructures induced by laser irradiation: Potential applications to energy storage

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Classical molecular simulations have been used to investigate the possibilities of controlling the geometry of nanostructures by laser irradiation at the resonant plasmon frequency [1]. Specifically, the formation and dynamics of cavities in gold nanospheres has been addressed. This type of research may lead to potential applications in different areas which include energy storage.

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Exposure models and risk mitigation measures during the production of ENMs and nano-enabled products

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Nanotechnology is a widely applied cross-sectional technology with innovations and potential applications in almost all industry sectors. The unique properties of Engineered NanoMaterials (ENMs), including their much larger specific surface area and surface activity, may result in new health and environmental hazards, different from the bulk substance.
Studies conducted so far point out that a significant release of single particles, aggregates and agglomerates (< 1000 nm) can be expected during the production and subsequent use of ENMs. Additionally, incidental nanomaterials (INMs) can also be generated in accidental spills or releases from wear and tear of materials containing ENMs, leading to non-negligible exposure levels.
As a way to safely design the ENMs and the working places, different models have been developed to model how the concentration of an ENM evolves with time in a working environment and from there how severe is the worker's exposure.
The exposure to ENMs out of the workplace is difficult to characterize mainly because its diverse origin. Outdoors, the different sources are intermingled and may even recombine and undergo changes at the physicochemical level.
Despite the growing concern about the effects of ENMs, information regarding exposure levels and well-established techniques of characterization are lacking. Besides, there is no agreed verification procedure of the effectiveness of the containment measures.

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Figures

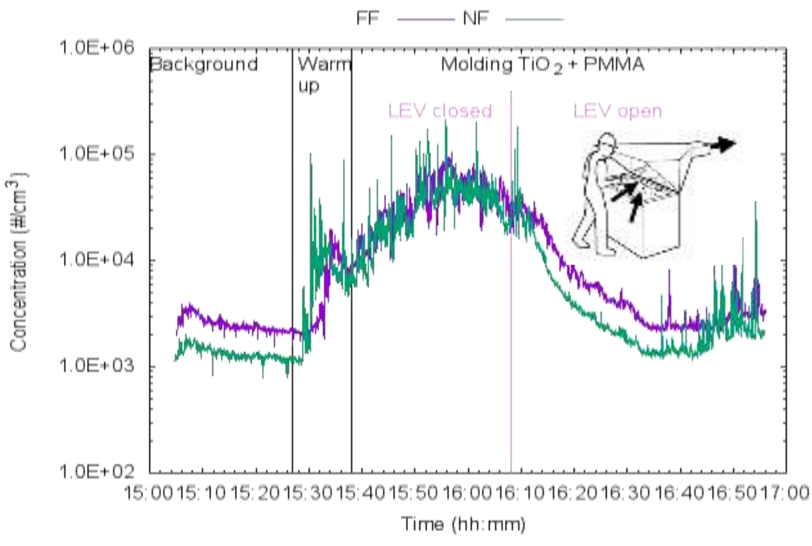

Figure: Example of exposure to a process of injection molding with ENMs and effectivity of ventilation systems.

Graphene-based composite supercapacitors for enhanced capabilities

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Energy storage devices are key in multiple technologies of interest for the security and defence sectors such as hybrid and electric vehicles, mobile communications, portable and wearable electronics, smart sensors and internet of things. Graphene offers an outstanding material platform for enhancing the capabilities of these devices not only in terms of specifications but also in versatility, as it can be incorporated into flexible substrates and textiles.

In this presentation, various graphene-based supercapacitor technologies using composite hierarchic electrode structures will be presented [1-5]. The graphene porous scaffolds are fabricated either by chemical vapor deposition of graphene on sacrificial 3-dimensional metal foams or by laser-driven conversion of compact graphene oxide layers into 3-dimensional open networks of exfoliated flakes of reduced graphene oxide. These scaffolds are then functionalized with nanostructured pseudo-capacitive materials including conducting polymers and metal hydroxides. The unique combination of high specific surface area and outstanding electrical and mechanical properties of the graphene porous scaffolds and their composites offers new possibilities in energy storage devices.

Acknowledgments: MINECO project ENE2017-88065-C2-1-R and grant RyC-2015-18968.

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Track & Trace systems based on marking using security inks for excisable tax and critical goods

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"The scope and scale of illicit trade and organized crime is inherently difficult to measure. The global value of illicit trade and transnational criminal activities have been estimated at between 8% and 15% of global GDP, with the value of narcotics trafficking at US$ 750 billion to US$ 1 trillion; the sale of counterfeit goods at US$ 650 billion worldwide; environmental crime at US$ 20 billion-40 billion; and human trafficking, at US$ 20 billion. Including money laundering, this figure increases to an astonishing US$ 3 trillion compared with a legitimate global trade figure of about US$ 10 trillion-12 trillion." [1]

Track and Trace systems has proven as an efficient way to tackle illicit trade and fraud by industries and governments.

Efficient Tranck and Trace systems are based on four essential pillars:

1) Create **PRODUCT IDENTITY** to enable traceability using secure marking technologies.
2) Provide devices and tools to check the **AUTHENTICITY** of the marks in the goods.
3) Create **PRODUCT HISTORY** by collecting events across the whole distribution chain.
4) Create **INTELLIGENCE** through monitoring, inspections and controls.

We will present success stories on the implementation of our Track & Trace solution called SICPATRACE® based in the mentioned four pillars.

References

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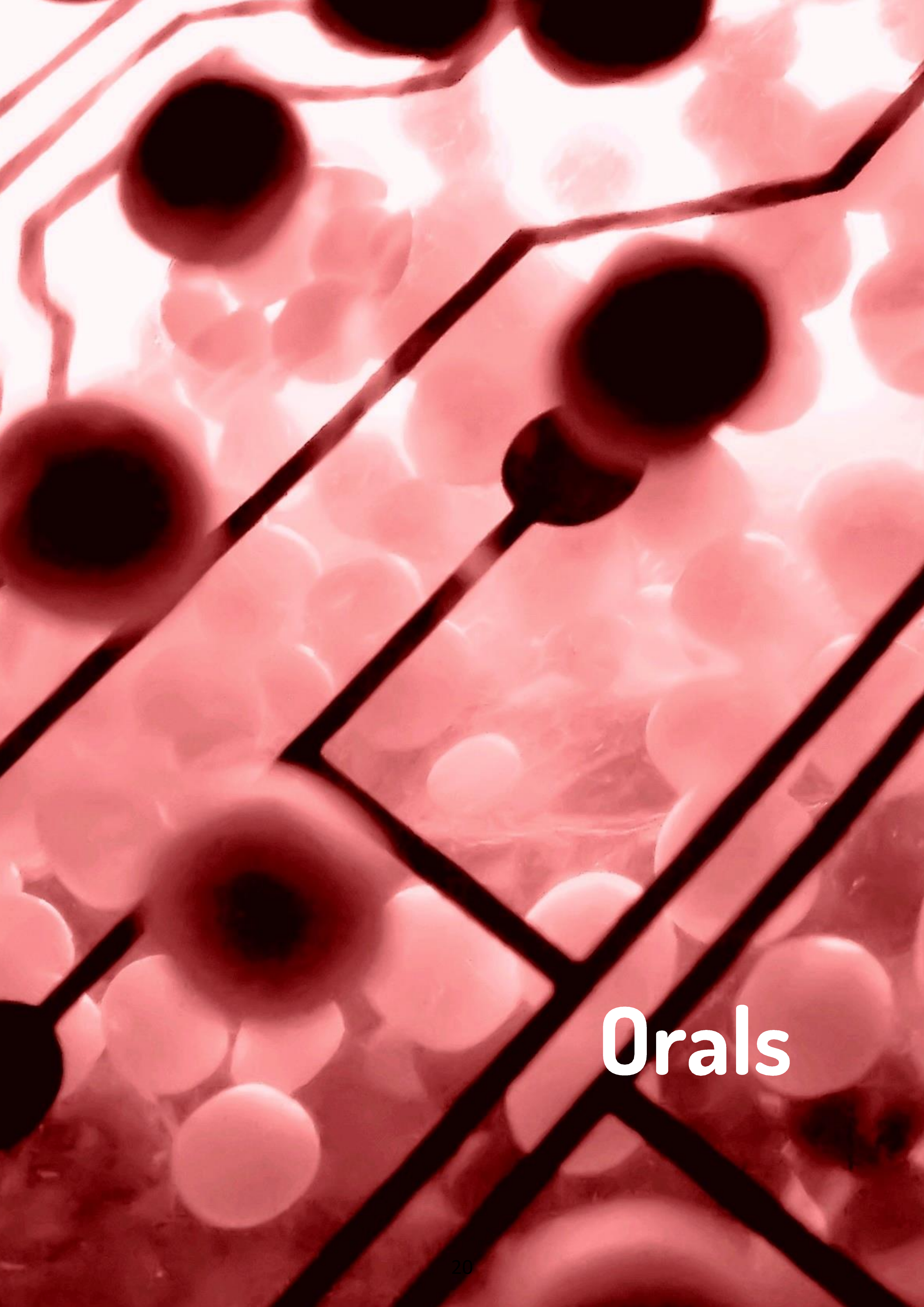
Figures

Figure 1: Comprehensive Track&Trace systems to achieve increasing levels of supply chain security.



Orals

Monolithic Quantum Light Sources for Space QKD Applications

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Back in 2002, Toshiba released its pioneer Quantum LED design. [1] It opened a route for electrically driven quantum light sources (QLS) adapted to different spectral ranges and environments. Single photon and entangled photon pair sources are necessary to surpass security loopholes of current commercial QKD cryptographic systems based on decoy states. [2] They are also at the heart of linear optical quantum computing integrated devices. In harsh environments, like orbital-orbital or orbital-terrestrial quantum links, the number of optical elements must be kept at a minimum both for weight and vibration constraints. An electrically driven QLS connected to a simple power supply might have clear advantages in this environment over systems based on bulky optical setups and non-linear frequency conversion.

We will present our own design for an electrically driven single photon source. [3] The device comprises of two separated electrical injection and electrical tuning regions in a bi-polar transistor configuration. The connection between them is purely optical and thus avoids the sheet resistance problems that plague other approximations, especially when applied to nanophotonic devices. The first fabricated devices show single photon emission with $g^2(0)<0.1$ at injection currents as low as 100 mA/cm^2 and fully linear conversion between electrical power and single photon flux.

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Figures

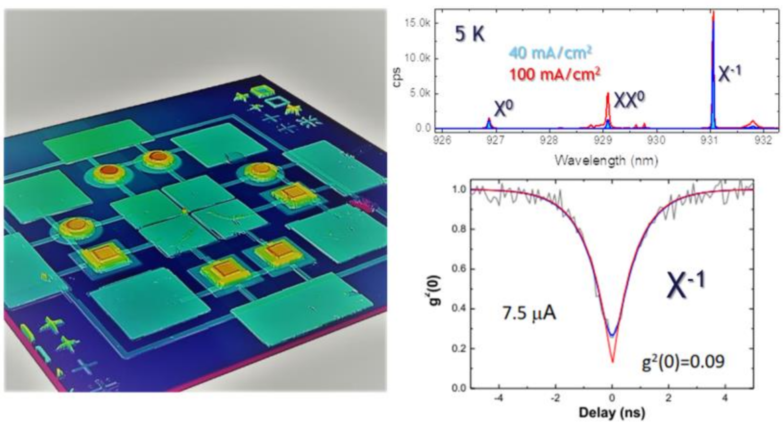

Figure 1: Left: Image of a device comprising eight electrically driven QLS (800x800 μm^2). Right: Single QD emission spectrum at two different bias (up) and single photon coincidence spectrum (down).

A review on security and technology research activities for terrestrial and space applications

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In this presentation we will focus on the capabilities of our group in applying both theoretical research and empirical technologies to solve specific needs in different industrial sectors. These technologies can be applied to a broad range of areas, e.g. communication, sensing, metrology, automotive, textile or maritime and either for space or for terrestrial domains.

First we will talk about photonic integration. Photonic integration is emerging as a new standard for providing cost effective and high-performance miniaturized and optical systems for a wide range of applications. The possibility of integrating complex and advanced photonic functionality into a single chip enables system designers and manufacturers to unite various optical devices into a single package, thereby offering significant enhancements in energy consumption, system size, costs and reliability. We will show the use of Integrated Photonics design/fabrication/characterization applied to optical communications (microwave/RF, FTTH, datacom), sensing and quantum technologies (communication CV-QKD and computation).

Concerning the space domain we will show our expertise developing complete space systems based on small satellites including all the lifecycle of the space mission. All of our internal engineering and management processes are based on the ECSS standards philosophy properly tailored. This allows us to achieve high quality and reliable results in our projects and to successfully design, manufacture, assembly, integrate, test and operate 3 Cubesats in recent years and to prepare for launching four new satellites in forecoming years.

Finally, we will show our strong expertise in the field of quantum cryptography in discrete variable quantum key distribution systems being recognized as international experts in the analysis of the security of these systems. We have also collaborated in several projects with several experimental groups, which has allowed know first-hand the problems associated with implementations of QKD systems.

Light matter interaction graphene/h-BN and graphene/h-BN/graphene heterostructures mediated by surface acoustic waves

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Surface plasmon polaritons (SPPs) in graphene– hybrid excitations of Dirac quasiparticles and photons – have emerged as an outstanding platform for exploring light-matter interaction at the nano-scale. These SPPs couple strongly to surface optical (SO) phonons in the substrate leading to hybridized surface plasmon-phonon polaritons (SPPPs). Moreover, unlike conventional SPPs in metals, graphene SPPPs can be tuned in situ through the modulation of the carrier density by electrostatic gating, covering the mid-IR to THz range. Owing to their extremely short wavelengths, however, to experimentally excite them, a large mismatch in momentum needs to be overcome by a photon to couple with a plasmon into a SPP. Here we demonstrate that a surface acoustic wave (SAW) can be used to generate propagating SPPPs in graphene/h-BN and graphene/h-BN/graphene heterostructures on piezoelectric substrates over a broad energy range (fig 1a and 1b). The h-BN between the graphene and the piezoelectric substrate not only significantly changes the SPPP dispersion but also enhances the lifetime as compared to the previously studied graphene/piezoelectric system [1]. The SPP dispersion of graphene splits into multiple branches due to the coupling with the SO phonons of both h-BN and piezoelectric substrate [2]. In addition, hyperbolic phonon branches appear in the case of multilayer h-BN which then also couple to graphene plasmon and leads to hyperbolic plasmon-phonon polaritons (HPPPs). Moreover, the addition of a second graphene layer is shown to further disperse and strengthen the SPPPs (see fig. 1(c). Also, in case double layer graphene additional modes, acoustic modes, will appear (as shown in fig. 1(b) because of interlayer carrier-carrier interaction which further increases the magnitude to correlation energy and decreases the quasiparticle velocities (~c/300) and highly confined closed to particle-hole continuum.

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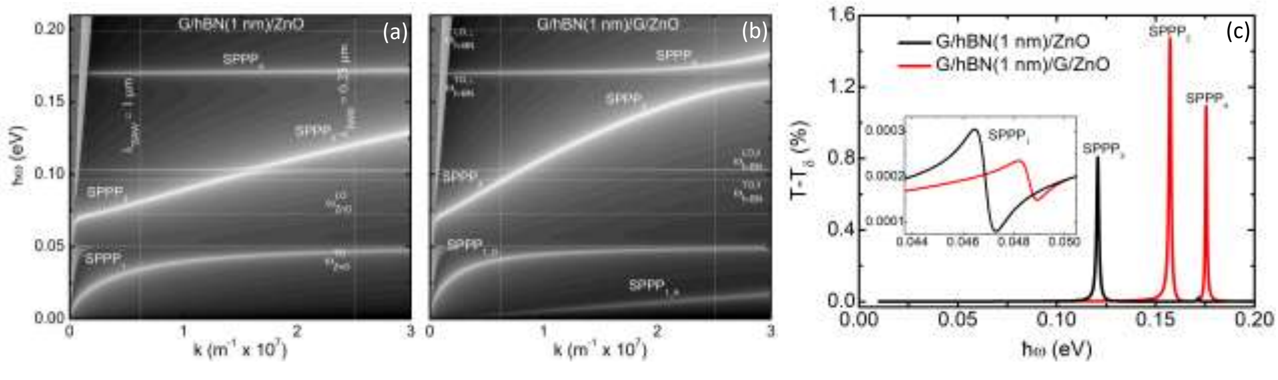

Figure 1: SPPPs dispersion in (a) G/h-BN/ZnO and (b) G/h-BN/G/ZnO. (c) Generation of SPPPs by a SAW with wavelength λ_{SAW} = 250 nm.

Conceptual Design of a Tritium Breeding Blanket based on Nanostructured Lithium Ceramics

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One of the main challenges of fusion power plants is the self-sufficiency of its own fuel consumption. To fulfill such a requirement the power plants rely on breeding blankets with a high lithium content that use fusion neutrons for tritium production by means of n-lithium reactions. Other functions of the blanket are extraction of thermal power and shielding against radiation. Several concepts have been developed by different groups around the world. In this work, we focus on a laser fusion pre-comercial power plant defined in the framework of the European project HiPER. We have designed a breeding blanket based on nanostructured lithium ceramics. Ceramic materials like lithium titanate (Li2TiO3) exhibit well known advantages with good performance. In terms of tritium release, moisture sensitivity, and activation, and it also has a reasonable atom density and a good compatibility with structural materials Nanostructuring is essential to promote rapid tritium release avoiding too high tritium inventories as well as tritium fuel deficit. Some techniques assure the required nanostructuring as e.g., synthesis via a cetyltrimethylammonium bromide (CTAB)-assisted hydrothermal method. The tritium breeding ratio (TBR) is enhanced by a neutron multiplier, by means of (n, 2n) reactions, due to its relatively large cross section, beryllium is an excellent neutron multiplier choice. In addition, it exhibits good thermal conductivity and mechanical stability further increased when mixed with Li2TiO3. In our simulations, we consider a breeding blanket based on Li2TiO3 and beryllium multiplier, with a reflector around the chamber to enhance the TBR. We have optimized parameters such as the reflector thickness or the overall concentration of beryllium (number of beryllium plates). We will show that for appropriate geometries lithium enrichment is not needed, which makes the design simpler and cheaper. Values of TBR as high as 1.37 were obtained with natural lithium with beryllium at 25 % (atomic fraction) in a breeder of 40 cm of thickness, constituting our best case.

Composites containing graphene-related materials: potential defense applications

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The development of graphene-related materials (GRM), such as graphene nanoplatelets (GNP), graphene oxide (GO) or reduced graphene oxide (rGO), has led to a wide range of applications in the field of composite materials and nanocomposites. Initially, polymer/GRM nanocomposites have attracted the interest of researchers in order to improve the thermal, mechanical and electrical properties of polymers [1-3] and carbon fiber reinforced polymers (CFRP) [4-5]. More recently, the research in this field is focused in the improvement of the multifunctional behavior, for example health monitoring, EMI shielding or system integration [6-8].
Among the functionalities that could be useful for military applications, GRMs have shown a great potential in the flame retardancy of polymers and composites [9-11]. In addition, it was reported the use of GRMs or other nanomaterials could improve the impact resistance of polymers and FRPs [12].

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Quantum technologies for Defence applications

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In this talk I will explain how the raise of quantum technologies will affect the applications in Defence and Security. Quantum technologies hold the promise to change the way we perform computations, communications and sensing. This has been acknowledged by several countries, like the USA, UK and Australia. Europe has launched the Quantum Flagship program with special emphasis in Defence applications. As early as 2014, the Defence Science and Technology Laboratory in the UK wrote a document [1] explaining how the Quantum Technologies could affect our ability to act in offensive and defensive situations. From the wealth of Quantum Systems, I will focus on the interest of my group in nanoscale Quantum Sensors which will have a great impact in Defence as well as Civil applications. In particular, we are working in some magnetic and inertial sensors based on levitated nanoparticles (see image below). These systems are versatile as we can use different particles to suit different needs. They also allow for the possibility of optically manipulating the particle, which can be delivered with optical fibers to the position of the particle, thus allowing remote sensing and encapsulation of the particles.

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Figures

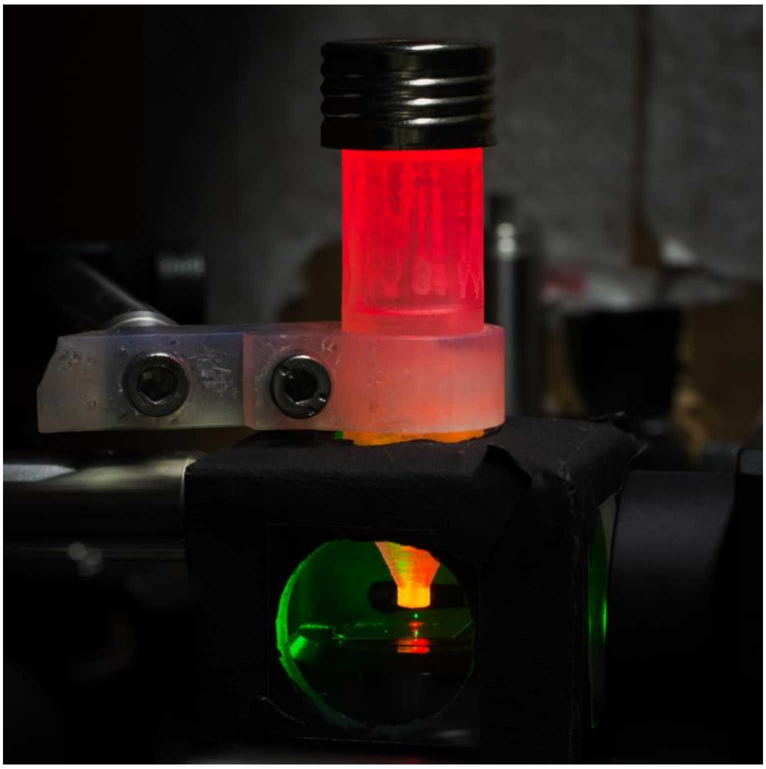

Figure 1: Nanodiamond levitating over a microscope slide due to optical forces

Low-cost, high-sensitivity, fast and easy detection of liquids or gases by a nanophotonic sensor and a smartphone

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Abstract

We present a new way of easy, optical detection using a nanophotonic sensor. The sensor uses plasmons in nanowires [1] that can be affected by the surrounding environment, especially liquids, but also gases or some solids. The sensor can be coupled to a smartphone for an easy detection of the properties of the substance. Applications can be from detection of the quality of food (virgin or mixed olive oil, wine or beers, quality of pure or mixed alcohols, etc.) to identification of specific labeling and security. The nanophotonic sensor only needs a very small volume for detection of 0.0025 mL and can detect a mass as small as 0,1 mg or a volume as small as $8x10^{-5}$ mL. The detection can be as fast as 1 second. The sensor is low-cost produced and can be easily replaced or just disregarded for the identification of biological or biohazard substances or other dangerous specimens.

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Figures

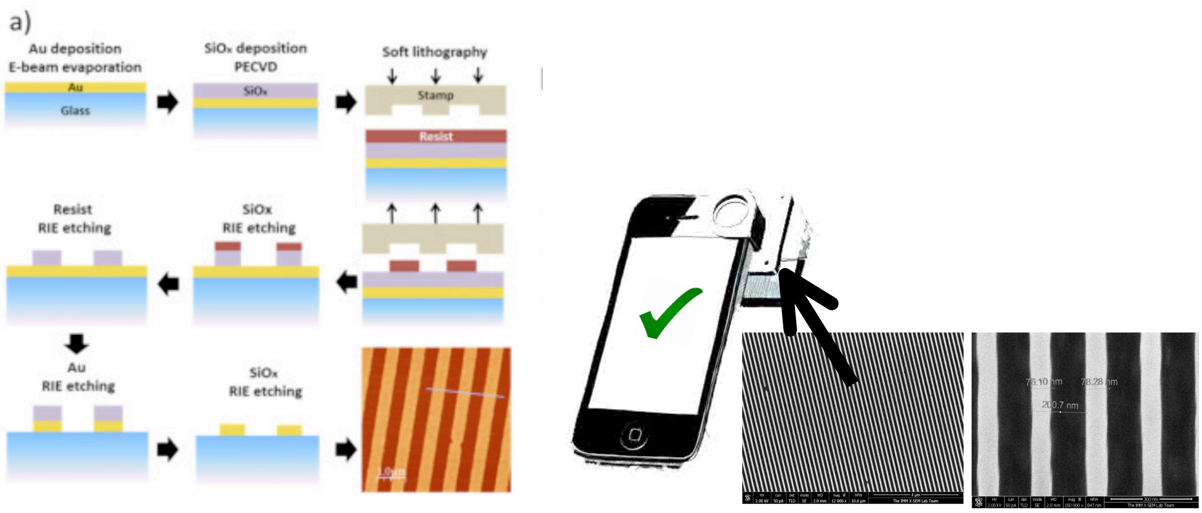

Figure 1: (a) Fabrication process for the nanophotonic sensor, based on low-cost soft-lithography. Thousands of sensors can be fabricated on a single step. Detection can be performed by a smartphone.

PTML predictive model por evaluation of nanomaterials linked to vitamines

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El trabajo investigativo se enmarca en el campo de la gestión de la nanotecnología en el sector alimenticio a nivel público, en concreto versa sobre la seguridad de los alimentos, dado que existe incertidumbre en el impacto que los nanomateriales pueden tener en la salud de los consumidores (Bowman, 2007) y ello además perjudica económicamente al sector (Lyndon, 1989). Por ello los ensayos de toxicidad son de especial interés; sin embargo, la literatura se ha mostrado proclive a utilizar métodos alternativos como los modelos QSAR/QSTR (Richarz, 2017). Reduce costes y tiempo, además de alinearse con el propósito de reducir, refinar y reemplazar ensayos in vivo (Slikker Jr, 2018). Por ello se debe contar con una regulación eficiente que aplique el principio de precaución, capaz de aprobar o denegar los productos que incorporen nanomateriales dependiendo de su toxicidad, acorde con la información de la que se dispone en la literatura. A través de este trabajo se construye un modelo basado en el Perturbation Theory Machine Learning (PTML) que ayuda a prever la toxicidad de los nanomateriales vinculados a vitaminas, suponiendo un gran avance para prever la toxicidad con nanomateriales junto con aditivos alimenticios.

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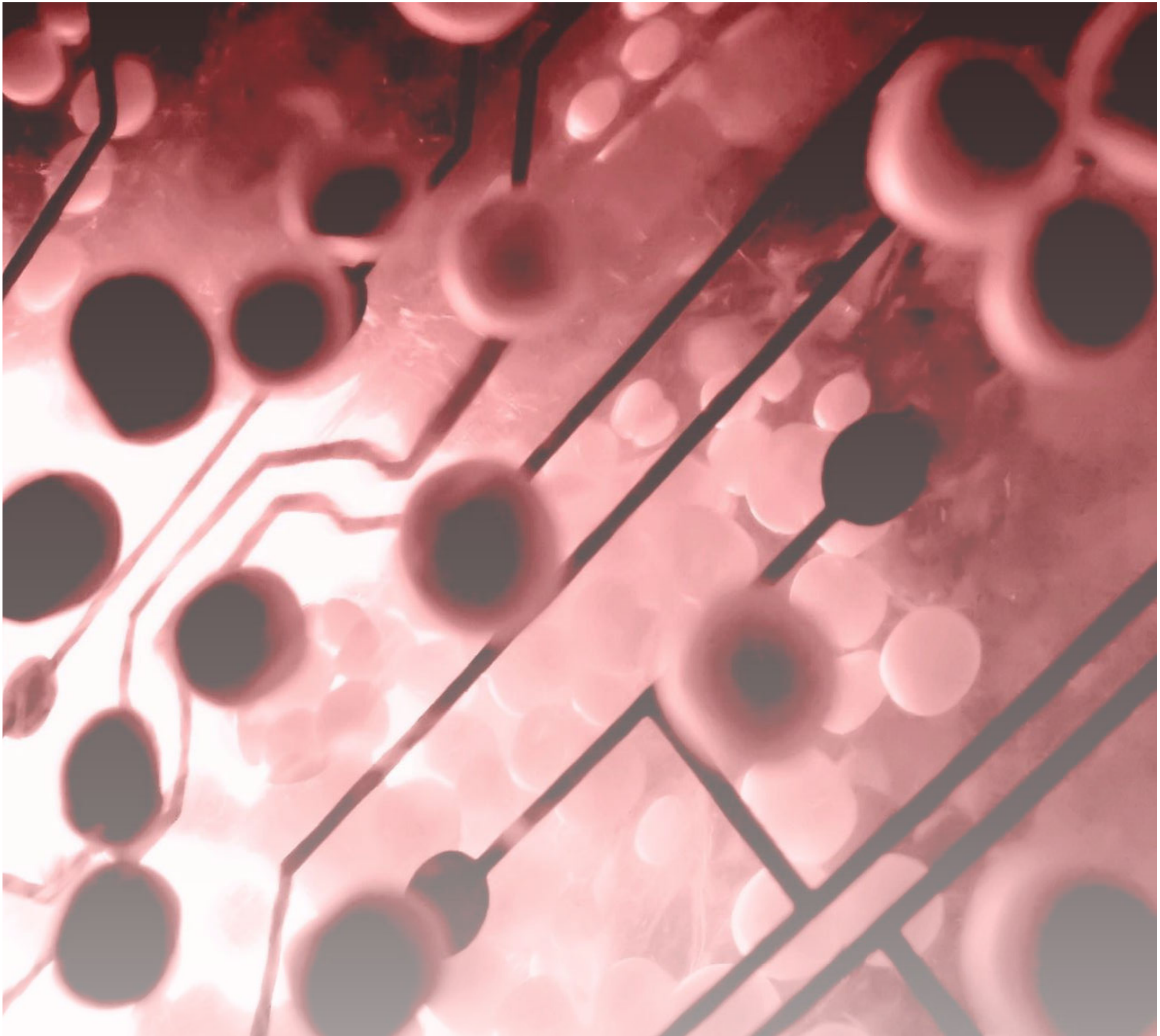

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