AUFRANDE   Aix Marseille université Socialement engagée   RMIT UNIVERSITY

Position Description

1. General Information

Name of the position	**Laser-synthesized nanomaterials for new biological applications**
Foreseen enrolment date	1 October 2024
Position is funded by	• COFUND, Marie Skłodowska-Curie Actions (MSCA), Horizon Europe, European Union • Aix-Marseille Université (AMU) • RMIT University (RMIT)
Research Host	Aix Marseille Université
PhD awarding institutions	Aix-Marseille Université & RMIT University
Locations	Primary: Marseille, France Secondary: Melboune, Australia
Supervisors	Andrei Kabashin (AMU) Elena Ivanova (RMIT)
Group of discipline	Chemistry and Physics of nanoparticles, Biocidal properties of nanomaterials

2. Research topics (only one of these projects will be funded)

Project 1: *Mechanical antibiotics and anti-viral nanomaterials synthesized by laser-ablative methods*
It was established only recently that smaller nanoparticles and nanostructures are increasingly deadly for bacteria (1-3 micrometers) and virus (~0.1 micrometer). However, the mechanism of the biocidal action (hence antibiotic), spanning more than one order of magnitude in size of nano-“killer” objects, needs a further refinement. We will test the existing perception/hypothesis that nano-particles could be bio-toxic and that nano-textured surfaces can perform better as biocidal agents. Nano-surfaces are perceived as surfaced-fixed nanoparticles. Validity of this statement will be scrutinised in this Project and practical guiding principles will be established for the use of nano-materials (particles and surfaces). By using nano-coatings on substrates, a controlled laser melting/ablation will be creating different chemical composition of nano-textured surfaces which will be closely matching or identical to the chemical composition of nanoparticels made by ablation in solution. Fractal aspect of nano-textures ranging 0.1 – 10 micrometers in size will be created on laser ablated surfaces with chemical composition corresponding to that of nanoparticles. Plasma deposition as well as atomic layer deposition (ALD) will be used for coatings over laser treated surfaces (accessible via collaboration in Melbourne).

This project has received funding from the European Union’s Horizon Europe research and innovation programme under the Marie Skłodowska-Curie grant agreement № 101081465

This Project combines experts in nanoparticle fabrication using laser ablation in solution (Andrei Kabashin, Aix-Marseille University) and assessment of their biocidal activity and biocompatability (Elena Ivanova, RMIT).

A. Kabashin's team (France) are specialists in the development of non-chemical laser-ablative routes for the synthesis of ultrapure colloidal nanomaterials, namely the pioneers of methods based on ultrashort laser ablation in liquid ambient. These methods are now considered as the most efficient among laser-ablative pathways to finely control size and physico-chemical characteristics of formed nanomaterials. In contrast to conventional chemical routes, laser ablation unique in providing essentially non-equilibrium conditions for nanostructure growth, which makes possible the synthesis of nanoformulation of virtually any material or the combination of seemingly unimaginable materials in one nanoformulation (e.g., plasmonic-semiconductor, plasmonic-magnetic, etc.). In addition, the synthesis can be performed in ultrapure environment (e.g., deionized water), which excludes any contamination of formed nanomaterials. This technique was advantageous for the synthesis of a variety of nanomaterials (TiN, ZrN, MoS2, WS2, Bi, B, etc.), which look extremely promising for biomedical tasks (photothermal therapy, nuclear medicine, bioimaging). Biocidal and bio-toxicity of this new class of materials will be examined by E. Ivanova, RMIT.

It was originally discovered (E. Ivanova, RMIT) that some insects, possess high aspect ratio nanoscale pillars on the waxy epicuticular layer of their wing membranes that exhibit bactericidal activity. This phenomenon was first observed on the wings of cicadas, which contain regular arrays of vertical nanopillars. The irregular pattern of longer nanopillars present on the wings of dragonflies demonstrated improved bactericidal activity against a wider array of bacterial cell morphologies, indicating such nanofeatures can be optimised for improved performance. Synthetic analogues with similar high aspect ratio nanoscale features were created, most notably titanium and black silicon (S. Joudkazis, SUT, E. Ivanova, RMIT). These nanostructured surfaces lyse bacterial cells through a mechanical rupture process. As cells come into contact with the high aspect ratio surface nanofeatures, they strongly adsorb, which causes the cell membrane to stretch between adjacent features, eventually resulting in rupture of the membrane and cell lysis. This provides a novel solution to the issue of bacterial colonization, as a biomimetic template for the design of synthetic antibacterial surfaces.

This PhD project will combine expertise of French partner in the synthesis of new functional nanomaterials and their deposition on surfaces (including nanostructured surfaces prepared by the Australian partners), and further assessment of biocidal action of such nanostructures by the Australian partners.

The project will have access to laser-ablative facilities of Aix-Marseille University and nanofabrication facilities at Swinburne Univ. Technol. and Melbourne Center of Nanofabrication (MCN) at Australian National Fabrication Facility (ANFF), and advanced electron microscopy (free of charge access), materials characterisation and PC2 facilities at RMIT. Technical expertise of S. Juodkazis (SUT) will be available for nanofabrication and optical/structural characterisation of the nanotextured surfaces and nanoparticles. Capability to produce nanoparticles by femtosecond laser ablation in solution at Swinburne is readily available and can be accessed by French team. In addition, during our first discussions, an Australian company Quoba Systems (https://quobasystems.com.au/) expressed their interest in this PhD project for a potential commercialization of results.

Supervisors: Andrei Kabashin (AMU), Elena Ivanova (RMIT), Saulius Juodkazis (Swinburne University of Technology)

Research Fields: Nanotechnology, Nanomaterials, Nano-Bio-physics, laser-ablative processing and synthesis of nanomaterials

Project 2: *Magnetic control of biocidal properties using laser-synthesized nanomaterials*

It was established only recently that smaller nanoparticles and nanostructures are increasingly deadly for bacteria (1-3 micrometers) and virus (~0.1 micrometer). However, the mechanism of the biocidal action (hence antibiotic) spanning more than one order of magnitude in size of nano-"killer" objects needs a further refinement. Magnetic field applied during laser ablation for nanoparticle generation or nanotexturing of surfaces has profound effects on morphology and

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composition as established by supervisor teams. When ultra-short laser pulses are used, highly energetic electrons leave the laser exposed region with ions lagging behind. Depending on the orientation of magnetic B – field, the ion and electron currents spins in opposite directions and different radius. Effects of surface morphology used for biocidal actions will be tested as well as nanoparticles produced with and without magnetic fields. Current results hint that B-field results in smaller nanoparticles as well as sharper nanotextures. This hypothesis will be tested in this Project. Trapping of magnetic nanoparticles on nanotextured surfaces (magnetic and non-magnetic) using external magnet are expected to control initial adhesion and biofouling of surfaces, which is currently not resolved issue to stop bacterial colonisation. Magnetic control of nanoparticles will be relevant across several biomedical imaging techniques. Application potential: anti-biofouling of large scale surfaces used underwater.

This Project combines expertise in the fabrication of nanomaterials, including magnetic nanostructures (Fe_3O_4, Fe_3O_4-Au core-satellites, etc.) using laser ablation in liquid ambient (Andrei Kabashin, Aix-Marseille University), fabrication of laser treated surfaces and their further coating by magnetic materials (RMIT in collaboration in Melbourne), and evaluation of their biocidal activity and biocompatibility (Elena Ivanova, RMIT). Plasma deposition as well as atomic layer deposition (ALD) will be used for coatings over laser treated surfaces (accessible via collaboration in Melbourne).

A. Kabashin's team (France) are specialists in the development of non-chemical laser-ablative routes for the synthesis of ultrapure colloidal nanomaterials, namely the pioneers of methods based on ultrashort laser ablation in liquid ambient. These methods are now considered as the most efficient among laser-ablative pathways to finely control size and physico-chemical characteristics of formed nanomaterials. In contrast to conventional chemical routes, laser ablation unique in providing essentially non-equilibrium conditions for nanostructure growth, which makes possible the synthesis of nanoformulation of virtually any material or the combination of seemingly unimaginable materials in one nanoformulation (e.g., plasmonic-semiconductor, plasmonic-magnetic, etc.). In addition, the synthesis can be performed in ultrapure environment (e.g., deionized water), which excludes any contamination of formed nanomaterials. This technique was advantageous for the synthesis of a variety of nanomaterials, including magnetic ones (nanoparticles of Fe, Co Ni and composites such as Si-Fe, Fe-Au nanostructures). Biocidal and bio-toxicity of these new class of material will be examined by E. Ivanova, RMIT.

The project will have access to nanofabrication facilities at Swinburne Univ. Technol. and Melbourne Center of Nanofabrication (MCN) at Australian National Fabrication Facility (ANFF), advanced electron microscopy (free of charge access), materials characterisation and PC2 facilities at RMIT. Technical expertise of S. Juodkazis (Swinburne) will be available for fabrication and optical/structural characterisation of the nanotextured surfaces and nanoparticles. Capability to produce nanoparticles by femtosecond laser ablation in solution at Swinburne is readily available and can be accessed by French team. In addition, during our first discussions, an Australian company Quoba Systems (https://quobasystems.com.au/) expressed their interest in this PhD project for a potential commercialization of results.

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Research Fields: Nanotechnology, Nanomaterials, Nano-Bio-physics, Magnetic materials

Project 3: *Chirality as tool to control biocidal nanomaterials/textures*

It was established only recently that smaller nanoparticles and nanostructures are increasingly deadly for bacteria (1-3 micrometers) and virus (~0.1 micrometer). However, the mechanism of the biocidal action (hence antibiotic) spanning more than one order of magnitude in size of nano-"killer" objects needs a further refinement. Many important biomolecules could occur as enantiomers, including amino acids and sugars. We will use chirality of optical field (circular polarisation) to produce nanoparticels and nanotextures on surfaces by ablation for test of biocidal activity, Chirality control in Raman scattering/spectroscopy has become an established field revealing importance of usually overlooked effects of chirality and symmetry breaking, By use of ultra-short laser pulses, highly non-equilibrium

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formation of nanomaterials and nanotextures is taking place and bears signatures of energy deposition, which has strong chiral effect. Nanoparticles and nanotextured surfaces will be produced with chiral and non-chiral (linear polarisation) laser pulses and will be tested for their optical activity for chiral sensors as well as biocidal activity. This is largely unexplored domain of control in nanomaterials, which already shows strong application potential in sensors. Chirality can be engineered also by non-symmetric material deposition over non-chiral textures. This approach to produce chirally active nano-surfaces for biocidal functionality will be explored in this project.

Laser-ablative processing will be used to fabricate functional colloidal nanomaterials and provide nanostructured surfaces exhibiting chiral properties. Plasma deposition as well as atomic layer deposition (ALD) will be used for coatings of formed laser-synthesized nanoparticles over laser treated surfaces (accessible via collaboration in Melbourne).

This Project combines experties of nanoparticle fabrication using laser ablation in solution (Andrei Kabashin, Aix-Marseille University) andevaluation of their biocidal activity and biocompatibility (Elena Ivanova, RMIT).

A. Kabashin's team (France) are specialists in the development of non-chemical laser-ablative routes for the synthesis of ultrapure colloidal nanomaterials, namely the pioneers of methods based on ultrashort laser ablation in liquid ambient. These methods are now considered as the most efficient among laser-ablative pathways to finely control size and physico-chemical characteristics of formed nanomaterials. In contrast to conventional chemical routes, laser ablation unique in providing essentially non-equilibrium conditions for nanostructure growth, which makes possible the synthesis of nanoformulation of virtually any material or the combination of seemingly unimaginable materials in one nanoformulation (e.g., plasmonic-semiconductor, plasmonic-magnetic, etc.). In addition, the synthesis can be performed in ultrapure environment (e.g., deionized water), which excludes any contamination of formed nanomaterials. This technique was advantageous for the synthesis of a variety of nanomaterials (TiN, ZrN, MoS_2, WS_2, Bi, B, etc.), which look extremely promising for biomedical tasks (photothermal therapy, nuclear medicine, bioimaging). Biocidal and bio-toxicity of these new class of material will be examined by E. Ivanova, RMIT.

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Project will have access to nanofabrication facilities at Swinburne Univ. Technol. and Melbourne Center of Nanofabrication (MCN) at Australian National Fabrication Facility (ANFF), advanced electron microscopy (free of charge access), materials characterisation and PC2 facilities at RMIT. Technical expertise of S. Juodkazis (Swinburne) will be available for fabrication and optical/structural characterisation of the nanotextured surfaces and nanoparticles. Capability to produce nanoparticles by femtosecond laser ablation in solution at Swinburne is readily available and can be accessed by French team. In addition, during our first discussions, an Australian company Quoba Systems (https://quobasystems.com.au/) expressed their interest in this PhD project for a potential commercialization of results.

Supervisors: Andrei Kabashin (AMU), Elena Ivanova (RMIT), Saulius Juodkazis (Swinburne University of Technology)

Research Fields: Nanotechnology, Nanomaterials, Nano-Bio-physics, Magnetic materials

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3. Employment Benefits and Conditions

Aix-Marseille Université offers a 36-months full-time work contract (with the option to extend up to a maximum of 42 months).

The remuneration, in line with the European Commission rules for Marie Skłodowska-Curie grant holders, will consist of a gross annual salary of 28,764 EUR. Of this amount, the estimated net salary to be perceived by the Researcher is 1,926 EUR per month (before the deduction of tax at source). However, the definite amount to be received by the Researcher is subject to national tax legislation.

Benefits include

- Access to all the necessary facilities and laboratories at Aix-Marseille Université, RMIT University and access to nanofabrication facilities at Swinburne University of Technology and Melbourne Center of Nanofabrication (MCN) at Australian National Fabrication Facility (ANFF).
- Yearly travel allowance to cover flights and accommodation for participating in AUFRANDE events.
- 10,000 EUR allowance to cover flights and living expenses for up to 12 months in Australia.
- Tuition fee waiver at both PhD awarding institutions.
- 25 days paid holiday leave.
- Contractual doctoral students are subject to the same sick leave rights as other contractual employees of the State Civil Service, namely: the contractual agent in activity benefits, on presentation of a medical certificate, during twelve consecutive months if its use is continuous or during a period including three hundred days of effective services if its use is discontinuous, of sick leave within the following limits
    - After 4 months of service:
        - 1 month on full pay and 1 month on half pay;
    - After 2 years of service:
        - 2 months on full pay and 2 months on half pay;
    - After 3 years of service:
        - 3 months on full pay and 3 months on half pay.
- Parental leave: if the employee has at least 1 year's seniority at the date of the child's birth, he/she is entitled to parental leave at his/her request (after maternity leave for the mother or paternity leave for the father). This leave ends at the latest when the child is 3 years old. The leave is granted for renewable periods of 2 to 6 months. He/She must apply for it at least 2 months before the start of the parental leave.

4. PhD enrolment

Successful candidates for this position will be enrolled by the following institutions and must comply with their specific entry requirements, in addition to AUFRANDE's conditions.

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Applicants must hold a Master's or equivalent degree with research component comprised of at least 25% of a full-time academic year (or part-time equivalent) with an overall high distinction or a master degree without a research component with at least a high distinction average.

Applicants will also need to meet English proficiency requirements: https://www.rmit.edu.au/study-with-us/international-students/apply-to-rmit-international-students/entry-requirements/english-requirements.

More information on Aix-Marseille Université's requirements

Important: doctoral candidates holding a Master's degree outside the Bologna process or a degree equivalent to a Master's degree must submit an application for a Master's Degree for validation to the doctoral school secretariat prior to their enrolment.

Visit the website: https://college-doctoral.univ-amu.fr/en

More information on RMIT University's requirements

Visit the website: https://www.rmit.edu.au/research/research-degrees/how-to-apply

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