PhD Program in Bioengineering and Robotics

Curriculum Bionanotechnology

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The Bionanotechnology curriculum is related to basic and applied research programs oriented to the comprehension of fundamental phenomena at the nanoscale and to the application of nanotechnologies to bioengineering, biophysics, applied physics, material sciences and life sciences, and to the development of new technologies and approaches as a challenge for the next twenty years. Bionanotechnologies have a broad field of appeal, namely: from cells-to-chip and chip-to¬cells technologies to nanobiosensors, from nanodiagnostics to advanced characterization and imaging tools, from intelligent drug delivery to artificial tissues, from functional nano-addressable surfaces to smart materials. Among others, research developments include elucidating molecular mechanisms behind degenerative (neuro or oncological) misfunctioning of biological systems within the biomedical scenario. As well, most of the applications are conceived starting from the IIT platforms (Energy, Biomedical, Robotics) to numerous others, including technology transfer perspectives. The candidate will be immersed in the frontiers of science and technology.

Science and technolgy developments aim

- to advance the exploitation of nanostructures, fabricated by nanotechnological approaches, as building blocks for engineered self assembly architectures across multiple length scales, from the molecular level up to the macroscopic world and the development of new strategies related to the utilization of micro and nanomanufacturing to produce Micro Electric Mechanical Systems (MEMS), micro electrodes and scaffolds with dimensions comparable to cells and innovative plasmonic devices for different applications;
- to design, realize and utilize advanced methodologies and instrumentations within the framework of optical spectroscopy and microscopy, scanning force microscopy and optical nanoscopy, oriented to the study and characterization of nanostructured, biological and hybrid materials/specimens at the nanoscale - i.e. having at least one of the here spatial dimensions controllable at the nanometric or subnanometric scale. The focus is on the development of new strategies for the assembly of nano-systems able to realize new nanoparticles and nanostructured environments, to design and realize architectures to characterize materials, both artificial and biological, within a scale ranging from single molecules or particles or nanostructured complexes to the full biological scale, molecules, cells, tissues, organs and human bodies. As well several projects we aim integratingdifferent design and knowledge levels from a 2D (x,y) to a 4D (x, y, z, t) space.
- to take advantage of nanotechnology for the development of new materials based on
- polymers to produce smart multifunctional devices easily processable at scalable-low cost, with a wide range of exciting and outstanding applications. Nanoparticles and Nanocomposites are conceived, here, for tailoring the properties of fibrous & non-woven & nano/micro structured materials - e.g. cellulose fibers and polymer Foams. The development of all-polymer composites with tailored properties allows controlling surface wettability, mechanical properties and antibacterial activity among others. Developed nanocomposites - polymer matrices incorporating nanofillers - will be endowed of tailored magnetic properties, conductivity, thermomechanical properties and surface wettability towards the growing demand of striking performances in bionanotechnologiy.

International applications are encouraged and will receive logistic support with visa issues, relocation, etc.

1. Natural Polymer Composites

Tutors: Ilker S. Bayer, Athanassia Athanassiou

Department: Nanophysics (IIT)
http://www.iit.it/en/research/departments/nanophysics.html

Description: The student is expected to develop new bio-plastics and bio-plastic composites using cellulose based materials as well as biodegradable polymers. The main focus of this doctoral project will be to produce novel bio-plastics with properties matching that of plastics obtained from petroleum resources. The raw materials will be cellulose and cellulose derivatives, starch, modified starch as well as agro-waste in the form of inedible residues from industrial food processors. The student is expected work on fabrication processes that will include compounding with other biodegradable polymers, acid-base treatment, ionic liquid and mechanical processing including extrusion. Detailed characterization experiments will be conducted in order to assess the properties of the developed bio-polymers. Characterization techniques will include but not limited to microscopy, FTIR, Raman, XRD, mechanical tests, surface wetting and moisture and gas permeation. Strong collaboration with other research groups within the Smart Materials group at IIT will be necessary.

Requirements: background in polymer science, chemistry, materials science, or chemical engineering. A positive attitude for problem solving and interest in understanding/learning basic polymer chemistry are desirable.

Contacts: ilker.bayer@iit.it, athanassia.athanassiou@iit.it

2. Intelligent Drug Delivery Systems

Tutors: Elisa Mele, Athanassia Athanassiou

Department: Nanophysics (IIT)
http://www.iit.it/en/research/departments/nanophysics.html

Description: Applications are invited for a PhD position in the development of intelligent drug delivery systems based on nanofibers or nanoparticles realized by nanofabrication strategies.
The project intends to create a new generation of nano-carriers that are able to delivery active agents in a controlled way for application in personalized healthcare. To this aim, natural compounds, such as biopolymers and plant extracts, will be particularly used, due to their properties of biocompatibility, low toxicity, biodegradability and environmental sustainability. The project will involve the processing of composite and nanocomposite polymeric materials by techniques including electrospinning, mini-emulsion, flow-focusing microfluidic systems, and chemical synthesis methods. The candidate will gain experience in a range of characterisation techniques, including morphological, chemical, thermo-mechanical, and biological analysis. These will include scanning electron microscopy, atomic force microscopy, dynamic light scattering, Infrared and Raman microscopy, antimicrobial and biocompatibility tests. Interaction with collaborating academic groups and industrial partners working in this area can be expected, as well as attendance at international conferences.

Requirements: Bachelor Degree in one of the following areas: Material Science, Physics, Biotechnology, Chemistry or a closely related discipline. Previous experience on polymeric materials and natural polymers, micro- and nano-fabrication procedures, and generation of micro- and nanoparticles will be highly appreciated.

Contacts: elisa.mele@iit.it, athanassia.athanassiou@iit.it

3. Bioinspired Adhesion to Solids

Tutors: Despina Fragouli, Athanassia Athanassiou

Department: Nanophysics (IIT)
http://www.iit.it/en/research/departments/nanophysics.html

Description: Soft polymeric systems with controlled surface properties will be developed, for the formation of novel materials able to adhere in a controlled way on solid surfaces under wet or dry conditions. The project will focus on the bioinspired modification of the morphological characteristics and surface chemistry of diverse polymers and nanocomposite materials. The utilized techniques will be mainly related to microfabrication such as soft molding, or laser treatment for inducing special surface characteristics on the surface of the polymeric films. In parallel, self-assembly, spraying, etc of different functional molecules, will be utilized in order to induce the appropriate chemical modification of the surface. In this way an ideal substrate able to adhere to solids under ambient or extreme conditions will be formed. The adhesion properties will be studied with homemade systems, and the ideal candidate should be able to modify and fine tune the system according to the needs. The wetting characteristics, thermo mechanical properties, and surface chemistry and morphology of the developed materials will be extensively studied

Requirements: background in engineering, materials science, physics or related disciplines. Attitude for problem solving.

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4. Neuro-Plasmonics

Tutors: Francesco De Angelis

Department: Nanophysics (IIT)
http://www.iit.it/en/research/departments/nanophysics.html

Description: Research neuronal signaling is the subject of a very large community, but progresses face a dense multi-scale dynamics involving signaling at the molecular, cellular and large neuronal network levels. Whereas the brain capabilities are most likely emerging from large neuronal networks, available electrophysiological methods limit our access to single cells and typically provides only a fragmented observation, on limited spatial/temporal scales. Therefore, broadening the spectrum of scales for observing neuronal signaling within large neuronal networks is a major challenge that can revolutionize our capability of studying the brain and its physio-pathological functions, as well as of deriving bio-inspired concepts to implement artificial system based on neuronal circuits. We propose the development of an innovative electro-plasmonic multifunctional platform that by combining different methodologies emerging from distant fields of Science and Technology will provide a radically new path for real time neurointerfacing at different scale levels:

1. The molecular scale: 3D plasmonic nanoantennas will give access to information at molecular level by means of enhanced spectroscopies with particular regard of time resolved Raman scattering.
2. The single-neuron scale within neuronal networks: by both in-cell and extra-cell couplings with 3D nanostructures which work at the same time as plasmonic antennas and CMOS 3D nanoelectrodes.
3. The scale of large neuronal networks: by CMOS high-density electrode arrays for spatially and temporally resolving neuronal signaling form thousands of measuring sites.

This is achieved by exploiting an innovative nanofabrication method able to realize 3D nanostructures which can work at the same time as plasmonic nanoantennas and as nanoelectrodes. These structures will be integrated on CMOS multi-electrode arrays designed to manage multi-scale measurements from the molecular level up to network level on several thousand of measurement sites.

Requirements: This research theme strongly relies on nanofabrication advanced techniques and candidates should have a master in Physics, Electronic Engineering or similar. Background in Biophysics is strongly appreciated.

Contacts: francesco.deangelis@iit.it

5. PanLab: Plasmonic Advanced NanoLab

Tutors: Francesco De Angelis

Department: Nanophysics (IIT)
http://www.iit.it/en/research/departments/nanophysics.html

Description: This project relies on a synergic combination of advanced Nanofabrications, Plasmonics, and Raman Spectroscopy. By employing a new lithographic approach we can fabricate innovative kinds of plasmonic hollow nanoantennas. In particular, gold and silver nanovolcanos, nanotubes, and nanodoughnuts with holes size of few nm can be obtained with nanometric control on their geometry. The proposed structures can be integrated with microfluidic chip to force molecules of interest to flow through the plasmonic antenna, and during the flow, molecules exert the plasmonic field accumulated inside the nanochannel. Thanks to these features the devices are able at the same time to trigger and to investigate chemical/physical processes otherwise inefficient or impossible. The investigation can be carried out by means of different spectroscopy in the visible/near IR region. Among them, Raman analysis provides a clear chemical and physical insight of the nano-environment under study: chemical structure, binding event, chemical and physical interactions, and local temperature, can be accurately investigated with sensitivity down to single molecules. Even time resolved studies of vibrational spectra of chemical reactions were demonstrated on the femtosecond landscape. Time resolved Raman Spectroscopy will give a clear insight of the triggered reaction with an unprecedented spatial and temporal resolution. The proposed approach paves the way to novel electro-plasmonic devices and their integration with microfluidics, opening the route to the convergence between the emerging fields of optofluidics and optoelectronics.
This groundbreaking "nanoLab" will be applied to the investigation of mechanisms that rule the plasmon assisted physico-chemical processes at molecular level. Current examples are: electro-photo-catalytic chemical reactions such as water splitting or carbon monoxide catalysis, and hot electron generation. the molecular level up to network level on several thousand of measurement sites.

Requirements: This research theme strongly relies on nanofabrication advanced techniques and candidates should have a master in Physics, Chemistry, Electronic Engineering or similar.

Reference: 3D hollow nanostructures as building blocks for multifunctional plasmonics. F. De Angelis et al., Nano Letters, 8 (2013), 3553-3558

Contacts: francesco.deangelis@iit.it

6. Driving molecules at the nanoscale

Tutors: Francesco De Angelis

Department: Nanophysics (IIT)
http://www.iit.it/en/research/departments/nanophysics.html

Description: The detection of few molecules from highly diluted solution is of extreme interest in different fields such as biomedicine, safety and eco pollution from rare and dangerous chemicals. Nanosensors cannot directly be used for detecting molecules dissolved in femto/atto molar solutions because of the so called "diffusion limit". In other words, they are diffusion limited and their detection performance becomes unpractical at those concentrations. To overcome this limitation, molecules of interest, initially dispersed in solution, can be guided toward the active area of the sensors exploiting superhydrophobic and superoleophobic surface. By combining plasmonic nanosensors with hydro/oleo-phobic surface unprecedented sensitivity levels can be reached, and the problem of detection of highly diluted sample can be faced radically.

Requirements: This research theme strongly relies on nanofabrication advanced techniques and candidates should have a master in Physics, Chemistry or similar.

Reference: F. De Angelis et al., Nature Photonics, 2011, 5, 682-687.

Contacts: francesco.deangelis@iit.it

7. Plasmon Adiabatic Nanoscopy

Tutors: Francesco De Angelis

Department: Nanophysics (IIT)
http://www.iit.it/en/research/departments/nanophysics.html

Description: In the last decade the fields of Raman/Infrared, and Atomic Force Microscopy experienced a huge but independent development. The potential progress derived by unifying these techniques is of primary importance for obtaining simultaneous and complementary information at level of single molecule study. The incredible proliferation of Nanofabrication technologies over the past decade is exactly what these fields needed to converge, allowing the development of a pioneering nanoscope. Our aim is to exploit the most recent progresses of Plasmonics and Nanotechnology to combine the mentioned techniques in one single tool, able to perform a comprehensive study of the molecular structure and interactions in native environment. The physical mechanism exploited is the adiabatic generation and compression of surface plasmon polaritons, used in combination with AFM technologies. The proposed Plasmon Adiabatic Nanoscope will be employed to study cell surface and membrane proteins in their native environment and label-free conditions. The use of this tool can be extended in the THz domain, that shows great promise to increase our knowledge on hydration-water properties - a crucial issue for understanding biomolecular function in a cellular context.

Requirements: This research theme strongly relies on nanofabrication advanced techniques and candidates should have a master in Physics, Chemistry or similar.

Reference: F. De Angelis, et al., 3D adiabatic compression of surface plasmon polaritons for nano-mapping at 10 nm spatial resolution, Nature Nanotechnology, 5 (2010) 67-72.

Contacts: francesco.deangelis@iit.it

8. Electrochemical characterization of novel nano-size materials

Tutors: Remo Proietti Zaccaria, Claudio Capiglia

Department: Nanophysics (IIT)
http://www.iit.it/en/research/departments/nanophysics.html

Description: This interdisciplinary project aims at the development of novel materials fabricated with top down and bottom up nanotech fabrication techniques, and to the characterization of these materials with electrochemical techniques.
To improve the electrochemical properties of the synthesized materials, the candidate will be requested to elaborate mathematical structural modeling to be verified with experimental data. Prior knowledge of Comsol FEM software will be considered an advantage.

Requirements: Applicants should hold a master degree within a relevant discipline. A suitable background would be, physics, chemistry, engineer, material science, electrochemistry or similar. Experience with electrochemistry and programming will be favourable. Publications and any other work which the applicant wishes to be taken into account must be enclosed. Joint works will be considered provided that a short summary outlining the applicant's contributions is attached.
The application must include a statement of purpose related to the present call. This statement should be precise and brief, and states the candidate's academic and research interests. The applications must also include a motivation letter, CV, diplomas, and reference letters

Contacts: remo.proietti@iit.it or claudio.capiglia@iit.it

9. Ultrafast characterization of Plasmonic nanodevices for Strong Coupling Regime

Tutors: Remo Proietti Zaccaria

Department: Nanophysics (IIT)
http://www.iit.it/en/research/departments/nanophysics.html

Description: The candidate will be asked to theoretically study and experimentally realize plasmonic nanostructures for strong coupling regime applications. In particular, the candidate is

expected to design, simulate, fabricate and finally statically characterize plasmonic nanodevices capable of showing Rabi splitting in the visible/IR spectrum.
Furthermore, the ultrafast characterization, based on 100fsec system, will be accomplished together with a team partner located at the Key State Laboratory at the College of Electronic Science and Engineering, Jilin University, China. In case of a more than satisfactory proficiency from the candidate, its staying in China for the time necessary for the experiment might be considered.
The candidate will have at disposal also a number of numerical codes (FEM, FDTD, FIT, etc.) in order to analyze realistic structures which will be fabricated in IIT.

Requirements: master degree within a relevant discipline. A suitable background would be, physics, chemistry, engineer, material science, electrochemistry or similar. Experience with electrochemistry and programming will be preferable. Publications and any other work which the applicant wishes to be taken into account must be enclosed. Joint works will be considered provided that a short summary outlining the applicant's contributions is attached. The application must include a statement of purpose related to the present call. This statement should be precise and brief, and states the candidate's academic and research interests.
The applications must also include a motivation letter, CV, diplomas, and reference letters

Contacts: remo.proietti@iit.it

10. New materials for magnetoplasmonics

Tutors: Remo Proietti Zaccaria, Andrea Toma

Department: Nanophysics (IIT)
http://www.iit.it/en/research/departments/nanophysics.html

Description: Magnetoplasmonic hybrid media are composed of near-field-coupled plasmonic and magnetic materials. The intertwining of the plasmonic response to incident electromagnetic fields with the magnetic reaction to applied magnetic fields triggers the appearance of novel functionalities in the composite materials, like the magnetic tuning of the plasmonic properties or the plasmonic modulation of the magnetic/magneto-optical response. The mutual influence of the magnetic response on the plasmonic properties and viceversa critically depends on the materials employed and their geometry, hence their degree of near-field coupling. The aim is to engineer new materials and their configuration in order to maximize the magnetic/plasmonic coupling, both in top-down and bottom-up approaches, and exploiting ultra-controlled environment for fabrication. Morphological characterization of the materials will be performed by advanced microscopy techniques, and the magnetic response by spectroscopic magneto-optics, all backed by chemical and optical spectroscopy characterization. The successful applicant should have a strong background in physics and material science, and the capability of working in an interdisciplinary environment. Previous knowledge of sample nanofabrication techniques and/or spectroscopy is a plus.

Requirements: Applicants should hold a master degree within a relevant discipline. A suitable background would be, physics, chemistry, engineer, material science, electrochemistry or

similar. Experience with electrochemistry and programming will be favourable. Publications and any other work which the applicant wishes to be taken into account must be enclosed. Joint works will be considered provided that a short summary outlining the applicant's contributions is attached.
The application must include a statement of purpose related to the present call. This statement should be precise and brief, and states the candidate's academic and research interests. The applications must also include a motivation letter, CV, diplomas, and reference letters

Contacts: remo.proietti@iit.it or andrea.toma@iit.it

11. All-optical hydrogen sensing

Tutors: Remo Proietti Zaccaria

Department: Nanophysics (IIT)
http://www.iit.it/en/research/departments/nanophysics.html

Description: The development of hydrogen-based fuel-cell technologies makes hydrogen sensing a vital safety issue, since concentrations of hydrogen exceeding 4% may ignite explosively. All-optical hydrogen sensing would represent a clean and safe way to fabricate safe, spark-free sensors. Plasmonic-based sensors represent, in this respect, one of the most promising sensing schemes. The frequency, bandwidth and amplitude of plasmons are strongly sensitive to the dieletric environment, hence plasmons “sense” small variations of local environment induced by external agents. The aim is to exploiting the hydrogen sensitivity of palladium’s optical constants in innovative plasmonic heterostructures that amplify the hydrogen-induced plasmonic response of Pd via its optical near-field coupling with a plasmonic resonator.
The systems will be realized combining top-down and bottom-up approaches. The systems will be characterized by advanced microscopy, spectroscopy and X-ray-based chemical-sensitive techniques. Their plasmonic response will be characterized under controlled-atmosphere conditions for testing their hydrogen sensitivity, and accordingly optimized for their integration in devices.

Requirements: The successful applicant should have a strong background in physics and material science and the capability of working in an interdisciplinary environment. Previous knowledge of sample nanofabrication techniques is a plus.
Publications and any other work which the applicant wishes to be taken into account must be enclosed. Joint works will be considered provided that a short summary outlining the applicant's contributions is attached.
The application must include a statement of purpose related to the present call. This statement should be precise and brief, and states the candidate's academic and research interests.
The applications must also include a motivation letter, CV, diplomas, and reference letters

Contacts: remo.proietti@iit.it

12. Fabrication and characterization of plasmonic nanostructures for magnetic hot-spot generation

Tutors: Andrea Toma, Francesco De Angelis

Department: Nanophysics (IIT)
http://www.iit.it/en/research/departments/nanophysics.html

Description: PhD activity will consist on the fabrication by means of advanced lithographic techniques (i.e. electron beam lithography and focused ion beam) of size-dependent plasmonic nanostructures with inter-particle separation below 10 nm, with the aim of investigating magnetic-like plasmonic resonances. Due to the low magnetic susceptibility of plasmonic metals, the generation of intense magnetic hot-spots is nowadays an open issue inside the plasmonics community. The fabrication of strongly coupled nano-systems (in the shape of oligomers) can promote giant field enhancement in highly localized nano-volumes, thus allowing for the generation of resonating displacement currents in the interparticle gap regions. The proposed work is part of a research project devoted to the innovative fabrication and optical characterization of complex plasmonic architectures made of noble metals with various shapes and spatial arrangements. The candidate will acquire a good clean room expertise combined with spectroscopic characterization (both in the VIS and IR spectral range), working in a multidisciplinary environment across nanofabrication and nano-optics.

Requirements: Candidates should have a M.D. in Physics, Material Science or Engineering, better if accomplished with a good background in electron beam lithography technique and/or FTIR measurements

Contacts: andrea.toma@iit.it

13. Bioactive materials design for tissue engineering applications.

Tutors: Dr. Silvia Scaglione

Description: Joints trauma and disease is one of the most prevalent disorders of the musculoskeletal system, involving structural damage to the articular tissue. This project will put forward separate solutions to engineer both meniscus and osteochondral tissues for articular tissue repair. Specifically, it will pursue the integration of advanced polymer-based material processing technologies and nanotechnologies to obtain three-dimensional hierarchical grafts mimicking the microenvironment and structure of the natural anisotropic tissues. Different experimental approaches will be explored to functionalize such scaffolds, considering the intrinsically distinct architectural and biochemical features of the articular cartilage/subchondral bone system and of the fibro-cartilaginous meniscus tissue. At this scope, functional graded materials will be investigated, offering a porous and chemical gradient that imitate the stratified structure of articular cartilage tissue.
Moreover, the capability of these bioactive scaffolds to adapt their 3D structure according to imposed mechanical loading will be investigated by using custom-made bioreactor systems able to mimic the complexity of the natural features of the joints tissues. The grafts potential to

guide and control a selective cell differentiation and tissue growth, according to their stimuli decoded by the cells, will be investigated through systematic and reproducible studies, with and without the use of bioreactors.

Requirements: background in one or more of the following fields: bioengineering, materials science, physics, chemistry, biomechanics. Interests in understanding/learning basic biology.

Contacts: silvia.scaglione@cnr.it

14. Nanostructured hybrid, organic and bio-materials for unconventional computing.

Tutors: Laura Pastorino/Carmelina Ruggiero

Department: DIBRIS (University of Genova)
http://www.dibris.unige.it

Description (MAX 1500 char): Living beings analyze information and perform calculations in a very different way with respect to that used by now available computers. Chemical and bio-inspired computers are based on non-linear chemical and electrochemical reactions, such as that taking place in living beings. In the case of bio-inspired computers, the basis material can be of different nature: both organic and inorganic. The main feature of such approach is the realization of bio-mimicking elements. The proposed project is focused on interfacing simple living organisms, such as slime mold systems, and colloidal nanoengineered containers with artificially made devices and circuits. It is intended to control the response of such systems with respect to external stimuli in physical, chemical, and biological media. Novel computational techniques and working prototypes of nonlinear element-based computers will be developed. The experimental activity will be parralled by computer based modeling specifically focused on cellular automata modeling, on molecular dynamics and on Monte Carlo based simulations.

Requirements: background in, bioengineering, chemistry, physics, materials science or related disciplines. Attitude for problem solving. Interests in understanding/learning basic biology.

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