PhD Program in Bioengineering and Robotics

Curriculum Bionanotechnologies

Research themes

1. **Sustainable, Active and Responsive Food Packaging** ................................................................. 2
2. **Flexible and Sustainable Electronics for Robotics** ........................................................................ 3
3. **Extraction of Polymers from Natural Sources for Biomedical Applications** .......................... 4
4. **Water Remediation** ....................................................................................................................... 5
5. **Development of Smart Coatings with Sustainable Approaches** .............................................. 6
6. **High-Speed Super-Resolved Microscopy** .................................................................................... 7
7. **Single-Molecule-Tracking with Single-Photon Detector Array** ................................................. 8

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 optical characterization and imaging tools, from intelligent drug delivery to artificial tissues, from functional nano-addressable surfaces to smart materials. Among others, research developments include developing new sustainable materials and approaches for packaging and electronics, and implementation of new microscopy techniques for investigating life at the nanoscale. As well, most of the applications are conceived starting from the IIT domains (Robotics, Nanomaterials, Lifetech, Computational Sciences) to numerous others, including technology transfer perspectives. The candidate will be immersed in the frontiers of science and technology.

*International applications are encouraged and will receive logistic support with visa issues, relocation, etc.*
1. Sustainable, Active and Responsive Food Packaging

**Tutor:** Dr. Athanassia Athanassiou

**Institute:** Istituto Italiano di Tecnologia

**Research Unit:** Smart Materials

https://www.iit.it/research/lines/smart-materials

**Description:** Packaging of food and beverage represents almost two-thirds of total plastic packaging waste of the planet. This is because food packaging is usually thrown away after use, opposite to other applications of plastics. Hence, the necessity for green and biodegradable materials that can be used in contact with food and protect it against possible contaminations, is becoming an immediate need. On the top, even if hundreds of million tons of packaging are produced every year, still an estimated one-third of all food produced globally is lost or wasted. Therefore, other functionalities than a simple passive protection need to be added to food packaging to prevent food waste. For example, active packaging can release active principles like antioxidant or antibacterial agents that can prolong the self-life of food. Responsive packaging, on the other hand, is able to monitor the condition of the packaged food and provide immediate qualitative visual information on the freshness of the product, upon interaction of the indicator molecules with substances formed upon food spoilage, such as CO₂ produced during bacterial or mold growth on foods, sulfur-containing compounds, organic acids, amines, etc.

The aim of this PhD is the development of green packaging systems from sustainable resources that can be in contact with food, protect the food from oxygen and humidity and at the same time can release protective agents and provide fast and easy detection of food spoilage. The group of Smart materials has a long standing expertise in the production of sustainable bioplastics that combined with the right organic compounds can be turned into very efficient smart packaging materials.

**Requirements:** the ideal candidate must have a Bachelor’s Degree in one of the following areas: Bioengineering, Chemical Engineering, Material Science, Chemistry, Physics, Biology.

**Contacts:** atanassia.athanassiou@iit.it
2. Flexible and Sustainable Electronics for Robotics

Tutor: Dr. Athanassia Athanassiou

Institute: Istituto Italiano di Tecnologia
Research Unit: Smart Materials
https://www.iit.it/research/lines/smart-materials

Description: The yearly generated electronic waste reached 44.7 million tons in 2016 (United Nations), and at the same time it comprises 70% of the overall toxic waste of the planet. As the lifetime of electronic devices is getting shorter every year, we plan to address this problem by developing sustainable biocomposites, flexible and biodegradable suitable for electronics.

The aim of this PhD is the design and development of various electronic parts like RLC circuits, sensors, and actuators using the biocomposites combined with conductive fillers like carbon nanowires, graphene, metallic nanoparticles, etc. The developed flexible and sustainable devices will be tested and employed on humanoid robot prototypes of IIT, aiming at improved sustainability and reduction in costs and fabrication complexity of the already used robotics part, as well as enhanced mechanical, electrical and thermal properties.

Requirements: the ideal candidate must have a Bachelor’s Degree in one of the following areas: Material science, Material engineering, Physics, Chemical Engineering, Chemistry, or related fields.

Contacts: athanassia.athanassiou@iit.it
3. Extraction of polymers from natural sources for biomedical applications

**Tutors:** Dr. Athanassia Athanassiou

**Institute:** Istituto Italiano di Tecnologia  
**Research Unit:** Smart Materials  
[https://www.iit.it/research/lines/smart-materials](https://www.iit.it/research/lines/smart-materials)

**Description:** Recent trends in biomedical and pharmaceutical research indicate that natural polymers are increasingly explored as vehicles for drug delivery but also as active components of scaffolds for efficient wound healing. Being biocompatible and biodegradable, they can be absorbed into the body fluids without any toxic effects. Natural polymers (polysaccharides, proteins, polyesters) will be extracted from various bio-resources (plant residues, wool, fungi, and microalgae). During the extraction procedure other substances like essential oils, waxes etc. will be also separated in order to be eventually used in the final composite materials. The aim of this PhD project is the development of natural composite materials with superior physical properties in order to provide novel sustainable and active alternatives to biomedical devices used in wound management and infections, cosmetics and personal care. Dedicated scaffolds or medical devices will be obtained for each application, such as micro or nano-beads, fibrous mats, films, multi-layered coatings. The improvements of the bioavailability of the delivered substances will be also targeted.

**Requirements:** the ideal candidate must have a Bachelor’s Degree in one of the following areas: Chemistry, Chemical Engineering, Material Science, Bioengineering, Physics, Biology.

**Contacts:** [athanassia.athanassiou@iit.it](mailto:athanassia.athanassiou@iit.it)
4. Water remediation

Tutor: Dr. Despina Fragouli

Institute: Istituto Italiano di Tecnologia

Research Unit: Smart Materials

https://www.iit.it/research/lines/smart-materials

Description: Human activities, sudden water pollution accidents and inappropriate wastewater management result in the continuously increasing presence of hazardous pollutants in water, affecting human health and aquatic organisms. Therefore, research has been intensified for the development of effective, robust, and low-cost methods for water treatment.

The aim of this PhD project is the development and characterization of porous materials for water remediation applications. In particular, porous polymeric composite membranes and foams will be designed and developed, able to selectively remove typical and emerging organic pollutants from water, such as industrial chemicals, pharmaceuticals, pesticides, flame-retardants, etc. The successful candidate will learn how to design and proceed methodically with the experimental work, and will gain experience on polymeric materials processing, molecular interactions, and on various experimental methods such as foaming, electrospinning, scanning electron microscopy, spectroscopic methods such as FTIR, XPS and UV-vis, XRD, porosimetry, etc.

Requirements: the ideal candidate must have a Bachelor’s Degree in one of the following areas: Bioengineering, Material Science, Physics and Chemistry.

Contacts: athanassia.athanassiou@iit.it
5. Development of Smart Coatings with Sustainable Approaches

**Tutors:** Dr. Ilker S. Bayer

**Institute:** Istituto Italiano di Tecnologia

**Research Unit:** Smart Materials

[https://www.iit.it/research/lines/smart-materials](https://www.iit.it/research/lines/smart-materials)

**Description:** Smart coatings have many diverse applications ranging from energy harvesting, sensing, signal transport and controlled release of drugs and nutrients. Moreover, many coating applications including commercial paints increasingly ask for superhydrophobic properties, self-cleaning toward dirt management and longer lifetime against mechanical abrasion the aging. It is difficult to design a coating that can have multi-functionality, such as superhydrophobicity but also drug release properties, for instance, but also maintain a certain degree of robustness. This PhD activity aims on developing such smart coatings using sustainable and green materials and processes in order to address today’s ever-increasing environmental issues without compromising efficiency. Coating fabrication will be based on standard processes such as spray, rod or dip coating. As solvent, water-based including emulsion formulations will be developed by the student. The main focus will be to ensure that the coatings have hydro-repellent properties but with other added functionalities such as good thermal or electrical conductivity, antioxidant and antiseptic on-demand release capability and tunable biodegradation rates. As substrates, many technologically important surfaces will be available such as glass, metals ceramics and membranes depending on the desired application.

**Requirements:** the ideal candidate must have a Bachelor’s Degree in one of the following areas: Chemical Engineering, Materials Science, Physics and Chemistry with materials science specialization.

**Contacts:** thanassia.athanassiou@iit.it
6. High-Speed Super-Resolved Microscopy

Tutor: Dr. Giuseppe Vicidomini

Institute: Istituto Italiano di Tecnologia
Research Unit: Molecular Microscopy and Spectroscopy
https://iit.it/research/lines/molecular-microscopy-and-spectroscopy

Description: The aim of the Molecular Microscopy and Spectroscopy group is the theoretical design, development and validation of novel optical and analytical tools that allow the modern biologists to peer inside living biological systems with unprecedented temporal/spatial abilities and massive information content.

Within this context, the prime goal of the project will be to establish a new three-dimensional fluorescence microscopy technique for high-speed (fast) and super-resolution imaging [1,2] of living cells/tissues/organisms. To this end the candidate will explore both hardware and software strategies. In particular: (i) a wide-field microscopy architecture (structure-illumination or selective-plane-illumination) will be explored to “instantaneously” generate large field-of-view images of the sample; (ii) adaptive optics methods will be investigate to provide three-dimensional imaging also into thick specimen; (iii) image reconstruction and denoising will be used to work at a reduced photon flux (both for the emission and for the excitation).

Requirements: (i) master degree or equivalent degree preferably in engineering, physics or computer science; (ii) ability and motivation to work independently as well as collaboratively in an interdisciplinary team; (iii) ability to gather and analyze data from different resources with the aim of building, comprehensible and convincing story; (iv) coding skills (Python and/or Matlab, C#) are highly desirable; (v) expertise in microscopy and controlling system will be considered as a plus.

References:


Contacts: giuseppe.vicidomini@iit.it
7. Single-Molecule-Tracking with Single-Photon Detector Array

**Tutor:** Dr. Giuseppe Vicidomini

**Institute:** Istituto Italiano di Tecnologia

**Research Unit:** Molecular Microscopy and Spectroscopy

[https://iit.it/research/lines/molecular-microscopy-and-spectroscopy](https://iit.it/research/lines/molecular-microscopy-and-spectroscopy)

**Description:** The aim of the Molecular Microscopy and Spectroscopy group is the theoretical design, development and validation of novel optical and analytical tools that allow the modern biologist to peer inside living biological systems with unprecedented temporal/spatial abilities and massive information content.

**The BrightEye Project (ERC–CoG–2018)**

The overall objective of the BrightEyes project is to develop a set of innovative and non-invasive imaging and spectroscopy tools able to observe a single-biomolecule at work in a living multi-cellular system. Specifically, by exploring novel single-photon avalanche diode (SPAD) arrays detector, the BrightEyes project will implement an optical system able to continuously (i) track in real-time a biomolecule of interest; (ii) measure its nano-environment and its structural changes; (iii) observe its interactions with other biomolecules; (iv) visualize its sub-cellular micro-environment with nanometer resolution.

Within the context of the BrightEye project, the prime goal of the project will be the implementation of a feedback-based single-molecule tracking (SMT) system on a point-scanning microscope equipped with a small SPAD array detector – instead of the classical single-point detector. In essence, the candidate will implement a feedback controlling system which uses the signal provide by the SPAD array detector to control the actuators of the microscope’s beam scanning architecture and continuously maintain the tracked molecule in the centre of the excitation/detection volume of the microscope.

**Requirements:**

(i) master degree or equivalent degree in engineering, physics or related disciplines; (ii) ability and motivation to work independently as well as collaboratively in an interdisciplinary team; (iii) ability to gather and analyse data from different resources with the aim of building, comprehensible and convincing story; (iv) expertise in controlling system (LabView, VHDL) is a must; (v) coding skills (Python and/or Matlab, C#) are highly desirable; (vi) expertise in microscopy will be considered as a plus.

**References:**


**Contacts:** giuseppe.vicidomini@iit.it