UNIVERSITÀ DEGLI STUDI DI GENOVA

ISTITUTO ITALIANO DI TECNOLOGIA

# Università degli Studi di Genova – Istituto Italiano di Tecnologia

## Corso di Dottorato "Scienze e Tecnologie della Chimica e dei Materiali"
## Curriculum "Nanochemistry"

Anno Accademico 2017-2018
Ciclo XXXIII

## Research Themes

## 10 positions available with scholarship

### 1. Development of novel plasmonics nanomaterials

In the last few years, colloidal nanocrystals (NCs) of semiconductor materials have generated much interest for tunable plasmonics as their electrical conductivity and their localized surface plasmon resonance (LSPR) can be controlled, in general, by means of doping. Their absorption features, arising from the LSPR, can be actively modulated across visible, near-infrared, and mid-IR wavelengths by varying the density of dopants during their synthesis, and, post-synthesis, by reversibly charging/discharging the materials through appropriate electrochemical methods. Some examples of plasmonic semiconductors NCs are metal calcogenides NCs, in particular Cu2-xE (E=S, Se, Te), and doped metal oxide NCs. Thanks to their tunable optical and electrical properties, these compounds show great potentialities for numerous applications, such as smart windows, displays, solar cells and, in medicine, for photothermal therapy. The aim of this project is the synthesis and the characterization of new semiconductor nanomaterials exhibiting a LSPR in the visbile-NIR spectral range. Of particular interest is, also, the synthesis of engineered nano heterostructures containing one or more plasmonic materials that can be used in highly performing smart windows or for efficient photothermal therapy. The resulting materials will be deeply characterized and tested in prototype devices.

Requirements: The ideal candidate must have a Bachelor's Degree in one of the following areas: Material Science, Chemistry, Chemical Engineering or Physics.

For further details concerning the research theme, please contact: liberato.manna@iit.it; luca.detrizio@iit.it

### 2. Development of new materials for energy conversion

The research activity proposed here will be dedicated to the fabrication and comprehensive characterization of nanomaterials, with applications in energy conversion. Solar cells, allowing direct conversion of solar energy into electrical power, perfectly embrace the current increasing demand for new "green" energies to replace fossil fuels. Also thermoelectric (TE) devices, capable of converting heat directly into electricity, are emerging for the production of economically competitive renewable energy. Colloidal semiconductor nanocrystals (NCs) have been shown as promising materials for low-cost and high efficiency solar cells and thermoelectric devices thanks to their unique properties as well as simple and safe solution phase syntheses and film fabrication. This research activity will be first focused in the synthesis of nanocrystals, including for example metal chalcogenide and halide perovskites. These materials will then be processed and tested for thermoelectric and photovoltaic applications.

Requirements: The ideal candidate must have a Bachelor's Degree in one of the following areas: Material Science, Chemistry, Chemical Engineering or Physics.

For further details concerning the research theme, please contact: liberato.manna@iit.it; luca.detrizio@iit.it

## 3. Development of new materials for photonic and optoelectronic applications

Fluorescent nanocrystals are attractive materials for photonics and optoelectronics. Some of these materials are already on the market as fluorescent probes in bio-imaging, or as color-converting phosphors in computer, tablet, and TV displays. Such applications critically rely on an efficient and robust light emission, and the possibility to tune the emission color by controlling the size and composition of the nanocrystals. This research activity will be devoted to the development of new types of strongly fluorescent nanocrystals, for example halide perovskites. The photo-physical properties of these materials will be studied in detail, and they will then be processed and tested for applications in light emitting diodes, lasers, and in concentrators for solar cells.

Requirements: The ideal candidate must have a Bachelor's Degree in one of the following areas: Material Science, Chemistry, Chemical Engineering or Physics.

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## 4. Development and analysis of composite nanomaterials for sensors and actuators

In the last years a great effort has been devoted to the self-organization of colloidal nanocrystals in planar or three-dimensional structures (as for example aligned or interconnected arrays of nanodisks or nanorods) that possess promising opto-electronic properties. Since most of the technology is moving toward the miniaturization of their components, this approach is a cost – effective solution to build nano-objects. The possibility to tailor the geometry and composition of nano-objects suggests their use for sensing or actuating micro-devices that can be of use in robotics. For such applications it is relevant to have structures that can change their response (morphology related properties) when exposed to external inputs and this can be reached by encapsulating them in polymers that can also respond to such signals. This research activity will be first focused on the integration of self-assembled structures made of metal chalcogenides and perovskite nanocrystals in polymer films, especially planar structures in thin films. Then in a second stage they will be further processed and tested for applications in sensors (pressure, strain, temperature…) and actuators that could be improved in a last stage for testing their use in robots.
Requirements: The student should have a degree in materials science, engineering or physics, with a strong interest in experimental designs and physics of nanomaterials.
For further details concerning the research theme, please contact: liberato.manna@iit.it, milena.arciniegas@iit.it

## 5. Manipulating light emission with metamaterials

Metamaterials can lead to many exciting properties such as ultrahigh gain, negative refractive index, and directionally dependent dielectric permittivity. Hyperbolic metamaterials (HMMs) are a particularly interesting case that can be realized by alternating dielectric and metallic layers. In this project, we will develop hyperbolic metamaterials for the visible spectral range that, thanks to the selected fundamental components and/or their specific geometric design, manifest special features in the VIS-NIR range, among which perfect lensing, resonant gain amplification and ultra-subwavelength collimation of light, are only a few interesting examples. Such specifically designed HMMs find application in the framework of nano-lasers, ultra-subwavelength resolution for new conception diagnostic imaging, UV exposure sensors and more. Challenges are doping of the dielectric with fluorescent dyes for loss compensation, exploring new dielectric or plasmonic materials in order to endow the HMMs with opto/electric/thermal spectral tuning and achieving super-resolution nano-lasers. We foresee mainly layered metamaterials that can be fabricated by sputtering, thermal evaporation, atomic layer deposition and spin-coating. The successful candidate will work on device design, simulation, and fabrication, as well ason the study of their optical properties in a state-of-the-art clean room and spectroscopy labs.

Requirements: We are looking for excellent and highly motivated candidates with a degree in physics, chemistry, electrical/electronic engineering or material science. Experience in metamaterials, optical spectroscopy, ellipsometry, simulations or clean room fabrication is a plus.

For further details concerning the research theme, please contact: roman.krahne@iit.it; vincenzo.caligiuri@iit.it

## 6. Novel materials for nanoscale optoelectronics

Solution processable semiconductor nanomaterials are a very interesting alternative for low cost optoelectronic devices such as light-emitting diodes, lasers, sensors, and photoconductors. In particular chalcogenide and perovskite nanocrystals have demonstrated their great potential in this respect. This project aims at proof of concept and prototype devices based on recently developed nanomaterials. The successful candidate will optimize the nanomaterial synthesis for the targeted device application, will fabricate the devices and characterize their optoelectronic properties. We are looking for a chemist who is driven by the application of the materials that he/she fabricates, and who is familiar, or wants to learn, about the physics of semiconductor devices. The work is equally balanced between nanomaterial synthesis and device fabrication.

Requirements: We are looking for excellent and highly motivated candidates with a degree in chemistry, material science, or physics who have hands on experience in nanomaterial synthesis and fabrication of optoelectronic devices.

For further details concerning the research theme, please contact: roman.krahne@iit.it

## 7. Synthesis and in vitro characterization of drug delivery systems based on inorganic nanoparticles

In current anticancer chemotherapy a critical drawback is related to the drugs being delivered not only to malignant cells. Existing treatments could be by far more efficient if the drugs are carried and released selectively to the tumour site under tumor related stimuli. The present PhD project will focus on the development of polymer that can respond to cellular stimuli such as the enzymatic action (i.e. enzymatic degradation, glucose oxidase, etc.) or to the presence of radical oxygen species (ROS). These polymer will then can act as nanocontainers for encapsulation, protection, and transport of chemotherapeutic agents with trigger release mechanism based on oxidative stress or enzymatic action. Furthermore, the inclusion within the polymer of inorganic nanoparticles will add additional advantages: i) the magnetic nanoparticles will facilitate the delivery of the nanocontainer under a magnetic field to a tumour site and they will act as a hyperthermia agents to heat locally; ii) the presence of inorganic nanoparticles that can promoted the ROS production will facilitate, under stimulation (heat or UV laser irradiation), the production of ROS and thus the opening of the drug containers.
The candidate should mainly work on the preparation of the right stimuli-responsive polymers with a control over composition, disassembly properties, biodegradability and physical properties, on the combination of such polymers with inorganic nanoparticles, on the drug encapsulation and on the triggered drug release study.

Requirements: Candidate with expertise in polymer chemistry are mainly seeking. Expertise also on in vitro characterization study is also welcome.

For further details concerning the research theme, please contact: teresa.pellegrino@iit.it

## 8. Production of graphene and 2D crystal-based inks and electrodes for energy storage applications

The aim of this research theme is devoted to the development of graphene and two dimensional (2D) crystals for energy storage applications and their integration with other nanoparticles such as silicon. The emphasis will be on lithium ion battery applications, for which one key step is to identify novel candidate 2D crystals for the electrodes and the fine tuning of the electrochemical performances of hybrid electrodes 2D crystals/nanoparticles. The focus will be mainly on nanoscale layered materials, such as transition metal dichalcogenides and layered metal oxides, which are capable of hosting lithium in between the layers. The first part of the research activity will be devoted on the production of graphene and other 2D crystal inks with controlled morphological and rheological properties, by a top-down synthesis approach for the realization of such inks. The as produced inks will be studied in detail for what concerns their optical, structural, electrochemical and electrical transport properties. In addition, electrochemical studies will be carried out at every stage of the project, starting from the as-prepared nanocrystals up to the final battery assembly.

Requirements: We especially look for candidates with top class degrees in Chemistry, Materials Science, Physics or Chemical Engineering.

For further details concerning the research theme, please contact: francesco.bonaccorso@iit.it; vittorio.pellegrini@iit.it

## 9. Novel polymeric composites based on two-dimensional crystals as fillers with different aspect ratio.

This research theme is devoted to the development of graphene and two dimensional (2D) crystals-based composite materials for flexible electronic, energy conversion and storage, and photonic applications. One of the main targets will be the production of graphene and other 2D crystal inks containing dispersed 2D crystals with controlled morphological properties, i.e. surface area and thickness. We will develop a top-down synthesis approach for the realization of such inks, which will be first of all studied in detail for what concerns their optical, structural, electrochemical and electrical transport properties. Significant effort will be put in the design of novel composite materials based on graphene and two-dimensional crystal inks and a class of techno-polymers produced both by extrusion process and direct mixing. The graphene and 2D crystals-based polymer composites will be fully characterized by assessing their thermal, optical, structural, electrochemical and electrical transport properties. The final aim of the research theme is the exploitation of the graphene-based polymer composites in the field of flexible electronics, energy and photonic. In addition, graphene and 2D crystals-based polymer composites will be exploited in 3D printing technique for the realization of 3D structures for applications in the aforementioned fields of application.

Requirements: We especially look for candidates with top class degrees in Chemistry, Materials Science, Physics or Chemical Engineering.

For further details concerning the research theme, please contact: francesco.bonaccorso@iit.it; vittorio.pellegrini@iit.it

## 10. Polymeric porous materials for water-oil separation

Sustainable composite materials can be engineered into porous structures with specific wetting properties such as superhydrophobic and oleophilic, underwater oleophobic, etc. properties for the remediation of oil spills and the purification of water contained in emulsions. Optimization of the porosity, surface chemistry, and mechanical properties will be targeted for the efficient solution of the different problematics like light and heavy oil absorption, oil in water or water in oil stabilized emulsions. The chemistry of natural materials and their affinity to oily substances will be exploited. Nanotechnology solutions for the functionalization of the porous structures will be also studied. Absorption and filtering techniques will be developed.

Requirements: The ideal candidate must have a Bachelor's Degree in one of the following areas: Material Science, Chemistry, Chemical Engineering or Physics.

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