Course in:
SCIENCE AND TECHNOLOGY OF CHEMISTRY AND MATERIALS In agreement with the Foundation of the Italian Institute of Technology (Fondazione Istituto Italiano di Tecnologia – IIT)
Curriculum: NANOCHEMISTRY

1. **Development of new colloidal nanocrystals for energy related applications**

Tutors: Liberato Manna, Luca De Trizio

About the Project

The need to accelerate decarbonization is increasingly pushing research toward the development of new materials that can be used in energy conversion devices and/or that can decrease the energy demand of devices (for example light emitters). Solar cells or solar concentrators, for instance, enable the direct conversion of the solar energy into electrical power, thus generating "green" energy. Also, the pervasive use of light emitting diodes (LEDs), which are currently the most efficient light sources, is lowering the power required in lighting and displays. Colloidal semiconductor nanocrystals (NCs) have been shown to be promising materials for low-cost and high efficiency solar cells, solar concentrators and LEDs thanks to their unique properties and to the low costs associated with their synthesis. The optical properties of colloidal NCs can be finely tuned to match the required standards, and the NCs, in the form of inks (i.e. dispersion of NCs in a desired solvent) can be readily employed in low cost ink-jet processes for the fabrication of devices. This research activity will be first focused on the synthesis of nanocrystals (targeting metal halide perovskites, metal chalcogenides and chalcohalides) and their complete (structural, chemical, surface and optical) characterization. Such materials will be engineered in order to optimize their optical and electrical properties. Possible strategies to be developed are the encapsulation of nanocrystals in proper inorganic shells (with the formation of nano-heterostructures), ligand and/or ion exchange procedures, for their subsequent use in devices.

Requirements: The ideal candidate must have a Master 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. **Optoelectronics of plasmonic/semiconducting low-dimensional nanomaterials**

Tutor: Roman Krahne

About the Project

We aim to develop new concepts for optoelectronic devices based on photonic architectures and state-of-the-art nanomaterials such as colloidal nanocrystals and nanoparticles. One material class of great recent interest are low-dimensional semiconductor materials such as 2D layered perovskites. Based on a fundamental understanding of their optical and electrical properties, we will develop proof-of-concept devices for sensing, light emission, and signal processing.
The PhD candidate will work on time-resolved optical spectroscopy on these materials, their functionalization via surface chemistry and ion-exchange processes, and on nanofabrication of optical and electrical devices. We also aim to combine the nanomaterials with optical or plasmonic cavities for enhanced light emission and strong light-matter coupling.
The PhD position is hosted by Optoelectronics group (https://www.iit.it/it/web/optoelectronics) that is embedded in a highly stimulating and collaborative environment at the headquarters of the Italian Institute of Technology (IIT) in Genoa, Italy.

Requirements: The ideal candidate should have a degree in materials science, physics, chemistry or engineering, with a strong interest in the photophysics of nanomaterials and related device applications.
For further details concerning the research theme, please contact: roman.krahne@iit.it

3. **Surface and crystal volume engineering of colloidal nanocrystals for targeted radiotherapy and thermal-therapy**

Tutor: Teresa Pellegrino

About the Project

Magnetic-plasmonic nanoheterostructures enable to combine magnetic hyperthermia with plasmonic hyperthermia. Furthermore, semiconductor-based heterostructures can be also employed in cation exchange reactions to insert radiotherapy in the crystal structure of the semiconductor domain. Furthermore, the heterostructure surface can be modified with tumor ligand molecules to selectively redirect the heterostructures against tumor cells. All these features makes the heterostructures appealing for tumor treatment by exploiting a multimodal approach. The aim of this project is to develop protocols to tune the crystals composition and the surface of inorganic hetero-structures composed of at least two distinct domains, one magnetic, and one based on semiconductor, to merge magnetic hyperthermia, photo-ablation, radiotherapy while being able to selectivity target cancer cells. At the same time, the PhD student will acquire knowledge on characterizing those materials as imaging probes in magnetic resonance imaging, magnetic particle imaging, and positron emission tomography.

Requirements: The ideal PhD candidate with a preferable background in material science and chemistry will develop new skills on surface functionalization of heterostructures, material characterization and post synthesis manipulation of such inorganic heterostructures, including structural transformation (such as intercalation reaction with radioisotopes). Also as a part of his/her research the candidate will develop procedure for water transfer and stabilization in saline media and surface modification of these nanoparticles to make the nano-heterostructures specific towards bio-molecular targets associated to cancer or for sorting and detection applications. The candidate will be a member of a multidisciplinary team composed of chemists, biologists, physicists and engineers. At IIT, state-of-the-art chemistry and a full equipped material characterization facility is available together with biology laboratory for in vitro and in vivo characterizations. For any further information, please refer to teresa.pellegrino@iit.it and iulia.manolache@iit.it

4. **Engineering light-matter interactions with 2D materials at the nanometre level via substrate patterning**

Tutor: Michele Tamagnone

About the Project

This research activity will be focused on creating new nanophotonic devices based on 2D materials including (but not limited to) graphene, boron nitride and transition metal dichalcogenides. The goal is to enhance and control at the nanoscale the interaction between light and these materials for bio-chemical sensing and optoelectronics applications. This will be achieved using a new nanofabrication technique to create a patterned substrate with features of less than five nanometers and then transferring 2D materials on top of this substrate. The candidate will be working on the fabrication of these new devices in the cleanroom facilities at the Italian Institute of Technology and on their characterization with multiple techniques including optical and electrical measurements, electron microscopy and atomic force microscopy. While an important focus of the project is the nanofabrication of these devices in cleanroom, the research activity will be interdisciplinary and include the numerical modelling of the observed phenomena. In addition to significantly advancing the state of the art of nanophotonics, this project will offer to the candidate an excellent opportunity to learn advanced cleanroom nanofabrication skills and materials characterization techniques and acquire cutting-edge knowledge in multiple technical disciplines. She/he is expected to work independently but in strong collaborations with other researchers.

Requirements: The successful candidate should have a degree in materials science, engineering or physics, with a strong interest in cleanroom micro-nano fabrication, nanomaterials, experimental optics and optoelectronics. Work experience within a micro/nano-fabrication facility will be positively considered. A working knowledge of Matlab or Python programming is desirable.

For further details concerning the research theme, please contact: michele.tamagnone@iit.it

5. **Multi-electron processes for light driven electrodes and electrolytes in conversion and storage of solar energy**

Tutor: Ilka Kriegel

About the Project

The global demand for clean energy encompasses two equally important issues: production, but also access to energy. Although solar energy is the most promising and abundant renewable source, for a more sustainable energy development its storage is equally crucial. A more effective storage makes it possible to respond both to the intermittent nature of the source and to fluctuations in consumption demand. A very attractive solution consists in combining the absorption and storage of energy in a single device, thus also avoiding the losses associated with the compartmentalization of these two functions. In this context, the miniaturization and manipulation of materials at the nanoscale can offer a concrete answer to these needs.

The proposed research project is based on the exploration and analysis of low-dimensional materials, in which light harvesting can combine with very competitive charge storage capacity through multiple charge transfer processes. The objectives of the project therefore concern both the synthesis and the fundamental characterization of a new set of nanomaterials, but also of their mutual interactions. Starting from these materials, in fact, the preparation of composite/hybrid systems is envisaged, which bring together and coordinate the electro-optical properties for the fabrication of innovative devices based on flow cell systems and electrolytic-like capacitors. The PhD scholarship is based on the FET Proactive project "LIGHT-CAP" (https://cordis.europa.eu/project/id/101017821) carried out by a research consortium with highly interdisciplinary and collaborative environment involving a number of different groups from Italy, Germany, Spain and Switzerland. Within this framework, the PhD student will acquire an important experience in the management of extra-laboratory activities and dissemination and communication activities. The international character of the project also includes the periodic interfacing with the consortium, which constantly stimulates discussions on the research plan. Likewise, the project encourages the possibility of visits and short research stages within the different groups involved. The PhD project will be carried out within the Functional Nanosystems group (https://www.iit.it/research/lines/functional-nanosystems). The interdisciplinary research approach of the Functional Nanosystems group located between nanochemistry, material science, spectroscopy and optoelectronics delivers a stimulating environment, representing the atmosphere of the Central Research Lab at IIT, one of the biggest research centers in Europe.

Requirements: We especially look for candidates with degrees in Chemistry, Materials Science, Physics or Engineering and who are interested in a very interdisciplinary research approach between materials science and characterization, optical microscopy and spectroscopy, electrochemistry and theoretical modeling.
We explicitly encourage female applicants for this position.
For further details concerning the research theme and any related questions, please contact: ilka.kriegel@iit.it

6. **Novel light-emitting nanomaterials for optoelectronics**

Tutor : Francesco Di Stasio

About the Project

Colloidal semiconductor nanocrystals are nowadays employed in consumer electronics products such as displays and lighting. Yet, semiconductor nanocrystals can be exploited in quantum technologies as single-photon emitters but much effort is still required to improve their performance before this class of nanomaterials can compete with other single-photon generation venues. Importantly, single-photon emission is at the very base of quantum technologies as computing and secure communication.

The research activity aims at developing synthetic routes to obtain luminescent semiconductor colloidal nanocrystals, exploit such materials in light-emitting diodes (LEDs) and single-photon emitting devices and, identify which synthetic and structural parameters promote device performance. Post-synthetic chemical treatments of colloidal nanocrystals can promote enhanced performance in devices while detailed studies of the physicochemical properties of nanocrystals are required to identify which composition, structure and shape are best to fabricate light-sources with innovative architectures.

As discussed above, the interest in developing and study novel semiconductor nanocrystals is twofold: improve the performance of LEDs based on this class of nanomaterials and, development of non-classical light sources. Therefore, the research activity is expected to have an impact on both established and developing technologies.

The PhD candidate will carry out synthesis of metal chalcogenides and halide perovskites nanocrystals, study of chemical processing to enhance their emission or stability and, carry out detailed photo-physical characterization both at the single-nanocrystal level and as ensembles. The studied nanomaterials will then be exploited for the fabrication of both classical and non-classical electrically driven light-sources.

Funding for this position is provided by the European Research Council trough the 2019 Starting Grant "NANOLED". The project aims at developing light-emitting diodes based on individual colloidal NCs, thus paving the way to novel electrically driven single-photon sources with small footprint that are embeddable in photonic quantum networks.

Requirements: The ideal candidate must have a master's degree in one of the following areas: Materials Science, Chemistry, Chemical Engineering or Physics. The candidate must be interested in a very interdisciplinary research activity encompassing chemistry, engineering and physics.

For further details concerning the research theme, please contact: Francesco.distasio@iit.it

7. Fabrication and development of optoelectronic devices based on nanomaterials

Tutor : Francesco Di Stasio

About the Project

Colloidal semiconductor nanocrystals are intrinsic single-photon emitters thanks to quantum confinement. Single-photon emission from individual and isolated nanocrystals has been studied in details using optical excitation. Yet, the possibility to obtain single-photon emission from a nanocrystal under electrical pumping (i.e. direct electron-hole injection) still requires major developments concerning nanocrystal positioning, electrodes deposition and general device architecture design.

Here, the research activity will aim at the development of tools for deterministic positioning of colloidal semiconductor nanocrystals, fabrication of device architectures and characterization of the obtained light-sources. Single nanocrystal deposition will be carried out on functionalized substrates previously prepared via lithographic tools. In addition to substrate functionality, solution deposition control is also important to obtain ordered arrays of isolated nanocrystals. Therefore, the PhD candidate will study which solution deposition method promotes high reproducibility in isolated nanocrystals array production and how substrate-solution interactions affect the overall fabrication. Afterward, the PhD candidate will use nano/micro fabrication tools to electrically access individual nanocrystals thus obtaining a single-nanocrystals electroluminescent device which will then be characterized optically in terms of emission statistics.

The research activity will first focus on the exploitation of metal chalcogenides and halide perovskites nanocrystals.

Funding for this position is provided by the European Research Council trough the 2019 Starting Grant "NANOLED". The project aims at developing light-emitting diodes based on individual colloidal NCs, thus paving the way to novel electrically driven single-photon sources with small footprint that are embeddable in photonic quantum networks.

Requirements: The ideal candidate must have a master's degree in one of the following areas: Materials Science, Chemistry, Chemical Engineering or Physics. The candidate must be interested in a very interdisciplinary research activity encompassing chemistry, engineering and physics.

For further details concerning the research theme, please contact: Francesco.distasio@iit.it

8. Plastic particles and their interactions with other water pollutants

Tutors: Despina Fragouli, Athanassia Athanassiou

About the Project

Nano and microplastics are emerging water pollutants released to the environment by diverse products and processes or by the degradation of plastic litter. Plastic particles interact with various chemicals and living organisms, and can readily pass to humans through the food chain, the inhalation and the skin penetration. The smaller the size of these plastic particles the more difficult is to recover them from the environment and for this reason commercially available polymeric particles of specific type (mainly polystyrene) are used in order to conduct studies on their fate and interactions with other environmental components. However, polystyrene particles are not really representative to the actual nature and surface chemistry of these complex water pollutants, and therefore the obtained results for these studies may be misleading.

This PhD activity will point to the fabrication of nanoplastic and submicron particles of diverse polymeric nature, in order to fill the existent gap of knowledge in the nanoplastics field. This will be succeeded by adopting top-down approaches starting from bulk polymeric films and following innovative fabrication methods such as the laser ablation of solid targets in liquid environments. After the complete characterization of the fabricated particles, their interactions with common and emerging water pollutants, such as pesticides, drugs, dyes, heavy metal ions, flame retardants etc. will be investigated, in order to define the most stably interacting systems. Then, the interactions of the formed components with biological systems will be studied in collaboration with other research groups, in order to evaluate the effects that such pollutants can have to the living organisms.

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

For further details concerning the research theme, please contact: Despina.Fragouli@iit.it

9. **Multifunctional porous materials for advanced water treatment**

Tutors: Giovanni Perotto, Despina Fragouli

About the Project

Providing fresh water universally in a sustainable and affordable manner is a challenging task. Among the different strategies adopted to face up this problem, the recovery of freshwater from various polluted sources is of crucial importance. For this reason, the current research is focused on the development of novel multifunctional materials for advanced water technologies such as multicomponent water remediation and freshwater recovery.

This PhD activity will point to the development and characterization of multifunctional porous materials of natural origin for advanced water technologies. In particular, will be developed hydrogel based composite systems with special surface properties that permit to recover water from unconventional sources. The thesis will focus on natural based components, and various materials engineering approaches will be adopted in order to develop hydrogel based systems with the desired structural and physicochemical properties that permit the highly efficient interaction with water and the entrapment of targeted water pollutants.

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

For further details concerning the research theme, please contact: Giovanni.Perotto@iit.it; Despina.Fragouli@iit.it