DOCTORATE SCIENCES AND TECHNOLOGIES OF CHEMISTRY AND MATERIALS

NANOSCIENCE RESEARCH THEMES

1) Development of colloidal nanocrystals for energy related applications

Tutor: Liberato Manna
Co-Tutor: Luca De Trizio

Project description: The need to reduce the pollution connected with the combustion of petrol and carbon is increasingly pushing research toward the development of new materials that can be used in energy conversion devices, such as solar cells or solar concentrators, and/or that can decrease the energy demand of optoelectronic devices. Colloidal semiconductor nanocrystals (NCs) working in the visible range have been shown to be promising materials for low-cost and high efficiency solar cells, solar concentrators and light emitting devices thanks to their unique properties and to the low costs associated with their synthesis. Emerging NC materials operating in the infrared range could enable low-cost infrared technologies, such as night and fog vision systems, food quality assessment devices, and more, making them accessible to consumer markets rather than limited to niche ones.

In general, 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 both visible or infrared emitting materials such as III-V semiconductors, metal halides, and metal chalcogenides. Another important synthesis direction will comprise the production of nano-heterostructures, which are nanocrystals composed of two (or more) domains of different materials, rationally selected in order to achieve desired optical and electronic properties. The nanocrystalline products will be subjected then to a complete (structural, chemical, surface and optical) characterization. Both the nanocrystals and the heterostructures will be engineered in order to optimize their optical and/or electrical properties.

Requirements: as a prerequisite, the ideal candidate must have a degree in Materials Science, Chemistry, Physics or related fields. The candidate should have a strong interest in interdisciplinary research combining materials science and characterization. Candidates with experience in nanomaterial synthesis and characterization are particularly encouraged to apply.

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

2) Synthesis of colloidal nanocrystals and advanced spectroscopy

Tutor: Liberato Manna
Co-Tutor:

Project description: 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 focused on the synthesis of nanocrystals targeting those with optimal optical properties either in the visible or the infrared spectral regions with particular attention to metal pnictides (e.g. InAs or InSb), metal halide perovskites, metal chalcogenides and chalcohalides. 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.

A fundamental part of the research activity will involve the complete optical characterization of NCs via advanced optical techniques, including photoluminescence lifetime, quantum yield, and transient absorption measurements.

Requirements: as a prerequisite, the ideal candidate must have a degree in Materials Science, Chemistry, Physics or related fields. The candidate should have a strong interest in an interdisciplinary research approach that bridges materials science, characterization, and optical spectroscopy. Candidates with experience in nanomaterial synthesis and/or optical characterization are particularly encouraged to apply.

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3) Fabrication and investigation of light sources based on colloidal quantum dots

Tutor: Liberato Manna
Co-Tutor: Di Stasio

Project description: Colloidal Quantum Dots (QDs) are nowadays employed in consumer electronics products such as displays and lighting given their efficient emission of visible light. Nonetheless, recent developments allow QDs also to efficiently emit light in the near and short-wave infrared spectral (NIR and SWIR, respectively) regions. Importantly, NIR and SWIR light-sources are of interest for a variety of applications such as hyperspectral imaging, night vision, telecommunication systems, point-of-care testing, LIDARS, etc…
The Nanochemistry group, in collaboration with the Photonic Nanomaterials group, aims to develop light-emitting diodes (and other optoelectronic devices) operating in the visible, NIR and SWIR spectral ranges exploiting the unique properties of QDs. In fact, QD chemistry enables on-demand tailoring of the light-emission properties of the final nanomaterial in combination with solution processing, thus enabling low-cost fabrication of light-emitting diodes (LEDs) and other optoelectronic devices.
Currently, the research group is focusing on the development of LEDs (either small or large-footprint ones) based on InAs QDs with emission between 900 and 1500 nm. In particular, colloidal InAs QDs are emerging as a promising substitute to heavy-metal containing compositions as they are fully RoHS-compliant and, thanks to recent progress in material synthesis, they can demonstrate stable and highly efficient emission.
The PhD candidate will focus on the post-synthesis treatment of colloidal QDs and their implementation in LEDs carefully designed to obtain high external quantum efficiency and brightness. In addition, the PhD candidate will carry out detailed optical characterization of the synthesized QDs (steady-state and time-resolved photoluminescence, photon statistics, etc…) to correlate chemical properties with light-emission ones. Importantly, the PhD candidate will engage in collaborations with other group members, given the interdisciplinary nature of the proposed research theme, which requires a variety of skills for implementation.

Requirements: The ideal candidate must have a master's degree in Materials Science, Chemistry, Physics or related discipline. The candidate must be interested in a very interdisciplinary research activity encompassing chemistry, engineering and physics.

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4) Synthesis of colloidal nanocrystals and advanced electron microscopy

Tutor: Liberato Manna
Co-Tutor: Giorgio Divitini

Project description: The growing demand for alternative energy sources to replace fossil fuels is driving scientific research toward the development of new *smart materials* that can be employed either to convert natural energy sources into electricity or to fabricate optoelectronic devices with improved energy efficiency.

Colloidal semiconductor nanocrystals (NCs) have emerged as promising materials for low-cost optoelectronic applications thanks to their unique physical properties and the simplicity and safety of their solution-phase syntheses. The optical properties of colloidal NCs can be finely tuned to meet specific requirements, and NCs, when processed as inks (i.e., dispersions of NCs in a suitable solvent), can be readily utilized in low-cost inkjet printing processes for device fabrication.

This research activity will initially focus on the synthesis of nanocrystals, with particular emphasis on infrared-emitting materials such as III–V semiconductors, metal chalcogenides, and chalcohalides. A key part of the research will involve comprehensive electron microscopy characterization of the NCs using high-resolution transmission electron microscopy (TEM) and scanning TEM (STEM). The candidate will also perform STEM–energy-dispersive X-ray spectroscopy (STEM–EDX) to determine the composition of individual nanocrystals, scanning electron diffraction (4DSTEM) and other hyperspectral techniques.

Requirements: as a prerequisite, the ideal candidate must have a degree in Materials Science, Chemistry, Physics or related fields. The candidate should have a strong interest in an interdisciplinary research approach that bridges materials science, characterization, and electron microscopy. Candidates with experience in nanomaterial synthesis and/or electron microscopy are particularly encouraged to apply. Fluency in python is considered a plus.

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