UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Nanotechnology & Innovation

2526-1-FSM02Q016

Aims

The aim of the course is to provide in depth knowledge on various classes of nanomaterials that will constitute the main ingredient of future nanotechnologies. For each materials class, the synthesis approaches and the physical mechanisms underpinning their functionality will be studies discussed in detail with particular focus on size-related processes, such as quantum and dielectric confinement.

Applications of nanomaterials in various technological fields will be considered and their functioning principles will be studied, highlighting promising strategies for their design and optimization.

Regulation aspects regarding health, safety and environmental aspects of nanotechnology will be discussed.

Learning outcomes expressed through the five Dublin Descriptors:

1. Knowledge and understanding
   By the end of the course the student will be able to:

- Describe the main classes of nanomaterials – metal clusters, plasmonic nanoparticles and colloidal semiconductor nanocrystals – highlighting their electronic structure, optical properties and size-dependent phenomena such as quantum and dielectric confinement.
- Explain top-down and bottom-up synthesis routes, surface-functionalisation strategies, and the design criteria for heterostructures and optoelectronic devices.
- Illustrate plasmonic resonance, Coulomb blockade, wave-function engineering and the effect of dimensionality on the electronic density of states.
- Discuss the historical development of nanotechnology together with current regulations, health, safety and environmental (HSE) considerations.

2. Applying knowledge and understanding
   The student will be able to:

- Select the most suitable synthesis procedure (e.g. colloidal chemistry, laser ablation, lithography) to obtain nanomaterials with the desired size, shape and composition.
- Design nanoparticles and clusters optimised for optical/electronic performance in sensors, photonics, bio-imaging or thermal therapies.
- Apply confinement models to predict band-gaps, exciton energies and absorption cross-sections.
- Analyse experimentally UV-Vis and photoluminescence spectra, TEM/SEM images, and magneto-optical data to extract key parameters such as size distribution, density of states and dopant concentration.

3. Making judgements
   The course will develop the ability to:

- Critically evaluate trade-offs among functional performance, production cost and HSE requirements for nanomaterials intended for commercial devices.
- Compare alternative synthesis pathways and post-growth treatments, identifying those that are the most sustainable and scalable.
- Identify potential risks (toxicity, environmental release) and propose mitigation strategies compliant with current standards and regulations (e.g. REACH, ISO/TS 80004).

4. Communication skills
   On completion of the course students will be able to:

- Write technical dossiers and laboratory reports that cover theoretical background, synthesis protocols, data analysis and safety assessments.
- Deliver project pitches for novel nano-enabled devices (e.g. colloidal LEDs, plasmonic heaters) using clear language and effective visual aids.
- Engage in multidisciplinary teamwork with chemists, physicists, engineers and HSE managers, justifying design choices and regulatory implications.

5. Learning skills
   The course will enable students to:

- Independently consult scientific literature and industry standards to stay abreast of rapid developments in materials, synthesis techniques and regulations.
- Broaden their experimental toolkit by exploring advanced doping methods, self-assembly strategies or the integration of nanomaterials into hybrid architectures.
- Transfer the acquired concepts – confinement, plasmonics, interface engineering – to emerging fields such as nanomedicine, quantum photonics and flexible electronics.

Contents

The following classes of nanomaterials will be discussed:

1. Metal clusters: Bottom-up and top-down synthesis approaches, surface functionalization, electronic structure and size effects. Optical properties and photophysical processes. APplication in optoelectronic devices, sensors and biologic imaging.

2. Plasmonic metal nanoparticles: basic principles of plasmonics in dielectric confined nanomaterials, dielectic confinement, plasmon resonance and size/environment effects. Optical properties vs. size and dimensionality. Hot carriers in nanoaterials. Plasmon enhanced Raman spectroscopy. Plasmon enhanced fluorescence. Coulomb blockade effect and the concept of charge quantization. Applications in thermotherapy and sensing.

3. Colloidal semiconductor nanocrystals: Synthesis and surface chemistry, density of states in 3D and in 2-0

dimensional systems, electronic properties, excitonic (fine) structure, size an shape effects. Heterostructures and wave function engineering. Detailed photophysics, Electric transport. Doping and magnetic properties. Applications in LASERS, LEDs, bioimaging and energy technologies.

Detailed program

0. Introduction to Nantechnology:

- Hystory

- Health and safety aspects

- Regulations on nanomaterials

1. Metal Clusters:

- Synthesis approaches (top-down and bottom-up)

- Surface functionalization

-Electronic structure and size effects

- Photophysics and optical properties

- Optoelectronic devices, sensors and biomarkers based on metal clusters.

2. Plasmonic Nanoparticles

- Basic principles of plasmonics in low-dimensional systems

-Dielectric confinement

- Plasmonic resonance vs. size and envronment

- Coulomb blockade

- Applications in thermo-therapy and sensing

3. Colloidal Semiconductor Nanocrystals

- Colloidal synthesis, mechanisms

- Surface chemistry

- Electronic confinement and density of states in semiconductor nanostructures

- Electronic properties and exciton structure

- Size effects on the electronic properties

- Heterostructures: design criteria and synthesis aproaches

- Wavefunction engineering

- Doping

- Photophysics and magnetic properties

- Application in LASERS, LEDs, bioimaging and renewable energy technologies.

Prerequisites

Basic chemistry and chemical physics. Quantum mechanics, solid state physics.

Teaching form

All classes (48 hours in total) are taught in conventional in-presence lectures (so called 'didattica erogativa').

Textbook and teaching resource

Books suggested by the lecturer (e.g. Klimov, Nanocrystal Quantum Dots, ASBN:1420079263), slides and review articles provided during the course.

Semester

First semester

Assessment method

Presentation by the candidate (20-25 minutes with 15-20 powerpoint slides) on 2-3 literature papers on a subject of choice pertinent to the course followed by oral exam on the course program. There are no interim evaluations during the course. The following will be assessed: knowledge and understanding of the course topics, presentation skills, ability to critically analyze the literature examined, overall vision of the problems associated with nanotechnologies.

Office hours

To be agreed with the professor.

Sustainable Development Goals

QUALITY EDUCATION | AFFORDABLE AND CLEAN ENERGY | INDUSTRY, INNOVATION AND INFRASTRUCTURE | SUSTAINABLE CITIES AND COMMUNITIES