

CELTIC ADVANCED LIFE SCIENCE
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Advances in Nanomaterial Synthesis Techniques: Vision for the 2020s

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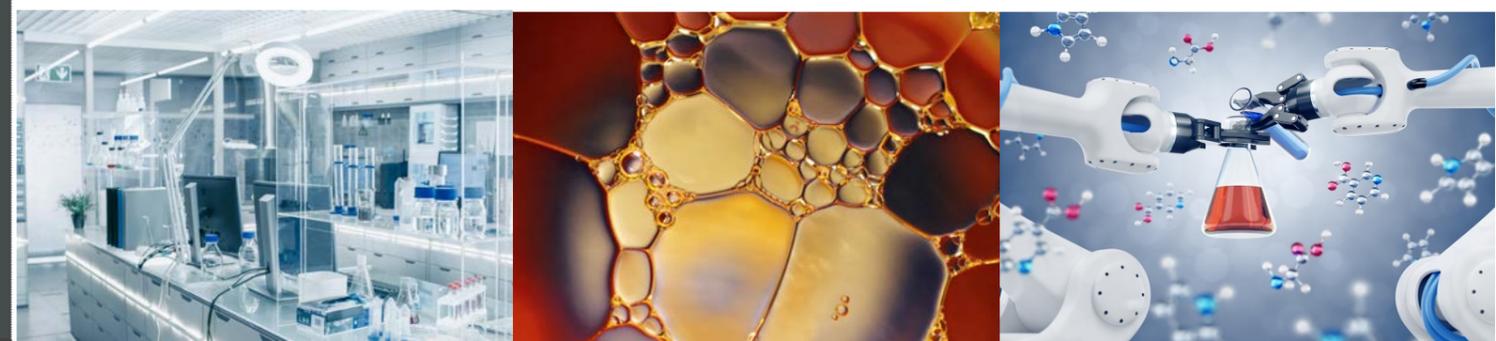
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Advances in Nanomaterial Synthesis Techniques research overview

Nanomaterials, in a broad sense, are defined as materials with at least one external dimension in the range between 1-100 nm. They show different chemical and physical properties from the bulk material they are made from, e.g., scattering of light, enhanced electronic and magnetic properties, size dependent optoelectronic properties and many other features.

Thanks to their distinctive properties, nanomaterials are used in a broad range of applications: from electronics to cosmetics, environmental engineering, food industry, aerospace as well as paint industry. They are particularly promising in medical science where their application may allow a remarkable advancement in the delivery of anti-tumour drugs and imaging contrast agents, as shown in in vitro and in vivo laboratory tests. However, to date, there have only been a few commercial formulations that exploit nanoparticles for drug delivery, mainly due to the low delivery efficiency of nanomaterials when used in clinical conditions.

In biology research, nanoparticles are used in detection, localization and quantification of proteins and DNA, in understanding cell signalling and endocytic membrane trafficking, as well as other applications, such as using them as nanoscale vehicles to stimulate specific functions in the cell such as in the immune system.

Why are Advances in Nanomaterial Synthesis Techniques important?

Nanomaterials have found and continue to find a wide range of applications both in industry and academia. According to GVR Nanomaterials Market Size, Share and Trends Market Analysis Report, the global nanomaterials market size was valued at USD 8.5 billion in 2019 and is expected to grow at a compound annual growth rate (CAGR) of 13.1% from 2020 to 2027. The report states that the high potential for product adoption for aerospace applications, in order to improve the strength and durability of aircraft parts, as well as rapid developments in healthcare technology, growth in the medical diagnostics industry, and various advantages of medicinal imaging applications are expected to drive the market in the forecasted period.

Some of the applications are exemplified below in more detail:

- Electronics: Quantum dots for televisions, carbon nanotubes for low cost electrodes for fuel cells, silver nanoparticle-based inks for printing circuits
- Environmental science: Photocatalytic copper tungsten nanoparticles for breakdown of oils into biodegradable compounds, gold nanoparticles as a catalyst to breakdown volatile organic pollution in air
- Medicine: Iron oxide nanoparticles as contrast agent for MRI and for treatment of tumours by hyperthermia, gold nanoparticles for biosensing, polymeric nanoparticles for drug delivery
- Chemistry: Nanoparticles have been exploited as a catalyst for reaction because of their high surface area per mass ratio, and are often used as a tool to purify chemical products from the crude of the reaction

To meet the requirements of such wide array of applications, innovative approaches to nanomaterial synthesis techniques have been required to provide distinct higher quality nanomaterials with enhanced properties.

Application of Advances in Nanomaterial Synthesis Techniques in the current climate

In the last decade, the advancement in synthesis strategies enabled researchers to obtain nanoparticles from different types of materials such as metal-based nanoparticles (e.g. gold, silver or iron oxide nanoparticles), polymeric nanoparticles (e.g. silica and polystyrene) and biological like nanoparticles (e.g. liposomes and protein particles). There are a number of key nanoparticle features that have direct impact on their function, including size, size distribution and shape. Indeed, the scientific community have put a lot of effort in developing new synthesis methods for controlling particle size and shape, and obtain a low level of polydispersity. A very interesting technique, from this point of view, is the flow chemistry, where the chemical reaction occur in a continuously flowing stream rather than in batch. Originally applied in organic chemistry, it is a good way to scale up reactions as it allows continuous production and when applied to the synthesis of nanomaterials, enables fine tuning of size and shape and generation of particles with a very low grade of polydispersity.

Another highly beneficial advancement in nanomaterial synthesis has been the combination of different materials in the same structure, giving rise to the so called core-shell structures. These nanocomposites have the advantage of retaining combined properties of different materials in just one structure. In this way these core-shell can carry put more than just one function, for examples, silica nanoparticles doped with organic dye and with a magnetic core has been used to study the intracellular trafficking using fluorescent microscopy and then their magnetic properties have been exploited to isolate the lysosomes, their end-destination inside the cells.

Potential impacts of Advances in Nanomaterial Synthesis Techniques in both academia and industry moving forward?

Currently, the nanomaterial synthesis techniques are well established and most allow a fine control over shape, size, size distribution and crystallinity composition. However, the continuous expansion of desired applications of nanomaterials give rise to new challenges:

- The increasing demand on nanomaterials require more efficient and green methods for their synthesis. Often the scale up of nanoparticle synthesis is challenging and many nanomaterials require harsh conditions to be produced. These factors limit their applications, increase their cost and has overall a bad impact for the environment. In the future, new synthesis routes are expected to be established in order to produce nanomaterials at industrial scale in environmentally friendly ways.
- One of the main benefits of nanomaterials is their large surface area which is exploited in several applications, from purification of waste waters to catalysis of chemical processes. In the future, synthesis of nanomaterials of different shapes that maximize their surface area and their surface functionalisation are expected to gain momentum and drive the research in the field.
- Nanoparticles have been proposed as drug delivery agents, however, this application presents many challenges to overcome. Future nanoparticle synthesis methods for this application will focus on controlling the amount of drug loaded in the nanocarrier, its protection from the biological barriers, controlled targeting of the organ and cellular compartment by surface bio-functionalisation and controlled drug release over time.

The scientific community will need to address these and further challenges in order for next generation nanomaterials to be safely and effectively used in applications that have a direct impact on human life and environmental sustainability.

Summary of thoughts and how is your institution working towards utilising this to drive innovation:

CBNI is constantly working at the edge of innovation in nanotechnology. We have a strong background on nanomaterial synthesis and most of the particles used for studying nano-bio interactions are synthesized in our chemistry lab. We work with different nanomaterials, gold, silica, iron oxides and polystyrene just to name a few.

From the point of view of the synthesis, we have a long tradition on gold nanoparticles, for which we synthesized many different shapes, we have few devices for producing NPs in flow and we are developing many core-shell structures for testing in biology.

In more recent years, we started to work on molecular surface modifications, such as passivation by PEGylation or functionalization with antibodies for mapping the epitopes on biological samples.

Eventually, the lab is equipped with all the most used techniques for nanoparticle's characterization, from dynamic light scattering to disc centrifuge sedimentation, to nanoparticle tracking analysis and we have access to more sophisticated techniques such as transmission and scanning electron microscopy, flow cytometry, NMR and many others provided by UCD.



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