Good things in small packages

Dr Alexandros Lappas, coordinator of NANOTAIL, gives us an overview of his team's work in developing cutting-edge nanotechnology at the new nanocrystals facility at the IESL-FORTH labs, Greece

Can you provide an overview of the aims and focus of the NANOTAIL project?

The main objective of the NANOTAIL project is to exploit colloidal chemistry routes to develop hybrid nanocrystals (HNCs) with controlled shape and composition. We aim to raise the functionality of such nanoscale particles by combining different material properties (eg. optical and magnetic) in a single building block. Our focus is on the fundamental understanding of the control of these systems as a prerequisite for realising their potential advantages in diverse applications.

The synthesis and characterisation of such hybrid nanostructures requires a combination of advanced methods and technologies, some of which have been independently developed in selected European laboratories. The project aims to transfer the required know-how from carefully selected partners to the host laboratory – the Institute of Electronic Structure and Laser at the Foundation for Research and Technology-Hellas, Greece (IESL-FORTH) – in an effort to advance its limited research activity in an otherwise thriving, international technological field.

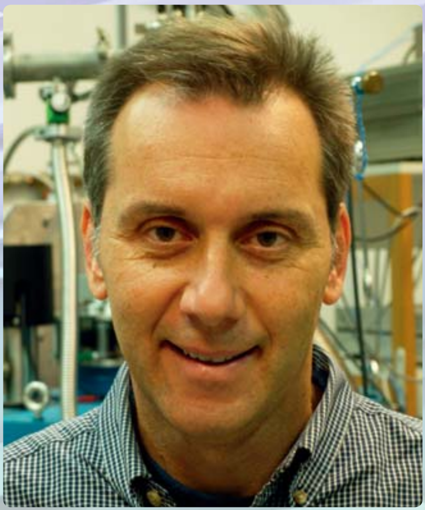
Can you underline the significance of the new state-of-the-art nanocrystals (NCs) syntheses facility at IESL-FORTH?

The development of a sustainable nanochemistry laboratory facility at the host institute offers cost-efficient, easily scalable and accessible nanomaterial fabrication for the ever-demanding field of nanosciences. The new NCs facility at IESL now has the capacity to uncover multifunctional nanomaterials that can offer alternative test-bed systems for discovering and understanding novel physical and bio/chemical mechanisms. The new laboratory is structured so that it can provide a high-level training framework for young scientists, and is anticipated to have a catalytic contribution in developing their career through research synergies in a cross-disciplinary field (ie. nanosciences) of high importance within the European research arena.

What are the main challenges associated with the development of hybrid NCs (HNCs), and how is the NANOTAIL project addressing these obstacles?

A major challenge for HNCs is to identify pathways that permit us to select the topological configuration through which one material phase couples to another, with emphasis on how to rationally design their functionality. Progress, though, is hampered by insufficient understanding of the role of the inherent characteristics of the seeds (the pre-formed NCs upon which a nanoheterostructure is grown), namely: crystal structure, size/shape, faceting, and surface defects. These can influence the development of HNCs, as they pass on important changes to the shared inorganic interfaces. For instance, interfacial strain due to lattice misfit can determine the preference for the deposition of the second material on a seed, as well as the range over which the geometric characteristics of the heterostructure could be fine-tuned.

In an effort to integrate non-homologous physical properties (eg. magnetism and optical response) on a single nanoscale building block, NANOTAIL has developed strategies leading to simple colloidal architectures that can be used as test-beds. At least one component (as seed or secondary inorganic domain) was of a magnetic iron-oxide phase, with significant technological potential (straddling magnetic recording to biomedical diagnostics), while a luminescent material domain (zinc oxide) was chosen to share a common interface. We optimised the reaction schemes to avoid detrimental effects on the properties of the hybrid structure. This required deep structural insight to decide on factors that control the geometric parameters of the oxide seeds, their HNCs, and their topological configurations. With control over such steps, the milestone of demonstrating HNCs with magneto-optical response was addressed by two approaches: either tweaking the intrinsic physics of the nanoheterostructure components, or harnessing collective photonic crystal-like behaviour generated by the induced assembly (eg. by an applied magnetic field) of the colloidal building blocks.



Can you offer a summary of the progress made over the course of the project? What would you highlight as the project's most notable achievements?

We have set up an interdisciplinary working laboratory and have built a strategic network of close collaborators, enabling us, it is hoped, to become competitive on the international landscape. We have amassed important, fundamental knowledge to gain some control of the architectural complexity of technologically important nanoscale systems. This was only possible because of the transfer of know-how from our selected European partners, which entailed a combination of novel synthetic techniques as well as the appropriate advanced tools for structural and physical property characterisation.

The recruitment strategy allowed us to facilitate bi-directional, working-level interactions between team members and partners, as well as access and training on the most up-to-date instrumentation methods. Furthermore, the project has generated interest within the host itself by means of catalysing synergistic actions with fellow researchers pursuing projects at the vanguard of nanoscience.

Nanocrystal culture

We are rapidly entering the age of nanotechnology, where devices and materials are increasingly fashioned at the molecular level. NANOTAIL is a collaborative European project that aims to develop affordable nanocrystal technology for the 21st Century

In its four years of activity, NANOTAIL has delivered concrete contributions in the development of cost-effective and multi-purpose hybrid nanocrystals

AS A CONCEPT, nanotechnology has existed for at least several decades, although its realisation was only achieved during the 1980s. The last decade has seen huge advances in this field, necessitated by the need for smaller, high-performance, energy-efficient materials for a myriad of applications. These include distributed light emission and ultra-fast magneto-optical data recording, energy storage/production, electro-optical interconnects, catalysis, biological sensing/labelling, and medicine.

The fabrication of nanomaterials has, until now, been predominantly facilitated via a 'top-down' approach, where a material is whittled down to produce a tiny unit of the desired shape and size, in a fashion similar to a mason carving a piece of stone. This is the preferred technique (cf. photolithography) employed in the production of circuits used in electronic components. However, as structures are now more frequently needed in the scale of tens of nanometres (nm), this approach is rapidly becoming obsolete due to the technical difficulties and prohibitive expense of production. Therefore, these means are very likely to be superseded by the only recently achievable 'bottom-up' approach, which involves assembly of materials from the nanoscale itself.

THE BOTTOM-UP WAY FORWARD

NANOTAIL (Hybrid Crystals Exhibiting Advanced and Tailored Properties) is a European Commission-funded project, supported through the Marie Curie Transfer of Knowledge Programme, set up to develop reliable means of manufacturing nanomaterials using a bottom-up approach. This technique has considerable benefits, as Dr Alexandros Lappas, the project coordinator, explains: "Powerful bottom-up pathways to nanotechnology are more suitable to implementation with modest technological resources. No specialised, expensive equipment is necessary, and these approaches are normally pursued by individual researchers in an ordinary chemistry lab".

NANOTAIL has left a legacy that allows IESL-FORTH, with its pre-existing expertise in complementary disciplines, to excel within the international nanotechnology platform

The team has focused on developing reliable methods to manufacture nanocrystals (NCs), which are made from an inorganic crystalline core stabilised by a layer of surfactant molecules. By adjusting variables such as the temperature and the concentration of metallic molecular precursors and organic stabilisers, NC formation can be controlled and structurally directed by anchoring of specific molecules on nanocrystal surfaces in a liquid solution. Success in this regard results in a self-assembled material with specific chemical or physical properties, ranging from optical to electrical, and magnetic to catalytic, while at the same time ensuring high-performance and functionality at a low enough cost to be suitable for large-scale production.

THE RIGHT SHAPE AND SIZE

The key to creating materials with such a vast range of different applications has been the development of a new kind of NCs. Recent innovations in chemistry have allowed the production of a selection of different NC shapes, with different properties dependent on their shape and size; these can be joined and grown as a single unit without the need for an organic linker. Such multicomponent nanoheterostructures are known as hybrid NCs (HNCs), and are able to perform multiple tasks.

Examples of possible NCs applications are numerous. For instance, NC surface manipulation – such as coating with surface polymers or proteins – could lead to novel diagnostic or therapeutic applications, for instance, in assisting drug delivery to highly specific anatomical regions, or as traceable tags to aid in the screening of diseases. Optical properties can also be made use of, for example with cadmium selenide (CdSe) crystals, which have continuously tuneable luminescence when grown at sizes under 10 nm, opening the way for use in optical devices and biomedical imaging. At ever-decreasing dimensions particles do not have permanent magnetic moments in the absence of an external field but can be highly responsive to an applied field. Such superparamagnetic entities are becoming invaluable as contrast markers in magnetic resonance imaging (MRI), as well as for use in magnetic recording media. Therefore, engineering heterojunctions across neighbouring domains of non-homologous phases (such as those mentioned above) can bring about fascinating coupling mechanisms, often leading to synergistic behaviour in the hybrid NC derivatives. The versatility of these fabulous materials is a source of great excitement for Lappas: "HNCs can represent 'manmade' platforms on which electronic communication effects across neighbouring material connections can lead to reinforced and/or tuneable physico-chemical responses, or even the appearance of unique properties not accessible by any of the

INTELLIGENCE

NANOTAIL

HYBRID NANOCRYSTALS EXHIBITING ADVANCED AND TAILORED PROPERTIES

OBJECTIVES

The project seeks to develop reliable synthetic routes to hybrid nanocrystals through a combination of novel synthetic approaches, advanced tools of structural analysis and suitable theoretical methods that model the growth and the physical behaviour of inorganic materials at the nanoscale. The project aims to transfer knowledge between leading European laboratories.

FUNDING

Marie Curie Transfer of Knowledge Programme

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DR ALEXANDROS LAPPAS received his BSc degree in Physics from the University of Crete, Greece (1988) and his DPhil in Chemical Physics from the University of Sussex, UK (1993). Since 1999 he has been based at IESL-FORTH, Greece, where he is presently a Principal Researcher. He is interested in strongly interacting systems (straddling bulk solids to hybrid nanocrystals) exhibiting collective electronic and/or magnetic phenomena, with potential in magneto/optoelectronics.

single component parts or their physical mixture counterparts," he states.

GOING FORTH

In its four years of activity, NANOTAIL has delivered concrete contributions in the development of cost-effective and multi-purpose HNCs. The programme's primary objective has centred on the establishment of a sustainable, state-of-the-art nanochemistry facility at the host laboratory, IESL-FORTH (Institute of Electronic Structure and Laser at the Foundation for Research and Technology-Hellas). The fulfilment of this goal was only possible due to the assistance of the project's partners, as Lappas explains: "The expertise provided by our European collaborators allowed us to learn the colloidal chemistry techniques, as well as to proceed with setting up a nanocrystal synthesis and purification facility". Partners included experts in the fields of nanochemistry (NNL, Lecce; IIT, Genoa), electron microscopy (CEMES, Toulouse), and magnetic resonance (NMR, University of Milan; FMR, University of Duisburg), as well as visiting lecturers from other institutions. However, this transfer of knowledge was not just one-way: "For its successful evolution, the host investigators, fellows and partner institutes form a small-length consortium to allow close research collaboration, laboratory infrastructure sharing, and training activities for a 'bi-directional' transfer of knowledge," Lappas elucidates.

The interdisciplinary approach has stood the project well, and has been harnessed in tandem with a well thought-out recruitment strategy that has sought out experienced postdoctorate fellows and given them the highest standard of training, both in-house and through the project's collaborators. Recruiting the right staff relative to the project's needs was a challenge, as Lappas elaborates: "NANOTAIL is a project based on a frontier research topic at the cutting-edge of nanoscience. Since it aims to open new directions in the field of nanotechnology (materials and devices), it is highly attractive to young researchers as it can create new job opportunities across different disciplines, and is especially valuable for regions in the periphery of Europe". This approach means that NANOTAIL has left a legacy that allows IESL-FORTH, with its pre-existing expertise in complementary disciplines, to excel within the international nanotechnology platform. The team has already established protocols for growing technologically useful iron oxide and/or zinc oxide-based HNCs (eg. in biological diagnostics and therapy), affording a tuneable magneto-optical response. They have also demonstrated control of HNC assembly in magnetically responsive photonic crystal-like structures. The future promises much more, even though NANOTAIL itself ended in September 2010.

In order to build on their progress, Lappas and the team at IESL-FORTH are already planning their next step. They aim to disseminate their findings through peer-reviewed journals and international conferences, and seek to obtain further funding from the EC, as well as nationally (in collaboration with the Greek Universities and Research Centres, and with the support of the Ministry of National Education, Life-long Learning & Religious Affairs). Furthermore, to put their work into practice, they also aim to talk to appropriate businesses – for which Lappas explains his reasons: "Seeking synergy between academia and industry may promote the EU's competitiveness and improve quality of life. It will enable us to tackle green and economical synthesis of nanoparticles for nanoscale detection and control techniques, biocompatible implantable devices, solid-state lighting, and screening and cure of tumours". A huge goal for such tiny entities.

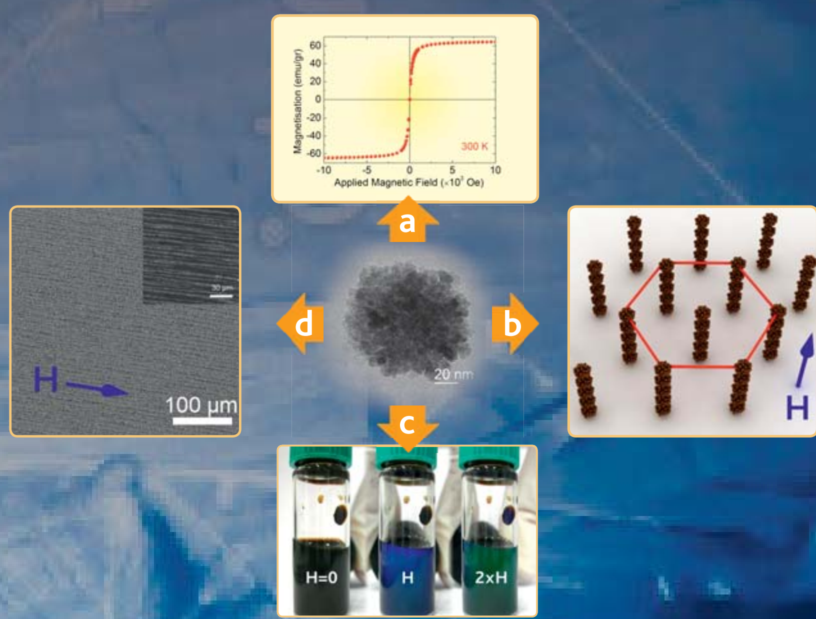

Figure 1. Multifunctional nanomaterials (~90 nm nanoclusters) developed through a bottom-up approach: entails assembly of 10 nm iron-oxide nanocrystals (centre). (a) Upon the application of an external field, H, they develop a large magnetic moment at room temperature, which means (b) they are highly field-responsive entities that organise in liquid media and on surfaces, attaining (c) photonic crystal-like behaviour and (d) tunable dimension chain-like structures. **For related images and information, visit http://dx.doi.org/10.1016/j.photonics.2010.07.001**