Title: Traceable characterisation of nanostructured devices

Abstract

Rapid technological developments in nano-structured material systems for semiconductor electronics and photovoltaics (inorganic and organic) are driving the need for traceable characterisation techniques for multiple parameters. The implementation of new materials in complex spatial arrangements, including the new 'self-assembled' nanostructures, requires the qualification of complementary analytical techniques to provide reliable quantities on physical and chemical properties of nano-domains, buried nanolayers and interfaces. 3D techniques with high-definition at the nanoscale and non-destructive analytical methodologies with high information depth are crucial to achieve and to ensure the functionalities of nanotechnology based devices in R&D and process control.

Conformity with the Work Programme

This Call for JRPs conforms to the EMRP Outline 2008, section on "Grand Challenges" related to Health, New Technologies & Fundamental Metrology on pages 9 and 25.

Keywords

Nanotechnology, nanoparticles, new materials, traceability in materials characterisation, advanced nanoelectronics, photovoltaics, self-assembly, thin films, surface chemistry, surface nanostructures, nanolithography, physical and chemical properties, nanolayer, morphology, compositional characterisation

Background to the Metrological Challenges

In order to further develop and control the functionality of emerging complex devices of new materials in nanotechnology it is necessary to reliably characterise their physical and chemical properties. These parameters include buried nanolayer thicknesses, elemental composition and chemical binding states, coordination, morphology and molecular orientation, trace and matrix depth profiles as well as corresponding buried interface and buried contamination or passivation characteristics. These requirements are driven by the semiconductor industry, where the integrated device density has pushed fabrication and device structures to 30 nm, and from the organic electronics industry including displays and photovoltaics.

The microelectronic world is experiencing a revolution and in order to tackle the new challenges in terms of miniaturization, power consumption, power density and processing speed, new inorganic semiconductor materials (Ge, InGaAs, GaN, SiC, etc.) and new 3D-architectures (Multiple Gates FETs, Nanowire T-FETs, etc.) are being developed and progressively introduced.

In parallel is the emergence of electronics based on organic semiconductors made of single molecules in highly ordered assemblies and polymeric semiconductors in thin films. The motivations for their development and application are low cost, the use of flexible substrates and the ability to generate these structures on very large surfaces up square metres with industrial processes. A broad set of organic/polymeric based prototypes have been developed, demonstrating the strong potential of these materials: transistors, sensors, electro-chromic devices, biosensors, photodiodes, photovoltaic cells. Unfortunately the metrology challenges related to these organic systems represent an even more demanding metrology problem compared to their inorganic counterparts, as not only the determination of atomic and electrical distributions but also the chemical and molecular configuration on the nm-scale is a key issue. As a consequence, there is a growing need for new two- and three-dimensional electrical and chemical (compositional) characterisation techniques that would work on both inorganic and organic semiconductor materials. Ideally, they need to offer high spatial resolution (sub-nm in inorganic and sub-10nm in organic semiconductors), very good sensitivity and repeatability (3 % to 5 % variation) over a wide dynamic range of 4 to 5 decades and able to probe very specific properties such as element and molecular distribution, and electrical properties.

The self-assembly of materials from nano-objects is one of the goals of nanotechnology. Within the past few years, this aim is starting to be realised using standard lithographic processes that control the organisation of nano-objects; a procedure termed ‘directed self-assembly’. This new technology shows excellent promise, but requires the development of new approaches and procedures in measurement. Particular challenges include the categorisation of structures, dimensional metrology to establish repeat and coherence lengths, determination of defect densities and the ability to resolve chemical contrast on the nanometre scale.

Scientific and Technological Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the JRP-Protocol.

The JRP shall focus on the traceable measurement and characterisation of physical and chemical properties of the next generation of integrated nano structured devices with dimensions sub 30nm and using novel 3D architectures.

The specific objectives are

1. Non-destructive methods for the characterisation of nanolayers and buried interfaces, i.e. chemical depth-profiling of nanolayers with trace level sensitivity and high information at depths up to 200 nm.
2. 3D Nano-chemical analysis of nano-structured organic electronic materials, i.e. 3D chemical characterisation of nanolayers and interfaces with depth resolutions of better than 10 nm at depths of up to 400 nm and with spatial resolution to better than 100 nm.
3. 3D Nano-electrical characterisation of nano-structured organic electronic materials, i.e. the electrical properties (e.g. conductivity and charge mobility) of materials inside thin films with nanoscale resolution (better than 30 nm).
4. Metrological characterisation of self-assembled structures, i.e. repetition lengths and angles, coherence length, 2D defect densities, thickness of assembled layers and chemical contrast with better than 30 nm lateral and/or depth resolution.

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. To enhance the impact of the research, the involvement of the appropriate user community such as industry, and standardisation and regulatory bodies, is strongly recommended.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this. The proposed JRP should clearly explain any relationship with existing results and techniques delivered or scheduled from previously funded EMRP JRPs and demonstrate how it extends any relevant outputs from such JRPs, in particular related to

- T3 J1.1 Nanoparticles: Traceable characterisation of nanoparticles
- IND07 Thin Films: Metrology for the manufacturing of thin films

The total eligible cost of any proposal received for this SRT is expected to be around the 2.7 M€ guideline for proposals in this call.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community. This may be through the inclusion of unfunded JRP partners or collaborators, or by including links to industrial/policy advisory committees, standards committees or other bodies. Evidence of support from the “end user” community (eg letters of support) is encouraged.

You should detail other impacts of your proposed JRP as detailed in the document “Guide 4: Writing a Joint Research Project”

You should detail how your JRP results are going to:

- feed into the development of urgent documentary standards through appropriate standards bodies, for example the committee ISO TC229 (nanotechnologies)

- transfer knowledge to the semiconductor, electronics and photovoltaics sectors.

You should also detail how your approach to realising the objectives will further the aim of the EMRP to develop a coherent approach at the European level in the field of metrology. Specifically the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of Member States and countries associated with the Seventh Framework Programme whose metrology programmes are at an early stage of development to be increased
- outside researchers & research organisations other than NMIs and DIs to be involved in the work

Time-scale

The project should be of up to 3 years duration.