EMRP Call 2012 – Open Excellence, Industry and SI Broader Scope

Selected Research Topic number: **SRT-i16**
Version: 1.0

Title: Novel electronic devices based on control of strain at the nanoscale

Abstract

Control of materials at the nanoscale through the application of strain opens up a wide range of innovative new high technology products e.g. next generation (beyond CMOS) transistors using strain control of channel resistance, strain enhancement of CMOS semiconductors, optical and plasmonic controls in nanoparticles and nano-structured physical and bio-sensing. The development of traceable measurements of strain in nanoscale systems should drive innovation in these major technological areas, enabling the development of a Piezoelectric-Effect-Transistor (PET). This represents a step change in transistor design. The metrology required to achieve this high-technology product should be developed.

Conformity with the Work Programme

This Call for JRPs conforms to the EMRP Outline 2008, section on “Grand Challenges” related to Industry & Fundamental Metrology on pages 8, 9, 11, 13 and 23.

Keywords

Strain, piezoelectric, transistors, microfabrication, beyond CMOS, MEMS/NEMS, X-ray diffraction, piezo-response force microscopy (PFM), infrared near-field microscopy (IR-SNOM)), transmission electron microscopy (TEM).

Background to the Metrological Challenges

Traditional semiconductor transistors reached their performance limit ten years ago. Piezoelectric coupling can modify conductivity in nanoscale devices to introduce a new paradigm in computing technology where electromechanical coupling replaces charge transport. This will enable major increases in speed with reductions in size and power consumption, accelerating the growth of the portable consumer electronics market. Major emerging industrial applications also include ultra-high speed and resolution printing, configurable chemical and optical sensors, and EM memory. A major hurdle is the lack of metrology capable of non-destructive measurement of nanoscale strain.

Strained silicon is an integral feature of the latest generation of transistors and electronic devices. Strain is expected to have an important role in future devices based on nanowires, optoelectronic components and nano electro-mechanical devices in general (NEMS). Different strategies have been used to engineer strain in devices, leading to complex strain distributions in two and three dimensions. Non-destructive strain measurement at the nanoscale has been unsuccessful. TEM and high-resolution transmission electron microscopy (HRTEM) and dark-field electron holography have been used to destructively measure nano-scale strain (unsuitable for devices). However, challenges include improving the reliability of specimen preparation. It is also hoped that local measurement of other properties like ferroelectric polarisation will be possible. Such measurements will need to be modelled and related to more macroscopic metrology techniques. A methodology which combines nanoscale measurements, with more statistically significant metrology could be very powerful.

Other techniques for nanoscale strain measurement include, high resolution X-ray diffraction (XRD), high resolution electron back-scatter diffraction (EBSD), confocal Raman microscopy (CRM), and the combined use of TEM and Infrared near-field microscopy (IR s-SNOM). To meet the need by industry for nanoscale strain metrology requires ambitious multi-national research. The metrological relationship between these techniques and the definition of strain at the nanoscale also requires fundamental modelling of strain at the nanoscale and strain transfer in nanostructures.

The theoretical treatment of strain in materials and devices, typically based on atomistic simulation of simple structures or Finite Element Simulations of bulk homogenous materials, has provided useful insight into how to control certain functional properties (through *strained layers* for example). To meet the future need for materials' prediction at the nanoscale requires a hybrid approach whereby strain coupling at the meso-scale may be modelled from a first principles approach that successfully aligns with the materials' macroscopic properties. This should facilitate better materials design, process optimisation and should help to form the basis of a traceable metrology supporting strain measurements at the nanoscale.

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 strain at the nanoscale in novel electronic devices. Control of strain at the nanoscale is the overall aim.

The specific objectives are

1. To verify the functional performance of manufactured devices that utilise a coupling between piezoresistive hysteretic material (PRHM) and the piezoelectric component of a Piezoelectric-Effect-Transistor (PET). Traceability of strain measurement based on changes in atomic and crystallographic parameters should be developed with spatial resolution for mapping these changes to 100 nm and strain resolution to 100 ppm. Sub-picometre normal displacements equating to a bulk strain measurement of 1 ppm on samples down to a minimum thickness of 20 nm are required.
2. To provide traceable measurement of strain in nanoscale objects. Nanoscale digital image correlation (DIC) should be modified to accommodate the data sets that are derived from the complementary methods that are used when probing strain. Probe forces of up to 10 µN and mapping, at a spatial resolution of 1 nm, will be required.
3. To extend traceable validation of the methodology described above to established destructive methods such as Transmission Electron Microscopy (TEM) and novel holographic TEM. The uncertainty caused by the additional strain from the preparation of TEM slices should also be investigated.
4. To model strain coupling in nanoscale piezoelectrics and piezo-nanostructures and to develop a full multiphysics and multiscale approach to predict the complex coupling in MEMS / NEMS devices to support the metrology developed in 1 through 3.

Proposers shall give priority to work that meets documented industrial needs and include measures to support transfer into industry by cooperation and by standardisation. An active involvement of industrial stakeholders is expected in order to align the project with their needs.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this.

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. The available budget for integral Research Excellence Grants is 42 months of effort.

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 how your JRP results are going to:

- feed into the development of urgent documentary standards through appropriate standards bodies
- transfer knowledge to the IT and many other sectors.

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

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 and includes the best available contributions from across the metrology community. 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.