Title: Metrology for the manufacturing of thin films

Abstract

Thin films play a major role in many industrial products. They provide new functionalities unavailable in bulk, and help reduce resources. The different length scale and structure compared to the bulk require specific measurement solutions.

Quality and high throughput manufacturing of thin-film optoelectronic devices require the development of metrological tools and methods such as to correlate the electronic and thermal device performance with materials composition and structure, and include deposition characterisation, water permeation rate, small-scale spatial optoelectronic, thermal and chemical characterisation, plus in-line tests for production control.

In many thin films, the optical properties play a key role in their functionality or provide the most convenient way of measuring their thickness and quality. This requires the development of traceable measurement methods of thin films and their optical properties, ultimately in the form of fast inline measurements.

Conformity with the Work Programme

This Call for JRPs conforms to the EMRP 2008, section on "*Grand Challenges"* related to *Industry & Environment* on:

Page 14: "quantify the complex interplay of the microscopic state and the resultant properties" of novel materials (in this case thin film optoelectronic materials).

Page 14 "Major challenges exist in validating and understanding the interrelationship of measurements in four areas: Physical-chemical properties, Structural and compositional analysis, Constitutive properties of materials, Modelling of materials" These strongly depend on processing conditions and therefore impacts manufacturing and product quality.

Page 13 "reliability and comparability for new analytical technologies such as in-line and on-line measurements in industry" which is an identified "particular metrological challenge" Moreover, establishing confidence in process control by reliable metrology of consequent materials properties

Page 14 "enables European Directives, certification and other regulative requirements to be met"

Keywords

Thin films, foils, coatings, film thickness, ellipsometry, in-line measurements, roll-to-roll processing, process and quality control, high-throughput manufacturing, flexible and thin-film optoelectronics, optical properties, spatially and depth resolved non-disruptive and traceable materials characterisation, physical-chemical and thermal materials properties

Background to the Metrological Challenges

Thin films are important for many industrial applications including flexible and printed electronics (organic, inorganic and composite materials), optics (e.g. anti reflection coatings, hydrophobic coatings etc), semiconductors, solar photo voltaic, and so on. Thin films offer exciting possibilities of

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reducing in material and energy costs while maintaining functionality, and enabling functionality to be added to other objects (e.g. thin film solar cells added to windows)

Novel devices are based on complex structured multilayers and/or composite materials are strongly influenced by processing methods and conditions, indeed the functionality of a thin film is often related to layer thickness, and is not necessarily related to the bulk material properties. Research is required to ascertain which are the key parameters to monitor, to understand the link between materials properties and overall device performance.

The use of diverse non-traceable measurement methods and inaccurate device models leads to a wide variation in reported performance parameters, even when comparing nominally the same materials and device structure. A lack of traceability and standardisation of the relevant measurement methods slows device optimisation, and is hindering moves to optimise production efficiency, and maximise the advantages of high throughput manufacturing.

Specific metrology challenges include:

- Measurement of thin film materials properties (thickness, chemical, optical, microstructure at various length scales…) and spatial uniformity of such properties, as well as the impact of these on final product performance.
- Film thickness must be controlled with high accuracy. Variations of a few nanometres can lead to changes in the brightness in displays, or reduced photocurrents in photovoltaic devices.
- Subtle differences in the surface chemistry of substrates have significant impact on film coating and electronic performance. Current testing methods do not make these spatial distinctions, so the films may meet the specifications macroscopically, but not be uniform across all areas or across the depth.
- Development of traceable metrology for reliable, non-destructive characterisation of new complex materials. The pace of technological changes, with the introduction of tens of new materials systems every month, requires changing the status quo of qualifying materials from comparison to reference standards towards the use of traceable analytical methods.
- For many novel products, in particular organic-based electronics, device lifetime is hindering commercial viability, in part due to degradation related to water vapour ingress. There is a need for analytical methods to measure very low permeation rates (down to 10^{-6} g/m^2/day) through barrier layers.
- Resolution and process stability of patterning is insufficient for many applications, including thin film transistors. Variations in local surface energy adversely affect coatings and therefore patterning.
- There is a need for accurate measurements of thermal transport properties of thin films (as well as the interface thermal resistance between substrate and adjacent layers) under their conditions of use. Constant miniaturisation of optoelectronic components makes the performance and reliability of multilayer devices highly dependent on effective thermal management. For instance, thermal conductivity and diffusivity can vary considerably when going from bulk to thin films, therefore it may not be possible to estimate thermophysical properties of a thin layer from those of the bulk material having the same chemical composition.
- Impurity concentrations, elemental depths profiles as well as the respective chemical binding states critically affect both the electrical and thermal properties of advanced functional materials such as transition metal chalcogenides. The characterisation of both the physical and chemical properties of novel materials has, thus, a steadily increasing impact on the further development and preservation of core competencies for the European optoelectronics industries.

Several of these needs are also mentioned in a recent review document, produced as part of the EU funded project Co-Nanomet [3].

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 overall aim of the JRP is to develop metrological tools and methods to underpin the production of thin films and thin-film optoelectronic devices. You should aim to provide validated and reliable measurements / methods with traceability wherever it is practicable to do so.

The specific objectives are:

1. Development of new techniques for measurement of film thickness and optical/optoelectronic properties (e.g. dicroism, birefringence, complex refractive index for large wavelength range) over large areas and/or with spatial discrimination for in-production applications
2. Development of traceable optical measurements for inhomogeneous thin films and for difficult substrates (e.g. strongly curved, patterned, rough, flexible);
3. Control of film processing by micrometre / sub-micrometre length-scale surface energy / wettability characterization
4. Characterisation and development of reference materials and transfer standards relevant to production
5. Traceable, accurate measurement of water vapour transmission rate through barrier layers to low levels (down to 10^{-6} g/m^2/day)
6. Morphology characterisation by non-destructive and contact-less measurements (e.g. surface chemical mapping, elemental analysis and depth profiles of thin-film stacks)
7. Traceable, accurate measurement of materials and thin film properties (e.g. impurity concentrations, chemical binding states and coordination of buried films, charge carrier mobility, work function, thermal transport properties)

Proposers shall give priority to work that meets documented industrial needs and that which supports transfer into industry e.g. by cooperation and/or by standardisation.

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

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 (e.g. letters of support) is encouraged.

Where a European Directive is referenced in the proposal, the relevant paragraphs of the Directive identifying the need for the project should be quoted and referenced. It is not sufficient to quote the entire Directive per se as the rationale for the metrology need. Proposals must also clearly link the identified need in the Directive with the expected outputs from the project.

You should also detail other Impacts of your proposed JRP as detailed in the document “Guidance for writing a JRP”

You should detail how your JRP results are going to:

- feed into the development of urgent standards through appropriate standards bodies
- transfer knowledge to the; flexible and printed electronics, optics, optoelectronic and semiconductor 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 3 years duration.

Additional information

The references were provided by PRT submitters; proposers should therefore establish the relevance of any references.

1) Printed, Organic & Flexible Electronics Forecasts, Players & Opportunities 2009-2029, IDTech 2009
2) Printable Electronics Market Outlook: An Applications-Based Assessment, NanoMarkets® 2008
3) R.K. Leach et. al., Consultation on a European Strategy for Nanometrology, www.co-nanomet.eu
4) Press release EECA-ESIA for December 2009, available via http://www.eeca.eu.
5) Alsema, E.A.; Wild - Scholten, M.J. de; Fthenakis, V.M. *Environmental impacts of PV electricity generation - a critical comparison of energy supply options* ECN, September 2006; 7p. Presented at the 21st European Photovoltaic Solar Energy Conference and Exhibition, Dresden, Germany, 4-8 September 2006.
6) UKDL KTN survey 2009
7) OE-A roadmap 2009, VAMAS TWA36 survey 2009
8) OLAE SRA 09