European Metrology Research Programme

EURAMET

# Industry impact report

A summary of the outputs and impact of the first EMRP joint research projects in the Industry theme.

The aim of research in this theme is to develop metrological methods and techniques to improve the measurement infrastructure for industry in order to support product innovation, process improvement and quality assurance. The research is focused on advanced manufacturing processes in a wide range of industrial sectors.

EURAMET e.V. - the European Association of National Metrology Institutes

# Measurement matters

**Measurement underpins virtually every aspect of our daily lives, helping to ensure quality and safety, support technological innovation and keep our economy competitive.**

Supported by the European Commission, EURAMET's **European Metrology Research Programme (EMRP)** brings together National Measurement Institutes in 23 countries to pool scientific and financial resources to address key measurement challenges at a European level.

The programme is designed to ensure that measurement science meets the future needs of industry and wider society. Research is structured around four themes – Energy, Environment, Health and Industry – as well as the measurement needs of emerging technologies and the fundamentals of the SI measurement units that form the basis of Europe's measurement infrastructure.

# Contents

# Introduction: Metrology for industry

**European manufacturers need to remain competitive in a global market. Europe's competitive advantage is high-quality, high-performance products manufactured in modern, efficient production facilities, underpinned by world-class quality assurance and continuous product and process innovation.**

Metrology plays an important role in the competiveness of manufacturing sectors. It supports efficient production of the products of today and the innovation needed to develop the products of tomorrow.

## Productivity

Robust and reliable data is essential to efficient process control and quality assurance. Automated production relies heavily on measurement to optimise and control processes and to validate product quality. Reliable data – the same everywhere, trusted by everyone – also supports an efficient supply chain where the extra costs and time of additional product quality assessments are unnecessary.

## Innovation

Measurement is essential to innovation. The innovation process relies on accurate measurements to investigate and validate the performance of new technologies, materials and production methods. Reliable measurement data ensures the benefits of new or improved products and processes can be clearly demonstrated to customers. Metrology research also supports innovation in the instrumentation, measurement and control sector.

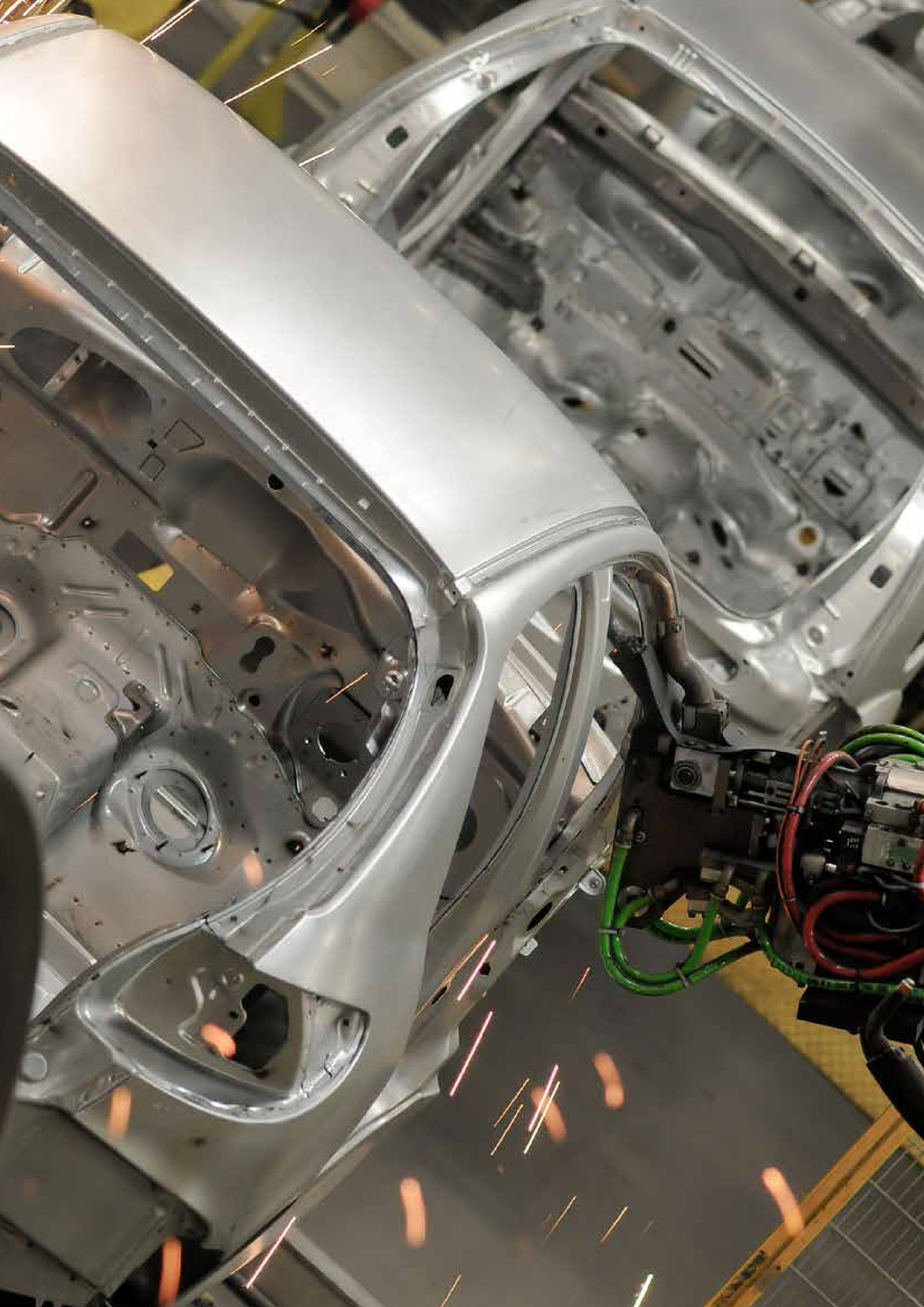
## Measurement requirements

To stay competitive the manufacturing sector has to keep innovating. Continuous innovation in products and processes requires continuous improvement in measurement capabilities – these include increased measurement accuracy, extended measurement ranges and measurements in a range of different and challenging production environments.

EURAMET's European Metrology Research Programme (EMRP) supports a coordinated approach to research in metrology for industry, providing Europe's manufacturing businesses and instrumentation companies with access to the combined experience and capability of Europe's National Metrology Institutes (NMIs).

110 research groups from 28 metrology institutes came together with academia and industry to conduct research under the first call of the EMRP Industry theme in 17 pan-European collaborative research projects. These projects aimed to improve measurement methods and data quality to support European innovation, growth and competitiveness. The research addressed the needs of the whole supply chain, from materials, sensors and instrumentation suppliers to manufacturers of high-performance final products in sectors such as aerospace, automotive and electronics.

This report presents the key technical achievements of these research projects and highlights early examples of the impact generated. The projects are grouped into two sub-themes: metrology for **advanced manufacturing** and metrology for **electronics and ICT**.

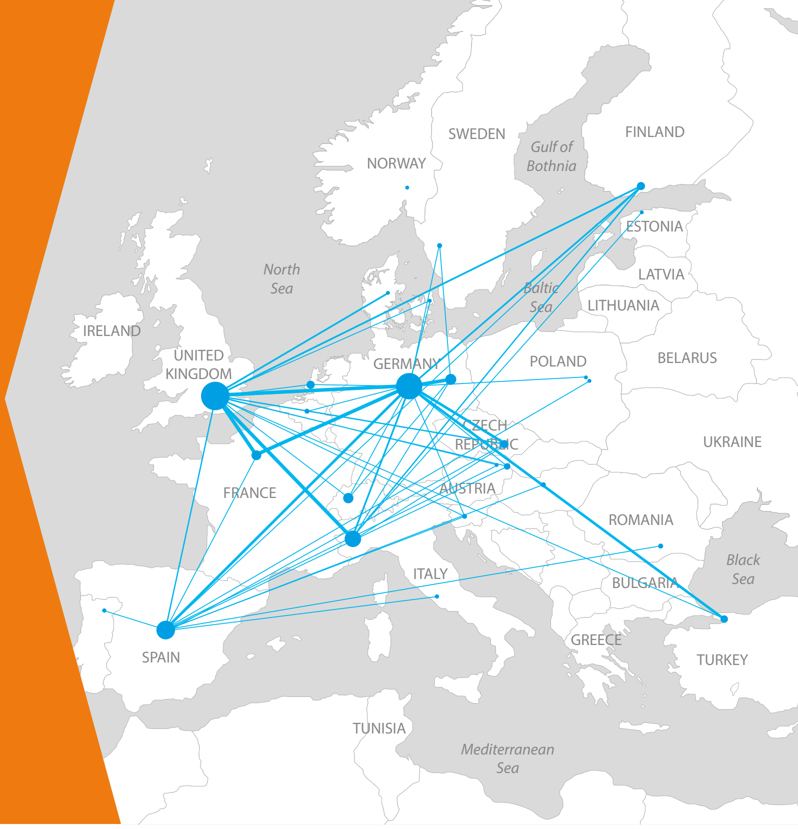


# Highlights

## Metrology for an innovative and competitive manufacturing sector

Industrial requirements for advanced measurement tools and techniques are key drivers of developments in metrology. Under EMRP the European metrology community is able to work collaboratively to develop metrology solutions for industrial measurement challenges.

The European Commission and national governments invested €54M in collaborative industrially-focused research, involving research groups in 28 European NMIs and Designated Institutes (DIs), along with 46 academic groups and 96 businesses. The research addressed a wide range of themes in the high-tech manufacturing sectors, addressing measurement needs in sectors such as aerospace, automotive, semiconductors, advanced materials and petrochemicals.




## Accurate analytical measurements for innovative materials

Advanced analytical instrumentation based on a range of atomic and spectroscopic effects offers the ability to understand and assess the characteristics and performance of a wide range of innovative materials. These instruments are used in a wide range of sectors – such as electronics, optoelectronics, aerospace and medical devices – where the chemical and physical structure of surfaces and thin films is critical to the functionality and performance of devices and components. Establishing traceability for these instruments increases their value to product and process innovation as it provides reliable quantitative assessments of material structure and performance. EMRP project teams developed reference materials and transfer standards for a range of analytical instrumentation that are being used by instrumentation manufacturers to validate their products, provide traceability to their customers and support instrument R&D.

For example, Bruker Nano Analytics has used certified reference materials to improve its energy dispersive X-ray spectroscopy (EDS) instruments that support innovation in catalysts for car exhaust systems and coatings for faster and more durable microelectronics. Kratos Analytical, a manufacturer of high-value X-ray photoelectron spectroscopy (XPS) instrumentation, has used reference materials to improve the performance of its XPS instruments for innovation in biomaterials, polymers and catalysts.

## Metrology for fuel-efficient vehicles

Improvements in the accuracy of pressure measurements at the highest metrological levels are helping the automotive industry to design and manufacture the next generation of diesel engines. To meet consumer demands and comply with emissions regulations, engines need to be more fuel efficient. A key element in fuel efficiency is the use of higher pressures in the fuel injection process. EMRP research has developed improved metrology in high and dynamic pressures that is supporting European engine research and development. Working closely with the automotive and instrumentation sectors, the metrology community is also helping to ensure that measurement instrumentation for high-pressure manufacturing processes and in-line process control equipment is being developed.

## Innovation in the ICT sector

The ongoing demand for faster, smaller electronics and communications technologies places challenging demands on the metrology infrastructure.

Next-generation communication systems are dependent on signal processing electronics and testing equipment that can operate at ever-faster speeds. EMRP research has developed the metrology capabilities to enable the validation of ultrafast electronics in the GHz range and ensure appropriate test equipment will be available to support future communications systems. EMRP research is also ensuring that the functionality and performance of electromagnetic materials can be accurately assessed across the wide range of processing and communications frequencies, from radio frequencies (kHz) through to microwave frequencies (GHz).

## Instrumentation innovation

Improved metrology supports innovation in the instrumentation sector. Improved metrology capabilities at NMIs directly support the development of commercial measurement and test instrumentation, both by enabling the performance of innovative products to be assessed and by acting as a demanding customer of instrumentation and component suppliers. EMRP research teams collaborated and shared research results with a large number of companies in the instrumentation sector.

For example, INFICON, a manufacturer of instruments for gas analysis, used a new NMI vacuum metrology system to demonstrate that its innovative gauge for dynamic pressure responded twenty times faster than the previous model. This offers opportunities to INFICON's customers in the semiconductor sector to reduce the processing time for manufacturing steps conducted in vacuums.

TETRA, a manufacturer of automation and robotic equipment, developed a novel optical sensor for a high-performance friction test system at a metrology institute. This sensor has since been used to improve TETRA's own high-end positioning system, making it one of the best on the market and supporting new sales.

Bartington Instruments, a manufacturer of high-performance fluxgate sensors, used new metrology facilities for magnetic measurements to validate the performance of its sensors across a wide temperature range. These sensors have been used as part of the preparation of navigational instruments for future gravitational astronomy missions like LISA.

## Quantum cryptography

Quantum cryptography offers the potential for completely secure communications as quantum key distribution (QKD) processes provide assurance that the encryption key has not been intercepted. However, practical implementation of QKD requires that the critical physical parameters of a QKD system can be assessed. EMRP research developed methods to characterise the three key components of QKD systems: single-photon sources with unknown quantum states that carry information about the encryption key, the quantum channel used to transfer the key and single-photon detectors. The project team provided important metrological expertise to support a real-world demonstration of QKD, led by industry, over a single field-installed fibre. This work makes QKD a more attractive commercial proposition and will accelerate its commercial deployment.

# First EMRP Industry projects at a glance

Total investment €54M

Pooling expertise of 28 NMIs and DIs from 22 European countries plus the NMIs from USA, Japan, Korea, Brazil and Argentina

46 academic research groups

96 businesses

19 published newsletters and press releases

96 presentations at workshops and seminars, reaching an audience of 12,000 people

**224** articles in peer-reviewed journals

**84** training courses delivered to over **3,000** people

**841** presentations at conferences

**97** contributions to **47** technical committees and working groups of standards organisations

Supported the development of improved instrumentation with projected sales of **€93M**

**23** articles in the trade and popular press

**5** contributions to draft standards and published standards

# Key technical achievements:

# Advanced manufacturing

**The manufacture of high-performance, high-value products requires complex and efficient production processes and continuous innovation to remain competitive. Drivers of change – such as shorter product lifetimes, increased customisation, flexible manufacturing systems and waste reduction – place ever-greater emphasis on reliable data at all stages of product development and manufacture. Change in the automotive sector, for example, is driven by fuel efficiency, emissions regulations and consumer demand for cost-effective performance and customisation. Aerospace innovation is similarly driven by fuel efficiency, as well as aircraft reliability and new business models.**

## Measurement challenges

High-performance products and manufacturing systems require accurate measurements for a wide range of parameters and in a wide range of production environments.

Computer-aided design, for example, creates complex shapes and forms to meet aerodynamic performance targets for fuel efficiency and the aesthetic requirements of consumers. These shapes and forms push the boundaries of traditional approaches to dimensional measurements.

Complex and efficient manufacturing systems often use processes operating in challenging or even hostile environments – at high temperatures, at very-high or very-low pressures or using rapidly-changing mechanical inputs, such as force, torque and pressure. These create corresponding challenges for the metrology infrastructure, not only requiring improved capabilities at NMIs but also practical solutions for the manufacturing plant.

High-performance products rely on high-performance materials and coatings to provide, for example, durability, strength and weight advantages. The performance of novel materials needs to be characterised and understood.

EMRP research has supported projects covering this wide range of industrial measurement challenges:

**Measurements in challenging environments**

- High-temperature measurement in challenging environments
- Dynamic measurements of mechanical quantities
- High-pressure measurement in industrial applications
- Vacuum measurement in production environments
- Radiological safety in the metallurgical industry

**Complex dimensional measurements**

- Optical and tactile metrology for absolute form characterisation
- Thermal design and time-dependent dimensional drift behaviour of sensors, materials and structures

**Properties of innovative materials**

- Dynamic mechanical properties and behaviour of viscous materials
- Durability and function of engineered surfaces
- Quantitative surface chemical analysis for industrial applications

## High-temperature measurement in challenging environments

High temperatures, above 1000 °C, are routinely used in a range of European industries and in the production of iron, steel, glass and ceramics. These temperatures have to be carefully controlled during manufacturing, but measuring high temperatures accurately is challenging as environmental conditions affect the performance of measurement devices. At high temperatures, contact thermometers, such as thermocouples, become brittle and damaged while the performance of non-contact thermometers changes over time. In harsh environments, stopping processes to access measurement devices for recalibration or replacement is costly and the ideal solution is robust and stable temperature measurement devices.

The EMRP project IND01 High temperature metrology for industrial applications developed methods to improve reliability and robustness of contact and non-contact high-temperature measurement, including:

- **Demonstration of self-correcting thermocouples** that self-calibrate without having to be removed from their operating environment.
- **A facility to assess the performance of new thermocouples** made from exotic materials, which may be better suited to harsh conditions. The performance of such thermocouples needs to be clearly understood and validated before they can be used in industry.
- **A method to self-correct radiation (non-contact) thermometers** using blackbodies that emit radiation at fixed temperatures, allowing periodic assessments of thermometer accuracy.
- **A demonstration of real-time, accurate temperature measurement for laser hardening,** an industrial mass-production technique that hardens materials using a high-temperature laser.

The techniques and facilities developed are contributing to more accurate measurement of high temperatures in industry. Self-correcting contact thermocouples and novel materials for thermocouples are being developed further in the EMPIR project 14IND04 EMPRESS. This project will develop more durable high-temperature thermocouples that will be trialled in industry. The technique using fixed-temperature black bodies to validate non-contact temperature measurements has been used by the French Alternative Energies and Atomic Energy Commission (CEA) to study the effects of high temperatures on glass and concrete under critical conditions. The method developed for temperature measurement during laser hardening has been incorporated into the laser-hardening systems of an R&D organisation and material processing company in Germany.

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| **More information is available at** | IND01 High temperature metrology for industrial applications (>1000 °C) (HiTeMs)<br>www.euramet.org/project-IND01 |
| | Details of the follow-on project:<br>14IND04 Enhancing process efficiency through improved temperature measurement (EMPRESS)<br>www.euramet.org/project-14IND04 |
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## Dynamic measurements of mechanical quantities

Measurements of force, pressure and torque are important to most manufacturing sectors. However, while the sensors used to make these measurements (transducers) are calibrated in static conditions, they are often used in dynamic conditions, where force, pressure and torque vary with time, often varying over large ranges very rapidly. For example, an increase in fuel injection pressure in vehicle engines increases fuel efficiency and enables the development of cleaner cars. On ignition, pressures within engines rise several hundred-fold within a fraction of a second, and accurate measurement of this fast-changing pressure is needed to develop innovative and competitive products. In the energy sector, accurate assessment of rapidly-changing force, pressure and torque is needed to improve monitoring of safety-critical systems.

The EMRP project IND09 Traceable dynamic measurement of mechanical quantities developed methods for calibrating dynamic measurements of force, pressure and torque. The project developed and extended the range of validated calibration methods and devices, traceable to primary standards, for a variety of force, pressure and torque transducers operating in dynamic modes. As a result of the project:

- **Force transducers** can now be calibrated against primary standards for periodic measurement variations with frequency ranges up to 1 kHz and force amplitudes up to 10 kN.
- Methods to calibrate pressure transducers for **dynamic measurements of shock pressures** with amplitudes up to 500 MPa and transducers for **periodic torque** were investigated and new services will be available in the near future.
- Methods to calibrate **amplifiers used in the dynamic mode** traceable to national standards were developed.
- **Mathematical and statistical models** were developed that estimate measurement uncertainties of dynamic measurements throughout the calibration chain.

The project outputs are already in use in the industrial and standardisation communities. Transducer manufacturers are using the improved calibration capabilities at NMIs and a transfer standard developed in the project is expected to become a commercial product. The methodology for calibrating sensor amplifiers has been incorporated into a German DKD guideline and an ISO draft standard, and a supplement to the international Guide to the Expression of Uncertainty in Measurement is planned. A web-based best practice guide providing practical information for engineers and technicians in industry is also available. Wider uptake of project results will, ultimately, allow European industry to accurately measure and control forces, pressures and torques, to support product and process innovation.

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| **More information is available at** | IND09 Traceable dynamic measurement of mechanical quantities (Dynamic)<br>www.euramet.org/project-IND09 | |
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## High-pressure measurement in industrial applications

High-pressure manufacturing techniques are increasingly used in a range of European industries, including pharmaceuticals, petrochemicals and automotive. The techniques use high pressures to create durable, high-performance components at relatively-low cost, allowing European manufacturers to produce internationally-competitive and more sustainable products. Higher pressures allow higher-performance products to be produced but the use of high pressures in industry was limited by the calibration capabilities of the European NMIs. NMIs only provided traceable calibrations up to 1 gigapascal (GPa), while industry requires calibrations to 1.5 GPa.

The EMRP project IND03 High pressure metrology for industrial applications created a European NMI capability for the calibration of industrial pressure sensors up to 1.5 GPa. The project developed:

- **A primary high-pressure standard,** based on a pressure balance system, that is capable of measuring pressures up to 1.6 GPa.
- **Transfer standards for industrial users to calibrate their high-pressure measurements.** These are pressure transducers, accurate up to 1.5 GPa, that transfer the calibration from the primary high-pressure standard to industrial pressure measurement devices.
- **Recommendations and standards for high-pressure materials and procedures,** including the most suitable materials, liquids and components for developing high-pressure measurement devices, and the optimum procedures for calibrating pressure transducers.

These developments are supporting the accurate measurement of high pressures throughout European industry. A facility at PTB has been used by a world-leading manufacturer of high-pressure equipment to develop autofrettage machines that operate over higher pressure ranges than were previously achievable. These autofrettage machines have since been used by manufacturers to develop more durable engine components for the European automotive industry, leading to the production of more fuel-efficient diesel engines. Project results have also been shared with manufacturers of high-pressure equipment to support the selection of suitable materials and components, and optimum measurement and calibration procedures for pressures above 1 GPa. The PTB facility is also being used by commercial calibration laboratories to gain accreditation for pressure calibration above 1 GPa for industrial users, in line with ISO 9001 and other international standards.

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| **More information is available at** | IND03 High pressure metrology for industrial applications (HighPRES)<br>www.euramet.org/project-IND03 |
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## Vacuum measurement in production environments

The manufacture of computer chips, flat-panel displays, mobile phones and solar cells relies on processes carried out in a vacuum environment, with the semiconductor industry alone making up around 40 % of the vacuum market. Vacuum is also an important and indispensable tool for many other industrial processes in the lighting, pharmaceutical and food packaging sectors. Modern vacuum systems need to meet demanding performance requirements as the quality of the vacuum directly affects the quality of the products being made while the speed at which a vacuum can be achieved affects process efficiency. Improved measurements of very-low and rapidly-changing pressures as vacuums are created, as well as leak and contamination detection, are necessary for efficient and effective process control.

Prior to the project, existing vacuum measurement standards provided traceability from $10^{-9}$ Pa to $10^{5}$ Pa for pure gases under stable equilibrium conditions. Industrial processes, however, very rarely work in such conditions. The EMRP project IND12 Vacuum metrology for production environments developed facilities, methods and reference standards for improved traceability of industrially-relevant vacuum and low-pressure measurements, including:

- **A new dynamic vacuum facility** to calibrate industrial vacuum gauges for rapidly-changing pressures (from 100 kPa to 100 Pa within 23 ms).
- **A calibration system for partial pressures** to characterise and calibrate quadrupole mass spectrometers used in industrial settings, available for the first time in Europe.
- **Reference outgassing samples** for a range of important industrially-relevant gas species, such as water vapour, providing traceable and comparable measurements of the outgassing (i.e. the release) of the unwanted contaminants from vacuum equipment.
- **A practical guide for leak measurements** using commercial leak detectors, for users of leak detectors and the standards-developing committees.

The project team worked closely with measurement instrumentation manufacturers and standardisation bodies, ensuring that the project's outputs are used to improve instrumentation and incorporated in relevant specification standards. New technical specifications on characterisation of quadrupole mass spectrometers and outgassing rate measurements will be drafted under the ISO vacuum standards committee (TC 112), and a manufacturer of vacuum instrumentation has developed and validated a commercial ultrafast pressure measurement gauge. These developments will significantly improve industrial vacuum measurements, reducing set-up times and improving process control and product quality.

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| **More information is available at** | IND12 Vacuum metrology for production environments (Vacuum)<br>www.euramet.org/project-IND12 | |
| **Contact** | Karl Jousten (PTB) | karl.jousten@ptb.de |

## Radiological safety in the metallurgical industry

Steel mills across Europe use radiation detection portals to test incoming scrap material for the presence of radioactive sources. However, under certain circumstances, detection portals can fail to detect radiation, leading to contamination of steel and steel by-products and expensive clean-up costs. In addition, the use of different detection systems in steel mills, based on different technical approaches, leads to different assessments of radioactivity, making it difficult to compare detection results between mills. This creates the potential for trade disputes and contaminated steel products. Therefore, improved detection devices, based on the best-performing technologies, are needed to provide improved and more reliable identification and quantification of contaminants at all stages of the steel production process.

The EMRP project IND04 Ionising radiation metrology for the metallurgical industry aimed to establish common standards for radioactivity monitoring in steel mills and reliable certification of the non-radioactivity of steel and by-products. The project:

- Developed **SI-traceable methods optimised for the control/measurement of radioactivity at each stage of the smelting process**. This included the development of certified reference materials representative of typical scrap loads, metal products and fume dusts found in the smelting industry, and recommended industrial measurement methods.
- Made the recommendation that the **best alternative to the current measurement systems** used in industry to measure the activity of cast steel and slag samples is **gamma ray spectrometric devices** using either a germanium (Ge) detector or $BeCr_3$ scintillator.
- **Designed and validated prototype gamma ray spectrometric devices** based on Ge detectors and $BeCr_3$ scintillators for scrap loads, metal products and fume dusts.

The project successfully tested the prototype devices at steel mills in Portugal, the Czech Republic and Spain demonstrating that they could rapidly and accurately identify contaminants and meet the level of technical performance required by the smelting industry. The certified reference materials developed are already in use at five steel mills across Europe leading to better detection of radioactivity during production and more consistent certification of steel batches. The project team are also in discussion with the steel industry and standardisation committees regarding the development and improvement of technical standards for certifying cast steel. The longer-term aim is robust and consistent certification of steel, so ensuring human and environmental safety while reducing unnecessary 'false alarm' events at industrial sites.

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| **More information is available at** | IND04 Ionising radiation metrology for the metallurgical industry (MetroMetal)<br>www.euramet.org/project-IND04 |
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## Optical and tactile metrology for absolute form characterisation

The design and manufacture of optical components is dependent on the ability to measure the full 3D form of precision curved or flat optical surfaces. These components are used in high-performance photonics and precision engineering applications, as well as consumer products, such as cameras and spectacles, and scientific research. The performance of optical components is based on the shape and quality of the surface and, while modern manufacturing techniques enable a wide range of shapes to be produced, consistent high-quality manufacturing is dependent on the ability to measure and characterise the optical components produced. Two types of measurement tools are used – imaging and single-point scanning – both of which have advantages, as well as disadvantages that limit manufacturing capability.

The EMRP project IND10 Optical and tactile metrology for absolute form characterisation improved methods to accurately measure flat, aspheric and free-form optical surfaces. The project:

- **Improved the spatial resolution and measurement uncertainties for deflectometer measurements of flatness** – 1 nm peak-to-valley uncertainty and 0.1 µm resolution was attained. A new cost-effective flatness measurement technique based on capacitive distance sensors was also developed.
- **Characterised and improved the performance of a novel prototype optical interferometry instrument (a tilted-wave interferometer),** validating its performance as an alternative method to assess the form of optical components.
- **Improved the performance of tactile and optical single-point techniques** for curved surfaces. Critical parameters that influence the onset of distortion during tactile probe testing of soft materials were identified and methods for reducing the sources of errors in ultra-high precision single-point optical form measuring instruments were validated.
- **Developed a range of reference standards** with different optical characteristics to enable referencing of coordinate systems used to calibrate and characterise surface form measuring instruments and link industrial measurements to primary standards at NMIs.

The project team worked closely with an industry body – High Level Expert Meetings of the Competence Centre for Ultra-Precise Surface Manufacturing – to ensure the project met industrial needs and shared its results. The outputs of the project are already in use. A manufacturer is using the project developments to improve and commercialise a prototype tilted-wave interferometer, and predicts a significant market among manufacturers of optical components. In addition, a set of reference diamonds was characterised for the European diamond trading industry and improved measurement procedures are being incorporated into a new international standard for diamond classification.

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| **More information is available at** | IND10 Optical and tactile metrology for absolute form characterisation (Form)<br>www.euramet.org/project-IND10 | |
| | Details of a related project:<br>Reference algorithms and metrology on aspherical and freeform lenses (FreeFORM)<br>www.euramet.org/project-15SIB01 | |
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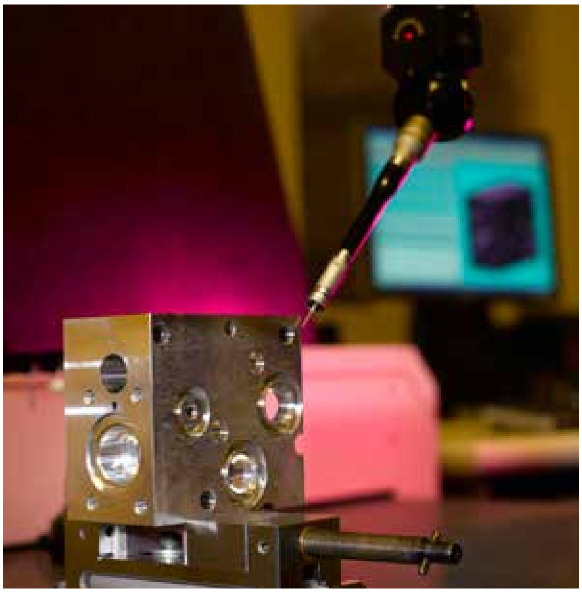
## Thermal design and time-dependent dimensional drift behaviour of sensors, materials and structures



Advanced industries such as aerospace and ICT rely on precision engineering and sophisticated production equipment to manufacture complex and miniaturised components and products. With precision engineering demanding ever-higher accuracies for industrial production and measurement equipment, temperature effects and time-dependent drift become a serious limitation to system performance.

The EMRP project IND13 Thermal design and time-dependent dimensional drift behaviour of sensors, materials and structures developed the metrological tools and methods to support optimisation of the thermal stability of ultra-precision engineering measurement and production tools over timescales of weeks to months. The project addressed material and joint properties (aging, thermal dilatation, indentation creep); temperature sensors (thermocouples, self-calibrating sensors with fixed points from alloys); thermal modelling and control (development of thermally-insensitive machine designs) and developed:

- **A picodrift interferometer** for assessing instrument dimensional stability capable of detecting at the nanometre level over days.
- **Novel procedures to calibrate the displacement of high-temperature nano-indentation equipment at elevated temperatures.**
- **Reliable and stable temperature measurement tools and sensors with uncertainties at the millikelvin level.**
- **Models for thermal-induced deformations of instrument structure** to support the design of stable instrumentation.
- **A prototype measurement system for ambient temperatures** based on highly-accurate thermocouples and precise temperature control. This system enables the performance of measurement instrumentation to be assessed under temperature fluctuations in ambient conditions.

The tools and methods developed in the project are all publicly available and some outputs are already in use. For example, the prototype measurement system for ambient temperatures has been used by a manufacturer to improve the performance of its instrument for ultra-precision dimensional measurements and a license to commercialise the prototype has been granted to a manufacturer in Germany.

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| **More information is available at** | IND13 Thermal design and time-dependent dimensional drift behaviour of sensors, materials and structures (T3D)<br>www.euramet.org/project-IND13 | |
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## Dynamic mechanical properties and behaviour of viscous materials

Components containing viscous materials, such as rubbers and plastic polymers (polymeric components) are increasingly used to make lighter, higher-performance and lower-cost products. Viscous materials deform under pressure and can change shape over time, changing the performance of the products they are used in. Therefore, manufacturers need to be able to measure changes in the shape and properties of polymeric components over time to better predict their performance and useful lifetime. To do so, techniques to measure the long-term deformation of viscous materials are required.

The EMRP project IND05 Dynamic mechanical properties and long-term deformation behaviour of viscous materials addressed this need by developing equipment and methods to accurately measure changes in the dimensions and properties of viscous materials, including:

- **An optical interferometer measurement system.** The system is accurate and highly-stable through time, and can distinguish genuine long-term changes in viscous materials from pseudo-changes caused by measurement instrumentation drift.
- **Methods to measure changes in shape, viscosity and elasticity** of viscous materials over time using the new optical interferometer system.
- **More sophisticated and comprehensive analysis methods.** New models and algorithms were developed to analyse and process measurement data, ensuring results can be compared with measurement standards and with results from other existing measurement techniques.

The new measurement system and methods are being used by European industry to measure the properties of viscous materials in products. A manufacturer of water management systems is using methods developed in the project to develop more durable, longer-lasting water storage chambers. A surface mechanics consultancy has used the project results to enhance its range of software products, including new algorithms and models to study the surface properties of a wide range of materials. Two instrument manufacturers have used results to improve their measurement products.

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| **More information is available at** | IND05 Dynamic mechanical properties and long-term deformation behaviour of viscous materials (MeProVisc)<br>www.euramet.org/project-IND05 | |
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## Durability and function of engineered surfaces

Friction and wear in industrial processes wastes energy and damages materials, increasing costs and reducing productivity. Low-friction, low-wear coatings can be applied to machinery and components to reduce friction and wear. A number of industries, including transport, energy, manufacturing and mineral extraction, are using these 'engineered surfaces' to improve process efficiency, but wider use is limited by a lack of techniques for the accurate measurement of very-low levels of friction and wear.

The EMRP project IND11 Metrology to assess the durability and function of engineered surfaces developed methods to accurately measure low-level friction and wear on engineered surfaces, including:

- **Techniques to measure nanoscale wear,** accurate to one billionth of a metre.
- **Stable methods to make long-term measurements of friction** on low-friction coatings.
- **Methods to measure temperature and chemical changes** at the points where industrial surfaces meet and interact.

The new measurement techniques have been described in five Good Practice Guides, to ensure they can be used effectively by industrial users, and have contributed to new CEN, ISO and ASTM industrial standards. A number of the techniques have been adopted by instrument manufacturers to develop new commercial measurement devices, including a modified ruby sensor that makes simultaneous measurements of surface friction and temperature. The techniques are also being used by the International Energy Agency in its Advanced Materials for Transportation programme, to explore the use of engineered surfaces in vehicle engines to increase efficiency and reduce emissions. Over the longer term, the new measurement methods developed will be used to make advances in surface engineering, leading to further reductions in friction and wear, more efficient manufacturing and higher-performance industrial products.

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| **More information is available at** | IND11 Metrology to assess the durability and function of engineered surfaces (MADES)<br>www.euramet.org/project-IND11 |
| **Contact** | Mark Gee (NPL) mark.gee@npl.co.uk |

## Quantitative surface chemical analysis for industrial applications

Surface chemical analysis is important to the development and manufacture of a wide range of products. It is a key element in microelectronics, bonding and corrosion for aerospace and transport applications, and also in life sciences for protein adhesion and toxicity for body implants and drug delivery systems. In these fields, the functionality of surfaces, thin films and the interfaces between materials plays an important role in product performance and functionality. The chemical composition of surfaces and interfaces, at the atomic level, is usually very different from that of the bulk material and is often key to the material behaviour and performance. Therefore, understanding chemical composition and structure at surfaces is key to new product development and manufacturing quality control.

The EMRP project IND15 Traceable quantitative surface chemical analysis for industrial applications addressed the need to improve the measurement performance of analytical instrumentation for surface analysis. The project focused on improving the accuracy of key spectroscopic techniques for surface analysis, such as X-ray photoelectron spectroscopy (XPS), secondary ion mass spectrometry (SIMS) and electron probe micro-analysis (EPMA), by developing certified reference materials for instrument calibration and methods to improve the capability of the various techniques. The project developed:

- **A universal certified reference material for quantitative analysis by EPMA using EDS** (energy-dispersive spectrometry), enabling a traceability chain for detector efficiency. This enables energy dispersive spectrometers to be calibrated to ISO 15632:2012 with only one measurement.
- **Certified reference materials** for quantitative chemical in-depth analysis of layered organic materials and **2D test structures for the determination of the field of view (FOV)** of surface analytical instruments.
- **A new diagnostic method based on valid liposome labelling of tissue and imaging time-of-flight (ToF) SIMS analysis** and **traceable fluorescence measurements for biodiagnostic device platforms.**
- **Metrology for new, fast, non-destructive quantitative methods of surface chemical analysis** by optical, mass spectroscopic and scanning probe techniques for industrial in-line quality control.

European instrumentation manufacturers are using the certified reference materials to validate and optimise the performance of their products and the results have been presented to the relevant ISO committees. A number of new ISO work item proposals are in development that will lead to new or revised standards, thus ensuring the wider use of the improved measurement methods.

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| **More information is available at** | IND15 Traceable quantitative surface chemical analysis for industrial applications (SurfChem)<br>www.euramet.org/project-IND15 |
| **Contact** | Wolfgang Unger (BAM) wolfgang.unger@bam.de |

# Key technical achievements:

# Electronics & ICT

**The electronics and ICT sectors are important drivers of product and process innovation. The evolution of the semiconductor industry, with increasing miniaturisation of devices and higher levels of performance, has been enabled by accurate measurement of ever-smaller dimensions, faster electrical signals and complex material properties. Likewise the emergence of nanotechnology was enabled by the ability to make measurements at the nano level.**

**Current trends in these sectors include: upgrading the mobile communications infrastructure for faster communications and increased bandwidth for 5G and beyond; continued miniaturisation and increased processing speeds of ICT components and devices; flexible low-cost polymer-based electronics; and the development of future ICT technologies when the limits of current materials and technologies are reached ('after CMOS').**

## Measurement challenges

The ongoing miniaturisation and increased operating speed of electronic devices not only challenge current measurement capabilities, but also create a requirement to characterise new ICT technologies. This requires the metrology infrastructure to continue to reduce uncertainties at the level of primary standards in order to meet current and future needs for accurate measurement at smaller and faster levels, as well as the ability to assess the performance of advanced electronic materials. In such a fast-moving industry, it is also necessary to plan for the longer term and develop the metrology infrastructure for the next generation of electronics technologies.

EMRP research has supported projects that address:

- **Metrology for ultrafast electronics and high-speed communications**
- **Metrology for advanced industrial magnetics**
- **Characterisation of electromagnetic materials at microwave frequencies**
- **Metrology for the manufacturing of thin films**
- **Metrology of small structures for the manufacturing of electronic and optical devices**
- **Metrology for industrial quantum communication technologies**
- **New generation of frequency standards for industry**

## Metrology for ultrafast electronics and high-speed communications

The steady increase in the operating frequency and data rates of communication systems is dependent upon signal processing electronics and test equipment that can measure at ever-faster speeds. This requires reliable ultrafast measurement equipment, such as sampling oscilloscopes and pulse generators, to characterise and validate ultrafast electronics and high-speed communications technologies during their development, production and implementation, as well as software tools to manage and assess the high volumes of data generated.

The EMRP project IND16 Metrology for ultrafast electronics and high-speed communications addressed key challenges in accurate ultrafast measurements: techniques for measuring continuous and pulsed high-frequency signals; management of data quality in very large volume data sets; investigating the properties of channels and antenna at potential new communications frequencies; and methods for calibrating vector signal generators and analysers. The project developed:

- **Waveform metrology for ultrafast detectors** comprising a broadband voltage pulse standard with 500 MHz frequency spacing and frequency components exceeding 500 GHz, and an asynchronous electro-optic sampling technique to measure electrical pulse generators.
- **A software tool for uncertainty propagation that can be applied to large data sets.** This enables uncertainty propagation between time and frequency domains and is available from the project website.
- **Tools and processes for propagation measurements and channel and antenna characterisation.** Measurements from 50 GHz to 325 GHz were performed in various scenarios relevant for future THz communication systems and the feasibility of implementing a 300 GHz communication system was investigated.
- **Capabilities to measure digital signal properties**, including a universal calibration method for vector signal analyzers and vector signal generators, and a simple software tool for demodulating basic digitally-modulated signals.

The project partners shared the new tools and techniques with other NMIs, manufacturers of measurement and test equipment, and commercial calibration laboratories to facilitate their adoption in the development of faster ICT technologies. The software packages are in use at a number of European companies, as well as NMIs worldwide. The partners also contributed to a new standard on the calculation of waveform parameter uncertainties (IEC TC 85, WG22), expected to be published in late 2016. The standard is applicable to all industries that generate, transmit, detect, receive, measure and/or analyse step- and impulse-like waveforms.

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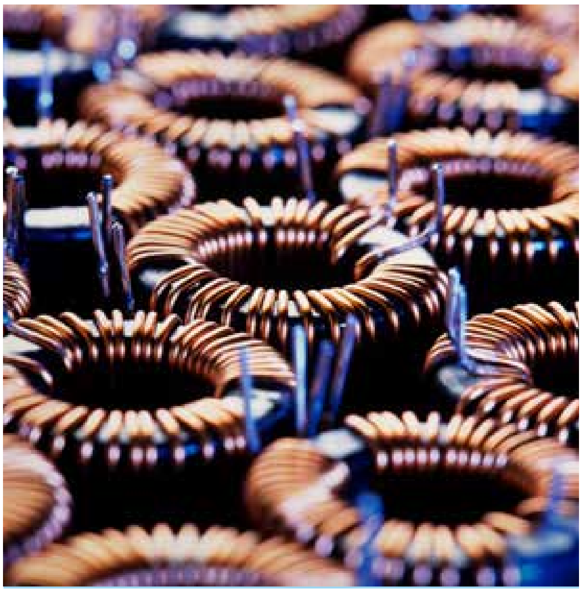
| **More information is available at** | IND16 Metrology for ultrafast electronics and high-speed communications (Ultrafast)<br>www.euramet.org/project-IND16 |
| **Contact** | Hans Werner Schumacher (PTB)    hans.w.schumacher@ptb.de |

## Metrology for advanced industrial magnetics



Magnetic sensors are used in industries that require accurate high-resolution data, such as the consumer electronics, ICT and automotive industries. The fast product development in these fields creates an ongoing need for advanced magnetic sensors with significantly-improved specifications in resolution, reliability and operation temperature. An improved understanding of the physical properties of magnetic materials is needed to enable sensor manufacturers to develop advanced anisotropic magnetoresistance (AMR) sensors that are ultra-small, with low noise and high sensitivity, and hence improve electronic measurements leading to more advanced products.

The EMRP project IND08 Metrology for advanced industrial magnetics developed new calibration facilities, tools and methods to enable the European magnetic sensor industry to develop advanced magnetic sensors and stay competitive in the global market. The project developed:

- **Metrological tools and methods for industrial magnetic sensor development** including tools for the micromagnetic modelling of micro- and nano-scale magnetic thin films, a metrology system for characterising key parameters of novel magnetic domain wall sensor devices and a new micro-Hall-sensor based method for the calibration of the stray fields of near-field probes for magnetic force microscopy (MFM).
- **Metrological in-line tools and methods for sensor production** including a method for the fast and non-destructive inductive determination of key material parameters for spin-torque (ST) materials and MFM in variable magnetic fields and under variable applied stress.
- **Metrology for sensor testing and calibration** including a novel calibration procedure for the calibration of tri-axial Helmholtz coil systems, a portable three-axis superconducting quantum interference device (SQUID) system to determine the magnetic noise vector field behaviour in industrial facilities, and a low magnetic field facility with a magnetic shielding and thermal isolation that provides a magnetically- and thermally-stable environment for noise measurements down to a frequency of 0.1 mHz.

The project team worked closely with sensor manufacturers and users to ensure the adoption of the metrological tools and methods. For example, a world-leading AMR sensor producer has optimised its magnetic manufacturing process using the MFM system. The low magnetic field facility has also been used to measure the magnetic moment of components for the European Space Agency EarthCARE mission. In addition, the new 3D magnetic field calibration systems have been used in precision calibrations for applications in geological exploration.

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| **More information is available at** | IND08 Metrology for advanced industrial magnetics (MetMags)<br>www.euramet.org/project-IND08 | |
| **Contact** | Mark Bieler (PTB) | mark.bieler@ptb.de |

## Characterisation of electromagnetic materials at microwave frequencies

Advances in electronics technology lie behind all developments in ICT and there is a world-wide demand for ever-faster electronics. To cope with the increasingly-high operational speeds of modern electronic equipment, new measurement techniques are required to assess the electromagnetic materials used in the fastest applications – at microwave frequencies up to 80 GHz.

The EMRP project IND02 Electromagnetic characterisation of materials for industrial applications up to microwave frequencies developed a suite of traceable metrological tools for characterising passive (dielectric and magnetic) and active 'functional' electromagnetic materials across the spectrum from low frequencies of 100 kHz through radio frequencies (RF) and up to microwave frequencies of 80 GHz. The project developed or improved the performance of a range of measurement instrumentation, for example:

- Two types of **nanoscale near-field scanning microwave microscopes** (NSMMs) were developed – one with a spatial resolution of tens of nanometres and one with tens of micrometres – to determine the dielectric, capacitive and conductive properties of materials at small scales across a material surface. Understanding these properties at this scale enables the selection of materials with specific features for electronics and other applications.
- The understanding of **microscale NSMMs** was significantly improved – it is now possible to make traceable measurements of complex permittivity at microwave frequencies.
- **Coplanar waveguide (CPW) and split cylinder (SC) techniques** were developed to provide traceable measurements on substrate materials and on functional thin films mounted on substrates. These are needed to assess the quality and performance of traditional silicon substrates at high frequencies during the manufacturing process and the performance of thin films.

The new facilities are available at European measurement institutes to support the development of electronic materials, production equipment and devices. An instrument manufacturer is using calibration artefacts and knowledge developed in the project to expand the range of electronic material properties that can be measured and ensure its NSMMs can meet industrial requirements. A company that designs and manufactures RF and microwave components for the mobile telecommunications industry used the tools to better understand and improve the performance of the dielectric resonators used in communications base stations.

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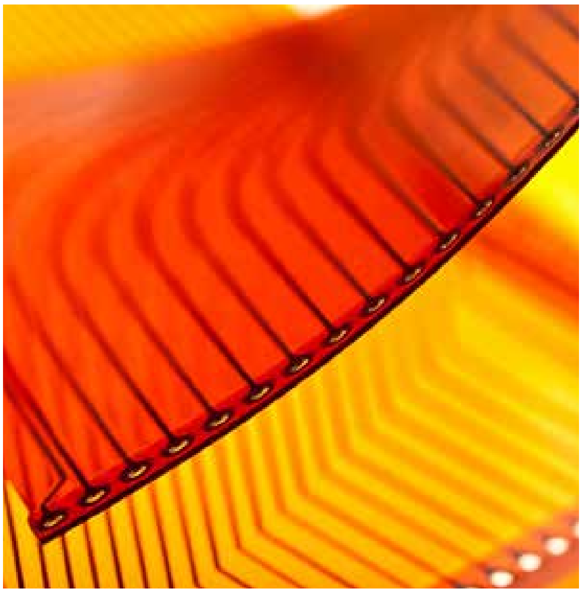
| **More information is available at** | IND02 Electromagnetic characterisation of materials for industrial applications up to microwave frequencies (EMNDA)<br>www.euramet.org/project-IND02 | |
| **Contact** | Bob Clarke (NPL) | bob.clarke@npl.co.uk |

## Metrology for the manufacturing of thin films



Thin-film materials possess novel properties not found in bulk materials, enabling their use in the production of high-value products in the optoelectronics industry, such as plastic and printed electronics, displays and lighting, solar cells and memory storage devices. A major challenge is controlling consistency in thin-film processing. Production of thin films is limited by a lack of understanding of precisely how changes in the composition and structure of thin-film materials affect properties such as electronic and thermal conductivity.

The EMRP project IND07 Metrology for the manufacturing of thin films established a pan-European metrology capability providing validated and/or traceable metrology for thin films. The project developed:

- **Traceable measurements and validated methods for thin-film properties** (thermal transport properties, charge carrier mobility and atomic fundamental parameters) including a novel facility for traceable measurement of thermal conductivity in thin films for temperatures up to 1000 °C and a protocol for charge carrier mobility characterisation of thin-film organic semiconductors that reduces uncertainties from 300 % to 20 %.
- **A facility for traceable measurements of water vapour transmission rate** through barrier layers that is a significant advance beyond existing methods and provides accuracy at a detection limit below $5 \times 10^{-5}$ g/m$^2$/day.
- **Microstructure characterisation (morphology) by non-destructive and contactless measurements.**
- A range of **reference materials and transfer standards** relevant to the production environment.
- **New techniques for measurement of film thickness and optical/optoelectronic properties** over large areas for in-production applications, including a prototype multi-electrode system for photo-electrochemical imaging of thin films and a protocol for accurate photocurrent mapping of challenging third-generation solar cells.

The new calibration samples and methodologies are already in use by manufacturers of instrumentation for thin-film characterisation. This disseminates measurement traceability across the value chain, targeting in particular test laboratories measuring key parameters for the semiconductor industry. Other equipment manufacturers have evaluated prototype calibration samples developed by the project and there is potential for commercial exploitation. Additionally, thin-film manufacturing companies gained insights into how manufacturing steps affect the performance and quality of their thin-film products.

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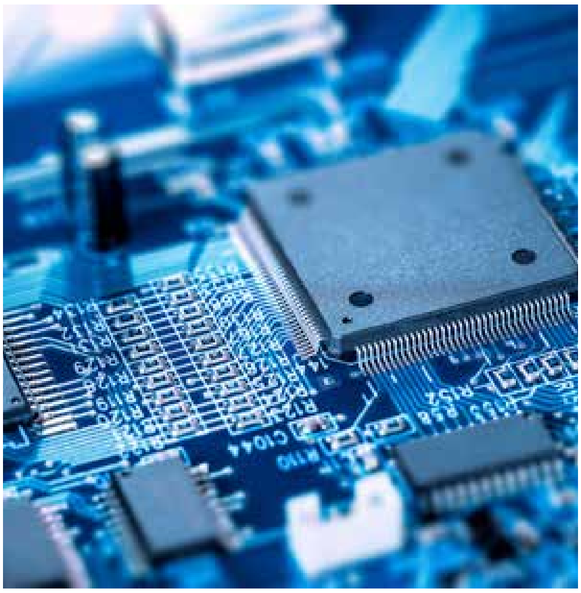
| **More information is available at** | IND07 Metrology for the manufacturing of thin films (ThinFilms)<br>www.euramet.org/project-IND07 |
| **Contact** | Fernando Araujo de Castro (NPL) fernando.castro@npl.co.uk |

## Metrology of small structures for the manufacturing of electronic and optical devices



The reliable measurement of small structures, less than one micrometre in size, is necessary to enable the ongoing miniaturisation of components in optical and semiconductor products. Scatterometry is a tool that measures surface structures at the nano level by scattering light across a surface and detecting the reflections. It is relatively fast compared with traditional techniques such as scanning electron microscopy (SEM) and atomic force microscopy (AFM), and could be more widely used during the manufacture of nanoelectronic and other miniature devices once its performance can be robustly validated via traceability to accurate standards.

The EMRP project IND17 Metrology of small structures for the manufacturing of electronic and optical devices established traceable and absolute scatterometric measurements and transfer standards for the characterisation and calibration of scatterometers. As part of the project:

- **Three relevant methods for dimensional and critical dimension (CD) metrology in the semiconductor industry** were improved: CD-SEM, CD-AFM and scatterometry. The project improved the comparability of these methods and developed data analysis schemes that enabled an additional reduction of measurement uncertainty.
- **Fast and reliable optical metrology methods** were developed and tested with scatterometry and Mueller polarimetry – these are available for the characterisation of diffractive and hybrid optical devices in the optics industry.
- **Scatterometry reference standards** have been designed, developed, characterised and calibrated to face the challenging requirements of the semiconductor industry as specified in the International Technology Roadmap for Semiconductors. For the first time, standards are available which are suitable for the test and calibration of scatterometers, AFMs and SEMs. This will facilitate the comparability of measurement results obtained using these different types of tools.

The project worked closely with European and international instrumentation suppliers and semiconductor manufacturers throughout, sharing results and developments. A number of companies are interested in the reference standards, measurement services and software developed. Sector organisations such as the international SEMI Microlithography Committee were also closely involved. The project team is continuing to work with one of these organisations to evaluate EUV (extreme ultraviolet) photomasks that will support the next generation of semiconductor manufacturing.

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| **More information is available at** | IND17 Metrology of small structures for the manufacturing of electronic and optical devices (Scatterometry)<br>www.euramet.org/project-IND17 |
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## Metrology for industrial quantum communication technologies

Quantum communication technologies such as quantum key distribution (QKD) can improve the security of the ever-increasing amount of sensitive information that is stored, transferred and accessed over computer networks. The unique feature of QKD is that, when implemented correctly, the system guarantees that the encryption key has not been intercepted. In theory, it is extremely effective but there are no agreed methods to demonstrate that practical implementations are robust. The main challenge is the identification of the physical system parameters critical to QKD and the development of appropriate metrics and measurement techniques for their quantification, in particular the properties of quantum sources, channels and receivers.

The EMRP project IND06 Metrology for industrial quantum communication technologies developed:

- **Techniques for traceable characterisation of photon sources with unknown quantum states** including methods for measuring the mean photon number at communications wavelengths traceable to the SI, a novel photon-number-resolving (PNR) detector capable of measuring more than one photon in a pulse, a high-resolution, high-transmission fibre-coupled single-photon spectrometer suitable for spectral analysis of pulsed sources at communications wavelengths and an optimised single-photon source as a reference for quantum sources.
- **Tools for traceable characterisation of quantum channels for optical fibre-based communication systems** including development of 'open system' quantum random number generators – an essential tool in encryption and the development of a single-photon polarimeter for reconstructing the polarisation state of a single photon transmitted down an optical fibre – used to measure system noise using conventional light levels transmitted via a standard communication fibre optic link.
- **Methods for traceable characterisation of single-photon detectors** including characterisation methods for determining parameters and properties of commercially-available single-photon detectors and a calibrated attenuator to simplify detector characterisation and determine quantum efficiency with an uncertainty of less than 3 %.

The project put in place a series of measurement systems that characterise the properties of individual particles of light, as well as QKD technologies, and has laid the foundations for a European measurement infrastructure able to validate the performance of QKD systems to support the development of next-generation communication systems and quantum networks. The project provided important metrological expertise to support a real-world demonstration, led by industry, of well-characterised QKD over a single field-installed lit fibre. This work makes QKD a more attractive commercial proposition and will accelerate its commercial deployment.

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| **More information is available at** | IND06 Metrology for industrial quantum communication technologies (MIQC)<br>www.euramet.org/project-IND06 |
| | Details of the follow-on project:<br>14IND05 Optical metrology for quantum enhanced secure telecommunication (MIQC2)<br>www.euramet.org/project-14IND05 |
| **Contact** | Maria Luisa Rastello (INRIM) m.rastello@inrim.it |

## New generation of frequency standards for industry

Increasing telecommunication speeds and improved technologies are required to continue to meet business and consumer needs. Better time and frequency synchronisation is essential to meet these needs and requires the generation of new reference standards that are compact, robust and well-suited for operation in industrial environments.

Atomic clocks provide frequency standards and current atomic clocks already meet laboratory performance requirements; however, they need to be smaller and capable of operating in harsh environments to be used in industrial applications.

The EMRP project IND14 New generation of frequency standards for industry focused on improving the robustness and portability of high-frequency atomic clocks for applications in space, aerospace, defence, astronomy, and optical and microwave communications. The project developed:

- **New gas-filled hollow-core fibre (HCF) prototype optical frequency standards.** These were produced in partnership with industrial collaborators who provide wavelength standards for the optical communications industry.
- **Novel local optical oscillator architectures** using both small cubic optical cavities and fibre spool interferometers.
- **Demonstrators for the performance of two practical approaches to microwave frequency standards** – trapped atom-on-a-chip and miniature caesium-filled clocks in hollow-core fibre. This included the first-ever accuracy evaluation of a miniature microwave clock with cold trapped atoms.

These results support the development of more stable, accurate clocks and improved synchronisation between them that will enable higher-speed data transfer with fewer errors and provide more reliable systems for industry and consumers. The industrial deployment of improved clocks rests upon the further refinement of system and device designs, and European SMEs are already developing some of the project's outputs – a licence for the cubic optical cavity has been agreed and a collaboration to develop the fibre spool interferometer has been established. The European Space Agency is also interested in the small, robust clocks being developed both for satellite-based atmospheric monitoring and for the STE-QUEST mission that aims to answer a range of questions in fundamental physics.

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| **More information is available at** | IND14 New generation of frequency standards for industry (Frequency)<br>www.euramet.org/project-IND14 | |
| | Details of a related project:<br>IND55 Compact and high-performing microwave clocks for industrial applications<br>www.euramet.org/project-IND55 | |
| **Contact** | Patrick Gill (NPL) | patrick.gill@npl.co.uk |

# Focus on impact

All EMRP projects engage widely with the user communities who can benefit from the research. For the Industry theme, this includes a wide range of industrial sectors that rely on effective measurement for process control and quality assurance, and for innovation to improve productivity and business growth.

The new metrology capabilities and skills developed in the projects will support process improvement and new product development over many years, and there are already examples of the adoption of the research outputs. An important early adopter is the instrumentation sector that makes use of improved metrology capabilities to develop new products for end users in, for example, the automotive, aerospace, electronics, telecommunications and medical equipment sectors.

A survey of companies that engaged with the EMRP Industry theme projects demonstrated early impacts in the form of innovative products and services with projected sales of €93M.

## Better heat-treatment process control

ALOtec, a German provider of materials processing services to the manufacturing sector, has improved the performance of its laser-hardening process. Laser hardening is a heat-treatment technique and precise temperature monitoring is required to control the process to ensure high-quality products and minimal waste.

Working with the EMRP project High temperature metrology for industrial applications (>1000 °C), ALOtec tested the portable 'fixed-point' temperature device developed in the project on its laser-hardening system, demonstrating its suitability as an in-situ calibration tool to correct the thermometers that control the process. Testing revealed that the device could correct for large deviations from the ideal processing temperature, where a deviation of 10 °C above or below the required temperature can cause faulty parts.

The information gained enabled ALOtec to optimise its laser-hardening process and provide an improved service to its customers in the manufacturing, automotive and power generation sectors, and mould- and tool-making industries.

## Improving nuclear reactor safety

The Alternative Energies and Atomic Energy Commission (CEA) has become the first user of high-temperature cells developed by the EMRP project High temperature metrology for industrial applications (>1000 °C). These new temperature cells are helping the CEA research how nuclear reactor containment materials would respond to both the high temperatures and radioactive materials present in the event of a severe accident. This will aid design of safer nuclear facilities and have wider implications for nuclear reactor safety research, design and energy use.

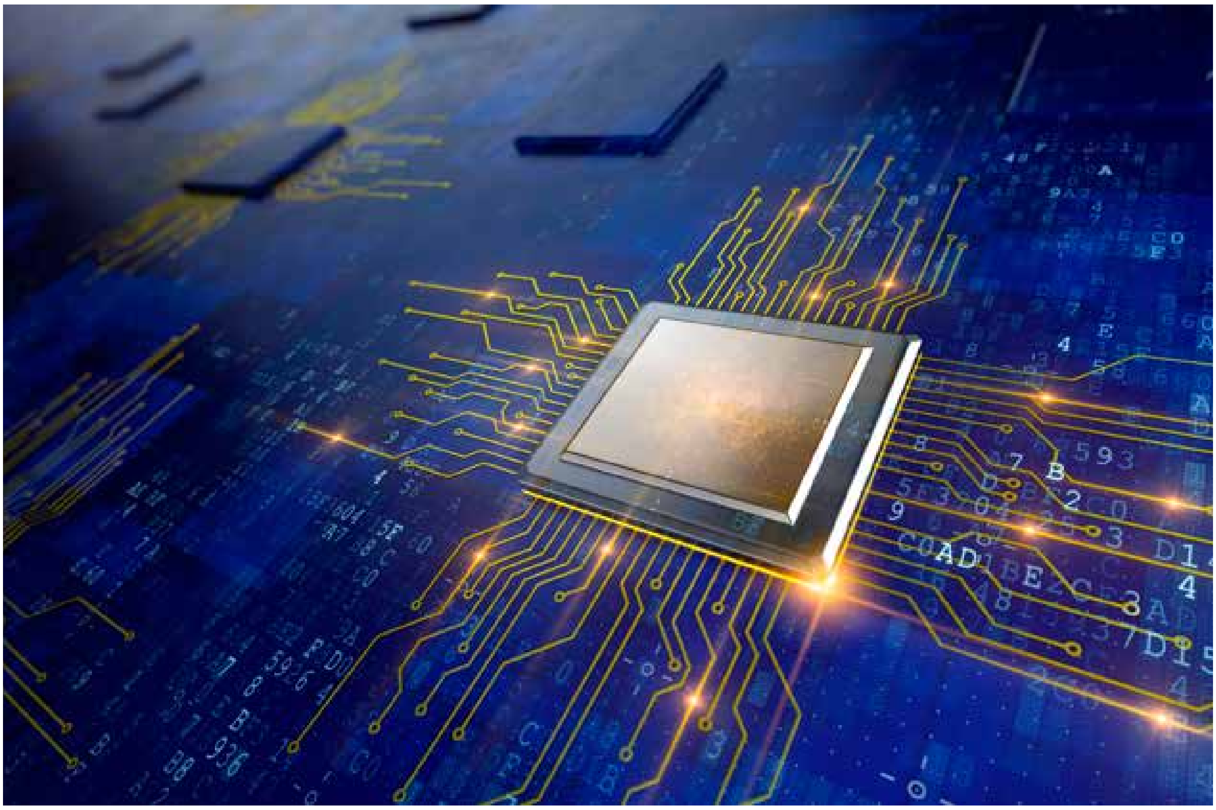
This EMRP project overcame longstanding problems of measurement uncertainties introduced by non-contact thermometer drift and contamination of measurement observation windows in the harsh environments in industrial furnaces.

## Investigating nano-defects

Keysight Technologies Inc, a major manufacturer of test and measurement equipment, can now offer customers accurate, traceably-calibrated atomic force microscopy-based near-field scanning microscopes (NSMMs) for measuring the electromagnetic properties of nanoscale electronic circuits.

Using reference materials and calibration methods developed by the EMRP project Electromagnetic characterisation of materials for industrial applications up to microwave frequencies, Keysight has been able to generate a traceable calibration route for its NSMM instruments. Upgrades to Keysight's analysis software are also being implemented to incorporate the project's models and algorithms, providing improved accuracy to analytical results.

The calibration techniques developed by the project give NSMM measurements traceability, making NSMMs viable for material electromagnetic characterisation measurements, offering an improved method for quality control of the next generation of microchips and supporting the development of new materials for future generations of faster electronics.



## High-performance self-heating materials

The Jožef Stefan Institute (IJS) in Slovenia has implemented a new measurement system for characterising positive temperature coefficient of resistivity (PTCR) ceramics. PTCR ceramics become extremely resistive when heated beyond a threshold temperature, making them ideal for use as PTC thermistors delivering temperature control in electronic devices.

IJS develops prototype PTCR ceramic materials for its customers in the electronics industry and was looking to reduce costs through a reliable, automated measurement system for characterising samples. New measurement test cells for PTCR ceramics were developed within the EMRP project Electromagnetic characterisation of materials for industrial applications up to microwave frequencies and automated for use in IJS's materials development facility.

The new system has enabled IJS to reduce the time taken to develop and test novel PTCR ceramics. STELEM, a major European producer of PTC thermistors used in domestic appliances and vehicles, is using the facilities at IJS to provide accurate characterisation of the components in its products, assuring their performance.

## Pressure-strengthened engines

Measurement instrument supplier HBM and high-pressure systems supplier Maximator have been two early beneficiaries of the new high-pressure facility developed by the EMRP project High pressure metrology for industrial applications.

HBM used the facility to calibrate one of its high-pressure sensors, P3MB Blue Line Top Class transducer©, creating an in-house standard which allows it to calibrate other sensors and provide reliable high-pressure measurement services to its customers who develop high-pressure technologies.

Maximator used the facility to verify its autofrettage systems, which use high pressure to strengthen materials. This has provided assurance to its automotive customers that its systems meet the pressures required for industrial strengthening processes for new, lower-emissions diesel engines. This is helping those customers meet new EU emissions standards and so remain competitive.

## Confidence in recycled steel

Two major steel recycling companies, Sidenor Aceros Especiales and Cyclife Sweden AB (formerly part of Studsvik NuclearAB), have adopted new calibration standards developed by the EMRP project Ionising radiation metrology for the metallurgical industry to assure the performance of their radioactivity monitoring systems.

Almost half the steel produced in Europe is recycled from scrap materials, some of which may be radioactively contaminated, such as waste from industry, medical facilities and decommissioned nuclear power plants. EU Council Regulation 333/2011 requires scrap metal recycling companies to provide certificates of radioactive content for each consignment produced. However, until recently, there were no calibration standards for steel in the forms commonly encountered in steel recycling.

Sidenor, a leading steel recycler in Europe, is using the standards as part of weekly quality assurance checks of its radioactivity monitoring systems, giving customers confidence in the contamination-free certificates issued. Cyclife is one of only a few steel producers able to recycle radioactive steel from the nuclear industry. Cyclife used the project's calibration standards to confirm the response of its radioactivity detectors, generating greater confidence in the measurements they routinely make of recycled steel.

## Plastic deformation testing

Anton Paar, a specialist in instruments for materials characterisation, has developed a new instrument for plastics and upgraded its existing product range. Through interaction with the EMRP project Dynamic mechanical properties and long term deformation behaviour of viscous materials, Anton Paar gained confidence in its instrument's excellent stability and trialled a prototype specifically for the plastics testing market. Anton Paar is now marketing a new nano-indentation test instrument for plastics with improved load control and incorporating the project's materials property model into its software. Similar upgrades have also been added across Anton Paar's nano-test instrument range. It has been estimated that over €15 million in increased sales will result from the introduction of these new and upgraded Anton Paar instruments.

The project's testing methodology has contributed to the development of a new ISO standard. This standard will help plastics manufacturers to understand how new feedstocks affect the variability of plastics and predict their behaviour and stability over their service life.

## Validating high-performance polymers

Mahr GmbH, a leading manufacturer of measurement equipment, has optimised its profilometers to provide reliable measurements of the polymers used in high-performance products such as electronic coatings and medical implants.

Profilometer measurements of surface features are used for quality assurance processes. However, polymers are relatively soft and can be easily deformed by the measurement process. Mahr used new reference materials developed in the EMRP project Dynamic mechanical properties and long term deformation behaviour of viscous materials to assess the performance of its profilometers when measuring polymers.

The knowledge gained through this assessment, along with correction algorithms also developed by the project, helped Mahr to control its profilometers' measuring force at low loads. This significantly reduces surface damage and measurement problems caused by material accumulating on the profilometer probe. Applications of Mahr's improved profilometers include measurements of plastic optics, as well as diamond-turned moulds for optical components.

## Modelling material change

The Saxonian Institute, a surface mechanics consultancy, has extended and validated its models used to predict in-service performance of material surfaces using highly-accurate measurement data generated by the EMRP project Dynamic mechanical properties and long term deformation behaviour of viscous materials.

Using this data, Saxonian was able to improve its material surface deformation modelling software FilmDoctor©. This relates different surface properties to each other and enables predictions of mechanical properties to be made based on a smaller range of measurements, reducing the need for extensive testing.

The validated Saxonian models are already being used to reduce research and testing time for a wide range of industries, including automotive, engineering and consumer products. For example, one customer of Saxonian, instrument manufacturer Anton Paar, has implemented these models into materials nano-testing instruments, improving their ability to provide detailed material property measurements. The FP7 project iStress has also received licences to use a modified Saxonian model as a design aid for predicting properties of novel reduced-wear coatings for engine fuel injector research, reducing the number of variants to be tested by homing in on the required coating properties.

## Advancing quantum communications

Toshiba has used the results of an EMRP project in the first public demonstration of a prototype communications system secured using quantum key distribution (QKD). QKD, which shares encryption keys using single photons, offers a level of security beyond that possible with classical communication techniques.

The measurement capabilities developed as part of the EMRP project Metrology for industrial quantum communication technologies were used to characterise Toshiba's laser system, a crucial element in the prototype communications system. After this performance validation, Toshiba had confidence in the laser's use as a single-photon transmitter, and it was used as part of the first public demonstration of a QKD system using commercially-available components on a standard fibre optic network.

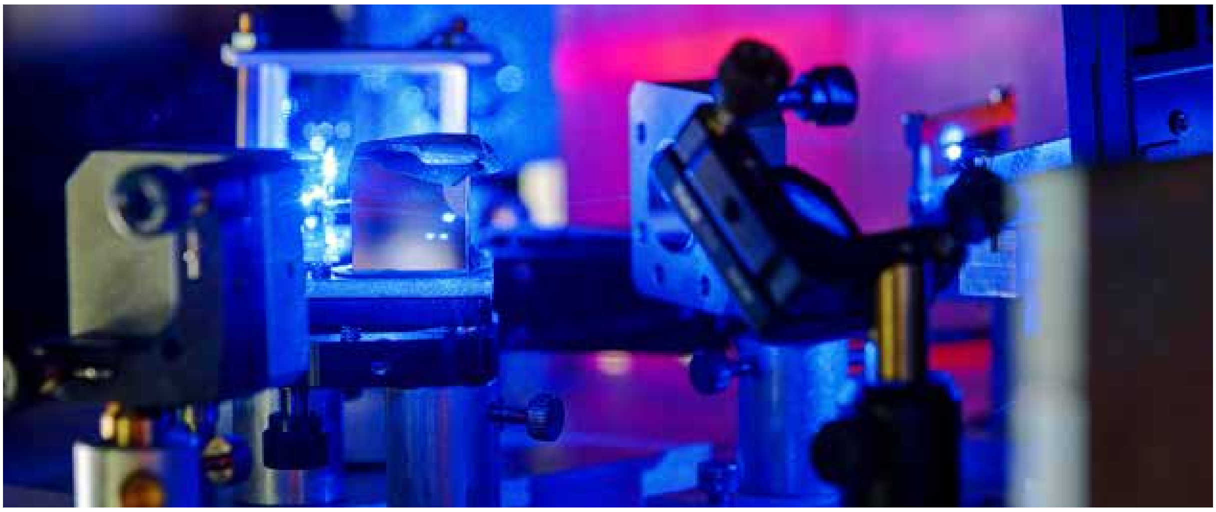
The success of this demonstration, conducted at telecoms company BT, provides validation of this next-generation communications technology and is an important step towards the widespread implementation of QKD networks for secure data transmission.

## Building trust in quantum technologies

Micro Photon Devices (MPD), a research establishment of leading producer of professional timing and adaptive optics systems Microgate Srl, has improved the accuracy of its single-photon counters' specifications using the new detector characterisation facility developed within the EMRP project Metrology for industrial quantum communication technologies.

Single-photon detectors are the key components underpinning many new and emerging photonic technologies. MPD produces single-photon counters based on these detectors, specifically designed and optimised for applications requiring low-noise and low-power measurements, such as single molecule detection or atmospheric sensing. Precise characterisation at the new facility gives MPD's customers in the research and development sector greater confidence in the performance of its detectors.

Reliable specifications for the components underpinning quantum communications will build end-user confidence and accelerate the introduction of next-generation quantum technologies.



## High-performance thin-film technologies

Plasma Quest, a developer of thin-film materials and deposition technology for customers in the electronics industry, has developed a new, cost-effective production technique for the high-performance barrier layers used to protect advanced thin-film products.

Plasma Quest used a new facility established by the EMRP project Metrology for the manufacturing of thin films to test the effect of different production techniques on barrier layer quality. This enabled the company to successfully demonstrate a new technique that enables high-volume production of barrier layers unhampered by dust in the production environment.

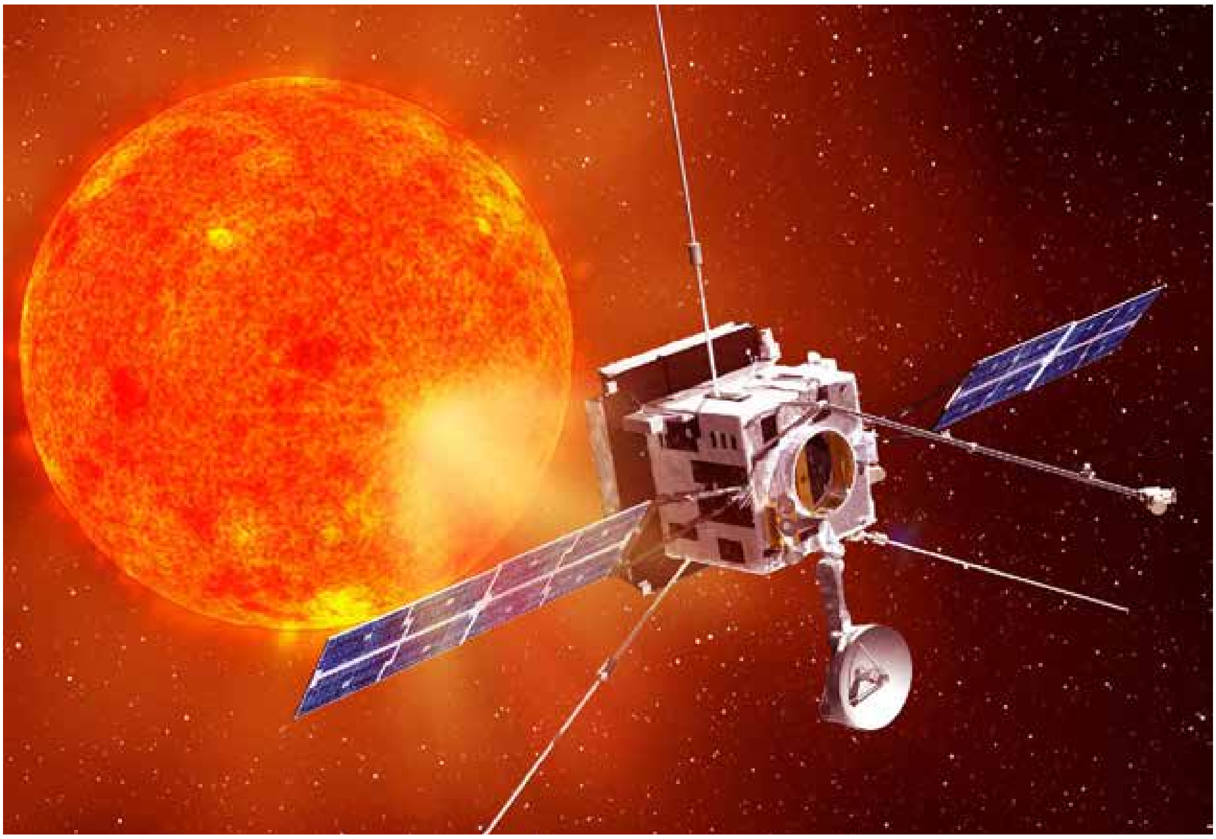
The ability to create effective barrier layers without the expense of maintaining clean-room conditions will significantly reduce production costs without any reduction in product performance, supporting the development of durable thin-film devices, reducing costs and opening new markets. Plasma Quest has already received enquiries from several manufacturers of mobile phone screens looking to implement the new technique.

## Advanced magnetic sensing

Bartington Instruments, a UK-based manufacturer of high-performance magnetic fluxgate sensors, validated the performance of its sensors across an extended temperature range using a new magnetic field calibration facility established by the EMRP project Metrology for advanced industrial magnetics. Bartington used the results to upgrade its own measurement procedures and validate the performance of in-house test equipment.

RAL Space, at the Rutherford Appleton Laboratory (RAL) in the UK, used Bartington's validated sensors as part of the preparation of navigational instruments for future gravitational astronomy missions like LISA. These missions require spacecraft to be 'magnetically clean' and Bartington's sensors correct for the effects of small magnetic fields induced by spacecraft components.

This is just one early example of the impact created by the new magnetic field calibration facility, which will benefit not only the space industry, but all industries that require magnetic sensor calibration at a greater accuracy and over a more extended temperature range.



Courtesy of ESA

## Under pressure: sensors for new engines

Kistler Instrumente AG, a leading Swiss manufacturer of dynamic pressure sensors, was one of the first users of a new calibration facility, which tested the performance of its pressure sensors under dynamically-changing pressure conditions. Kistler supplies sensors, electronics and software to a wide range of industries and is proposing to use the new facility, validated as part of the EMRP project Traceable dynamic measurement of mechanical quantities, in the development of new prototype sensors. These sensors must perform effectively under extreme conditions, and contribute to engine development aiming to reduce emissions and enhance efficiency and power.

The shock tube facility provides companies with more realistic and traceable measurements, as existing static calibration conditions differ from those experienced in service and can introduce measurement errors. This method to assure the performance of sensors in dynamically-changing pressure extremes has applications in the European automotive, aerospace and defence industries, where improved sensor validation contributes to competitiveness.

## Measuring dynamic torque

HBM, an international supplier of sensors and measurement instruments, was one of the first users of the dynamic amplifier analyses developed by the EMRP project Traceable dynamic measurement of mechanical quantities.

As a result of dynamic testing, HBM was able to upgrade its amplifier, improving signal analysis and creating a product with improved transfer function over the wide range of frequencies needed for dynamic measurements. This has been launched as the new HBM QuantumX MX410B conditioning amplifier.

Improvements in dynamic torque measurements based on the new device and calibration approach developed in the project will assist in designing and optimising next-generation dynamic torque transducers and conditioning electronics. This will help manufacturers of many types of engine and motor better understand where power is lost in the transmission system and enable the identification of design improvements to enhance performance and energy efficiency.

## Supporting high-quality consumer optics

Mahr GmbH, a leading metrology instrument manufacturer, has developed a new Tilted-Wave Interferometer, which is capable of measuring the free-form lenses used in high-quality consumer optics, such as cameras and DVD players, faster and with greater accuracy than previously possible.

Mahr tested a prototype device as part of the EMRP project Optical and tactile metrology for absolute form characterisation, and used the knowledge gained to upgrade the instrument's mechanical and electronic components, increasing the accuracy of its measurements. Algorithms used to process the data were also improved within the project, leading to more accurate results.

The ability to offer its customers a faster, cheaper and more accurate way of characterising free-form lenses means the new instrument will give Mahr a commercial edge in an increasingly-demanding and rapidly-growing market. Manufacturers purchasing the instrument will benefit from greater control during production processes, increasing confidence in the quality of their products and the capability to develop higher-quality, more innovative products.

## Supporting the Belgian diamond industry

SMD-ENS of Belgium's FPS Economy and instrumentation company AC Optomechanix have developed a new scanning contactless measurement head for the Zeiss F25 micro co-ordinate measurement machine to significantly improve the accuracy with which diamonds can be measured.

SMD-ENS and AC Optomechanix used the improved measurement strategies developed in the EMRP project Optical and tactile metrology for absolute form characterisation to optimise their measurement head during the design stage. The improved head, which will be operational within the next year, now achieves measurement uncertainties below the level needed by the Belgian diamond industry to guarantee the quality and value of its products.

The results of the project will lead to more accurately calibrated commercial instrumentation, which in turn will enable diamond facets to be measured more accurately, leading to a better distinction between the various diamond grades. By encouraging trade through increased consumer confidence, the infrastructure provided supports the continued success of an industry at the heart of the Belgian economy.

## New standards for nano-testing

Friction and wear in industrial processes waste energy and degrade materials. Durable engineered surfaces that reduce friction and wear, based on nanoscale surface coatings, can be used to develop high-performance products and improve process efficiency in transport, energy generation, manufacturing and mineral extraction.

The EMRP project Metrology to assess the durability and function of engineered surfaces developed best measurement practice in testing nano-material coatings, improving the accuracy of low-level friction and wear measurements on engineered surfaces.

The best practice guidance has contributed to a new ISO standard for testing diamond-like carbon films and a new standard being developed by the ISO Technical Committee on Nanotechnologies to support the wider adoption of this technique. Having these new standardised measurements in place will support the development of improved products, with longer lifetimes and greater efficiency, across many industrial sectors.

## Temperature and friction testing

The EMRP project Metrology to assess the durability and function of engineered surfaces has developed a new technique to improve the reliability of friction measurements for industrial components. By incorporating a temperature-sensitive ruby tip into existing friction probes, it is now possible to measure friction and temperature with a single probe. This overcomes a significant industrial problem, in which high temperatures at the point of contact during testing were compromising the measurements of the material response.

The new probe provides accurate temperature measurements, which can be offset when calculating the effects of friction, leading to a much better understanding of how engineered surfaces respond to friction. The probe is being patented and two manufacturers are now looking to incorporate it into their instruments. The improved measurements will help manufacturers in a range of industries – from automotive to mining – develop more durable products.

## Driving nano-precision positioning

TETRA, a developer of systems and components for sensors, robotics and automation, has developed a novel optical sensor for linear drives.

TETRA was commissioned by the EMRP project Metrology to assess the durability and function of engineered surfaces to develop a new optical sensor – the critical component in a linear positioning drive. TETRA's sensor meets the project's exacting requirements and is both compact and capable of positioning with nanometre precision.

The new sensor has wider application than the project and TETRA is incorporating this improved optical sensor into its highly-precise positioning systems giving them a market-leading capability. Increased precision in the operation of linear drives will improve positioning accuracy in many fields, from the precise location of surgical tools used in eye-surgery, to microscope stages, to the positioning of micro-components during manufacture in the aerospace and automotive industries.

## 3D surface wear imaging

Alicona Imaging GmbH has validated its MeX 3D measurement software, which turns highly-accurate 2D images from scanning electron microscopes (SEMs) into 3D visualisations of surface features.

The EMRP project Metrology to assess the durability and function of engineered surfaces made extensive measurements of surfaces before and after wear. Simulations of SEM images of typical wear features from a range of angles were then used to develop a highly-accurate model. Alicona was able to use these accurate and validated images to make comparisons with its own MeX 3D visualisation software, confirming the software's accuracy and providing independent validation.

This technology has applications in a wide range of surface engineering industries. One key application is helping manufacturers of machine tools better understand surface wear and so develop more durable products, which will offer substantial time and cost savings to engineering companies.

## Faster vacuums for faster production

INFICON, a manufacturer of world-class instruments for gas analysis, used a new vacuum gauge calibration facility to accelerate the development of its new fast-response gauge.

The facility, developed by the EMRP project Vacuum metrology for production environments, is capable of providing a well-defined rapid change in pressure, from 100 kPa down to 100 Pa in just 23 milliseconds. This enabled INFICON to demonstrate that its new Stripe™ High-speed Capacitance Diaphragm Gauge has a response time twenty times faster than the previous model and validates INFICON's claim that it is the 'fastest gauge in the world'.

Vacuum chambers are an important tool during manufacture of high-tech and high-value products such as semiconductors, photovoltaics and LED lighting. Fast, accurate measurements of vacuum play an important role in process control as product quality, process efficiency and productivity all depend on how quickly and consistently a vacuum can be applied. Improved vacuum measurements will assist Europe's precision manufacturing industries to develop more cost-effective products and processes.

## Ultra-sensitive temperature sensors

Three instrumentation manufacturers have obtained commercial benefits from a new prototype device for ambient temperature measurements developed by the EMRP project Thermal design and time-dependent dimensional drift behaviour of sensors, materials and structures.

Project collaborator MPro is commercialising the prototype to take better temperature control to a wider range of instrument manufacturers. This will lead to improved accuracy throughout high-precision manufacturing, seen as critical by these industries as they develop ever smaller and more complex parts.

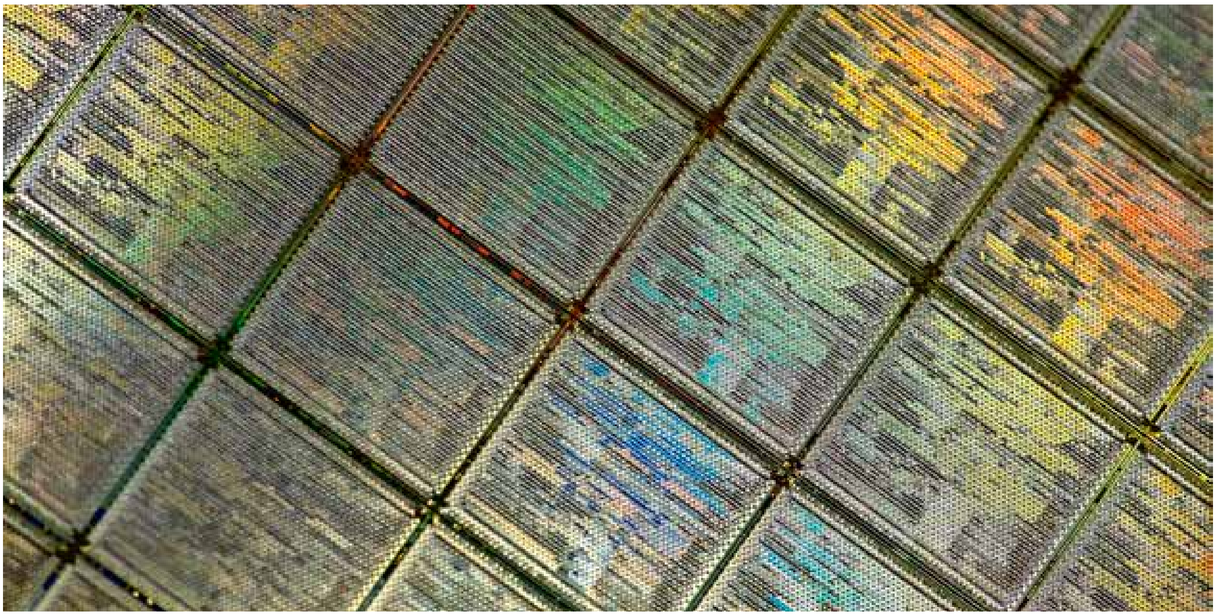
SIOS Messtechnik has been able to use the prototype to investigate how its precision dimension measurement instruments are affected by small changes in temperature in industrial environments. This has enabled it to develop calculations to offset these effects, providing greater accuracy to its customers.

An additional industry impact has been that Magnicon, which supplied a low-noise amplifier for the prototype, has used the project findings to identify a new line of business in temperature measurements.

## Non-destructive surface measurements

Bruker Nano Analytics makes energy dispersive X-ray spectroscopy (EDS) instruments for non-destructive measurement of surface structure. It is one of several manufacturers that have improved instrument accuracy and confidence through involvement in the EMRP project Traceable quantitative surface chemical analysis for industrial applications.

The project developed new SI-traceable certified reference materials (CRMs) with carefully created and certified surface chemistries. Using the new CRMs, Bruker identified stability improvements for its EDS instruments, which led to the development of a new, more accurate instrument. Access to CRMs are proving a valuable selling point for new and existing systems, helping Bruker maintain market share. This in turn is delivering higher levels of accuracy to the innovative products and processes produced by Bruker's customers, which include new catalysts for car exhaust cleaning and coatings to make faster and more durable microelectronics.



## Measuring organic layers

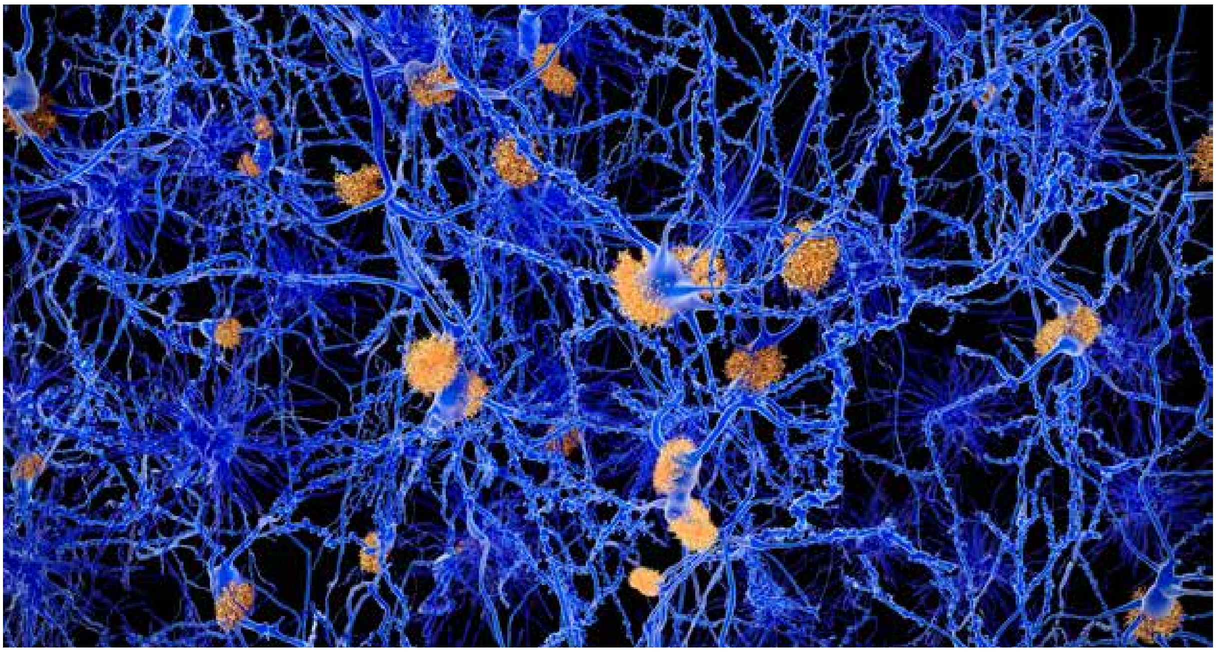
Kratos Analytical Ltd, which makes state-of-the-art spectrometers for material research, has proved the viability of a new measurement technique for layered organic surfaces using reference standards developed in the EMRP project Traceable quantitative surface chemical analysis for industrial applications. This technique is now helping sectors such as electronics and pharmaceuticals produce new, innovative products.

The project developed organic reference materials which validate and improve the accuracy of X-ray photoelectron spectroscopy (XPS), a technique being used by Kratos's customers to measure layered organic surfaces by removing and measuring one layer at a time. With accurate calibration, Kratos can now be confident in the use of XPS for surface chemistry research and product quality assurance. As a result, this technique is now being used to improve the surface chemistry of innovative multi-layer organic products used for solar cells, touchscreens and slow-release drug administration.

## Surface analysis for Alzheimer’s

SP Technical Research Institute of Sweden has used traceable time-of-flight secondary ion mass spectrometry (ToF-SIMS) to help investigate the causes of Alzheimer’s disease.

SP used a new technique, developed by the EMRP project Traceable quantitative surface chemical analysis for industrial applications, to identify plaques and tangles typical in the brains of patients with Alzheimer’s disease. The new technique is the first to enable traceable quantitative analysis with ToF-SIMS, allowing researchers to study the characteristic features of Alzheimer’s disease with greater confidence. This new technique will ultimately support further research into the causes of Alzheimer’s and other diseases.



## Semiconductor measurements

The Advanced Mask Technology Center (AMTC), a joint venture of GLOBALFOUNDRIES and Toppan Photomask, is developing photomasks used in the production of semiconductor devices. It is using calibration methods developed in the EMRP project Metrology of small structures for the manufacturing of electronic and optical devices to help measure the very small features on next-generation photomasks.

AMTC can now make traceable measurements with its scatterometry instruments. This has helped it to verify advanced photomasks with smaller features, below 80 nm, which will be used by AMTC’s parent company GLOBALFOUNDRIES to develop 14 nm and 7 nm technology.

The project results allow companies like AMTC to calibrate metrology tools based on scatterometry to improve production processes and develop more precise technologies. This supports the semiconductor industry in its mission to create ever smaller and faster products, fostering greater innovation and international competitiveness.

## Modelling small surface features

JCMwave, which produces finite element analysis (FEA) software for nano-optic design, has validated a new application of its software, for analysing the dimensions of small electronic features measured using scatterometry.

Through the EMRP project Metrology of small structures for the manufacturing of electronic and optical devices, FEA was investigated and demonstrated to be a viable technique for processing scatterometric data to provide accurate, rapid measurements of surface feature dimensions. This removes a barrier to the uptake of scatterometry and provides the electronics industry with fast, accurate surface dimension measurements in a production environment, speeding the development of smaller electronics.

# Further information

**More detailed information on the EMRP projects' outputs and the contact details for each project can be found at:**

www.euramet.org/emrp-industry-environment-2010

**Other projects in the EMRP Industry theme can be found at:**

www.euramet.org/research-innovation/emrp/emrp-calls-and-projects/emrp-call-2012-industry-si-broader-scope-open-excellence/

**Other projects in the EMPIR Industry theme can be found at:**

www.euramet.org/research-innovation/empir/empir-calls-and-projects/empir-call-2014/

# Europe's National Measurement Institutes working together

**The majority of European countries have a National Metrology Institute (NMI) that ensures national measurement standards are consistent and comparable to international standards. They also investigate new and improved ways to measure, in response to the changing demands.**

While traditional metrology stakeholders in manufacturing demand ever-increasing scope and greater accuracy, there is also a greater demand for accurate measurement in areas which support food safety, clinical medicine and environmental quality, as well as emerging areas such as biotechnology and nanotechnology. This requires resources beyond the scope of most national metrology systems and therefore it makes sense for NMIs to significantly increase the level of collaboration with each other. **The European Association of National Metrology Institutes (EURAMET)** is the body that coordinates collaborative activities in Europe.

EURAMET has implemented the European Metrology Research Programme (EMRP), a project programme organised by 23 NMIs and supported by the European Union, with a value of over €400M. The EMRP facilitates the formation of joint research projects between different NMIs and other organisations, including businesses, industry and universities.

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