DFM
Danish National Metrology Institute

ANNUAL REPORT
2014

METROLOGY: THE SCIENCE OF MEASUREMENT

Metrology is the science of measurements and is the backbone of our high-tech society. Most aspects of daily life are influenced by metrology, and increasingly accurate and reliable measurements are essential to drive innovation and economic growth in our society.

DFM PROFILE

DFM is appointed as the Danish National Metrology Institute and contributes to the integrity, efficiency and impartiality of the world metrology system. DFM is also responsible for coordinating the Danish metrology infrastructure. DFM is owned 100 % by DTU.

DFM ACTIVITIES

DFM's scientific research results in new knowledge, measurement techniques and standards, which support the needs of Danish industry and authorities for accurate measurements.

The services offered are high-level calibrations and reference materials traceable to national primary or reference standards, training courses related to metrology and consultancy services.

DFM has a special role in developing measurement capabilities needed by small and medium sized high-tech companies in order for them to evolve and prosper.

DFM works to ensure global confidence in Danish metrological services, which are critical for competing in the global market place.

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MANAGEMENT REPORT 2014

Michael Kjær, CEO and Steen Konradsen, Chairman of the Board.

2014 was a positive year for DFM with strong sales growth, increased metrology research activity and significant progress on several research areas, establishing a strong foundation for introduction of a growing number of metrology services in the coming years. The laboratory facilities were also increased to support the development. The total revenue increased 8 % to 27.3 million DKK, while the profit increased 41 % to 0.7 million DKK. The management is pleased with DFM's development, and considers the increase in both revenue and profit for the year as satisfactory.

Sales of commercial products and services grew by 22 % driven by sales of new services within photonics and nano-metrology. The revenue from participation in externally funded projects increased 13 % to 8.7 million DKK – the highest level in DFM's history.

The growth in commercial revenue and project revenue in 2014 highlights the growing need for state-of-the-art metrology services and competences within Danish industry. DFM is dedicated to meeting these metrological needs in order to create value for industry and society. In 2014 new research activities within quantitative analysis of substances were initiated in close collaboration with Danish pharmaceutical companies and other National Metrology Institutes.

The dedication and talent of our employees collaborating closely with industry, R&D institutions and other National Metrology Institutes is the foundation of our success and DFM is pleased that it has been possible to increase the number of employees again in 2014 as well as the number of peer reviewed publications.

2014 also marks the first year of the joint European Metrology Programme, EMPIR. DFM strongly supports the EMPIR goals of creating a more unified European Metrology Research structure facilitating closer integration of National Research Programmes, reducing duplication of activities, ensuring critical mass in research activities and boosting industrial uptake and support to standardization bodies. DFM is looking forward to contributing to these goals together with the six Danish Designated Institutes.

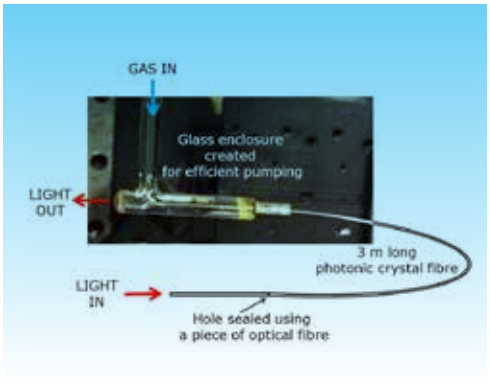
The management is expecting the current trend to continue in 2015 with a further increase in both research activities and the rate of introduction of new products and services. Concurrently it will be a goal to also increase participation in Danish – and international networks ensuring that DFM's new competences and services are used widely and create significant value in the target market segments.

Steen Konradsen
Chairman of the Board

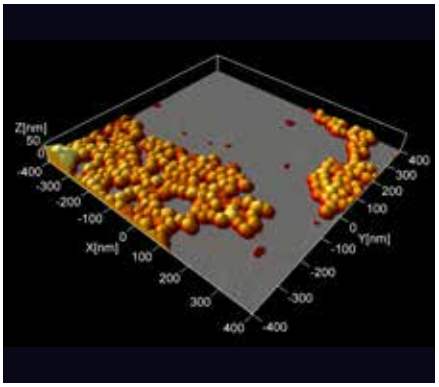
Michael Kjær
CEO

ESTABLISHING RAMAN SPECTROSCOPY AS A NEW METROLOGY AREA AT DFM

Raman spectroscopy is applied widely in the pharmaceutical industry for inspection and identification of chemicals



The application of hollow core photonic crystal fibres in Raman spectroscopy of liquids and gases builds on DFM's extensive experience with the fibre technology



Nanoparticle concentration and surface properties will be measured using advanced Raman spectroscopy techniques developed by DFM as part of the EMPIR Innanopart project

Raman spectroscopy is a technique for chemical identification and quantification that is growing in popularity, resulting in the emergence of a diverse group of university groups, instrument manufacturers and industrial users who are seeking to fulfil the technique's potential to make non-invasive and detailed spectroscopic measurements.

The application of Raman spectroscopy has been demonstrated in important industrial areas within Denmark, such as the Pharmaceutical industry, which use the technique for quality control purposes and qualitative measurement of the active ingredients. However, quantitative and reliable Raman spectroscopy measurements of pharmaceuticals are affected by problems of measurement reproducibility and sensitivity.

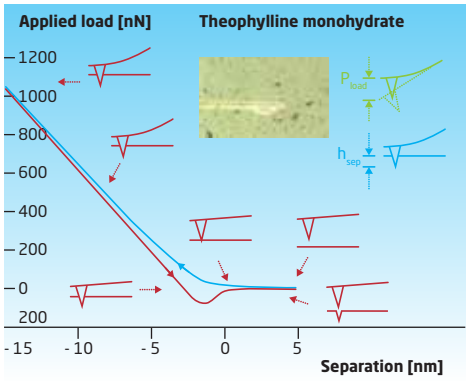
DFM is addressing these challenges and supports the development of this technique by establishing in-house research and metrology services. The aim is to establish a unique metrology service over the next decade. The development was initiated after an investigation of immediate measurement needs in Danish industry. The initiative is advised by a following group of experts who use Raman spectroscopy in their daily work.

The foundation of DFM's Raman spectroscopy research is the application of hollow core photonic crystal fibres, which offer a unique capability to constrain laser light and a liquid or gas sample within a large interaction volume, thereby increasing the sensitivity of Raman spectroscopy measurements. DFM has successfully built and applied Raman spectroscopy systems of hydrogen gas and glucose solutions.

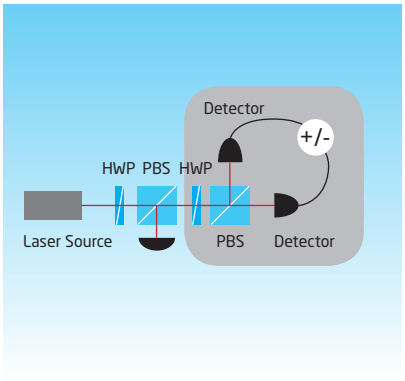
The incorporation of DFM's Raman activities within the broader framework of the European Metrology network was initiated by visits to the National Metrology Institutes PTB (Germany), NPL (UK) and NIST (USA). DFM is partner in an EMPIR project (Innanopart) that will make advanced measurements of nanoparticles. DFM will apply Raman spectroscopy to measure nanoparticle concentration and characterise nanoparticle surface properties.

DFM is installing and developing new Raman spectroscopy facilities to be used in research to improve the sensitivity of the technique. In addition, reference samples and optical probes for Raman spectroscopy of powder and tablet samples will be investigated, in response to the recommendations suggestions made by DFM's following group.

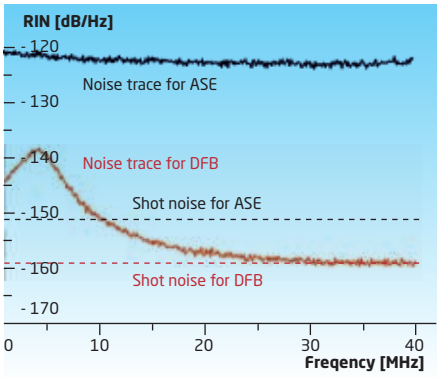
DFM SUPPORTS DANISH INDUSTRY



Plot of the force applied during a nanoindentation into a theophylline crystal approximately 100 µm wide. The elasticity and plasticity can be calculated from the force-curve.



A typical setup for measuring laser intensity noise at the shot noise limit. The laser output is attenuated (first HWP in combination with PBS), and focused onto the photodiode.



RIN measurements for two lasers. A distributed feedback laser (DFB) and Amplified spontaneous emission (ASE).

Scratching the surface

Diagnostics and cell culture are important areas for the large Danish pharmaceutical industry. Inmold A/S, is an SME specialising in protein-coated micro-channel systems for diagnostics and cell capture applications. DFM has assisted Inmold A/S in characterising their particular surface treatments, providing important hardness data on the coated surfaces.

DFM's new and specialized service to provide hardness data for a surface utilizes the diamond tip of an atomic force microscope (AFM) to make nano-indentations in the sample probing only the surface, which may have distinctly different properties than the underlying bulk material.

DFM's hardness service can also contribute to better predict flow parameters during tablet production for a granulate of the active pharmaceutical ingredient. This is important in an early stage of drug development where only small amounts of the ingredient are available. In the figure an indentation force curve is shown for the asthma drug theophylline from which the elasticity and hardness are calculated. Theophylline typically forms crystals much smaller than a millimetre and has mechanical properties similar to many other active pharmaceutical ingredients. The measurement thus shows the potential of the new service offered. From another branch Image Metrology is an SME developing and selling a software packages for nano- and microscale image processing. On a scientific level Image Metrology interacts with DFM on the hardness measurement methods where they see a potential for commercialization.

Providing traceability to laser RIN measurements

Relative Intensity Noise (RIN) provides a means of evaluating the power stability of a laser, regardless of the laser power

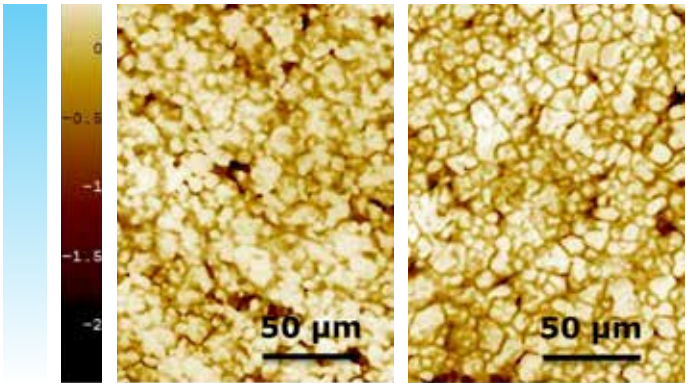
For lasers aimed at high-precision applications, stability of the laser power is a prime parameter, which in e.g. LIDAR or optical communications may turn out to be a limiting factor. Danish laser manufacturer NKT Photonics has specialised in stable lasers aimed at scientific, sensing and other applications, where power stability is a key parameter.

The output of an uncontrolled laser fluctuates slightly, and fluctuations scale with the power.

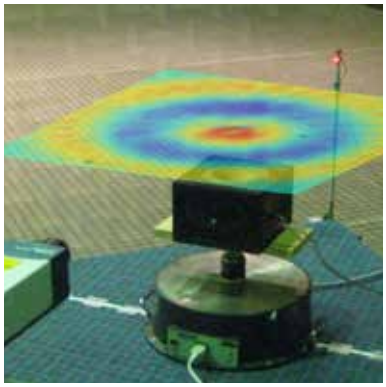
Relative intensity noise can originate from intrinsic variations in the laser: cavity vibration, fluctuations in the laser gain medium or simply from transferred intensity noise from a pump source. Since intensity noise typically is proportional to the intensity, the relative intensity noise is typically independent of laser power. Hence, when the signal to noise ratio (SNR) in a given application is limited by RIN, it does not depend on laser power.

In order to perform accurate RIN measurements, accurate power measurements are a required and the optical power standard of DFM was applied to provide traceability to the calibration of NKT Photonics' lasers, using a calibrated detector.

DFM is committed to support industry and institutions in performing challenging measurements. The following examples illustrate where DFM has contributed to everyday challenges of Danish industry.



Replication of a cold-rolled steel surface using a fast curing polymer. Confocal imaging with 50x magnification of the master (left) and the replicated surface (right). For direct comparison the replica image has been inverted.



Acousto-optic reconstruction of sound waves radiated by a loudspeaker

Investigating obscured surfaces using advanced replication techniques

Surface roughness is an important parameter in industrial design, especially in the nanometer range. However, most conventional surface characterization instruments are unable to measure 'hidden' areas such as the inside of a cylinder or at the bottom of trenches. DFM has therefore developed a method for fabricating replicas with an uncertainty of only 0.2 %.

The replica technique has been used at several Danish companies for measuring surfaces, where measurements would not be possible by conventional methods. In a project initiated by the national innovation network PlastNet, DFM has tested the technique on location at Danish companies. H. Lundbeck A/S was investigating flow behavior of powders in funnels for drug product manufacturing, aiming to improve the characterization of the inside of the funnels. With the replica technique, DFM was able to measure the surface roughness in the nanometer range.

The replica technique uses a polymer to create an exact replica of the surface topology. Depending on the polymer, the curing time ranges from one minute to several days. The curing process can be speeded up by increasing the temperature, but this induces shrinkage of the polymer. DFM has therefore performed a detailed study of the soft polymer polydimethylsiloxane (PDMS) and its shrinkage during curing, thus reducing the uncertainty from around 2 % to < 0.2 %.

Look and listen: Seeing the sound using acousto-optics

Until recently the measurement of sound fields has been an invasive measurement, as microphones placed in the sound field would inevitably disturb the propagation of the acoustic waves and thus influence these. A new method developed at DFM in cooperation with DTU Elektro has enabled non-invasive measurement of sound by means of a laser, and the method has been applied in measurements on loudspeaker units for Dynaudio and PointSource Acoustics and for measurements of impulse noise produced by a spark source for DPA microphones.

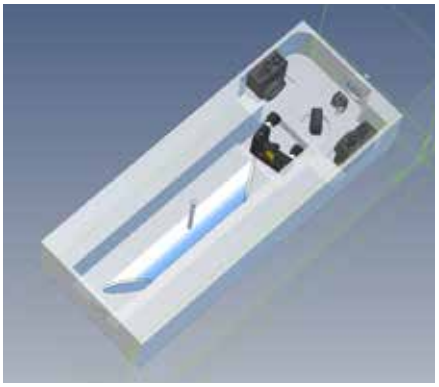
The acousto-optic method produces a visual representation of sound field measurements in two or three dimensions as required, and is based upon laser-based measurements of the refractive index changes in air caused by the pressure variations that characterize the sound field. A sound pressure of 1 Pa incurs a local change in the refractive index of air of approx. $2x10^{-9}$, thus altering the propagation of the light. Detection of the resulting minute phase changes in the light yields information on the sound field, which after mathematical transformation can be represented in an intuitive graphical reconstruction.

DFM's technology is versatile, featuring an extremely high temporal resolution in DPA's impulsive measurements or providing new insights into the radiation of sound in PointSource Acoustic's loudspeaker designs.

FREQUENCY STABILISATION OF LASERS

A computer rendition of the assembled box for the ESA laser project. The green lines are fibres and the hollow core fiber is spooled on the copper mounts in the center.

A rough model of the design for the JPx150. The glass cell with the angled windows contains the acetylene molecules and light is provided through the fiber input on the outside of the box.



Monolithic Assembly

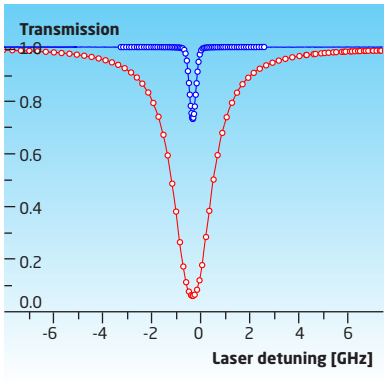
Lasers are indispensable tools in modern life. Usually there is no need for accurate control of the laser frequency. However, for a few applications it is imperative to reduce the frequency fluctuations by stabilisation of the laser to a stable frequency reference. These applications include length and frequency metrology, high bandwidth data transfer, and interferometric sensing.

DFM's activities in length metrology have resulted in strong competencies in stabilising laser frequencies to molecular references. For the past two years, DFM has coordinated a laser project for the European Space Agency (ESA) in collaboration with the Niels Bohr Institute at Copenhagen University and Danish fibre producer NKT Photonics, who specialises in hollow-core fibres. The project aims at constructing a compact, fibre-based laser system stabilised to a CO_2 absorption line at 2.05 µm. The CO_2 molecules are captured inside the tiny hollow core (10 µm diameter) of the optical fibre, while light from the laser is sent through the fibre to stabilise the laser frequency onto the molecular transition. Such a compact stabilised laser could eventually be used on a satellite in space for measurements of the CO_2 content of the Earth's atmosphere. The high degree of frequency stabilisation translates directly into more accurate measurements of the CO_2 content. The work for ESA builds directly on the competencies developed in the EMRP project New generation of frequency standards for industry, which ended in 2014.

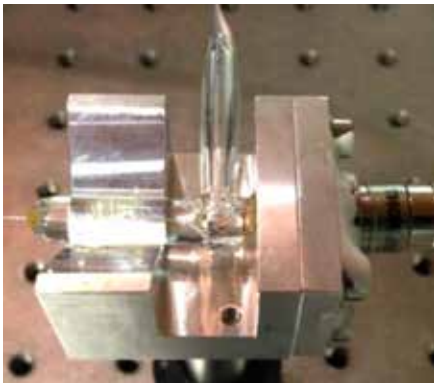
Another collaboration with NKT Photonics aims at constructing an extremely stable fibre laser – the JPx150. Here, instead of a fibre, a glass cell is used to contain acetylene molecules; increasing the performance significantly at the expense of a slightly more bulky design. The setup takes advantage of NKT's recent progress in producing fibre lasers with state-of-the-art short term stability. By using the molecular transition, DFM is able to improve the accuracy and long term stability thereby creating a laser product with relative accuracy and stability better than 10^{-12}, surpassing the performance of current commercially available references. One such laser was ordered by Aarhus University in 2014 with delivery in 2015.

Danish companies are not the only ones to recognize DFM's unique competencies. In 2014 DFM was approached by the Norwegian company Kongsberg, who had won a contract on developing a frequency stabilised laser to be used as calibration reference for satellite-based optical equipment. DFM entered a contract with Kongsberg under which DFM has developed methods for characterisation of the frequency stabilised laser and tested certain aspects of the laser design. The collaboration with Kongsberg is anticipated to continue in 2015.

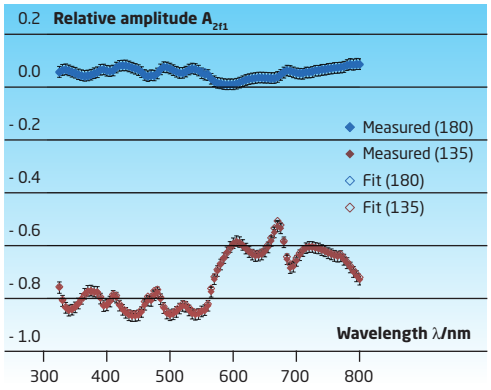
LAUNCH OF THE EUROPEAN METROLOGY PROGRAMME FOR INNOVATION AND RESEARCH – EMPIR



EMRP project EUMETRISPEC: Measurements and fits of a CO_2 absorption line at 2.0 µm used to determine the line strength with an uncertainty below 1 %.



EMRP project FREQUENCY: Compact alignment-free coupling from a conventional single mode fibre to a sealed gas-filled hollow-core fibre.



EMRP project SCATTEROMETRY: Two of sixteen signal components measured optically by spectroscopic Mueller polarimetry. The extracted parameters for the silicon grating were the width w = (268.2 ± 1,0) nm, height h = (307.0 ± 1.0) nm and period p = (498.7 ± 1.2) nm.

On the 6th of May 2014, the Council of the European Union adopted the legal acts for the EMPIR to be carried out under the EU's research and innovation framework programme, Horizon 2020. The programme runs for 10 years with a budget of 600 million EUR and 28 participant countries. The EMPIR is equally financed by the European Union and the participating countries.

The major part of the Danish financial contribution to the EMPIR is provided by the Danish Agency for Science, Technology and Innovation.

The Agency decided to subcontract programme administration to DFM, and this has been accomplished via a performance contract signed in December, 2014.

As the National Metrology Institute of Denmark, DFM is already responsible for coordinating the Danish EMPIR participation and representing Denmark in the EMPIR committee. It is expected that the administration of the national co-financing will be more efficient when all activities are assigned to a single entity. The performance contract runs for the full EMPIR period and has a value of 21 million DKK, which covers co-financing of the research projects, the Danish contribution to EURAMET's administrative costs, as well as costs related to administration of the contract. Only the members of DANIAmet-MI can obtain national co-funding via the performance contract.

About 70 % of the EU funding of EMPIR projects is allocated to the National Metrology Institutes and the Designated Institutes, which in Denmark corresponds to the seven members of DANIAmet-MI. The remaining 30 % of the EU funding is reserved for external project participants from industry and universities.

The first EMPIR call was launched in 2014 under the theme of metrology for industry with Danish participation in 11 applications (named Joint Research Proposals).

The average success rate in the 2014 EMPIR call was 46.7 %, and the DANIAmet-MI members achieved a success rate slightly above that. Five of the applications with Danish participation have been selected for funding and contract negotiations are now ongoing. DFM will participate in three of these EMPIR projects. The projects are scheduled to start in the summer of 2015.

METROLOGY TO SUPPORT NANOSTRUCTURES ON INJECTION MOULDED PLASTIC

Plastic brick with a colour effect to be measured in a high-resolution scanning probe microscope

Advanced light microscope developed at DFM for quality control on the floor of the factory.

NanoPlast was a project co-funded by the Advanced Technology Foundation from 2010 to 14. It was coordinated by DTU Nanotech and had 10 participants. 1 nanometre is a 0.000 001 millimeter

By focusing on new functionality of the surface Danish plastic industry can increase competitiveness.

Injection moulding is the most commonly used manufacturing process for producing plastic parts and works by injecting melted material into a mould. The Danish plastic industry employs more than 20,000 people scattered in many small companies and 70 % of the turnover is due to export. The purpose of NanoPlast was to superimpose a nanometre scale pattern into the plastic surface during the injection moulding process. Such nanometre scale surface patterns can create functionalities such as colour effects or a hydrophobic surface which is very difficult to wet. Promising future products include cheap colour decoration and self-cleaning surfaces.

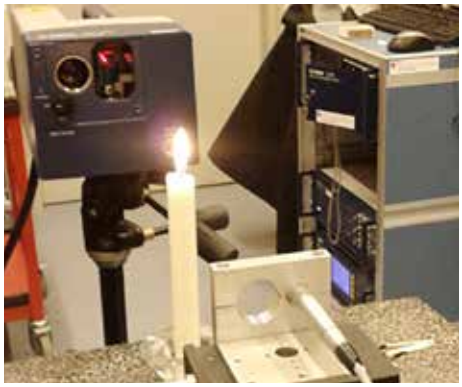
DFM's contribution to NanoPlast was to develop services for characterizing the nanopatterns on the surface of the moulds and the duplicated nanopatterns on the plastic parts. The developed services include accurate measurement of the surface roughness and the height of the nanopatterns. The quality of the injection moulding process was evaluated and deemed acceptable based on a comparison of the nanopattern of the mould and the nanopattern on the final plastic part.

Furthermore DFM developed, assembled and tested a new advanced microscope. This microscope was dedicated to inspect the plastic parts in the factory right after the production. This microscope consists of a light microscope and a so called "spectrometer" which measures the intensity of the reflected light as a function of the wavelength. Measurements can be performed in a fraction of a second with a resolution in the nanometre range. Finally the performance of the developed microscope was tested in the factory at one of the partners – see the figure.

A particular challenge was to measure the nanopatterns superimposed on the inside of a container. To do this DFM refined the accuracy of the so called "replication method". In the replication method a thin polymer film is applied onto the nanostructured surface. The hardened film is then removed for examination later. The film with a duplicate of the nanopattern was later thoroughly measured using DFM's standard instruments such as atomic force microscopy and confocal microscopy.

The services developed at DFM will be offered to a wide range of companies to improve commercialization of future products. In particular the project confirmed that it is important to be able to measure the quality of the final plastic during the production process. NanoPlast and the developed services have formed the background for an industrial PhD project concerning further surface characterization of nanostructures. The competence in replication has also been used in other tasks, see page 13 for a case.

EUROSTARS



Firedetect aims at detecting fire at an early stage by sensing minute temperature changes with a laser beam

Group photo from the kick-off meeting of the InFoScat project. The partners are ELDIM (Fr), Image Metrology (DK) and DFM (DK).

EUROSTARS is a joint programme between EUREKA – an intergovernmental European organisation with 40+ countries – and the European Commission. EUROSTARS supports the research efforts in European SMEs by facilitating cooperation with research and technology centres and other companies.

DFM was partner in three EUROSTARS project applications in 2014. All three were selected for funding – a very successful result, as only 11 projects with Danish partners were funded in total. The three projects cover several DFM competences and represent a total of four person-years of research effort and a total co-funding of 3.7 million DKK.

The three projects are:

FIREDETECT – "Advanced laser-based heat sensor for fire detection"

The aim of the project is to develop an innovative fire detection system based on advanced laser technology capable of identifying small temperature rises, providing an early and reliable detection of fire. The technology has advantages in dusty areas, where current systems show limited performance.

The other members of the consortium are Elotec A/S (coordinator, Norwegian), Dansk Brand- og sikringsteknisk Institut (DBI) (Danish)), and LAP Sikkerhed A/S (Danish).

DFM will provide know-how on a novel laser-based technology and develop a robust measurement technique, forming the basis for a final product complying with all the necessary fire safety requirements.

INFOSCAT – "Industrial Fourier Scatterometer"

InFoScat will develop an instrument for in-line characterization of micro/nano-textured surfaces and emissive displays (e.g. flat screens and computer monitors). Using a unique optical system, the scattered light from a surface is measured and used to characterize the surface texture. The technique is very robust, and can be used to estimate dimensional parametres of the texture with an uncertainty of a few nanometres directly in a production environment. The other members of the consortium are ELDIM S.A. (coordinator, French) and Image Metrology A/S (Danish). DFM will contribute by providing algorithms to a software package for the scatterometer and by validating the developed hardware.

NxPAS – "A novel non-invasive trace gas analyser platform targeting breath analysis"

The primary objective of NxPAS is to develop, test and demonstrate a novel non-invasive photoacoustic (PA) trace gas analyser platform for medical diagnostics based on breath analysis. The device will be capable of detecting early stages of disease – almost instantly – by providing data that allow diagnosis of e.g. various cancer types and metabolism failures in special patient groups. The other members of the consortium are COPAC ApS (coordinator, Danish), Laserspec BVBA (Belgic), Université de Liège (Belgic) . DFM will contribute with extensive knowledge in delivering quantitative PA measurements – a critical feature for disease screening.

DFM SUPPORTS DANISH PHARMA INTERESTS

DFM participated in the ISO/TC24/SC4 meeting in Beijing, April 2014

Pharmaceutical production lines located in clean rooms must be continuously monitored for unwanted contaminants that can enter the product and thereby ultimately endanger the patient's health. In a clean room, the main sources for contamination are airborne particles. Often these are chemicals from different processes in the same clean room plant, or viable microorganisms such as bacteria.

In order to provide harmonised requirements for the monitoring process, there are several internationally recognized documents, so called standards, which contain detailed requirements.

Next to regionally localized versions from, for example, the Japanese Standards Association, the standards ISO 14644 and ISO 21501 are globally applied when monitoring particulate airborne material in clean rooms.

With the ongoing research related to particle metrology and user requirements, it is necessary to continuously update those standards.

Changes are being proposed and discussed in international working groups, and revised standards are submitted for ballot among national standardization bodies. As countries have different interests in the outcome of this process, it is essential to participate actively in the working groups in order to reach an acceptable compromise. Having established a calibration facility for pharmaceutical particle counters used in Danish companies, DFM has gained knowledge in how to achieve metrological traceability and carry out evaluation of measurement uncertainty in the field. As a logical consequence, DFM has engaged in the ISO standardisation work in order to introduce these metrological concepts in future revisions of the relevant standards.

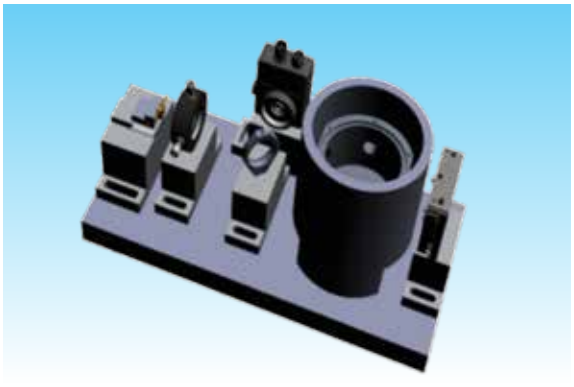
The participation of DFM in the ISO working group related to the standard ISO 21501 has already resulted in amendments to the future version. While still required to be accepted by all nations in the future ballot, the input from DFM has been welcomed by the participants of the working group.

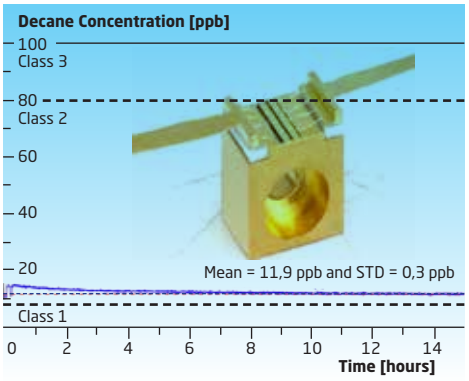
In order to further increase the support for Danish pharmaceutical industries, DFM has also moved the particle counter calibration facility to a new, dedicated laboratory. During the design of the new premises, not only ISO requirements have been adhered to, but also requests from the Danish pharmaceutical industry have been considered in order to allow conformity with the quality management of clean room production lines.

ISO standards

A standard is a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose. Consequently, International Standards help to harmonize technical specifications of products and services making industry more efficient and breaking down barriers to international trade. Conformity to International Standards helps reassure consumers that products are safe, efficient and of a comparable high quality.

DETECTION OF OIL IN COMPRESSED AIR (DOCA)





The figure to the left shows a 3D drawing of the DOCA prototype sensor. It consists of the sensor head (front) and an electronic unit (rear). The middle figure shows the optical parts and the round PA cell with flow buffer zone. The right figure shows Decane ($C_{10}H_{22}$) measurements as function of time with a mean concentration of 11.9 ppb and a standard deviation of 0.3 ppb. The measurements are performed at 3.39 µm with an Interband Cascade Laser (figure insert).

Oil contamination in compressed air systems, even at small concentration levels, can be disastrous and health threatening for a vast variety of industries

The aim of the DOCA project was to solve a major problem regarding the detection of oil contaminants in high purity compressed air systems. The sensor was designed to be a standalone online sensor (see left figure) that will detect oil contaminants in all its forms (liquid, aerosol and vapor) with a sensitivity better than 8 ppb corresponding to a Class 1 sensor according to the ISO 8573 series of standards. Oil is defined according to ISO 8573-1, as all hydrocarbons with 6 or more carbon atoms per molecule. The detection of oil contamination have been attempted before, however until now they have not been satisfactory in terms of accuracy, sensitivity, reproducibility and traceability. The DOCA sensor is based on the photoacoustic (PA) effect. The PA technique builds on the detection of sound waves that are generated by the molecules under investigation, due to absorption of modulated optical radiation. The performance of the DOCA sensor has been validated by dynamic generation of oil in air at amount of substance levels down to those relevant for ISO 8573 Class 1 (8 ppb) and lower concentrations (down to 0.3 ppb). The validation criteria included; time response, linearity, sensitivity to cross-interferences, reproducibility, repeatability, sensitivity and the influence of pressure and temperature. The DOCA sensor successfully passed all these tests making the sensor the first of its kind to fulfill the requirements of ISO-8573 measurement classification. The consortium partners were: DFM (Denmark), CMS, MEDIZINISCHE ANLAGEN UND SYSTEME GMBH (Germany), CASTLE GROUP LIMITED (England), PAJ SENSORS A/S (Denmark) and VSL (Holland).

ACCOUNTS OF PARTICULAR ACTIVITIES

Participation in committees and working groups under the Metre Convention and EURAMET

- EMRP Committee
- Consultative Committee for Amount of Substance (CCQM)
- Consultative Committee for Acoustics, Ultrasound and Vibration (CCAUV)
- EURAMET General Assembly (Eur GA)
- EURAMET Board of Directors (BoD)
- EURAMET Technical Committee for Mass (TC-M)
- EURAMET Technical Committee for Electricity and Magnetism (TC-EM)
- EURAMET Technical Committee for Length (TC-L)
- EURAMET Technical Committee for Photometry and Radiometry (TC-PR)
- EURAMET Technical Committee for Acoustics, Ultrasound and Vibration (TC-AUV)
- EURAMET Technical Committee for Time and Frequency (TC-TF)
- EURAMET Technical Committee for Interdisciplinary Metrology (TC-IM)
- EURAMET Technical Committee for Quality (TC-Q)
- EURAMET Technical Committee for Metrology in Chemistry (TC-MC)
- EURAMET TC-MC Sub Committee for Electrochemical Analysis
- EURAMET TC-EM Sub Committee DC and Quantum Metrology
- BIPM Director's ad hoc Advisory Group on Uncertainty
- Joint Committee on Guides in Metrology – Working Group 1, Guide to the expression of uncertainty in measurement (JCGM-WG1)
- Consultative Committee for Length – Working Group on Dimensional nanometrology (CCL-WGn)
- Consultative Committee for Amount of Substance – Working Group on Electrochemical Analysis (CCQM – EAWG)
- Consultative Committee for Mass and Related Quantities – CCM Working Group on the Realization of the kilogram (CCM-WGR-kg)
- Consultative Committee for Mass and Related Quantities – CCM Working Group on the Dissemination of the kilogram (CCM-WGD-kg)
- Consultative Committee for Acoustics, Ultrasound and Vibration – Working Group for key comparisons (CCAUV – KC)
- Consultative Committee for Ultrasound and Vibration – Working Group for RMO Coordination (CCAUV – RMOWG)
- Consultative Committee for Ultrasound and Vibration – Working Group for Strategic Planning (CCAUV – SPWG)

Participation in national and international projects

- Functional nanostructures on injection molded plastic (NanoPlast), HTF
- Strategic Research Center in Precision and Nano-scale Polymer Mass Replication of Biochips (PolyNano) , DSF
- Metrology of small structures for the manufacturing of electronic and optical devices (Scatterometry), EMRP/FI
- New generation of frequency standards for industry (Frequency), EMRP/FI
- Metrology for a universal ear simulator and the perception of non-audible sound (Ears), EMRP/FI
- Developing a practical means of disseminating the new kilogram (NewKilo), EMRP/FI
- Detection of oil in compressed air (DOCA), EU FP7 SME
- Spectral reference data for atmospheric monitoring (EUMETRISPEC), EMRP/FI
- Quantum sensor technologies and applications (QTEA), EU FP7 ITN
- Proof of concept for fotoakustisk spektroskopi til detektion af gas, FI
- Scanning neutral Helium microscopy (NEMI), EU FP7
- Online detektering af E.koli bakterier i drikkevand, MST
- Crystalline surfaces, self-assembled structures, and nano-origami as length standards in (nano)metrology (Crystal), EMRP/FI
- Shape-engineered TiO2 nanoparticles for metrology of functional properties (SETNanoMetro), EU FP7
- 2D Kalibrering, IF
- Center for LED Metrologi (LEDMET), IF
- Advanced laser-based heat sensor for fire detection (FireDetect), IF/EU H2020
- A novel non-invasive trace gas analyser platform targeting breath analyses (NxPAS), IF/EU H2020
- Industrial Fourier Scatterometer (InFoScat), IF/EU H2020
- Metrology for high-impact greenhouse gases (HIGHGAS), EMRP/FI
- Metrology for ammonia in ambient air (MetNH3), EMRP/FI
- Traceable characterisation of thin-film materials for energy applications (ThinErgy), EMRP/FI
- UV-induceret biofilmforebyggelse (BIOFORS), IF

DFM Reports

- **Marianne Heidam, David Balslev-Clausen, Lars Nielsen** *DFM Annual report 2013,* DFM-2014-R01
- **Kai Dirscherl,** *Undersøgelse af partikler fra olielamper med SEM og EDX.* DFM-2014-R02
- **Poul Erik Hansen,** *Mueller Polarimetry and Scatterometry of advanced structures.* DFM-2014-R03
- **Lars Nielsen,** *Rapport over syn og skøn, BS 2-1146/2009, Irbis Danmark ApS mod Arent Eriksen.* DFM-2014-R04
- **Pia Tønnes Jakobsen,** *DFM Measurement report for CCQM-K99 pH of physiological phosphate buffer.* DFM-2014-R05
- **Morten Hannibal Madsen,** *En verden med nanotråde,* Aktuel Naturvidenskab **1**, 12-14, 2014. DFM-2014-R06
- **Kai Dirscherl,** *Qualitative evaluation of the morphologic equivalence of nanoparticles.* DFM-2014-R07
- **Michael Kjær,** *Faglig rapportering til Forsknings- og Innovationsstyrelsen for 2013.* DFM-2014-R08
- **Mark Pollard,** *Ekoli status rapport – periode 3.* DFM-2014-R09
- **Pia Tønnes Jakobsen,** *DFM Measurement report for CCQM-P153.* DFM-2014-R10
- **Mark Pollard,** *Ekoli status rapport – periode 4.* DFM-2014-R11
- **Hans D. Jensen,** *Description of 'DFM Harned 1.0' – application programme for primary pH measurements.* DFM-2014-R12
- **Carsten Thirstrup,** *Description of 'ControlpHbathTemperature'.* DFM-2014-R13
- **Morten Hannibal Madsen, Nikolaj Agentoft Feidenhans'l, Marianne Lund Madsen,** *Målinger på nanoskala – sådan ser man græsset gro,* Dansk Kemi **95**, 12-15, 2014. DFM-2014-R14

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Publications in refereed journals

- **H. D. Jensen, C. Thirstrup.** *Direct Traceability for Ultra-Pure Water Conductivity.* NCSLI Measure J. Meas. Sci. **9**, 68-72, 2014. DFM-2014-P01
- **R. G. Barham, S. Barrera-Figueroa, J. E. M. Avison.** *Secondary pressure calibration of measurement microphones.* Metrologia **51**, 129-138, 2014. DFM-2014-P02
- **E. Højlund-Nielsen, J. Weirich, J. Nørregaard, J. Garnæs, N. A. Mortensen, A. Kristensen.** *Angle-independent structural colors of silicon.* J. Nanophoton. **8**, 083988, 2014. DFM-2014-P03
- **Lars Nielsen.** *Evaluation of mass measurements in accordance with the GUM.* Metrologia **51**, S183-S190, 2014. DFM-2014-P04
- **M. Lassen, D. Balslev-Clausen, A. Brusch, J. C. Petersen,** *A versatile integrating sphere based photoacoustic sensor for trace gas monitoring.* Optics Express **22**, 11660-11669, 2014. DFM-2014-P05
- **K. Gurzawska, R. Svava, Y. Yihua, K. B. Haugshøj, K. Dirscherl, S. B. Levery, I. Byg, I. Damager, M. W. Nielsen, B. Jørgensen, N. R. Jørgensen, K. Gotfredsen.** *Osteoblastic response to pectin nanocoating on titanium surfaces.* Materials Science and Engineering C **43**, 117-125, 2014. DFM-2014-P06
- **S. Daviðsdóttir, R. Shabadi, A. C. Galca, I. H. Andersen, K. Dirscherl, R. Ambata.** *Investigation of DC magnetron-sputtered TiO2 coatings: Effect of coating thickness, structure, and morphology on photocatalytic activity.* Applied Surface Science **313**, 677-686, 2014. DFM-2014-P07
- **M. J. Webb, C. Polley, K. Dirscherl, G. Burwell, P. Palmgren, Y. Niu, A. Lundstedt, A. A. Zakharov, O. J. Guy, T. Balasubramanian, R. Yakimova, H. Grennberg.** *Effects of a modular two-step ozone-water and annealing process on silicon carbide graphene.* Appl. Phys. Lett. **105**, 081602, 2014. DFM-2014-P08
- **M. Aggerbeck, S. Canulescu, K. Dirscherl, V. E. Johansen, S. Engberg, J. Schou, R. Ambat.** *Appearance of anodised aluminium: Effect of alloy composition and prior surface finish.* Surface & Coatings Technolog **254**, 28-41, 2014. DFM-2014-P09
- **V. C. Gudla, S. Canulescu, R. Shabadi, K.Rechendorff, K. Dirscherl, R. Ambat.** *Structure of anodized Al-Zr sputter deposited coatings and effect on optical appearance.* Applied Surface Science **317**, 1113-1124, 2014. DFM-2014-P10
- **M. H. Madsen, N. A. Feidenhans'l, P.-E. Hansen, J. Garnæs, K. Dirscherl.** *Accounting for PDMS shrinkage when replicating structures.* J. Micromech. Microeng. **24**, 127002, 2014. DFM-2014-P11
- **S. V. Søgaard, T. Pedersen, M. Allesø, J. Garnaes, J. Rantanen.** *Evaluation of ring shear testing as a characterization method for Powder flow in small-scale powder processing equipment.* Int. J. Pharm. **475**, 315-323 (2014) DFM-2014-P12

- **R. S. Frederiksen, E. Alarcon-Llado, M. H. Madsen, K. R. Rostgaard, P. Krogstrup, T. Vosch, J. Nygård, A. F. i Morral, K. L. Martinez.** *Modulation of Fluorescence Signals from Biomolecules along Nanowires Due to Interaction of Light with Oriented Nanostructures.* Nano Lett. **15**, 176-181, 2015. DFM-2014-P13
- **H. Andres, F. Lüönd, J. Schlatter, K. Auderset, A. Jordan-Gerkens, A. Nowak, V. Ebert, E. Buhr, T. Klein, T. Tuch, A. Wiedensohler, A. Mamakos, F. Riccobono, K. Dirscherl, R. Högström, J. Yli-Ojanperä, P. Quincey.** *Measuring soot particles from automotive exhaust emissions* EPJ Web of Conferences **77**, 00020, 2014. DFM-2014-P14

Confidential Reports

- **Philip G. Westergaard, Jan Hald, Jan W. Thomsen, Jens K. Lyngsø.** *ESA TN3: Experimental validation of preliminary conceptual designs and performance models refinement.* DFM-2014-F01
- **Philip G. Westergaard, Jan Hald, Jan W. Thomsen.** *ESA TN4: Concepts trade-off, versatile FRLS baseline design selection and performance model update.* DFM-2014-F02
- **Poul Erik Hansen.** *Biofilm Coating.* DFM-2014-F03
- **Philip G. Westergaard, Jan Hald, Jan W. Thomsen.** *ESA TN5: FRLS EBB for CO_2 at 2.05* µm*: detailed design and characterisation plan.* DFM-2014-F04
- **Michael Kjær, Jan C. Petersen.** *Strategi- og handlingsplan for: Nyt indsatsområde ved DFM.* DFM-2014-F05
- **Michael Kjær, Jan C. Petersen, Mark Pollard, Philip G. Westergaard.** *Kvantitativ identifikation af kemiske stoffer: Beslutningsgrund og handlingsplan.* DFM-2014-F06
- **Morten Hannibal Madsen.** *Equipment for color measurements.* DFM-2014-F07
- **Hans D. Jensen.** *Peer-Review of the National Metrology Laboratory of Justervesenet (JV), Kjeller, in the technical fields DC voltage, resistance and DC current.* DFM-2014-F08

Contribution at conferences

- **Nikolaj Feidenhans'l.** *Visual appearance for validating nanostructure dimensions,* PRN 2014: Polymer Replication on Nanoscale, Kgs. Lyngby, Denmark, May 2014. DFM-2014-K01
- **Morten Hannibal Madsen, Poul-Erik Hansen, Maksim Zalkovskij, Jørgen Garnæs.** *Adapting a commercial microscope for studying nano-textured surfaces,* PRN 2014: Polymer Replication on Nanoscale, Kgs. Lyngby, Denmark, May 2014. DFM-2014-K02
- **Antoni Torras-Rosell, Salvador Barrera-Figueroa.** *Loudspeaker characterization using the acousto-optic effect,* 12th School on Acousto-Optics and Applications, Druskininkai, Lithuania, June 2014. DFM-2014-K03
- **Morten Hannibal Madsen, Poul-Erik Hansen, Maksim Zalkovskij, Jørgen Garnaes.** *Fast and robust characterization of polymers with a nano-textured surface,* E-MRS Spring Meeting, Lille, France, May 2014. DFM-2014-K04
- **Morten Hannibal Madsen, Poul-Erik Hansen, Maksim Zalkovskij, Michael Døssing, Peter Torben Tang, Niels Jørgen Mikkelsen, Jørgen Garnæs.** *Adapting a commercial microscope for studying nano-textured surfaces* 8th Workshop Ellipsometry, Dresden, Germany, March 2014. DFM-2014-K05
- **Jessica Bolinsson, Katrine R Rostgaard, Caroline Lindberg, Morten H Madsen, Peter Krogstrup, Karen L Martinez, Jesper Nygård.** *InAs nanowire arrays for biological applications involving living cells,* Nanowires 2014, Eindhoven, The Netherlands, August 2014. DFM-2014-K06
- **Nikolaj Feidenhans'l, Jan C. Petersen, Rafael J. Taboryski.** *Topographic Characterization of Nanostructures on Curved Polymer Surfaces,* Pittcon 2014, Chicago, Illinois, March 2014. DFM-2014-K07
- **Mikael Lassen, Anders Brusch, David Balslev-Clausen, Jan C. Petersen.** *Compact Sensor for Photoacoustic Monitoring and Photochemical Dissociation of NO2, Laser Optics 2014, St. Petersburg, Russia, June 2014.* DFM-2014-K08
- **Jørgen Garnæs.** *Mechanical properties of polystyrene nanoparticles,* E-MRS Spring Meeting, Lille, France, May 2014. DFM-2014-K09
- **Mikael Lassen, Anders Brusch, David Balslev-Clausen, Jan C. Petersen.** *Integrating Sphere based Photoacoustic Sensor for Trace Gas Detection,* Frontiers in Optics 2014 – Laser Science, Tucson, Arizona, October 2014. DFM-2014-K10
- **K. Gurzawska, N. Pischon, B. Jørgensen, P. Ulvskov, K. Dirscherl, M. Weiss Nielsen, K. Gotfredsen, N. R. Jørgensen, R. Svava.** *Surface nanocoating with pectins of titanium implants in rabbit model,* Congress of International Association for Dental research IADR/PER, Dubrovnik, Croatia, June 2014. DFM-2014-K11
- **Poul Erik Hansen, Lars Nielsen.** *Setting up a metrological traceable Mueller Polarimeter.* 8th Workshop Ellipsometry, Dresden, Germany, March 2014. DFM-2014-K12
- **Poul Erik Hansen, Morten Hannibal Madsen.** *Polarization dependent measurements of nanostructured surfaces. E-MRS Spring Meeting – ALTECH2014, Lille, France, May 2014.* DFM-2014-K13

- **Hannu Husu, Poul Erik Hansen, Toni Saastamoinen, Janne Laukkanen, Juuso T. Korhonen, Janne Ruokolainen, Samuli Siitonen, Jari Turunen, Antti Lassila.** *Comparison of different methods for characterization of diffractive optical elements, EOSAM 2014, Berlin, Germany, September 2014.* DFM-2014-K14
- **Poul Erik Hansen.** *Scatterometry for characterisation of diffractive-optical structures, EOSAM 2014, Berlin, Germany, September 2014.* DFM-2014-K15
- **V. Werwein, D. Balslev-Clausen, J. Peltola, M. Valkova, J. Brunzendorf, T. Fordell, T. Hieta, A. Rausch, A. Serdyukov, M. Vainio, J.C. Petersen, O. Werhahn, V. Ebert.** *Validation of the EUMETRISPEC central FTIR-spectroscopy facility: a preliminary metrological intercomparison on N2O spectroscopy,* HRMS2014 , Bologna, Italy, September 2014. DFM-2014-K16
- **O. Werhahn, D. Balslev-Clausen, J. Brunzendorf, J. A. Nwaboh, A. Rausch, A. Serdyukov, , V. Werwein, J.C. Petersen, V. Ebert** *Intercomparison of laser- and FTIR-based CO_2 line data in the 2 µm combination band,* HRMS2014, Bologna, Italy, September 2014. DFM-2014-K17
- **Philip G. Westergaard, Marco Triches, Mattia Michieletto, Jens K. Lyngsø, Jan W. Thomsen, Jan Hald.** *Progress towards a Fibre-Based Frequency Reference for Atmospheric CO_2 Measurements,* EFTF 2014, Neuchatel, Switzerland, June 2014. DFM-2014-K18
- **Philip G. Westergaard, Marco Triches, Mattia Michieletto, Jens K. Lyngsø, Anders Brusch, Jan Hald.** *Optical Frequency Stabilisation using Gas-Filled Hollow-Core Photonic Crystal Fibres,* Atomic Clocks for Industry, Neuchatel, Switzerland, June 2014. DFM-2014-K19
- **A. Nwaboh, P. G. Westergaard, M. Triches, J. Hald, M. Michieletto, J.K. Lyngsø, O. Werhahn, V. Ebert, J. C. Petersen.** *An optimized hollow core fiber-based laser spectrometer operating at 2.05 µm,* FLAIR 2014, Florence, Italy, May 2014. DFM-2014-K20
- **Marco Triches, Jan Hald, Jens K. Lyngsø, Ole Bang, Jesper Lægsgaard.** *Hollow core fiber-based Optical Frequency Standard,* DOPS 2014, Roskilde, Denmark, November 2014. DFM-2014-K21
- **M. Triches, M. Michieletto, J. K. Lyngsø, J. Hald, J. Lægsgaard, O. Bang.** *Optical frequency stabilization using gasfilled hollow-core photonics crystal fibers,* SPIE Photonics Europe, Brussels, Belgium, April 2014. DFM-2014-K22

Other Talks

- **Kai Dirscherl.** *Optagelsesmekanismer af forbrændingspartikler i kroppen,* Astma-Allergi Danmark, Roskilde, 2014-01-15
- **Kai Dirscherl.** *Eksperimentelle metoder i bygningsenergi og indeklima-Metrologiens historik,* DTU course 11123, DTU BYG, Lyngby, 2014-01-17
- **Jørgen Garnæs.** *Traceability of AFM measurements,* DTU course 42215, DTU MEK, Lyngby, 2014-03-26
- **J. Hald.** *Metrologi – det fundamentale aspekt,* Eurolab Danmark medlemsmøde, DELTA, Hørsholm, 2014-03-28
- **J. Hald.** *Length metrology at the primary level,* DTU course 41731, DTU MEK, Lyngby, 2014-04-19
- **Kai Dirscherl.** *Fra målestok til mikroskop: En historisk rejse om måle- og regnemaskiner gennem flere årtusinde,* The festival of research, Stenhus gymnasium, Holbæk, 2014-04-24
- **Kai Dirscherl.** *Vinklernes alsidighed – med passer, ur og GPS,* The festival of research, Vinderup Realskole, Vinderup, 2014-04-25
- **Kai Dirscherl.** *Fra målestok til mikroskop: En historisk rejse om måle- og regnemaskiner gennem flere årtusinde,* The festival of research, VUC Syd, Sønderborg, 2014-04-26
- **Kai Dirscherl.** *Vinklernes alsidighed – med passer, ur og GPS,* The festival of research, VUC Syd, Sønderborg, 2014-04-26
- **Kai Dirscherl.** *Røde aftenhimle – Når sollyset spiller bold med nanopartikler,* The festival of research, SDU, Sønderborg, 2014-04-26
- **Jørgen Garnæs.** *Metrologi – en forudsætning for handel, konkurrenceevne og sikkerhed,* DFM course, DFM, 2014, 2014-04-29
- **H. D. Jensen.** *Beregning af måleusikkerhed,* GUM. DFM course, Gentofte, 2014-05-14.
- **Kai Dirscherl.** *EMRP – Danske aktiviteter indenfor partikelmetrologi,* Metrologiens dag, TI, Århus, 2014-05-20
- **Marco Triches.** *Standard meter – how to build a standard meter,* QTea Training Camp, Nottingham University, UK, 2014-06-20
- **J. Hald.** *Hvor lang er en meter – hvad vejer et kilogram?* ESOF2014 Science in the city, København, 2014-06-22
- **Kai Dirscherl.** *Eksperimentelle metoder i bygningsenergi og indeklima-Metrologiens historik,* DTU course 11123, DTU BYG, Lyngby, 2014-06-26
- **Marco Triches.** *Saturated absorption spectroscopy – laser noise reduction application,* QTea Training Camp, Nottingham University, UK, 2014-07-15
- **Jan C. Petersen,** *Lasersikkerhed,* DFM course, Birkerød, 2014-08-26
- **Carsten Thirstrup.** *Surface plasmon resonance sensors,* DTU course 34455, DTU Fotonik, Lyngby, 2014-10-01
- **Marco Triches.** *Fiber laser optical frequency standard for industries,* Frontiers of Matter Wave Optics summer school, Crete, Greece, 2014-10-02
- **Hans D. Jensen,** *Primære elektriske normaler,* Trescal, Silkeborg, 2014-10-07
- **Lars Nielsen.** *Introduction to DFM-GUM,* NEMI Seminar, DFM, 2014-11-28
- **Marco Triches.** *Spectroscopy in Hollow Core Fibers,* Seminar, Mainz University, Germany, 2014-12-03

INCOME STATEMENT AND BALANCE SHEET

INCOME STATEMENT (1000 DKK)	2014	2013
Commercial revenue	3 647	2 996
Project revenue	8 703	7 732
Government funding	14 993	14 681
Total revenue	**27 343**	**25 409**
Travel expenses	432	428
Other out-of-pocket expenses	3 013	3 339
Total out-of-pocket expenses	**3 443**	**3 767**
Gross profit	**23 900**	**21 642**
Staff costs	16 757	15 445
Other external expenses	3 844	4 209
Total costs	**20 601**	**19 654**
Operating profit before depreciation and impairment losses	**3 299**	**1 988**
Depreciation and impairment losses on property, plant and equipment	2 652	1 540
Operating profit before financial income and expenses	**647**	**448**
Financial income	58	50
Financial expenses	6	2
Profit before tax	**699**	**496**
Tax on profit for the year	0	0
Profit for the year	**699**	**496**
Profit for the year to be carried forward.		

BALANCE SHEET AT 31 DECEMBER (1000 DKK)

ASSETS	2014	2013
Deposits	657	372
Total investments	**657**	**372**
Equipment	8 462	9 580
Leasehold improvements	1 327	1 181
Total property, plant and equipment	**9 789**	**10 761**
Total non-current assets	**10 446**	**11 133**
Contract work in progress	**2 333**	**2 886**
Trade receivables	542	1 205
Prepayments	16	102
Other receivables	236	1 008
Total receivables	**794**	**2 315**
Cash at bank and in hand	**11 454**	**8 755**
Total current assets	**14 581**	**13 957**
Total assets	**25 027**	**25 090**

EQUITY AND LIABILITIES	2014	2013
Share capital	1 000	1 000
Retained earnings	15 500	14 801
Total equity	**16 500**	**15 801**
Prepayments from customers and of funding	5 261	3 258
Prepayments of government funding	0	3 191
Trade payables	584	364
Debt to associated companies	0	45
Other payables	2 682	2 431
Total current liabilities	**8 527**	**9 289**
Total equity and liabilities	**25 027**	**25 090**

KEY FIGURES

KEY FIGURES IN MILLION DKK	2010	2011	2012	2013	2014
Net sales	19.2	20.1	21.6	25.4	27.3
Gross balance	17.3	17.9	19.2	21.6	23.9
Profit or loss for the financial year [1])	0.6	1.0	0.9	0.5	0.7
Net capital	13.5	14.4	15.3	15.8	16.5
Commercial sale	2.2	2.7	2.8	3.0	3.6
- to small enterprises (less than 50 employees)	0.4	0.6	0.5	0.4	0.6
- to medium size enterprises (50-250 employees)	0.5	0.5	0.7	0.7	0.7
- to large enterprises (more than 250 employees)	0.5	0.5	0.5	0.8	0.8
- to Danish public institutions	0.2	0.6	0.6	0.0	0.1
- to foreign enterprises and institutions	0.7	0.5	0.5	1.1	1.4
Foreign net sales	1.6	0.9	2.2	6.5	5.9
RESEARCH AND DEVELOPMENT					
Number of collaborative projects	10	18	18	21	23
- thereof innovation consortia	2	1	1	0	2
- thereof international projects	5	7	9	12	16
R&D activities (million DKK)	18.6	18.5	21.2	25.4	26.2
- thereof self-funded	1.6	1.2	2.4	3.1	1.8
R&D work (man-year)	11.5	12.3	13.9	16.2	19.0
NUMBER OF CUSTOMERS					
Danish private enterprises	37	27	32	31	33
- thereof small enterprises (less than 50 employees)	19	10	14	14	15
- thereof medium size enterprises (50-250 employees)	6	6	8	6	9
- thereof large enterprises (more than 250 employees)	12	11	10	11	9
Danish public institutions	9	5	11	5	3
Foreign enterprises and institutions	21	18	24	18	17
Total customer base	67	50	67	62	53
NUMBER OF STAFF CATEGORIZED BY EDUCATION (MAN-YEAR)					
Dr & PhD	11	11	13	17	18
MSc	4	4	3	3	4
Other technical staff	3	3	3	3	3
Administrative staff	2	2	2	2	2
Average number of staff	20	20	21	25	27
NUMBER OF PUBLICATIONS					
Refereed publications	8	9	7	12	14
PhD - og Master theses	1	0	0	1	0
Other reports	24	23	24	15	14
Conference papers	11	14	22	18	22
Calibration certificates and measurement reports	271	442	442	417	495
Press cuttings	14	4	9	9	27
EDUCATION					
DFM courses (number of days)	9	5	2	2	2
DFM courses (number of participants)	22	39	21	4	25
Supervision/teaching at universities (number of students/courses)	2	3	9	0	6
Co-supervision of master thesis students (number of theses)	5	5	3	4	5
Contribution to teaching at universities (number of days)	4	8	5	5	6
Committee work (number of committees)	23	26	25	24	32
- thereof international committee work	20	22	22	21	27
EFFICIENCY					
Turnover per employee (1000 DKK)	976	999	1031	1011	1004
Profit per employee (1000 DKK)	36	49	43	20	26
Commercial turnover per DKK of governmental funding	0.2	0.2	0.2	0.2	0.3
R&D turnover per DKK of governmental funding	1.4	1.3	1.5	1.7	1.8

1) Excluding extraordinary items

DANISH METROLOGY INSTITUTES

According to the CIPM Mutual recognition Arrangement, a country can have one national institute (NMI) and a number of designated institutes (DI). In Denmark, these metrology institutes are appointed by the Danish Safety technology Authority (www.sik.dk). In the list below, each appointed metrology institute is identified by the acronym used in the BIPM database over Calibration and Measurement Capabilities. The fields covered by the appointments are indicated in the table on the next page.

BKSV-DPLA
Brüel & Kjær Sound & Vibration
Measurement A/S
Skodsborgvej 307, DK-2850 Nærum
Contact: Erling Sandermann Olsen
Phone: +45 7741 2000
ErlingSandermann.Olsen@bksv.com

DELTA
Delta Danish Electronics, Lights & Acoustics
Venlighedsvej 4, DK-2970 Hørsholm
Contact: Anders Bonde Kentved
Phone: +45 7219 4275
abk@delta.dk

DFM
DFM A/S, Danish National Metrology Institute
Matematiktorvet 307, DK-2800 Kgs. Lyngby
Contact: Jan Hald
Phone: +45 4525 5876
jha@dfm.dk

DTI
Danish Technological Institute
Kongsvang Allé 29, DK-8000 Århus C
Contact: Jan Nielsen
Phone: +45 7220 1236
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THE 12 SUBJECT FIELDS OF METROLOGY

Fundamental metrology in Denmark follows the EURAMET division into 12 subject fields, while the subfields reflect metrological activities in Denmark. Plans of action drawn up for each subject field serve as guidelines for the appointment of metrology institutes and give suggestions for other initiatives. The years in which plans of action have been published are shown in parentheses.

SUBJECT FIELD	CONTACT PERSON	SUBFIELDS	METROLOGY INSTITUTE
MASS	Lars Nielsen, DFM	Mass measurement	DFM
(1989, 1997, 2008)	ln@dfm.dk	Force and Pressure	FORCE
		Volume and Density	FORCE
ELECTRICITY AND MAGNETISM	Hans Dalsgaard Jensen, DFM	DC electricity	DFM
(1989, 1994, 2002)	hdj@dfm.dk	AC electricity	TRESCAL
		HF electricity	TRESCAL
LENGTH	Jan Hald, DFM	Basic length measurements	DFM
(1989, 1998, 2007)	jha@dfm.dk	Dimensional metrology	DTU & DTI
		Micro/Nano	DFM
TIME AND FREQUENCY	Jan Hald, DFM	Time measurement	DFM
(1992, 2000)	jha@dfm.dk	Frequency	
THERMOMETRY	Jan Nielsen, DTI	Temperature measurement by contact	DTI
(1992, 1999, 2007)	jnn@teknologisk.dk	Non-contact temperature measurement	DTU
		Humidity	DELTA
IONISING RADIATION AND RADIOACTIVITY	Arne Miller, DTU	Absorbed radiation dose - Industrial products	
(1992, 2000)	armi@dtu.dk	Absorbed radiation dose - Medical products	DTU
		Radiation protection	
		Radioactivity	
PHOTOMETRY AND RADIOMETRY	Anders Brusch, DFM	Optical radiometry	
(1990, 1996, 2004, 2014)	ab@dfm.dk	Photometry	DFM
		Colorimetry	
		Optical fibres	
FLOW	Jesper Busk, FORCE	Gaseous flow (volume)	FORCE
(1990, 1999, 2007)	jrb@force.dk	Water flow (volume, mass and energy)	DTI
		Flow of liquids other than water	FORCE
		Anemometry	DTI
ACOUSTICS, ULTRASOUND AND VIBRATION	Salvador Barrera-Figueroa, DFM	Acoustical measurements in gases	DFM & BKSV-DPLA
(1992, 2000, 2009)	sbf@dfm.dk	Acoustical measurements in solids	BKSV-DPLA
		Acoustical measurements in liquids	
AMOUNT OF SUBSTANCE	Pia Tønnes Jakobsen, DFM	Environmental chemistry	
(1992, 1995, 2004)	ptj@dfm.dk	Laboratory medicine	
		Products and materials	
		Food chemistry	
		Pharmaceutical chemistry	
		Microbiology	
		Electrochemistry	DFM
INTERDISCIPLINARY METROLOGY	Hans Dalsgaard Jensen, DFM	No subdivisions	
	hdj@dfm.dk		
QUALITY	Kai Dirscherl, DFM	No subdivisions	
	kdi@dfm.dk		

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Martin Aggerbeck, PhD student, DTU MEK
Matteo Calaon, PhD student
Simon Christensen, Bachelor student
Svava Daviðsdottír, PhD student
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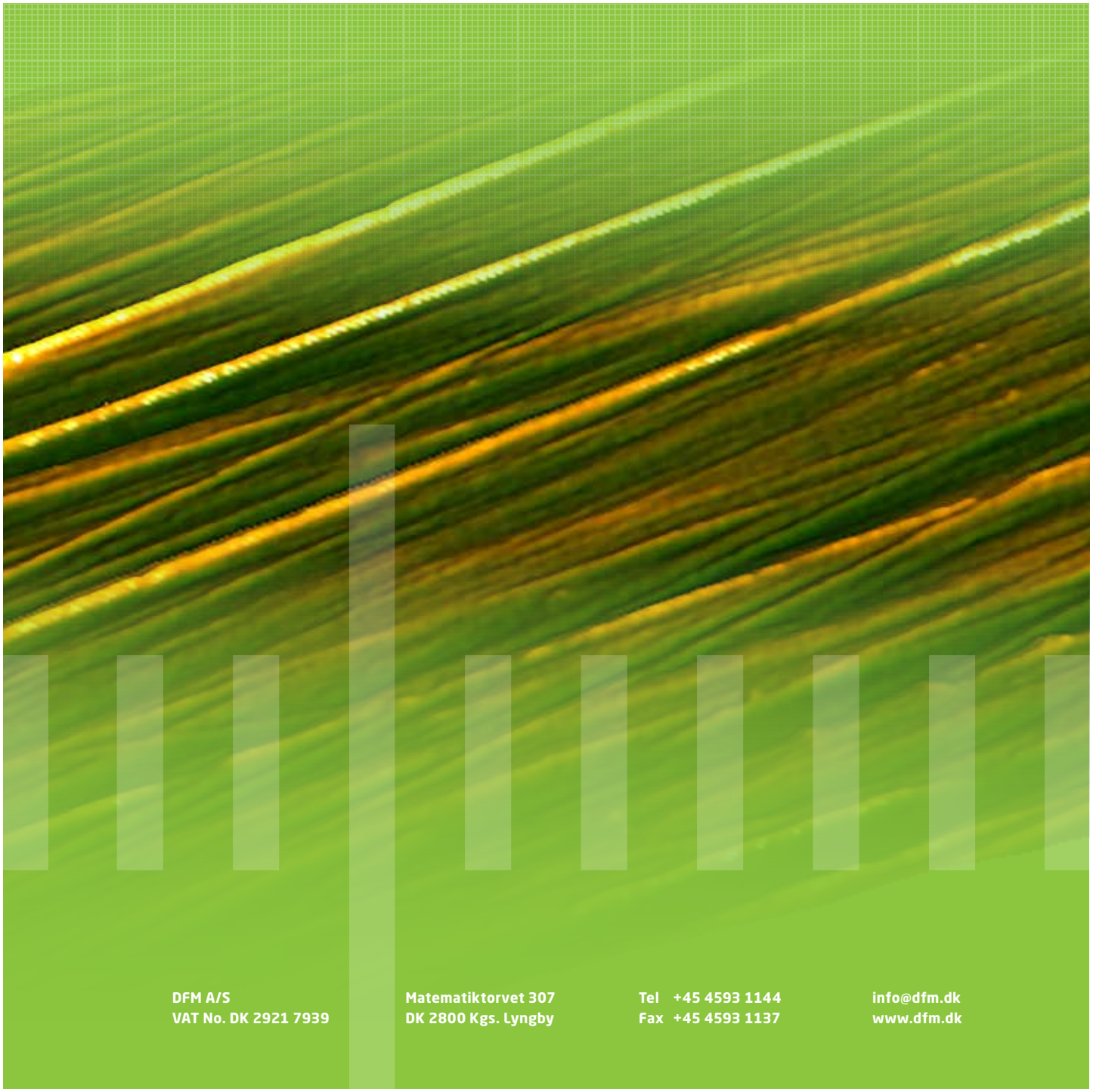

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