DFM
Danish National Metrology Institute

ANNUAL REPORT
2016

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.

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 a fully owned subsidiary of DTU, the Technical University of Denmark.

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 metrology services, which are critical for competing in the global marketplace.

ANNUAL REPORT 2016 EDITED BY
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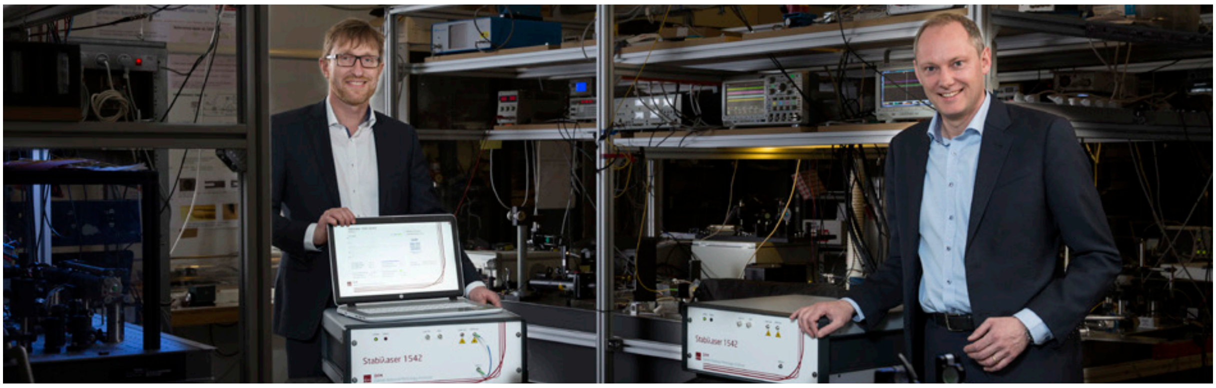


Bjarne Fjeldsted, Chairman of the Board, and Michael Kjær, CEO.

2016 was a positive year for DFM with total revenue increasing 16% to 31.6 million DKK. The profit was 0.4 million DKK similar to the 2015 result. The management is pleased with DFM's development and considers both revenue and profit as satisfactory.

Research activities within new emerging technologies such as optical spectroscopy, nanoscale metrology and sensor technology significantly increased in 2016. International collaboration with other National Metrology Institutes within these technology fields also increased in 2016. The activities have led to introduction of new services for Danish industry and ensured that DFM maintained a high number of publications in international refereed journals.

DFM's metrology infrastructure and research activities are supported by The Ministry of Higher Education and Science, and DFM is pleased that an additional contract was awarded in 2016 for DFM to develop new measurement technology and services ensuring traceability of measurements from drones. The contract will be implemented in 2017 and 2018 in close collaboration with Danish and international partners.

The strong growth in sales of calibration services and reference materials continued in 2016, driven primarily by sales to companies within pharmaceutical and acoustics industries. Contract research turnover was reduced compared to 2015, however the number of customers increased significantly in 2016 demonstrating the increasing need for advanced metrology competences and services from industry.

Supporting Danish SMEs with "state of the art" metrology competences and infrastructure is a key goal for DFM. Joint research projects are an efficient way to transfer technology to SMEs. DFM participates in a number of projects such as EUROSTARS, and DFM has been very successful in winning projects together with Danish SMEs. Two new projects were awarded in 2016 and DFM now participates in eight EUROSTARS projects in collaboration with Danish SMEs.

DFM's growth is expected to continue in the future, as industry demand for new advanced metrology services and infrastructure increases. DFM plans to move to a new and much larger facility at the end of 2017. The facility will include new and significantly improved laboratory infrastructure optimized for the metrology needs of the future and easily accessible for Danish industry.

Bjarne Fjeldsted
Chairman of the Board

Michael Kjær
CEO

VOLATILES MEASUREMENT SYSTEM: EXTENDING ELECTROLYTIC CONDUCTIVITY MEASUREMENTS


Preparing the VolaCond system for a measurement series. The system is designed to run automatically once the sample has been loaded onto the system.

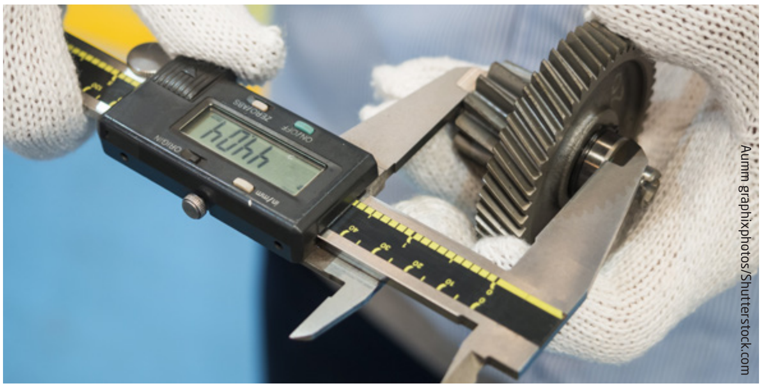
DFM expands its activities in the field of electrolytic conductivity measurements to cover low conductivity levels in volatile solutions such as ethanol.

With the increased focus on renewable energy generation, total or partial replacement of petroleum fuels by bioethanol in motor vehicles has been extensively researched worldwide. Bioethanol is one such renewable resource and can be produced from various crops and trees in many different climates, or even from waste biomass. It also has the advantages of being liquid, and capable of utilizing the existing distribution network for petroleum with few modifications. In many countries flex fuel vehicles have engines which are capable of working with ethanol–petroleum mixtures of up to 85% ethanol (E85) and in Brazil up to 100% (E100).

It is important to ensure the purity of the ethanol used in engines against the various impurities. One contaminant is acetic acid, produced from the oxidation of ethanol. The presence of acetic acid will reduce the lifespan of an engine due to the corrosive effect towards many of the engine materials. Testing for the presence of acetic acid in bioethanol can be performed using conductivity measurements; this method of analysis is chosen due to the low conductivity of ethanol and the relatively large effect on conductivity of small quantities of acetic acid. In many countries, this is enforced by a maximum conductivity value for bioethanol for motor vehicles (for instance, ~500 μS/m).

DFM undertakes to expand its activities in the field of electrolytic conductivity measurements. At present this includes: measurements of aqueous and non-aqueous chloride salt solutions in Jones-type open cells and probe-transmitter calibrations, using very low conductivity KCl (aq) solutions. DFM expands its activities to measure low conductivity levels in volatile solutions such as ethanol. Volatility combined with the low level of conductivity means that we cannot use our existing conductivity measurement systems. In 2016, the VolaCond system was constructed. The system is designed to run automatically once the sample has been loaded onto the system, with flexibility for adjusting experimental conditions to ensure high performance for various sample types over the whole range of conductivity. Initial work has helped to identify the areas where the volatility of the solutions poses the greatest challenges, including stressing the controlling role of head-space volumes throughout the setup, and has produced encouraging results. To date measurements with the system have taken place on solutions (including KCl (aq), HCl (aq), and propanol containing solutions) with conductivity values spanning 5 orders of magnitude. Work continues to integrate sampling of solutions, including use of syringes to avoid head-space in the instrument, into the system processes and create a final service-ready instrument for the provision of commercial calibrations.

METROLOGI.DK – EDUCATION IN MEASURING TECHNIQUE



The industry needs qualified technicians to ensure product quality and to stay competitive.

metrologi.dk

For more than a decade, education in metrology has had a low priority in Denmark. DFM and two other GTS institutes are now making a change to this by launching the project "metrologi.dk". Between 2016 and 2018, new teaching material for "korte og mellemlange uddannelser" (equivalent to technical and university based educations) is being developed.

Being at the onset of the fourth industrial revolution with increased automation in industrial production, staff with the relevant and up-to-date skills is increasingly in demand. Advanced instrumentation and larger numbers of sensors on production lines require skilled staff in order to sustain production quality. This can only be ensured by a fundamental and solid understanding of measurements, calibrations, and basic statistics, in other words: Metrology.

In order to meet these requirements, DFM teamed up with the Danish GTS institutes FORCE Technology and DELTA in order to create new teaching material targeting the relevant measurements types and industrial requirements. With funding from the Danish Agency for Science Technology and Innovation, the 3 year project named Metrologi.dk was launched in January 2016.

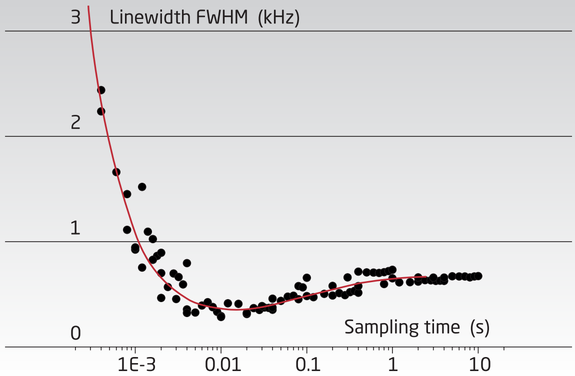
Metrologi.dk primarily targets the "korte og mellemlange uddannelser" at the Danish business academies. The project will provide new teaching material in written form, as well as movies, simulations etc., while seminars will be held for the teachers in order to strengthen and update their competences. Concurrently, the three partners will use their vast industrial networks to align the teaching material towards relevant industrial applications. DFM has carried out interviews with more than 10 Danish companies and interested organizations, assessing relevant topics, and possible case studies.

During 2016, the three partners executed 3 pilot projects with Zealand Institute of Business and Technology (EASJ), Aarhus School of Marine and Technical Engineering (AAMS), and the vocational training centre EUC-Syd. The collaboration with the educational institutions has been vital for creating teaching material that makes sense to both teachers and students. So far, three new text-based teaching material packets have been developed by DFM, which were well received by teachers. At one of the business academies, parts of the prepared material have already been included in the teaching plans for 2017.

The project partners look forward to increasing the awareness of the project during 2017, and plan to increase the number of involved companies, schools, and academies. Access to the developed teaching material will be provided free of charge at the website (metrologi.dk), where interested parties may find further information about the project.

INTRODUCTION OF THE STABIλASER 1542

The Stabiλaser 1542



The Stabiλaser 1542 linewidth vs. sampling time, Fourier limited at short times.

The first unit of DFM's new stabilized laser for next-level metrology research applications was delivered in 2016. More recently, it was introduced to the market at the Photonics West exhibition.

The Stabiλaser 1542 is DFM's first real serially-produced product to be introduced to the market. It was developed as a response to a growing need for a highly stable optical frequency reference for experiments involving frequency combs, and is available at a much reduced price compared with previous solutions.

The popular fibre-based combs do not have intrinsically narrow and stable comb teeth, thus requiring an external frequency reference. Optical cavities provide excellent short-term stability, but lack long-term accuracy. RF (radio frequency) references can provide the long term accuracy but do not have sufficient short-term stability.

The Stabiλaser 1542 is an acetylene-stabilized fibre laser that exhibits both narrow linewidth, excellent long-term stability, and high accuracy. The design maintains the short-term linewidth of a high-end fibre laser, and additionally adds the long-term stability and accuracy from the molecular transition of acetylene. Having excellent performance on both the short and long-term time scales in one convenient package makes the Stabiλaser 1542 very competitive indeed.

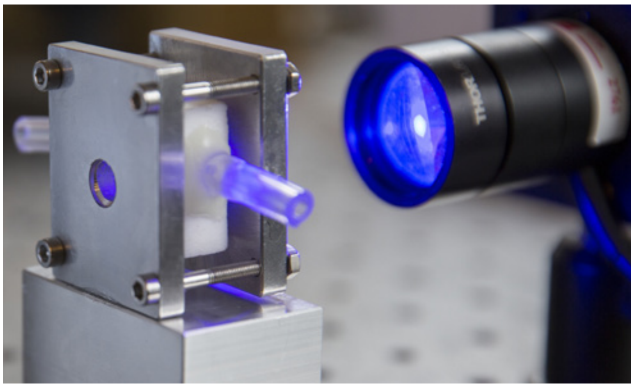
The Stabiλaser 1542 provides affordable access to the high levels of performance needed for cutting edge scientific research. The range of applications extends to length metrology, frequency combs used for stabilization and line narrowing of lasers for spectroscopy, laser cooling on narrow-line atomic or molecular transitions, as well as dual comb spectroscopy.

At the heart of the Stabiλaser 1542 is a compact ultra-low noise fibre laser stabilized to the acetylene $^{13}C_2H_2$ P(16) (ν1 + ν3) transition at λ = 1542.3837 nm. The laser meets the conditions of the CIPM recommendation on standard frequencies and can be used as a primary standard with an uncertainty of 5 kHz. The proprietary optical design and control software ensure both autonomous operation and a high quality laser output.

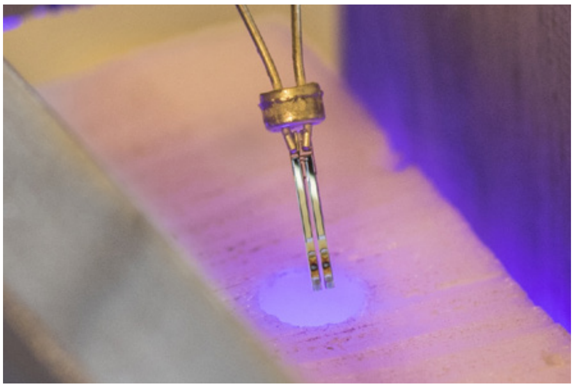
The first unit was delivered to Aarhus University, Denmark, during 2016. Since day one, the Stabiλaser 1542 has proved its value. Professor Michael Drewsen of Aarhus University, Denmark, explains: "We have applied Stabiλaser 1542 as a frequency reference for a frequency comb for over a year now. The ease with which the comb teeth are short-term stabilized to sub-kHz linewidths, as well as the long term absolute accuracy-drift, have impressed us very much. The stability of Stabiλaser 1542 is simply amazing."

With the recent introduction at Photonics West in San Francisco, California, the Stabiλaser 1542 has caught the interest of a wider audience, and has brought DFM much recognition.

BREATH ANALYSIS USING PHOTOACOUSTIC SPECTROSCOPY



The QEPAS compact sensor, the central component of the novel non-invasive trace gas analyser.



The sensing element, a quartz tuning fork (QTF).

Photo-acoustic spectroscopy (PAS) is a very promising method for medical diagnostics based on breath analysis.

Eurostars project: NxPAS - a novel non-invasive trace gas analyser platform targeting breath analysis.

Participants: Laserspec Bvba (SME, Belgium), DFM A/S, Copac ApS (SME, Denmark), and Université De Liège (Belgium)

Breath analysis enables the diagnosis of a specific disease through analysis of the changes in the exhaled breath gas composition. Tests revealing inflammatory processes in, for example, the lungs, neonatal jaundice, and allergies, based on changes in inorganic gas concentrations are already marketed. There also exists interest in measuring volatile organic compounds (VOC), as these can be used to diagnose multiple metabolic disorders.

Breath gas analysis is typically carried out using gas chromatography and mass spectrometry. These methods can help in screening patients for various diseases. However, cost and lack of speed have limited their clinical use. A cost effective and portable in-situ breath gas analysis screening platform is demanded. Gas measurements in the mid-infrared (MIR) and near-infrared (NIR) wavelength regions depend on strong absorption bands for the molecules present. This makes the spectroscopic method highly sensitive and particularly useful for breath analysis.

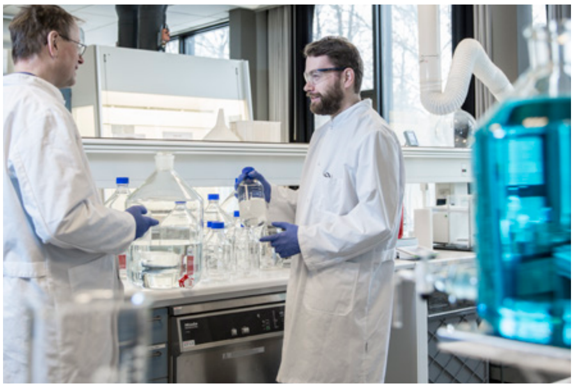
Photo-acoustic spectroscopy (PAS) is a very promising method due to its ease of use, relatively low cost, and its capability for trace gas measurements at the ppb sensitivity level. Targeting the major market of medical diagnostics based on breath analysis, DFM has successfully developed, tested, and demonstrated a novel, non-invasive trace gas analyser platform. The sensor developed will be capable of providing data almost instantaneously, potentially for diagnosis at early stages of diseases. The sensor will be non-invasive, and will have a fast screening capability, thus significantly improving early disease diagnosis to the benefit of patients.

The sensor used is a novel quartz-enhanced photoacoustic sensor (QEPAS), which has very low fabrication costs. The versatility of the sensor comes from using a tunable light source, an optical parametric oscillator (OPO) system that provides radiation in the 2.8 to 4.8 μm wavelength region, where many of the potential biomarker molecules have strong absorption transitions. The real breakthrough, however, is that the technology allows the use of cheap disposable gas chambers, thereby avoiding the need for cleaning after each test.

For funding of this project, we acknowledge the financial support from EUREKA (Eurostars program: E9117NxPAS), the Danish Agency for Science Technology and Innovation, and the Innovation Fund Denmark.

DFM SUPPORTS DANISH INDUSTRY

The industy relies on roughness calibrations for quality assurance



Electrochemistry was exceptionally busy in 2016

1. ROUGHNESS CALIBRATIONS: IN HIGH DEMAND

On January 1st 2016, accredited services within dimensional metrology were transferred from DTU to DFM. As a result, DFM has acquired many new Danish customers, in particular in the field of roughness measurements. In the previous year, DFM has calibrated an increasing number of roughness standards and instruments. Particularly SMEs delivering products to pharma and food industries depend on these calibrations in order to verify that their products satisfy the rigorous quality requirements from regulatory bodies. During 2016 DFM visited several of the new customers in order to identify their current and future needs within dimensional metrology.

As a part of DFM's effort on conveying knowledge about metrology, DFM has also organized a seminar on roughness measurements together with DAMRC (Danish Advanced Manufacturing Research Center) in Herning. The participants in this seminar were primarily SMEs from Jutland.

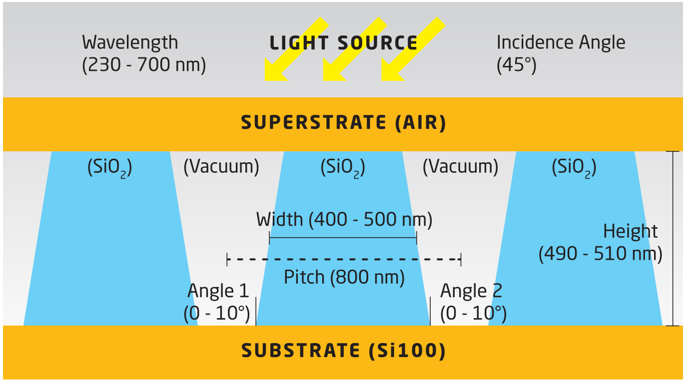
2. PROVIDING TRACEABILITY TO THE DIALYSIS SERVICE INDUSTRY

Administration of dialysis requires the presence of an aqueous sodium chloride solution of known concentration and purity, and the dialysis machine itself, which includes an electrolytic conductivity sensor. DFM has provided the measurement of commercial dialysis solution concentrations for several years, through the certification of conductivity on traditional measurement cells. In 2016, DFM furthered its contribution to the reproducible and safe administration of dialysis by additionally calibrating commercial conductivity sensors. The calibrations are performed on our flow-loop system against a primary reference cell, traceable to the SI through length and resistance measurements, in the ultra-pure water (5.5 µS/m) to intermediate conductivity range (140 mS/m). The values assessed on traditional and flow-loop measurement system are identical in the 10 -140 mS/m range.

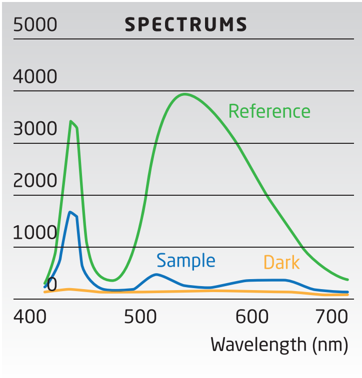
3. INCREASED PRODUCTION CAPACITY IN CERTIFIED REFERENCE MATERIALS

In recent years, DFM has provided certification of electrolytic conductivity solutions, through the sale of certified reference materials (CRM) in several of conductivity ranges. These are employed by our clients in a number of applications, primarily as reference solutions for the calibration of commercial conductivity sensors. Recently, demand for our low-level conductivity solution has been increasing. So, in 2016, we undertook the long-term investigation of a new process for the production of a larger batch size (from 10 L to 20 L) for our 10 mS/m solution. After thorough investigation of homogeneity and stability, DFM is pleased to announce we can now produce 10 mS/m conductivity solution in a larger batch size, while assuring the same quality as before. In 2017, a similar systematic investigation for the larger scale production of our 1 S/m CRM solution will commence.

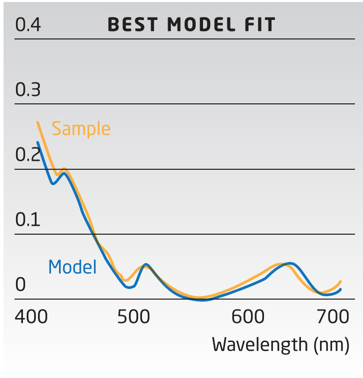
SOFTWARE FOR FAST AND ROBUST DIMENSIONAL MEASUREMENTS OF NANOSTRUCTURES



Sample model of a periodic grating used in computer simulations of diffraction efficiencies at different wavelengths. Numbers in parentheses indicate variation parameters.



The measured diffraction efficiencies of a sample, the background and a known reference.



Comparison between sample and modelled diffraction efficiency.

Algorithms developed by DFM for nanostructure characterization have been incorporated into the user-friendly InFoScat software

InFoScat (Industrial Fourier Scatterometry) is a Eurostars project started in 2014. The partners are DFM, Image Metrology (Denmark), and ELDIM (France). The aim of the project is to create a fast tool for measuring critical dimensions of repeated nanostructures, as well as a tool that is well suited for inline quality control in an industrial production environment. DFM has developed algorithms needed for nanostructure characterization based on scattered light analysis. Image Metrology has implemented the algorithms in the user-friendly InFoScat software package, which eases the complex analysis of nanostructures as well as thin films.

The InFoScat software package currently supports measurements of thin film thickness, as well as geometry measurements (height, width, and sidewall angle) of repeated 2D and 3D structures. Furthermore, the software can be used in conjunction with several optical characterization techniques, including: Spectroscopic Scatterometry, Angular Scatterometry, Fourier Lens Scatterometry, and Spectroscopic Ellipsometry. The software package complements DFM's development of scatterometry-based hardware solutions for quality control of nanostructured products. One hardware solution is currently being tested together with the Danish company NIL Technology as part of the EMPIR project "Metrology for highly-parallel manufacturing". Another test is under preparation with the German company Polyoptics as part of the Eurostars project "Optical plastic lenses with super-hydrophobic surface properties". The InFoScat software has been developed in close cooperation with an end-user and the distributor of the program; free test versions of the software may be obtained by contacting Image Metrology.

DFMs contribution was partly supported by funds from The Danish Agency for Science, Technology and Innovation.

Working Principle of the InFoScat software

A periodic structure diffracts light into diffraction orders. The measured diffraction efficiencies are used to derive the surface properties. For a sample (e.g. grating) with a known shape but unknown geometrical dimensions, the workflow is as follows:

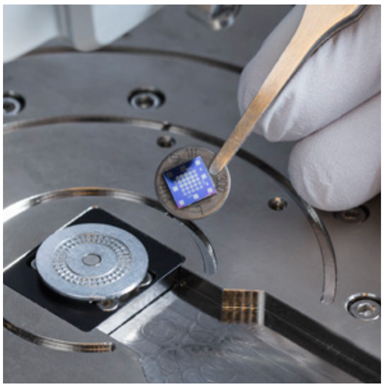
(A) Simulation database generation

The InFoScat software makes computer simulations of diffraction efficiencies for a user-specified range of dimensional parameters. The simulations are made for several wavelengths, heights, widths and angles. The results are stored in a database.

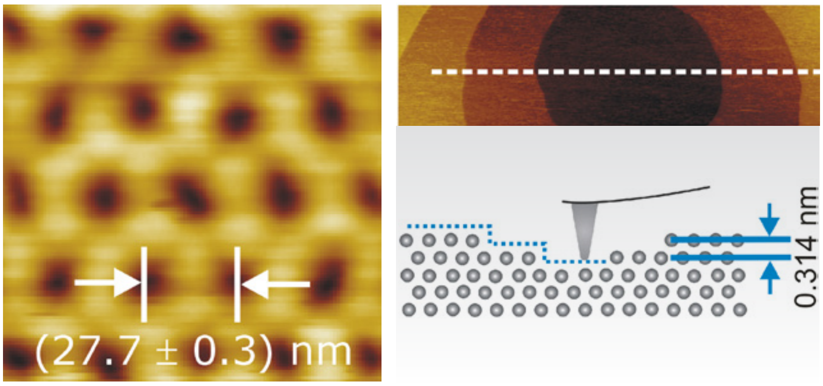
(B) Database comparison

Measured diffraction efficiencies spectra are loaded into the InFoScat software, which compares these measurements to those in the database. The best match is used to derive the dimensions, together with confidence intervals, of the structures on the sample. A sample can be measured and analyzed in just a few ms allowing inline quality assessments.

THE ULTIMATE NANOMETRE SCALE RULER



A new prototype nanometre scale transfer standard developed by PTB



Two atomic force microscopy images of two new standards developed. From the images an accurate nanometer scale calibration can be realized based on the ordered holey silicon structures of (27.7 ± 0.3) nm and the unchangeable spacing between layers of silicon atom of 0.314 nm.

New types of nanometre scale standards have been used to calibrate atomic force microscopes to improve measurement capability in the dimensional range of only a few atomic diameters.

DFM participated in the EMRP (European Metrology Research Programme) project "Crystalline surfaces, self assembled structures, and nano-origami as length standards in (nano)metrology", which ended in 2016. As part of this project, DFM has developed calibration methods tailored to new prototypes of nanoscale length standards based on self-organizing surface structures and special crystalline surfaces. The standards were manufactured by two of the project participants PTB and INRIM.

The new standards are used as nature's ultraprecise rulers for reliable geometrical measurements of dimensions below about 10 nm (smaller than a ten-thousandth of the width of a human hair). Height standards are based on the unchangeable spacing between layers of silicon atoms exposed on the surface of a crystal as step heights of only 0.314 nm. Lateral standard are based on ordered holey silicon structures obtained by means of self-assembly of special polymers with period between 13 nm and 50 nm. Such standards, which have not been available previously, are optimized for atomic force microscopy (AFM), which is an important high-resolution measurement technique at DFM.

The new standards have been developed as a response to demands from the innovative semiconductor and nanotechnology industries. For the same reasons, DFM facilitated the involvement of the Danish company Image Metrology as a collaborator and stakeholder.

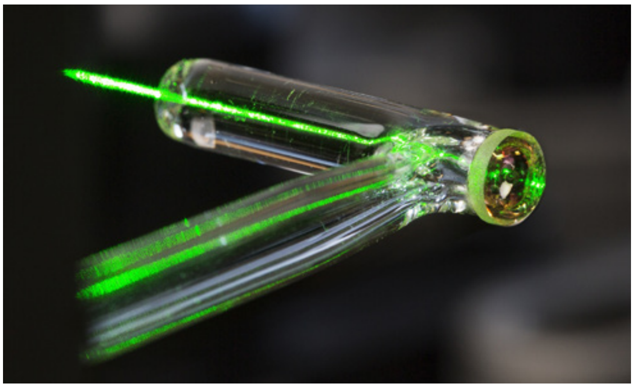
The focus of this research project was to underpin the development of the SI system of measurement units. However, the project outcome is of immediate practical importance for DFM. Current calibration services rely on traceability from calibrated artefacts, and the new transfer standards will be used to improve measurement capabilities in the range below 10 nm.

DFM's contribution to the EMRP project focused on processing of AFM images to deduce accurate dimensions, and the development of a calibration procedure for use with the new standards. The calibration procedure was summarized in a guideline, together with a discussion of uncertainty budgets.

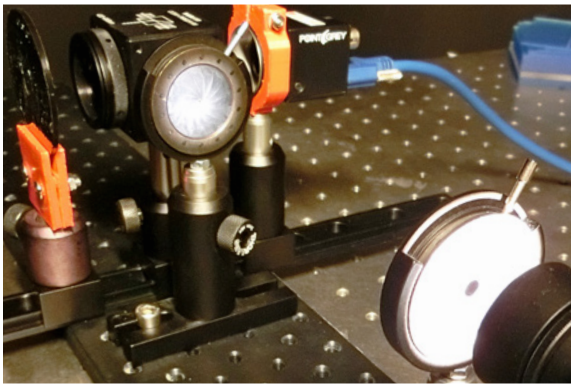
The measurement capability of smaller dimensions, coupled with smaller uncertainties, has for a long time been requested, for example, for the measurements of the roughness of very smooth X-ray mirrors in collaboration with DTU Space. An improved measurement capability can also be used in assessments of functionalised coatings and the sizing of nanoparticles, for instance, which are topics where DFM offers specialised measurement services.

DFMs contribution was partly supported by funds from The Danish Agency for Science, Technology and Innovation.

PHD PROJECTS AT DFM MAKE A DIFFERENCE



A glass ferule for gas filling and sealing of a hollow-core optical fibre. Green light is coupled into the fibre through the small optical lens attached to the ferule.



The scatterometry setup used for characterization of nanostructured surfaces.

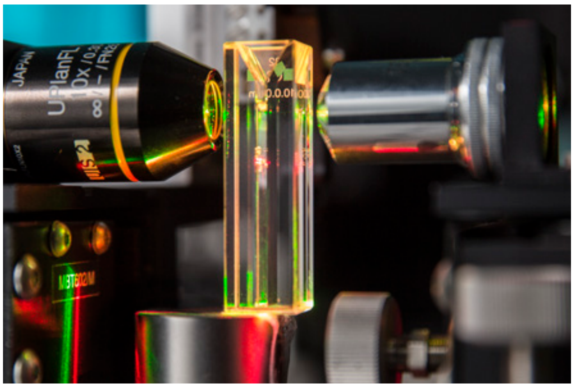
PhD projects finished in 2016 show a high level of academic research with practical applications

DFM research staff participate in the education of scientist in Denmark by being co-supervisors for PhD students. The students are registered at one of the Danish universities where the main supervisor is also located. It is part of DFM's strategy to maintain such close collaboration with universities. PhD students divide his/her time between the two involved institutes, which contributes to the enhancement of DFM's competences, as well as strengthening research collaboration, as manifested in joint publications in international peer reviewed journals.

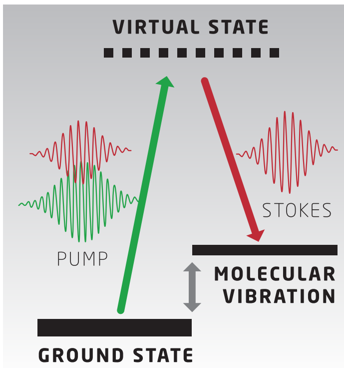
In 2016 two students finished their PhD work. Marco Triches worked for three years on the development of a fibre-based, portable optical frequency standard for the telecommunication wavelength band. As part of his PhD project, Marco developed tiny glass ferules for gas filling and sealing of hollow-core optical fibres in a configuration which allows efficient coupling of light into the optical fibre. These unique ferules have subsequently been used in a contract research project for the European Space Agency, as well as for DFM's Raman activities. Marco succeeded in developing a fibre-based frequency reference, which was successfully shipped to MIKES in Finland for several joint experiments. The PhD project was financed by the Marie-Curie Initial Training Network "Quantum Sensor Technologies and Applications" funded under the EU-FP7 program, and Marco was enrolled at DTU Photonics. He successfully defended his dissertation entitled "Laser Frequency Standards based on Gas-Filled Hollow-Core Fibers".

Nikolaj Agentoft Feidenhans'l focused on the development of a new method for fast, in-line characterization of periodic nanostructures, termed color scatterometry, which evaluates the color of only the reflected light using a standard RGB color camera. With color scatterometry, a single exposure to the camera is sufficient to evaluate the grating profiles for thousands of individual regions spanning a millimeter-sized area, from which small regions can be analyzed independently. His work also involved the use of angular scatterometry for characterization of nanoscale surface roughness; he compared three instruments: a confocal optical profiler, a high-resolution laboratory scatterometer, and a simple commercial scatterometer designed for in-machine measurements. The project was sponsored by the Danish Agency for Science, Technology and Innovation through the Industrial PhD Programme, and Nikolaj was enrolled at DTU Nanotech. He also successfully defended his dissertation titled "Optical characterization of nanostructured surfaces".

MEASUREMENT SOLUTIONS FOR PHARMACEUTICALS – RAMAN SPECTROSCOPY



Picture of the novel compact stimulated Raman setup. The compact, novel, and versatile SRS method combines a tuneable continuous wave (CW) probe laser, offering narrow linewidth and low noise, with a semi-monolithic nanosecond pulsed pump laser.



Schematic diagram of the energy levels involved in a typical Raman transition. For stimulated Raman spectroscopy two lasers are used, a pump laser (shown as green) and probe laser (shown as red). If the frequency difference matches a molecular vibration/rotational line of the sample stimulated excitation occurs, thus the probe beam will experience Raman gain. Tuning the wavelength of the probe laser results in a Stokes spectrum which represents a unique fingerprint of the chemical composition of the sample.

DFM's newly developed Raman facility is an essential step towards the deployment of spontaneous and stimulated Raman spectroscopy techniques for in-situ measurements.

In 2016, DFM entered a new research result contract ("Resultatkontrakt") with the Danish Agency for Science, Technology and Innovation on quantitative Raman spectroscopy. The research targets especially the pharmaceutical industry, which has a considerable need for improved spectroscopic tools for material analysis, including quantitative measurement methods for quality assurance in both production and development. The practical applications of Raman spectroscopy have grown rapidly over the past few years owing to increased sensitivity, reduced costs, and increased versatility towards detection and labelling of different substances. Raman spectroscopy, therefore, answers the demand for making measurements in-situ during production in a non-destructive manner. Unique quantitative measurements of sample properties (for example, polymorphism in active ingredients and conformation of proteins) are rendered possible using Raman spectroscopy.

Raman spectroscopy for identification and quantitation

Raman spectroscopy provides information about molecular vibrations that can be used for sample identification, and has the potential for quantification. Chemical identifications can, for example, be obtained by comparing the measured spectra with a Raman database. In molecular spectroscopy, the absorption features depend on the amount of substance. In Raman spectroscopy, the intensity of the Raman shifted light is proportional to the concentration, thus making Raman spectroscopy a potential quantitative method. However, only a very small amount of light is Raman shifted due to interactions between the pump light and the vibrational energy levels of the molecules in the sample. Two methods are currently being developed, spontaneous Raman spectroscopy and stimulated Raman spectroscopy (SRS). The latter typically provides a 10 000 fold increase in intensity. The gain in signal is, however, at the cost of a more complex setup. In SRS, the light at both the pump and the Stokes wavelengths is incident on the sample, which increases the Raman signal due to coherent stimulation.

Our mission

DFM has explicitly demonstrated improved sensitivity and repeatability with our novel compact SRS systems. This ensures optimal instrument operation, thus establishing confidence in the quality of recorded data. DFM now works towards quantitative measurements of chemical compounds within seconds, to µg/mL concentration.

With the system it is possible to perform measurement of chemical substances in all phases. For example, the left picture above shows a measurement of methanol diluted in water.

ACCOUNTS OF PARTICULAR ACTIVITIES

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

- EMPIR Committee
- Consultative Committee for Amount of Substance (CCQM)
- Consultative Committee for Acoustics, Ultrasound and Vibration (CCAUV)
- EURAMET General Assembly
- EURAMET Board of Directors
- 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 Electrochemistry
- BIPM Director's ad hoc Advisory Group on Uncertainty
- Joint Committee for 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-WG-N)
- Consultative Committee for Amount of Substance: Metrology in Chemistry and Biology - Working Group on Electrochemical Analysis (CCQM-EAWG)
- Consultative Committee for Mass and Related Quantities - Working Group on the Realization of the kilogram (CCM-WGR-kg)
- Consultative Committee for Mass and Related Quantities - Working Group on the Dissemination of the kilogram (CCM-WGD-kg)
- Consultative Committee for Acoustics, Ultrasound and Vibration - Working Group for Key Comparisons (CCAUV-KCWG)
- Consultative Committee for Ultrasound and Vibration - Working Group for RMO Coordination (CCAUV-RMO)
- Consultative Committee for Ultrasound and Vibration - Working Group on Strategic Planning (CCAUV-SPWG)

The list of DFM research projects includes no less than 7 Eurostars projects. Eurostars is a joint programme between EUREKA and the European Commission, and the projects are co-funded by EU and Innovation Fund Denmark. Eurostars supports SMEs in the development of innovative products and require participation from at least two member states. The applications with DFM participation have been very successful with a success rate close to 100% since 2014.

Participation in national and international projects

- Strategic research center in precision and nano-scale polymer mass replication of biochips (PolyNano), DSF
- Quantum sensor technologies and applications (QTEA), EU FP7/ITN
- Scanning neutral Helium microscopy (NEMI), EU FP7
- 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
- Center for LED Metrologi (LEDMET), RTI
- Advanced laser-based heat sensor for fire detection (FireDetect), IF/Eurostars
- A novel non-invasive trace gas analyser platform tageting breath analyses (NxPAS), IF/Eurostars
- Industrial Fourier scatterometer (InFoScat), IF/Eurostars
- 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
- Metrology for innovative nanoparticles (Innanopart), EMPIR/FI
- Metrology for highly-parallel manufacturing (MetHPM), EMPIR/FI
- Metrology for length-scale engineering of materials (Strength-ABLE), EMPIR/FI
- Leading Edge Roughness wind turbine blades (LER), EUDP
- Optical plastic lenses with super-hydrophobic surface properties (SuperLens), IF/Eurostars
- Advanced surface characterization of nanostructures on curved polymer surfaces, FI
- Photo-Acoustic sensor for oil detection in compressed air (PASOCA), IF/Eurostars
- Metrology for additively manufactured medical implants (MetAMMI), EMPIR/FI
- Metrology for modern hearing assessment and protecting public health from emerging noise sources (Ears II), EMPIR/FI
- Underwater acoustic calibration standards for frequencies below 1 kHz (UNAC-LOW), EMPIR/FI
- Traceable three-dimensional nanometrology (3DNano), EMPIR/FI
- Continuous pesticide sensing in the environment (CoPs), IF/Eurostars
- Quantum innovation center (Qubiz), IF
- Photoacoustic infrared microscope for automated histopathology (PIRMAH), IF/Eurostars

DFM Reports

- **O. S. Nielsen, J. C. Petersen.** *DFM Annual Report 2015.* DFM-2016-R001
- **L. Nielsen.** *Minimum coverage probability provided by coverage factor k = 2.* DFM-2016-R002.
- **M. Kjær.** *Faglig rapportering til Styrelsen for Forskning og Innovation for 2015.* DFM-2016-R003
- **L. Nielsen.** *Disseminating the unit of mass from multiple primary realisations.* DFM-2016-R004
- **M. H. Madsen.** *Feasability study of real-time scatterometry calculations.* DFM-2016-R005
- **P. G. Westergaard.** *Laser Spectroscopy in Hollow-Core Fibers: Principles and Applications* in "Applications of Molecular Spectroscopy to Current Research in the Chemical and Biological Sciences", Ed.: Mark T. Stauffer. DFM-2016-R006
- **S. R. Johannsen, M. H. Madsen.** *Behovsanalyse for deltidsuddannelse i "kvalitet og måleteknologi".* DFM-2016-R007
- **J. Garnæs, L. Nielsen, E. Jacobsen, M. Køcks, P. B. Pedersen, P. Wahlberg.** *Requirements to Measurements of Nanomaterials and Nanoproducts, 50 pp, Environmental Project No. 1802, 2015 Published by: The Danish Environmental Protection Agency 2016 ISBN no.978-87-93352-95-7.* DFM-2016-R08.

Calibration certificates and measurement reports

DC Electricity	3
Electrochemistry	361
Mass	14
Length	42
Optical Radiometry	2
Nano Structures	8
Acoustics	38
Particle Metrology	84
Total	**582**

Publications in refereed journals

- **M. H. Madsen, P. Boher, P. E. Hansen, J. F. Jørgensen.** *Alignment-free characterization of 2D gratings.* Applied Optics **55**, 317-322, 2016. DFM-2016-P01
- **M. H. Madsen, P. E. Hansen.** *Imaging scatterometry for flexible measurements of patterned areas.* Optics Express **24**, 1109-1117, 2016. DFM-2016-P02
- **P. G. Westergaard, J. W. Thomsen, M. R. Henriksen, M. Michieletto, M. Triches, J. K. Lyngsø, J. Hald.** *Compact, CO_2-stabilized tuneable laser at 2.05 microns.* Optics Express **24**, 4872-4880, 2016. DFM-2016-P03
- **K. Gurzawska, K. Dirscherl, B. Jørgensen, T. Berglundh, N. R. Jørgensen, K. Gotfredsen.** *Pectin nanocoating of titanium implant surfaces- An experimental study in rabbits.* Clinical Oral Implants Research **00**, 1-9, 2016. DFM-2016-P04
- **M. H. Madsen, P. E. Hansen.** *Scatterometry-fast and robust measurements of nano-textured surfaces.* Surf. Topogr.: Metrol. Prop. **4**, 023003, 2016. DFM-2016-P05
- **J. S. Madsen, P. E. Hansen, B. Bilenberg, J. Nygård, M. H. Madsen.** *Measuring multiple nano-textured areas simultaneously with imaging scatterometry.* Euspen conference proceedings 30 May-3 June, Nottingham, 2016. DFM-2016-P06
- **A. T. Rosell, S. R. Johannsen, K. Dirscherl, S. Daviðsdóttir, C. S. Jeppesen, S. Louring, I. H. Andersen.** *Comparing the photocatalytic activity of TiO2 at macro- and microscopic scales.* Environmental Science and Pollution Research, 1-8, 2016. DFM-2016-P07
- **R. Tanta, T. Kanne, F. Amaduzzi, Z. Liao, M. H. Madsen, E. Alarcón-Lladó, P. Krogstrup, E. Johnson, A. Fontcuberta i Morral, T. Vosch, J. Nygård and T. S. Jespersen.** *Morphology and composition of oxidized InAs nanowires studied by combined Raman spectroscopy and transmission electron microscopy.* Nanotechnology **27**, 305704, 2016. DFM-2016-P08
- **M. Lassen, L. Lamard, Y. Feng, A. Peremans, and J. C. Petersen.** *Off-axis quartz-enhanced photoacoustic spectroscopy using a pulsed nanosecond mid-infrared optical parametric oscillator.* Optics Letters **41**, 4118-4121, 2016. DFM-2016-P09
- **P. G. Westergaard and M. Lassen.** *All-optical detection of acoustic pressure waves with applications in photoacoustic spectroscopy.* Applied Optics **55**, 8266-8270, 2016. DFM-2016-P10
- **R. Barham, E. S. Olsen, D. Rodrigues, S. Barrera-Figueroa, E. Sadikoğlu and B. Karaböce.** *The calibration of a prototype occluded ear simulator designed for neonatal hearing assessment applications.* The Journal of the Acoustical Society of America **140,** 806-813, 2016. DFM-2016-P11
- **M. H. Madsen, J. S. Madsen, P. E. Hansen, P. Boher, J. Nygård, D. Dwarakanath, J. F. Jørgensen.** *Comparison of scatterometry, imaging scatterometry, AFM and confocal Microscopy.* Proceedings of the 4M/IWMF2016 Conference, (2016), DFM-2016-P12
- **M. Calaon, P. Chamberlain, M. H. Madsen, D. Hardt, G. Tosello, H. N. Hansen.** *Towards real time effective dimensional verification of high throughput Nano-Embossing manufacturing.,* Proceedings of the 4M/IWMF2016 Conference, (2016). DFM-2016-P13

- **L. Nielsen,** *Disseminating the unit of mass from multiple primary realisations.* Metrologia **53**, 1306-1316, 2016. DFM-2016-P14
- **D. D. M. Ferreira, A. C. Jakobsen, S. Massahi, F. E. Christensen, B. Shortt, J. Garnaes, A. Torras-Rosell, M. Krumrey, L. Cibik, S. Langner.** *X-ray mirror development and testing for the ATHENA mission. Space Telescopes and Instrumentation Proc.* SPIE **9905,** K1-K13, 2016. DFM-2016-P15.
- **M. Sonne, J. Cech, H. Pranov, G. Kofod, J. Garnaes, Y. C. Lam, J. Hattel, R. Taboryski.** *Modelling the deformations during the manufacturing of nanostructures on non-planar surfaces for injection moulding tool inserts.* Journal of Micromechanics and Microengineering **26**, 035014, 2016. DFM-2016-P16.
- **M. Matus, S. Haas, H. Piree, V. Gavalyugov, D. Tamakyarska, R. Thalmann, P. Balling, J. Garnaes, J. Hald, et al.** *Measurement of gauge blocks by interferometry.* Metrologia **53**, 04003, 2016. DFM-2016-P17
- **N. A. Feidenhans'l, S. Murthy, M. H. Madsen, J. C. Petersen, and R. Taboryski.** *Spatial characterization of nanotextured surfaces by visual colour imaging.* Applied Optics **55**, 9719-9723, 2016. DFM-2016-P18
- **A. Pogány, D. Balslev-Harder, C. F. Braban, N. Cassidy, V. Ebert, V. Ferracci, T. Hieta, D. Leuenberger, N. A. Martin, C. Pascale, J. Peltola, S. Persijn, C. Tiebe, M. M. Twigg, O. Vaittinen, J. v. Wijk, K. Wirtz, B. Niederhauser.** *A metrological approach to improve accuracy and reliability of ammonia measurements in ambient air.* Measurement Science and Technology **27**, 115012, 2016. DFM-2016-P19

Confidential Reports

- **H. D. Jensen.** *Måleteknisk sammenligning DPLE-04 – Måling af DC/LF Power.* DFM-2016-F01
- **M. Kjær.** *Udviklingskontrakt 2016 – 2018.* DFM-2016-F02
- **J. Hald, D. B.-Harder.** *Transfer of acetylene between sealed glass flasks.* DFM-2016-F03
- **L. Nielsen.** *DVK sammenligning 2015 – Klasse III vægt, Cely GSE 350 (30 kg).* DFM-2016-F04
- **M. Kjær, J. Hald, J. C. Petersen, J. Garnæs, M. Lassen, C. Thirstrup.** *Indspil til FORSK2025.* DFM-2016-F05
- **A. Brusch.** *BB electronics, opfølgende rapport om lyssikkerhed med fokus på brug af Excelitas kilde hos BB electronics.* DFM-2016-F06
- **L. Nielsen.** *Danvægt sammenligning 2016 – Klasse III vægt, Digi DS-673SS (6 kg).* DFM-2016-F07
- **L. Nielsen.** *Danvægt sammenligning 2016 – Klasse III vægt, Ohaus T31P/VE1500L (1500 kg).* DFM-2016-F08

Contribution at conferences

- **P. E. Hansen, L. Nielsen, M. H. Madsen.** *Characterization of Nano-textured samples using Mueller Polarimetry.* Workshop on advanced optical measurements, Berlin, Germany, January 2016. DFM-2016-K01
- **A. Torras-Rosell, K. Dirscherl, S. Davíðsdóttir.** *Establishing Traceability in Kelvin Probe Measurements for Photocatalytic Surface at the Nanometer Scale.* Nanoscale 2016, Wrocław, Poland, March 2016. DFM-2016-K02
- **J. Garnaes, M. H. Madsen, A. Torras-Rosell, A. Yacoot, M Lazzerini, V. Korpelainen, O. Lenck, I. Busch, L. Koenders, P. Klapetek, M. Valtr, P. Jelinek, D. Necas.** *Measurements and image analysis of atomic steps for calibration and improved correction of AFM measurement.* Nanoscale 2016, Wrocław, Poland, March 2016. DFM-2016-K03
- **J. S. Madsen, P. E. Hansen, B. Bilenberg, J. Nygård, M. H. Madsen.** *Measuring multiple nano-textured areas simultaneously with imaging scatterometry.* Euspen's 16th International Conference & Exibition, Nottingham, UK, May 2016. DFM-2016-K04
- **M. S. Nielsen, M. B. Munk, A. Diaz, M. Holler, J. Risbo, K. Mortensen, R. Feidenhans'l.** *Revealing the 3D nanostructure of extended colloidal networks in food emulsions using ptychographic X-ray computed tomography.* Neutrons and Food 2016, Special session on New X-ray Imaging Modalities for High Quality and Safe Food, Lund, Sweden, June 2016. DFM-2016-K05
- **M. Lassen, L. Lamard, Y. Feng, A. Peremans, J. C. Petersen.** *A Selective and Highly Sensitive MIR Photoacuostic Sensor for Trace Gas Monitoring.* LaserOptics2016, St. Petersburg, Russia, June 2016. DFM-2016-K06
- **A. Torras-Rosell, S.R. Johannsen, K. Dirscherl, S. Davíðsdóttir, C. S. Jeppesen, I. H. Andersen.** *Towards standardization and design rules for photocatalytic TiO2.* 9th European meeting on Solar Chemistry and Photocatalysis: Environmental Applications, Strasbourg, France, June 2016. DFM-2016-K07
- **P. E. Hansen, L. Nielsen, D. Dwarakanath, M. H. Madsen, J. F. Jørgensen.** *Mueller Matrix ellipsometry and Scatterometry: Simulation, Measurement and Analysis of Nano-textured Surfaces.* 7th International Conference on Spectroscopic Ellipsometry, Berlin, Germany, June 2016. DFM-2016-K08
- **M. H. Madsen, J. S. Madsen, P. E. Hansen, P. Boher, J. Nygård, D. Dwarakanath, J. F. Jørgensen.** *Comparison of scatterometry, imaging scatterometry, AFM and confocal microscopy.* 4M / IWMF, Kgs. Lyngby, Denmark, September 2016. DFM-2016-K09
- **M. H. Madsen, J. S. Madsen, P. E. Hansen, B. Bilenberg, D. Dwarakanath, J. F. Jørgensen.** *User-friendly Scatterometry.* European Optical Society Annual Meeting, Berlin, Germany, September 2016. DFM-2016-K10

- **M. Lassen, L. Lamard, Y. Feng, A. Peremans, J. C. Petersen.** *Quartz Enhanced Photoacoustic Spectroscopy with Off-axis Coupled Micro-Resonators.* The Conference on Photoacoustic and Photothermal Theory and Applications, Warsaw, Poland, September 2016. DFM-2016-K11
- **P. E.Hansen, M. H. Madsen, J. S. Madsen, L. Nielsen.** *Inverse problems solving and material properties determination.* European Optical Society Annual Meeting, Berlin, Germany, September 2016. DFM-2016-K12
- **M. H. Madsen, J. S. Madsen, B. Bilenberg, D. Dwarakanath, J. F. Jørgensen, P. E. Hansen.** *User-friendly Scatterometry.* European Optical Society Annual Meeting, Berlin, Germany, September 2016. DFM-2016-K13
- **M. Karamehmedovi´c, P. E. Hansen.** *A two-stage model of rough-interface scattering for embedded nano-structures.* European Optical Society Annual Meeting, Berlin, Germany, September 2016. DFM-2016-K14
- **K. Dirscherl, R. Ambat.** *Physicochemical properties and applications: photochemistry and photovoltaic.* International summer school "NANOSCIENCE meets METROLOGY", Torino, Italy, September 2016. DFM-2016-K15
- **H. Kerdoncuff, M. R. Pollard, P. G. Westergaard, J. C. Petersen, M. Lassen.** *Simultaneous acquisition of stimulated Raman gain spectra in orthogonal polarizations.* DOPS Annual Conference 2016, Kgs. Lyngby, Denmark, November 2016. DFM-2016-K16
- **J. S. Madsen, M. Calaon, P. E. Hansen, B. Bilenberg, A. Johansson, G. Tosello, H. N. Hansen, J. Nygård, M. H. Madsen.** *Characterization of nano-structured plastic using scatterometry. Euspen Structured & freeform surfaces***,** Kgs. Lyngby, Denmark, November 2016. DFM-2016-K17
- **M. Lassen, L. Lamard, Y. Feng, A. Peremans, J. C. Petersen.** *Quartz Enhanced Photoacoustic Spectroscopy with Off-axis Coupled Micro-Resonators.* DOPS Annual meeting 2017, Kgs. Lyngby, Denmark, November 2016. DFM-2016-K18

Other Talks

- **J. Garnæs.** *Atomic force microscopy.* Lecture at summer school in Nanotribology January 18-29 Technical University of Denmark under European Cooperation in Science and Technology, January 20, 2016
- **J. Hald.** *Status for den måletekniske udvikling - længdemetrologi på NMI niveau.* FVM Temadag, Korsør, 27 January 2016.
- **J. Hald.** *Coordination of metrology in Denmark.* EURAMET DI Workshop, Lyngby, 19 February 2016.
- **M. Lassen.** *Detection of light.* Presentation at PhD summer school Mid-IR science and technology, Humboldt University, Berlin, 29 February - 6 March 2016
- **J. Garnæs.** *Investigation on surface analysis and functionality with AFM.* Half day with lectures and exercise in course 42215 - Geometrical metrology and machine testing, The Technical University of Denmark, April 6, 2016
- **J. Hald.** *Length metrology at the primary level.* DTU course 42215, Lyngby, 13 April 2016.
- **P. E. Hansen, M. H. Madsen.** *Optical metrology for surface measurements: Past, present and future.* Presentation at World Metrology Day, DTU, May 20, 2016
- **J. Garnæs.** *Requirements to measurements of nanoparticles - how to make reliable measurements ("Krav til udmåling af nanopartikler - hvorledes laver man troværdige målinger").* The Environmental Protection Agency's network meetings (Nanonetværksmøder), Environmental Protection Agency, Copenhagen, August 18, 2016
- **J. Garnæs, M. H. Madsen.** *New applications of scatterometry, tactile measurements of mechanical surface properties, adhesion and surface structure.* 4M2020 Workshop on Micro and Nano Manufacturing: H2020 Pilot and FoF Activities 2017 Organised by 4M Association, 4M2020, HINMICO, Technical University of Denmark and University of Birmingham, September 12, 2016
- **J. Garnæs.** *Data Evaluation in Training I: Crystalline.* Lecture in the one-day training courses on Traceable Measurements at the Nanoscale organized by the partners in the EMRP project CRYSTAL - Crystaline surfaces, self-assembled structures and nanoorigami as length standards in (nano)metrology, PTB Germany, September 20, 2016
- **J. Garnæs.** *Data Evaluation in Training II: Organic.* Lecture in the one-day training courses on Traceable Measurements at the Nanoscale organized by the partners in the EMRP project CRYSTAL - Crystaline surfaces, self-assembled structures and nanoorigami as length standards in (nano)metrology, PTB Germany, September 21, 2016
- **J. Garnæs.** *Hand held roughness meters* ("Håndholdte ruhedsmålere"). Information meeting ("gå-hjem-møde") arranged by DFM in cooperation with DAMRC, Herning, October 3, 2016
- **M. Pollard.** *Raman Spectroscopy - Techniques and applications.* Information meeting ("gå-hjem møde"), November 8, 2016
- **C. Thirstrup.** *Kalibrering af ledningsevneudstyr* ("Calibration of conductivity equipment"). Information meeting ("gå-hjem møde"), December 5, 2016
- **A. Brusch.** *Lyssikkerhed* ("Light safety"). Information meeting ("gå-hjem møde"), December 13, 2016

INCOME STATEMENT AND BALANCE SHEET

INCOME STATEMENT (1000 DKK)	2016	2015
Commercial revenue	4 536	5 335
Project revenue	6 547	6 927
Government funding	20 474	14 974
Total revenue	**31 557**	**27 236**
Travel and out-of-pocket expenses	10 358	7 512
Total out-of-pocket expenses	**10 358**	**7 512**
Gross profit	**21 199**	**19 724**
Staff costs	17 759	17 061
Total costs	**17 759**	**17 061**
Operating profit before depreciation and impairment losses	**3 440**	**2 663**
Depreciation and impairment losses on property, plant and equipment	3 018	2 263
Operating profit before financial income and expenses	**422**	**400**
Financial income	2	19
Financial expenses	35	13
Profit before tax	**389**	**406**
Tax on profit for the year	42	0
Profit for the year	**347**	**406**
Profit for the year to be carried forward		

BALANCE SHEET AT 31 DECEMBER (1000 DKK)

ASSETS	2016	2015
Deposits	657	657
Total investments	**657**	**657**
Equipment	8 369	9 293
Leasehold improvements	247	1 002
Total property, plant and equipment	**8 616**	**10 295**
Total non-current assets	**9 273**	**10 952**
Contract work in progress	**3 456**	**3 603**
Trade receivables	695	949
Prepayments	143	241
Other receivables	289	299
Total receivables	**1 127**	**1 489**
Cash at bank and in hand	**14 014**	**8 510**
Total current assets	**18 597**	**13 602**
Total assets	**27 870**	**24 554**

EQUITY AND LIABILITIES	2016	2015
Share capital	1 000	1 000
Retained earnings	16 253	15 906
Total equity	**17 253**	**16 906**
Prepayments from customers and of funding	2 867	4 417
Trade payables	940	542
Other payables	6 810	2 689
Total current liabilities	**10 617**	**7648**
Total equity and liabilities	**27 870**	**24 554**

KEY FIGURES

KEY FIGURES IN MILLION DKK	2012	2013	2014	2015	2016
Net sales	21.6	25.4	27.3	27.2	31.5
Gross balance	19.2	21.6	23.9	23.7	27.8
Profit or loss for the financial year [1])	0.9	0.5	0.7	0.4	0.4
Net capital	15.3	15.8	16.5	16.9	17.2
Commercial sale	2.8	3	3.6	5.3	4.6
- to small enterprises (less than 50 employees)	0.5	0.4	0.6	0.4	0.6
- to medium size enterprises (50-250 employees)	0.7	0.7	0.7	0.8	0.9
- to large enterprises (more than 250 employees)	0.5	0.8	0.8	1.3	1.1
- to Danish public institutions	0.6	0	0.1	0.4	0.5
- to foreign enterprises and institutions	0.5	1.1	1.4	2.4	1.5
Foreign net sales	2.2	6.5	5.9	7.1	3.8

RESEARCH AND DEVELOPMENT					
Number of collaborative projects	18	21	23	23	29
- thereof innovation consortia	1	0	2	2	2
- thereof international projects	9	12	16	17	21
R&D activities (million DKK)	21.2	25.4	26.2	23.2	26.9
- thereof self-funded	2.4	3.1	1.8	2.1	1.8
R&D work (man-year)	13.9	16.2	19	17.5	17.3

NUMBER OF CUSTOMERS					
Danish private enterprises	32	31	33	25	59
- thereof small enterprises (less than 50 employees)	14	14	15	11	29
- thereof medium size enterprises (50-250 employees)	8	6	9	6	10
- thereof large enterprises (more than 250 employees)	10	11	9	8	20
Danish public institutions	11	5	3	5	10
Foreign enterprises and institutions	24	18	17	19	20
Total customer base	67	54	53	49	89

NUMBER OF STAFF CATEGORIZED BY EDUCATION (MAN-YEAR)					
Dr & PhD	13	17	18	19	21
MSc	3	3	4	4	3
Other technical staff	3	3	3	2	2
Administrative staff	2	2	2	3	3
Average number of staff	21	25	27	28	29

NUMBER OF PUBLICATIONS					
Refereed publications	7	12	14	23	19
PhD and Master theses	0	1	0	0	3
Other reports	24	15	14	14	15
Conference papers	22	18	22	15	18
Calibration certificates and measurement reports	442	417	495	521	582
Press cuttings	9	9	27	28	15

EDUCATION					
DFM courses (number of days)	2	2	2	2	3
DFM courses (number of participants)	21	4	25	22	18
Supervision/teaching at universities (number of students/courses)	9	0	6	3	3
Co-supervision of master thesis students (number of theses)	3	4	5	4	3
Contribution to teaching at universities (number of days)	5	5	6	4	3
Committee work (number of committees)	25	24	32	29	29
- thereof international committee work	22	21	27	23	23

EFFICIENCY					
Turnover per employee (1000 DKK)	1031	1011	1004	994	1011
Profit per employee (1000 DKK)	43	20	26	15	13
Commercial turnover per DKK of governmental funding	0.2	0.2	0.3	0.4	0.2
R&D turnover per DKK of governmental funding	1.5	1.7	1.8	2.1	1.6

1) Excluding extraordinary items

DANISH METROLOGY INSTITUTES

According to the CIPM Mutual Recognition Arrangement, a country can have one national metrology 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 for Calibration and Measurement Capabilities. The fields covered by the appointments are indicated in the table on the next page. DELTA, Danish Electronics, Lights & Acoustics, was a designated institute in the subfield humidity until the merger with FORCE Technology at the end of 2016. The activities in humidity continue under FORCE Technology's designation.

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

DTU
Technical University of Denmark
Anker Engelunds Vej 1, Building 101A
DK 2800 Kgs. Lyngby
Contact: To be announced

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

FORCE
FORCE Technology
Navervej 1, DK 6600 Vejen
Contact: Mogens Simonsen
Phone: +45 7696 1630
mss@force.dk

DTI
Danish Technological Institute
Kongsvang Allé 29, DK 8000 Århus C
Contact: Jan Nielsen
Phone: +45 7220 1236
jnn@teknologisk.dk

TRESCAL
Trescal A/S
Mads Clausens Vej 12, DK 8600 Silkeborg
Contact: Torsten Lippert
Phone: +45 8720 6969
Torsten.Lippert@trescal.co

THE 12 SUBJECT FIELDS OF METROLOGY

Fundamental metrology in Denmark follows the EURAMET division into 12 subject fields, while the subfields reflect a Danish subdivision of metrological activities. 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 parenthesis.

SUBJECT FIELD	CONTACT PERSON	SUBFIELDS	METROLOGY INSTITUTE
MASS AND RELATED QUANTITIES	Lars Nielsen, DFM	Mass measurement	DFM
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LENGTH	Jan Hald, DFM	Basic length measurements	DFM
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		Anemometry	DTI
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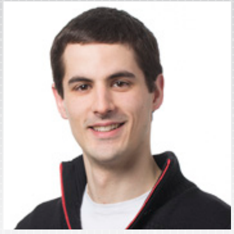

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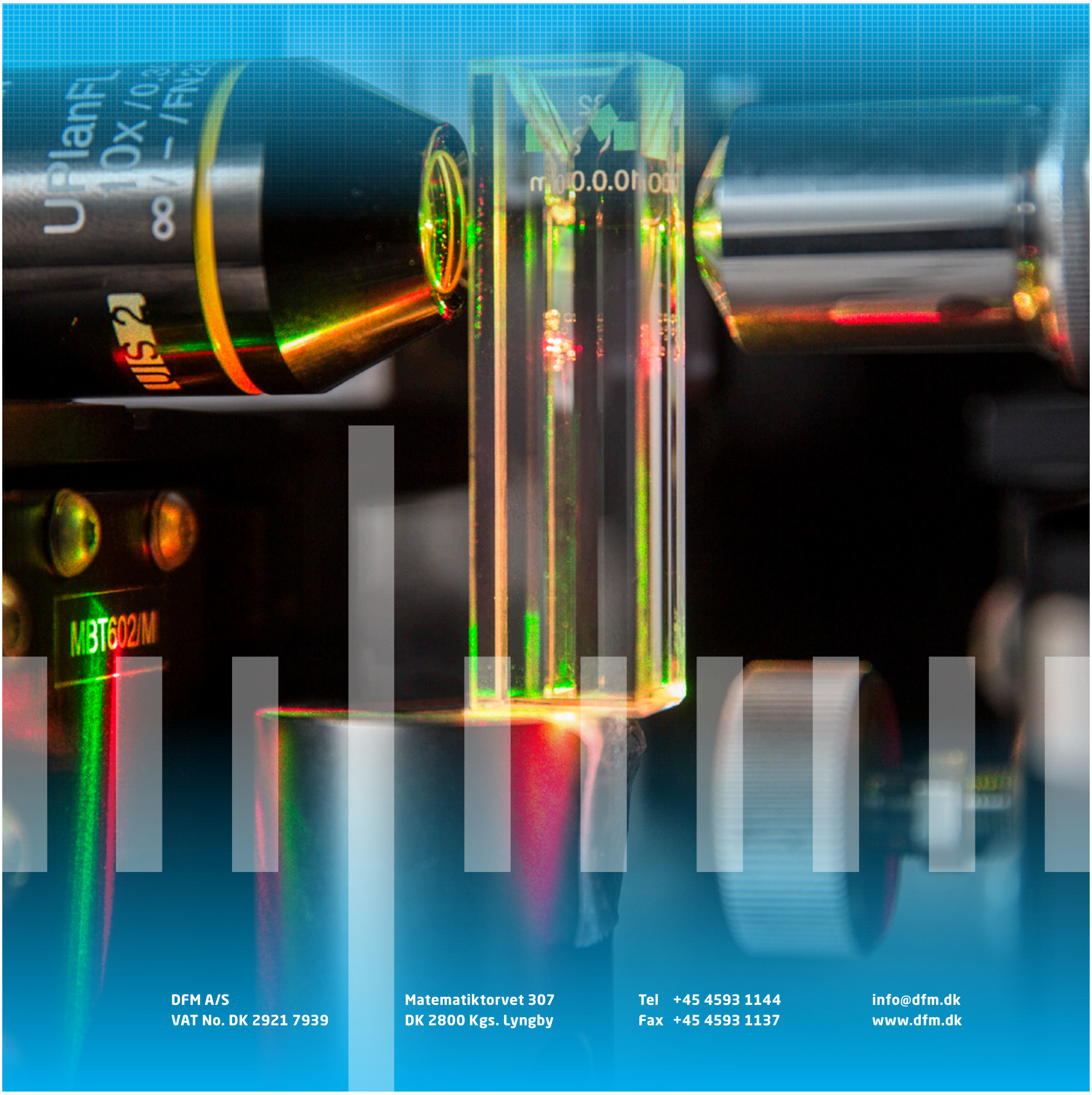

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