DFM
Danish National Metrology Institute

ANNUAL REPORT
2017

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 2017 EDITED BY
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TABLE OF CONTENTS

IMPACT OF METROLOGY

Measurement plays a critical role in providing a basis for accurate and fair trade, optimization of production, the promotion of consumer and business confidence in products, the development of new technologies, and continued innovation.

Measurements of physical and chemical quantities are part of our everyday lives. Industry relies heavily on accurate measurements to foster innovation and develop efficient manufacturing methods. A wide range of measurements are occurring daily, with the extent of their benefits on our daily lives generally going unnoticed. Fair trade, consumer protection, health & safety, law and order, and environment monitoring are just some of the areas of modern life, in which the benefits of accurate, trustworthy measurements have real impact.

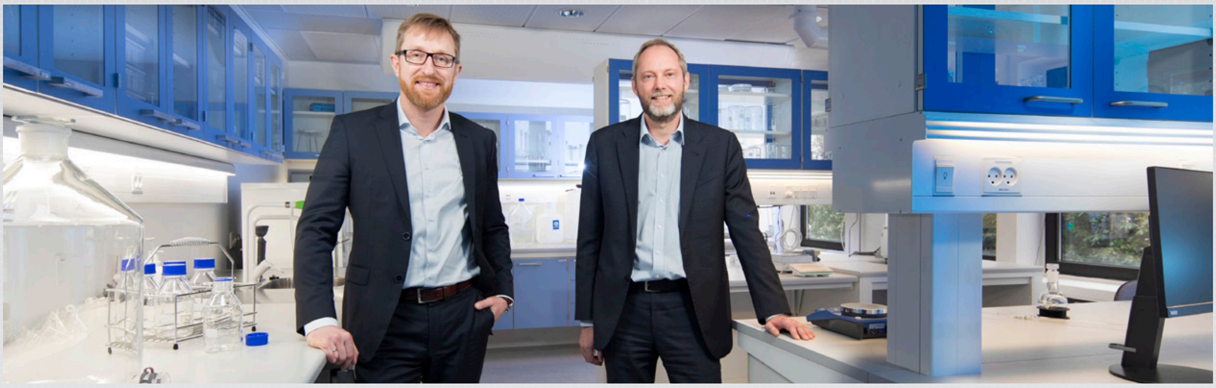
Metrology links science and economic activity closely, as measurement is a cornerstone for economic transactions, optimization of production, consumer and business confidence, and innovation.

Key economic benefits include reduced transaction costs, increased economic efficiency, and support for innovation.

Greater market efficiency arises from trust. Accurate measurements, based on agreed upon standards, methods, and systems of units, enable a common basis for quantification and quality assurance. Under this framework, a buyer can trust the specifications ascribed to a product, as supplied by the manufacturer/trader partner or assured by a third party (accredited laboratory), including the quality of the trade goods. Hence, time and money are saved through avoidance of re-verification of such properties. Dependable measurements thus facilitate more numerous and efficient economic transactions.

National measurement institutes, such as DFM, play a key role in managing and developing national measurement systems, providing measurement standards and calibration-testing facilities, and enabling businesses to make accurate and traceable measurements.

MANAGEMENT REPORT 2017



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

DFM has experienced significant growth in recent years, and at the end of 2016 it was decided to move all activities to a new and larger facility. The relocation was completed in December 2017. DFM's total revenue for the year grew 11 % to 35.0 million DKK – the highest in DFM's history. The profit was 0.5 million DKK in line with the budget. The management is pleased with DFM's growth, and considers both revenue and profit as satisfactory.

Overall research activities increased in 2017, partly due to increased participation in H2020 projects as well as other national and international projects, partly due to entering into a new metrology area "metrology for drones". The activities have led to introduction of new metrology services for Danish industry and ensured that DFM maintained a high number of publications in international refereed journals.

DFM invested 15,9 million DKK in new, improved and expanded laboratory infrastructure at the new facility. The infrastructure is optimized for future metrology requirements by Danish industry. The investment is by far the largest in DFM's history, and will ensure that DFM can continue to expand activities in the future as well as provide opportunities for industry to directly make use of DFM's infrastructure.

Sales of calibration services grew 36 % driven primarily by increased demand from the pharmaceutical sector. The total number of customers also increased, demonstrating the increasing need for advanced metrology competences and services.

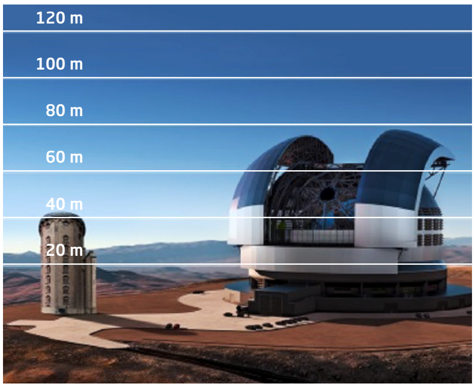
DFM continues to support Danish SMEs by providing new technology to underpin their growth. This is partly accomplished on a commercial basis, partly by collaboration in funded projects. There was an increase in total project activities as well as the number of involved SMEs. DFM was awarded a range of new H2020 projects in 2017 including Eurostars, Eureka Turbo and EMPIR projects.

DFM will continue to focus on developing new advanced metrology services required by industry and expects to continue to grow in the future, as demand continues to increase.

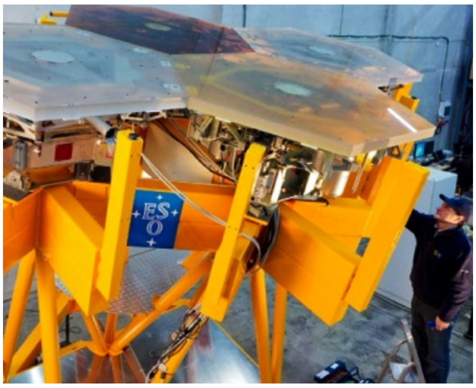
Bjarne Fjeldsted
Chairman of the Board

Michael Kjær
CEO

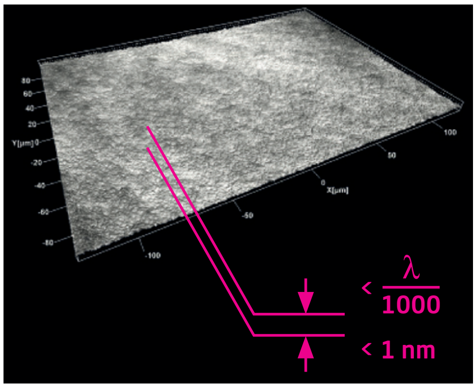
QUALITY ASSURANCE OF THE BIGGEST EUROPEAN MIRROR TELESCOPE



Artistic impression: The E-ELT compared to the Round Tower in Copenhagen, Denmark. Credit: ESO



Assembled E-ELT mirror segments undergoing testing. Credit: ESO/H.-H. Heyer



The mirror roughness is up to 1000x smaller than the wavelength of light.

As part of the maintenance of the reflective European Extremely Large Telescope, the development of a new beyond state-of-the-art procedure has been required. DFM has used its advanced nanometrology facilities to measure surface roughness with sub-nanometer accuracy, which is required to provide a performance 16 times better than the Hubble Space telescope.

The European Southern Observatory agency is currently constructing the European Extremely Large Telescope (E-ELT) on a Chilean mountain at 3000 m above sea level. The 39.3 m diameter reflecting telescope consists of 798 mirror segments that can be individually corrected for atmospheric disturbances by active optics (laser guide star units), complemented by adaptive optics. The observatory aims to gather 100 million times more light than the human eye is capable of, which is 13 times greater than the largest optical telescopes have achieved so far. It has around 256 times the light gathering area of the Hubble Space Telescope and, according its specifications, should provide images 16 times sharper than Hubble's. The E-ELT is planned to "see first light" (be operational) in 2024.

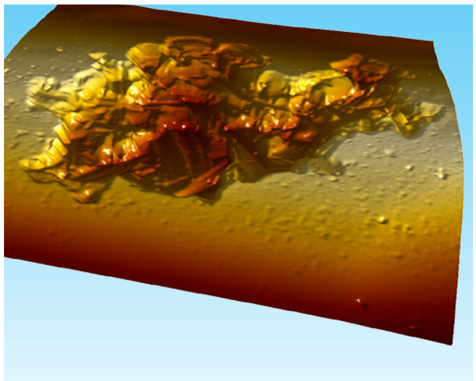
These ambitions require beyond state-of-the-art maintenance procedures for all the mirror segments, which need to undergo, periodically, a thorough recoating process. During this process, the reflection layer of each mirror is chemically stripped from the underlying glass substrate, followed by fresh re-deposition in order to consistently produce a high-quality reflective surface, with a surface roughness in the order of 1 nanometer. Existing state-of-the-art procedures are not applicable, as the observatory's isolated location poses huge logistic challenges for both the sourcing of stripping chemicals, as well as waste disposal. In addition, the sheer size of each hexagonal mirror segment (1.4 m across) requires a high level of homogeneity and thoroughness in each treatment. The situation gets further complicated by the anticipated occasional earth-quakes in the Chilean mountain region.

The existing stripping processes have been reviewed by DTU IPU and Professor P. Møller (DTU Mechanical Engineering). DFM has participated in this process with itsaccredited measurement capability for surface roughness with sub-nanometer accuracy. During the development of the highly sophisticated new cleaning procedure, DFM measured on various glass samples before and after they had undergone a series of cleaning sequences, which simulated the wear during a mirror's lifetime on the mountain top. Measuring methods have been applied using both optical non-contact interferometric microscopy and tactile atomic force microscopy in order to produce 3D images of the glass surfaces on the nanometer scale. With these high-resolution imaging techniques capable of seeing steps of single atomic layers on the substrate, DFM has contributed to assuring the partners that each mirror segment, over its total expected life time, with up to 20 cleaning processes anticipated, can be stripped and recoated with the same high-quality reflective finish over and over again. We look forward to 2024 and the E-ELT's "first light"!

RELIABLE MEASUREMENTS TO DOCUMENT THE STATE OF WIND TURBINE BLADES


Erosion damages on a blade are studied using replication molding.


Replica of the damage can be transferred to the lab for measurements.


Microscopy measurements reveal the surface topography of the erosion damage.

Erosion of wind turbine blades has a vital effect on their energy production capability. DFM is partner in a project developing a new blade inspection system that will provide reliable quantification of the erosion. This is highly correlated to the annual energy production of wind turbines.

Over time, an increasing leading edge roughness (LER) of wind turbine blades due to erosion reduces the aerodynamic performance and hence the annual energy production (AEP). With increasing erosion, the turbine owners have to decide if the loss in AEP becomes large enough to warrant repair. However, current methods of visual inspection of erosion give very limited information to aid in this decisionmaking. Accordingly, no tools currently exist for quantitatively linking the state of a blade to the aerodynamic performance and loss in AEP.

This is why DFM is partnering with DTU Wind, AAU, and Power Curve to develop a quantitative LER inspection tool in the EUDP project "Leading Edge Roughness of wind turbine blades". The system uses a flying drone developed by AAU to do high resolution 3D reconstruction of the blades' surface and quantify the amount of erosion. Subsequently, DTU Wind are turning these erosion measurements into estimates of reduced AEP. Ultimately, this system is to be sold by Power Curve.

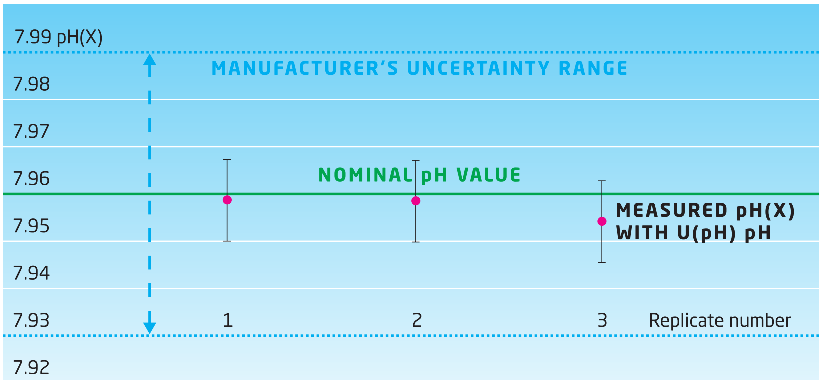
To ensure an accurate estimate of the AEP loss, the role of DFM is to validate the accuracy of the 3D reconstructions and ensure a reliable quantification of the erosion. DFM carried out 3D topography measurements on reference artefacts using microscopy methods. DFM then compared these results with the 3D reconstructions from the AAU system. Since very little knowledge about the geometry of blade erosion is available, a quantitative description has to be developed in the project. In order to study the topography of the erosion on real-life blades in the laboratory, DFM copied the selected area of the blade by replication molding. Then, DFM carried out a 3D measurement of the replica by means of microscopy.

LEADING EDGE ROUGHNESS (LER)

When in operation, the blades of a wind turbine move through the air at high speeds. For large turbines the rotation speed at the tip of the blade can exceed 300 km/h. Impact of dust particles and rain droplets on the leading edge at these speeds lead to erosion effects. Over time, the continued erosion removes the smoothly coated surface and leaves behind a rough surface topography. This impacts the aerodynamic performance of the blade. Large protrusions or cavities on the surface can cause the airflow to become turbulent which reduces the lift and increases the drag of the blade. In turn, a decrease in lift leads to a reduced annual energy production of the wind turbine.

"We have chosen to work with DFM because they have unique skills required to validate our "eyes" in the air. They develop validation and quality assurance tools for the 3D reconstructions as the accuracy is absolutely crucial" says Niels Fiil Brønnum (CEO of Power Curve). He continues: "When I sell the product, it is also a quality stamp to the customer that DFM has been involved to document the reliability of our measurements. The involvement of experts means a lot for the credibility of our product."

HIGH ACCURACY SECONDARY pH BUFFER MEASUREMENT



At 25°C, using two bracketing pH standards (pH(S1) = 7.413 and pH(S2) = 9.18), measurement of an unknown buffered solution with nominal pH(X) = 7.96 ± 0.03. Demonstrating the agreement between measured and nominal values, within manufacturer's uncertainty, improved expanded uncertainty of each measurement, and agreement between experimental replicates.

As a response to industrial demand, DFM can now provide secondary pH buffer measurements with lower uncertainty than previously available. Buffers used by industry generally have long shelf life and relative high uncertainty. DFM's new service will aid in reducing the uncertainties for the benefit of medical applications.

In chemistry, pH measurements are one of the most frequently measured parameters of aqueous solutions, in a wide variety of industries: manufacturing, pharmaceuticals, water treatment etc. Routine pH measurements are carried out using commercially-available pH electrodes: a very common tool, found everywhere from the classroom to the production floor. These deliver measurements which can be fast, reliable, and depending on the solution under measurement, dependable over the span of years. However, they are extremely sensitive, requiring stringent storage conditions, frequent regeneration and calibration procedures.

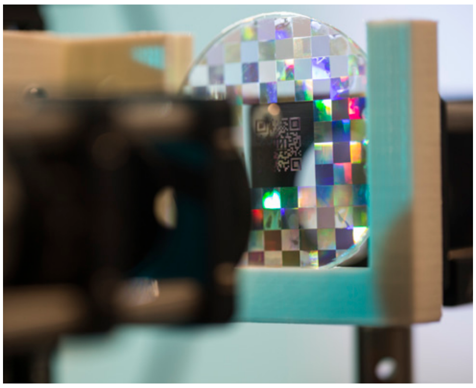
The accuracy of pH measurements made with commercial electrodes are dependent on the quality of the solutions employed for calibration. The pH of standard buffers, and the behavior of pH electrodes are temperature dependent. Such that, ideally, pH electrode calibration and routine measurements should be done under identical temperature conditions. Calibration buffers are available from a wide range of suppliers. These may come with a range of features, including added colorants for ease of use, but are all relatively cheap and have long shelf-lives, spanning multiple years. To accommodate the bottle-to-bottle differences of production batches, and gradual change over time, these commercial buffers may have relatively high uncertainties in their pH values.

The lowest possible uncertainties in pH values can be attributed to primary buffers: an internationally agreed set of 8 buffers, which have their pH values certified using the primary method. While DFM produces five of these buffers (pH 4-10) annually, the complexity of their production and certification, as well as extremely short shelf-lives, make their routine use for pH electrode calibration prohibitive. In 2017, DFM developed a system for the certification of secondary pH buffers. The certification setup includes a thermostated chamber, allowing temperature control of 0.005°C between 25 and 37°C.

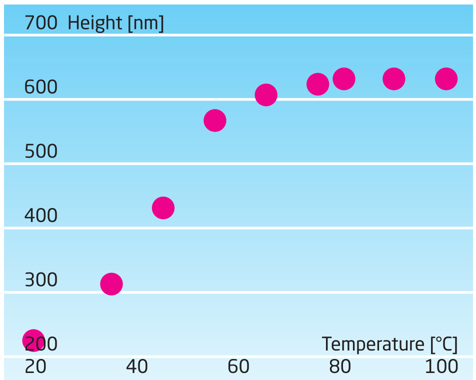
The certification of an unknown buffered solution is performed by a high quality pH electrode, which is calibrated in-situ, under identical temperature and mixing/flow conditions. The calibration procedure is bracketing (i.e., one pH value higher, and one lower than the solution under test), with two certified secondary pH buffers, traceable to DFM's primary pH buffers. Depending on the bracketing pH buffer combinations, the uncertainty of pH measurements of unknown solutions can be as low as 0.008 pH units (expanded uncertainty). This is demonstrated for a non-standard buffer, pH(X), at 25°C in the graph above.

TOWARDS IN-LINE CONTROL OF MASS-PRODUCED NANOSTRUCTURES

Portable scatterometer to characterize nanostructures at the fabrication sites.



Mass-produced nanostructured sample in scatterometer. The colors are a result of the surface structure alone.



Replicated structure height as a function of the molding temperature.

DFM has developed a portable scatterometer, including user-friendly software, for high-speed measurement of injection molded functional nanostructures. The instrument is well suited for in-line quality control of all produced items and thus contribute to minimizing faulty products and reducing costs for these highly demanded consumer products.

By accurate engineering on the nanometer scale, surfaces can be imparted functionalities such as colors without paint and self-cleaning properties. A common method for mass production of components is injection molding. To ensure that the nanostructures result in the desired physical properties (i.e., imparting colors to the molded parts), injection molded parts have very strict tolerances on the nanoscale. However, it is a challenge to perform quality control on the nanoscale in the short production time between mass-produced parts. This creates high market entry-barriers for companies that want to implement nanostructures in their production. New fast, accurate, and user-friendly metrology solutions are needed, before nano-structured products can be mass produced reliably.

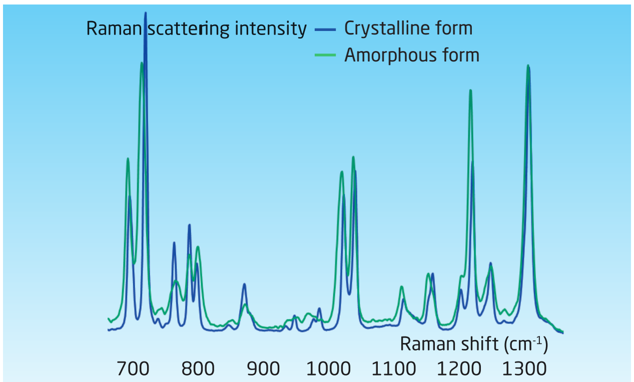
A promising technique for in-line nanoscale metrology is scatterometry. Scatterometry is an optical method, where nanostructures are reconstructed through inverse modelling based on an optical "fingerprint" of the sample. In several recently completed projects, DFM has aimed at improving the use of scatterometry for routine quality control. The InFoScat project has developed algorithms for simulation and comparison of these fingerprints. The algorithms have been implemented in a user-friendly software package by Image Metrology. During the SuperLens project a portable scatterometer was constructed for experimental measurements. This scatterometer uses the InFoScat software to characterize nanostructures in milliseconds. This scatterometer was tested at Polyoptics GmbH. There, the scatterometer demonstrated the required speed (less than one minute), accuracy, and robustness for in-line characterization of nano-textured injection molded samples. Furthermore, the scatterometer could be used to optimize injection molding recipes governed by a large number of system parameters.

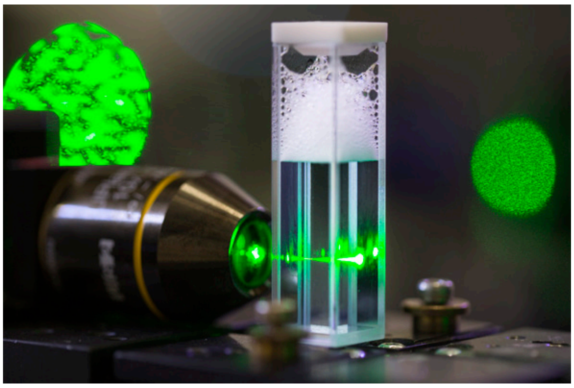
The DFM scatterometer and the InFoScat software helped us improving the injection molding process in such a short time with direct feedback on the quality of the replicated nanostructures

Lars Nakotte, Project manager at Polyoptics

By performing quality control on all parts, companies will be able to move from a good practice approach, where selected components are checked daily, to an approach whereby all components are checked for defects and production failures. This will result in fewer faults, and thereby cheaper and better products. Such rigorous quality control could be performed by means of scatterometry.

RAMAN SPECTROSCOPY – A POWERFUL ANALYTICAL TOOL FOR PHARMACEUTICAL FORMULATION DEVELOPMENT





The Raman spectra of the crystalline and amorphous forms of a drug (e.g., carbamazepine) often display clear differences. These enable identification and quantification of the solid-state properties of the drug. Typically, amorphous solids have Raman spectra with broader peaks that can appear slightly shifted, with different heights compared to their crystalline counterparts.

Raman spectroscopy has a large potential for quality assurance in the pharmaceutical industry. DFM is developing new methods and services for quantitative measurements of drugs, during each step in the manufacturing process, in close collaboration with actors in the field.

For several decades, infrared spectroscopy has been commonly used in pharmaceutical analysis for its capacity to provide reliable quantitative measurements of substances. Nowadays Raman spectroscopy is catching up by offering higher selectivity and versatility towards detection and quantification of different substances, especially in aqueous samples. It offers the possibility of non-destructive in-situ quantitative measurements, which are highly sought after in pharmaceutical and biomedical sciences. Due to the high specificity of Raman spectra, Raman spectroscopy also enables identification of material properties beyond chemical composition, such as protein structure and crystal structures.

A large number of new drug candidates have poor aqueous solubility, which strongly limits their bioavailability in conventional formulations. A solution is to use the amorphous form of the drugs, which has higher solubility, faster dissolution rates, and enhanced oral bioavailability. However, amorphous solids are unstable and tend to crystallize during preparation and storage. The bioavailability and stability of amorphous drug formulations are both major research topics in pharmaceutical sciences.

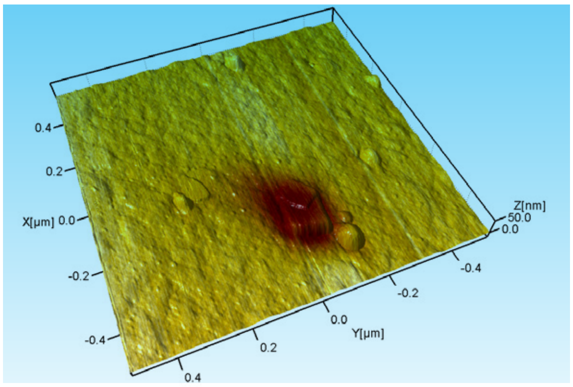
In 2017, DFM and Bioneer collaborated with the department of pharmacy at KU, in a pharmaceutical formulation study aimed at preparing amorphous solid dispersions of drugs in polymer, in order to achieve improved stability and bioavailability. The study investigated the efficiency of a novel preparation method, which consists of irradiating mixed tablets of drug and polymer in a commercial microwave oven. The resulting amorphous content of the microwaved tablets was measured by quantitative transmission Raman spectroscopy. Compared to conventional Raman spectroscopy, transmission Raman spectroscopy probes the bulk content of a sample thereby allowing for quantification of the proportion of amorphous and crystalline drug within the tablets.

The result of the study proved the effectiveness of Raman spectroscopy for acquiring accurate and reliable quantification of the solid-state properties of a drug formulation and confirmed its benefits for the pharmaceutical industry.

THE RAMAN SPECTROSCOPY ACTIVITY

Since 2016, DFM has been involved in a Results Contract ("Resultatkontrakt") with the Danish Agency for Institutions and Educational Grants with the aim of establishing expertise in the field of quantitative Raman spectroscopy. This research is performed in collaboration with another GTS institute, Bioneer, and especially targets the Danish pharmaceutical industry, which has a constant need for improved analytical tools in both development and production of pharmaceuticals.

PHOTOCATALYSIS UNDER THE MICROSCOPE



SKPFM 3D image showing two rectangularly shaped TiO_2 nanoparticles on top of each other. Due to the photocatalytic activity of the TiO_2 nanoparticles there is a drop in the contact potential at the nanoparticles' position compared to the rest of the surface. This drop in contact potential is seen as a red color in the image.

TiO_2 nanomaterials are known for their numerous and diverse applications. DFM, as partner in an EU project, has correlated a number of physical properties to the photocatalytic activity of TiO_2, which industry can use for optimizing the photocatalytic performance of TiO_2.

Titanium dioxide (TiO_2) has many remarkable properties, and is widely applied in a variety of industries, including cosmetics, paint and solar cell industries. Some of these properties were addressed in the pan-European SetNano-Metro project, where focus was on the use of TiO_2 in solar cell applications and TiO_2 as a self-cleaning coating; when illuminating TiO_2 with UV light, reactive radicals are created on the surface, which in turn will degrade organic material like dirt or oil, keeping the surface clean.

DFM can now characterize TiO_2 nanoparticles and coatings using a Scanning Kelvin Probe Force Microscope (SKPFM), where the contact surface potential enables distinction between materials with regard to their electronic pro-perties. DFM's contributions to the SetNanoMetro project consisted of measuring the photocatalytic activity using this technique. Due to the high resolution of SKPFM, it was possible to study single TiO_2 nanoparticles and their photocatalytic response to UV light. Various nanoparticles of different shape, size, and phase crystallinity were characterized in order to correlate these parameters to the photocatalytic activity of TiO_2. This approach resulted in some general design rules, which the industry can utilize to optimize the photocatalytic performance of TiO_2 nanoparticles and coatings.

DFM has developed a measurement procedure, which establishes traceability between nano- and macroscopic scale photocatalytic measurements. This has resulted in DFM providing a new service, verifying the photocatalytic activity of TiO2 nanomaterial samples and references, accompanied by a measurement report. The applied reference material is highly pure and produced in various morphologies, such as nano-sized rods and flat .nano-platelets, and is provided by the partners in SetNano-Metro.

THE SETNANOMETRO PROJECT

The SetNanoMetro project was supported by the European Commission under the 7th Framework Programme. Besides DFM, the project involved a total of 15 partners from nine European countries, and lasted for three years. The main task of the project was to analyze nano-crystals made of titanium dioxide (TiO_2), The project resulted in **1)** the design and production of certified reference materials of TiO_2, and **2)** the development of standard characterization procedures for obtaining knowledge of the size, shape, and crystalline phase of TiO_2 nanoparticles. DFM's expertise was needed in order to establish proper traceability and determination of uncertainty for the quantification of the photocatalytic effect of TiO_2 on the nanometer-scale.

NEW PART-TIME EDUCATION IN MEASUREMENT TECHNOLOGY

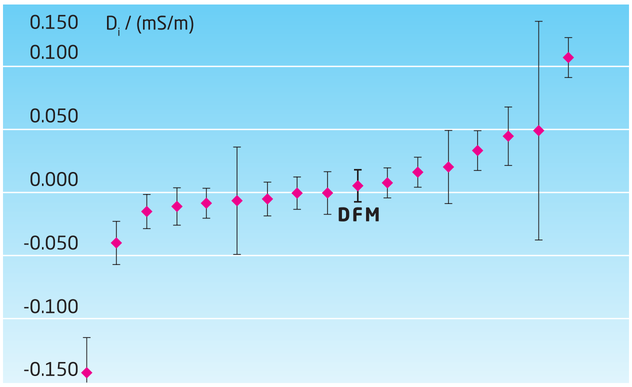
Viewpoints and requirements for educational training needs on measurement technology and metrology, were fruitfully discussed at the two Stakeholder workshops held in Århus and Roskilde, with participation from Danish production industries, business academies (EAAA and EASJ) and the metrology.dk partners.

DFM has led a project aiming at strengthening education in metrology in Denmark. A survey has demonstrated the need. In consultancy with educators, the project has generated substantial written material which support education in measurement technology, starting in 2018. This initiative will allow industry to hire well qualified metrology technicians in the future.

New education: Technical personnel who have a solid understanding of measurements, calibrations, and basic statistics are in high demand. However, the absence of a dedicated technical education in the field may pose a challenge to recruitment. This was substantiated in a questionnaire survey executed by DFM, Zealand Institute of Business and Technology, and Business Academy Aarhus. The 85 responding companies with relevant measurement activities were geographically well distributed across the nation, with a wide variety of sectors represented (50% Production, 30% Calibration & Consulting, and 16% R&D companies). Within the last couple of years, 82% of these companies had had troubles hiring personnel with practical competences within quality and technical measurement. Nearly 70% of companies supported that a new part-time education on quality and measurement technology should be created. Based on the responses, the nation wide need for upqualification of employees was estimated to be more than 5000 over the coming five years The companies also requested that a full-time education be initiated. In spring 2017, the Ministry permissioned the establishment of the new 2 year, part-time education, granting the title "måleteknolog"; the first classes will start summer 2018.

Activities: During spring 2017, a large emphasis was put on establishing new contacts with educators, by having more than 15 meetings at 10 different institutions. These meetings were crucial in establishing a better understanding of their requirements and in bringing about the realization that the demand for the teaching material was much greater than at first anticipated. During 2017, a new web-portal for metrology.dk was launched. The portal provides open access to all the teaching material. The latest statistics on the site show more than 6000 hits within a month, and that material has been downloaded by more than 30 users within the same period. Small-to-medium enterprises have also found the material helpful. Over the course of the first two years a total of 20 teaching packets have been developed by DFM and FORCE Technology. The material puts emphasis on providing the students with critical insight towards measurements and setting up uncertainty budgets. Preliminary evaluations provided by the educators are generally positive and there is a wide-scale request for more material. Therefore, a continuation of the project beyond 2018 will be applied for, seeking to establish an official network for metrology teaching material with representatives from GTS, industry and education, making metrologi.dk a common reference point.

INTERNATIONAL COMPARABILITY OF ELECTROLYTIC CONDUCTIVITY



Degrees of equivalence and the corresponding expanded uncertainties of the 5 mS/m HCl solution.

Electrolytic conductivity CRM production in the chemistry laboratory.

Excellent results in international key comparisons ensure that measurement services offered by DFM are of the highest international standard. Equivalence assures that Danish companies may operate and expand on international markets.

A particular highlight this year for Electrochemistry, was participation in an international key comparison, CCQM-K36 "Electrolytic Conductivity at 0.5 S m^{-1} and 5 mS m^{-1}", organized by the Consultative Committee on the Quantity of Material (CCQM), part of the Bureau International des Poids et Mesures (BIPM). This comparison helps to ensure that measurement services offered by Electrochemistry are of the highest standard, by testing the measurement capabilities of DFM relative to other National Metrology Institutes (NMIs). These comparisons are therefore very important, not only in DFM's role as the national metrology institute, but also for those who rely on DFM's services in electrolytic conductivity. By benchmarking our measurement capacity against global NMIs, we offer continued evidence of our world-class measurement proficiency, all traceable to the SI.

For CCQM-K36, two solutions of nominal conductivity and composition: 0.5 S/m $KCl_{(aq)}$ and 5 mS/m $HCl_{(aq)}$, were prepared at the coordinating NMI. Measurement of the 0.5 S/m $KCl_{(aq)}$ solution was straightforward; particularly given that we regularly produce CRM $KCl_{(aq)}$ solutions in the range 0.01 S/m to 10 S/m. The 5 mS/m $HCl_{(aq)}$ solution was observed, by the organizing laboratory, to drift with time, this made measurement of the sample and comparison of the obtained results more complex.

The 5 mS/m $HCl_{(aq)}$ solution was chosen as it is not possible to use purely aqueous salt solutions as reference standards for electrolytic conductivity at 5 mS/m or below. This is as the contribution from dissolved atmospheric carbon dioxide (CO_2) becomes significant, and the solutions are often unstable. CO_2 reacts with water to form carbonic acid, this is a source of charge carrying ions, thus contributing to solution conductivity. The instability is due to the variability of CO_2 in the solution, which changes with ambient atmospheric CO_2 and pressure. For this reason, non-aqueous, $HCl_{(aq)}$ or mixed solvent solutions must be used for CRMs in these low conductivity ranges. In these solutions, a lower CO_2 solubility results in the suppression of its effect on solution conductivity.

During CCQM-K36, the observed drift was determined to be approximately linear, this was compensated for during measurement at DFM and, between measurements, at the organizing laboratory. The final report for this comparison is available via Metrologia and the BIPM websites. From this report, it can be seen that the values obtained using DFM's equipment and procedures are in excellent agreement with the reported reference values for each solution.

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)
- NMI Directors Meeting

PARTICIPATION IN NATIONAL AND INTERNATIONAL PROJECTS

- Scanning Neutral Helium Microscopy (NEMI), EU FP7
- Center for LED metrology (LedMet), IF
- Advanced laser-based heat sensor for fire detection (Firedetect), IF/Eurostars
- A Novel Non-Invasive Trace Gas Analyser Platform Targeting Breath Analysis (NxPAS), IF/Eurostars
- Industrial Fourier Scatterometer (InFoScat), IF/Eurostars
- Metrology for Highly-Parallel Manufacturing (MetHPM), SIU/EMPIR
- Metrology for Innovative Nanoparticles (Innanopart), SIU/EMPIR
- Leading Edge Roughness Wind Turbine Blades (LER), EUPD
- Optical Plastic Lenses with Super-Hydrophobic Surface Properties (SuperLens), IF/Eurostars
- Photo-Acoustic Sensor for Oil Detection in Compressed Air (PASOCA), IF/Eurostars
- Metrology for Additively Manufactured Medical Implants (MetAMMI), SIU/EMPIR
- Metrology for Modern Hearing Assessment and Protecting Public Health from Emerging Noise Sources (Ears II), SIU/EMPIR
- Underwater Acoustic Calibration Standards for Frequencies Below 1 kHz (UNAC-LOW), SIU/EMPIR
- Traceable Three-Dimensional Nanometrology (3DNano), SIU/EMPIR
- Continuous Pesticide Sensing in the Environment (CoPS), IF/Eurostars
- Photoacoustic Infrared Microscope for Automated Histopathology (PIRMAH), IF/Eurostars
- Corrosion detection on offshore platforms by drones (OFFSHORE), the European Regional Development Fund "EU's Regional Fond"
- Traceable in-line Optical Measurement of Nano and Micro Roughness (OptoRough), IF/Eurostars
- Quantum Measurement Enhanced Gravitational Wave Detection (Q-GWD), IF/Eureka Turbo
- Shape-Engineered TiO_2 Nanoparticles for Metrology of Functional Properties (SETNanoMetro), EU FP7
- Metrology for High-Impact Greenhouse Gases (HighGas), SIU/EMRP
- Metrology for Ammonia in Ambient Air (MetNH_3), SIU/EMRP
- Traceable Characterisation of Thin-Film Materials for Energy Applications (ThinErgy), SIU/EMRP
- UV-induceret biofilmforebyggelse (BIOFORS), IF

- Metrology for Length-Scale Engineering of Materials (Strength-ABLE), SIU/EMPIR
- Quantum Innovation Center (Qubiz), IF
- Advanced Surface Treatments for Superior Plastic Injection Moulds (SuperMoulds), IF
- Aerosol Metrology for Atmospheric Science and Air Quality (Aeromet), SIU/EMPIR
- Metrology for Stable Isotope Reference Standards (SIRS), SIU/EMPIR

The list of DFM research projects includes no less than 8 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 requires participation from at least two member states.

DFM REPORTS

- **S.R. Johannsen, A.T. Rosell, K. Dirscherl, C.S. Jeppesen, S. Louring.** *Design Rules for Photo-catalytic Activity.*DFM-2017-R001
- **P.-E. Hansen, S.A. Jensen.** *Mueller Polarimetry data analysis of solar cells with large roughness.* DFM-2017-R002
- **P.-E. Hansen, S.R. Johannsen.** *Influence of oxygen exposure on organic solar cells materials.* DFM-2017-R003
- **S.A. Jensen, P.-E. Hansen.** *Good Practice Guide Mueller Polarimetry measurements on PV Films.* DFM-2017-R004
- **H. Kerdoncuff, W.-I. Lin, L.J. Wacker.** *Spectroscopic techniques for corrosion detection using drones.* DFM-2017-R005
- **A. Brusch, M. Lassen** *FaunaPhotonics, Opticstudio optimization.* DFM-2017-R006
- **O.S. Nielsen, J.C. Petersen, J. Hald, L.C. Deleebeeck.** *DFM Annual Report 2016.* DFM-2017-R007

CALIBRATION CERTIFICATES AND MEASUREMENT REPORTS

DC Electricity	2
Electrochemistry	448
Mass	11
Length	46
Optical Radiometry	28
Nano Structures	13
Acoustics	73
Particle Metrology	96
Total	**717**

PUBLICATIONS IN REFEREED JOURNALS

- **J. Wang, J.T. Barnett, M.R. Pollard, N.M. Kad.** *Integrating Optical Tweezers, DNA Tightropes, and Single-Molecule Fluorescence Imaging: Pitfalls and Traps.* Methods in Enzymology **582,** 171-192, 2017. DFM-2017-P01
- **T. Talvard, P.G. Westergaard, M.V. DePalatis, N.F. Mortensen, M. Drewsen, B. Gøth, J. Hald.** *Enhancement of the performance of a fiber-based frequency comb by referencing to an acetylene-stabilized fiber laser.* Optics Express **25,** 2259-2269, 2017. DFM-2017-P02
- **S.A. Jensen, K. Dirscherl, K.A.S. Hansen, J. Lorentzen.** *UV light from optical fibers to counteract biofilm in medical devices* – "UV-Lys fra optiske fibre til modvirkning af biofilm i medicinsk udstyr". Medicoteknik **2,** 22-23, 2017. DFM-2017-P03
- **J.C. Petersen, L. Lamard, Y. Feng, J.-F. Focant, A. Peremans, M. Lassen.** *Quartz-enhanced photo-acoustic spectroscopy for breath analyses.* Proc. Of SPIE **10055,** 1005503-1-6, 2017. DFM-2017-P04
- **M. Lassen, D. B.-Harder, A. Brusch, O.S. Nielsen, D. Heikens, S. Persijn, J.C. Petersen.** *Photo-acoustic sensor for detection of oil contamination in compressed air systems.* Optics Express **25,** 1806-1814, 2017. DFM-2017-P05
- **G. Aprile, F.F. Lupi, M. Fretto, E. Enrico, N.D. Leo, L. Boarino, F.G. Volpe, G. Seguini, K. Sparnacci, V. Gianotti, M. Laus, J. Garnæs, M. Perego.** *Towards Lateral Length Standards at the Nanoscale Based on Diblock Copolymers.* ACS Applied Materials & Interfaces **9,** 15685-15697, 2017. DFM-2017-P06

- **H. Kerdoncuff, M.R. Pollard, P.G. Westergaard, J.C. Petersen, M. Lassen.** *Compact and versatile laser system for polarization-sensitive stimulated Raman spectroscopy.* Optics Express **25,** 5618-5625, 2017. DFM-2017-P07
- **T.M. Nolte, N.B. Hartmann, J.M. Kleijn, J. Garnæs, D.v.d. Meent, A.J. Hendriks, A. Baun.** *The toxicity of plastic nanoparticles to green algae as influenced by surface modification, medium hardness and cellular adsorption.* Aquatic Toxicology **183,** 11-20, 2017. DFM-2017-P08
- **M.R. Pollard, S. Duraipandian, R. M.-Nilsen, L. Nielsen**. *Establishing a Calibration Procedure for the Energy-Shift Axis in Diverse Raman Spectrometers.* Spectroscopy Magazine **32,** 38-46, 2017. DFM-2017-P09
- **J.S. Madsen, L.H. Thamdrup, I. Czolkos, P.-E. Hansen, A. Johansson, J. Garnæs, J. Nygård, M.H. Madsen.** *In-line characterization of nanostructured mass-produced polymer components using scatterometry.* Journal of Micromechanics and Microengineering **27,** 085004 (7pp), 2017. DFM-2017-P10
- **C. Thirstrup, A. Snedden, H.D. Jensen.** *Bridging the Gap Between Ultrapure Water and Reference Materials in Electrolytic Conductivity Measurements.* IEEE Transactions on Instrumentation and Measurement **66,** 2745-2754, 2017. DFM-2017-P11
- **N. Wollschläger, L. Palasse, I. Häusler, K. Dirscherl, F. Oswald, S. Narbey, E. Ortel, V.-D. Hodoroaba.** *Characterization of the inner structure of porous TiO_2 nanoparticle films in dye sensitive solar cells (DSSC) by focused ion beam (FIB) tomography and transmission Kikuchi diffraction (TKD) in the scanning electron microscope (SEM).* Materials Characterization **131,** 39-48, 2017. DFM-2017-P12
- **S.A. Jensen, D.M. Rosu, A. Hartwig, P.-E. Hansen.** *Use of Rayleigh-Rice Theory for Analysis of Ellipsometry Data on Rough CIGS Films.* Physica Status Solidi C: Current Topics in Solid State Physics **14,** 1700217-1-5, 2017. DFM-2017-P13
- **S.A. Jensen, K. Dirscherl, G. Zeng, R.L. Meyer.** *UV inactivation of bacteria in suspension and as biofilm* – "UV inaktivering af bakterier i opslæmning og som biofilm". Hospital Drift & Arkitektur **7**, 4-5, 2017. DFM-2017-P14
- **C. Thirstrup, A. Snedden, L.C. Deleebeck.** *Addressing the challenges of traceable electrolytic conductivity measurements in water.* Measurement Science and Technology **28,** 124001 (9pp), 2017. DFM-2017-P15
- **P.-E. Hansen, M.H. Madsen, J. Lehtolahti, L. Nielsen.** *Traceable Mueller polarimetry and scatterometry for shape reconstruction of grating structures.* Applied Surface Science **421,** 471-479, 2017. DFM-2017-P16
- **P.-E. Hansen, J.S. Madsen, S.A. Jensen, M.H. Madsen, M. Karamehmedovic.** *Modeling surface imperfections in thin films and nanostructured surfaces.* Proc. Of SPIE **10330,** J1-J5, 2017. DFM-2017-P17
- **S. Murthy, H. Pranov, N.A. Feidenhans'l, J.S. Madsen, P.-E. Hansen, H.C. Petersen, R. Taboryski.** *Plasmonic color metasurfaces fabricated by a high speed roll-to-roll method.* Nanoscale **9,** 14280-14287, 2017. DFM-2017-P18
- **M. Calaon, G. Tosello, J. Garnæs, H.N. Hansen.** *Injection and injection-compression moulding replication capability for the production of polymer lab-on-a-chip with nano structures.* Journal of Micromechanics and Microengineering **27,** 105001 (9pp), 2017. DFM-2017-P20
- **S.V. Søgaard, N.E. Olesen, C. Hirschberg, M.H. Madsen, M. Allesø, J. Garnæs, J. Rantanen.** *An experimental evaluation of powder flow predictions in small-scale process equipment based on Jenike's hopper design methodology.* Powder Technology **321,** 523-532, 2017. DFM-2017-P22
- **L.C. Oliveira, A.M.N. Lima, H. Neff, T.A.T. de Sousa, C. Thirstrup** *Co-existence of Radiative and Non-Radiative Surface Plasmon Resonance Modes: Power Balance and Influence of Film Morphology.* Plasmonics **12,** 1561-1569, 2017. DFM-2017-P25
- **J.S. Madsen, P.-E. Hansen, P. Boher, D. Dwarakanath, J.F. Jørgensen, B. Bilenberg, J. Nygård, M.H. Madsen.** *Study on microgratings using imaging, spectroscopic, and Fourier lens scatterometry.* Journal of Micro and Nano-Manufacturing **5**, 031005 (7 pp), 2017. DFM-2017-P26

CONFIDENTIAL REPORTS

- **A. Snedden.** *DFM Measurement report for CCQM-K36.* DFM-2017-F01
- **P.G. Westergaard, J.W. Thomsen, M.R. Henriksen, M. Michieletto, M. Triches, J.K. Lyngsø, J. Hald.** *Summary report – ESA FRLS EBB.* DFM-2017-F02
- **J. Hald, J.W. Thomsen, J.K. Lyngsø.** *Abstract – ESA FRLS EBB.* DFM-2017-F03
- **M. Kjær, O.S. Nielsen, J.C. Petersen, M.T. Christensen, J. Hald.** *Report to the Danish Agency for Institutions and Educational Grants for 2016* – "Faglig rapportering til Styrelsen for Institutioner og Uddannelsesstøtte for 2016". DFM-2017-F04

- **A. Brusch.** *Detection of leaks in food packing* - "Detektion af læk i fødevarepakninger". DFM-2017-F05
- **S.R. Johannsen, A.T. Rosell, K. Dirscherl, C.S. Jeppesen, S. Louring.** *Design rules correlating photocatalytic activity with the NPs/films properties at molecular level.* DFM-2017-F06
- **L. Deleebeeck.** *A review of the use of Electrochemical Impedance Spectroscopy in the study of Li-ion battery.* DFM-2017-F07
- **M.S. Nielsen.** *Investigating the performance in replication of height structures.* DFM-2017-F08
- **M.S. Nielsen.** *Measurement report on step-height artefact and sandpaper.* DFM-2017-F09
- **J. Hald, M.R. Henriksen, J.E. Pedersen, M. Drewsen.** *Qubiz quarterly reporting WP2b - status after 12 months.* DFM-2017-F09
- **D. B.-Harder, J. Nwaboh, O. Werhahn.** *Fully validated and implemented optical transfer standard for CO and CO_2.* DFM-2017-F10
- **D. B.-Harder, J. Nwaboh, A. Manninen, J.C. Petersen, O. Werhahn.** *A standardized description of isotopic composition influences on spectroscopic transfer standards.* DFM-2017-F11
- **J. Nwaboh, J. Mohn, A. Manninen, D. B.-Harder, J.C. Petersen, O. Werhahn.** *Validation of OIRS $^{13}C/^{12}C$, $^{15}N/^{14}N$, $^{18}O/^{16}O$ and $^{2}H/^{1}H$ in (CO_2, N_2O and CH_4).* DFM-2017-F12

CONTRIBUTION AT CONFERENCES

- **J.C. Petersen.** *Quartz-enhanced photo-acoustic spectroscopy for breath analyses.* Photonics West 2017, San Francisco, USA, January 2017.
- **J. Hald.** *Lasers in Metrology.* Laserlab.dk Symposium, Kgs. Lyngby, Denmark, March 2017.
- **N.O.B. Lüttschwager, D. B.-Harder, D. Leuenberger, A. Pogány, O. Werhahn, V. Ebert**. *Development, characterization, and validation of an optical transfer standard for ammonia in air.* European Geosciences Union (EGU) General Assembly, Vienna, Austria, April 2017
- **M. Lassen, L. Lamard, Y. Feng, A. Peremans, J.C. Petersen.** *Quartz Enhanced Photoacoustic Spectroscopy with Off-Axis Coupled Micro-Resonators.* Conference on Lasers and Electro-Optics (CLEO), San Jose, USA, May 2017
- **D. B.-Harder, N.O.B. Lüttschwager.** *Improved fitting tools for uncertainty evaluation of optical transfer standards.* MetNH3 Workshop, Zürich, Switzerland, May 2017
- **M. Lassen, D. B.-Clausen, A. Brusch, O.S. Nielsen, D. Heikens, S. Persijn, J.C. Petersen.** *Photo-Acoustic Sensor for Detection of Oil Contamination in Compressed Air Systems.* Conference on Lasers and Electro-Optics (CLEO), San Jose, USA, May 2017
- **P.-E. Hansen, J.S. Madsen, D.M. Rosu, A. Hertwig, L. Nielsen.** *Ellipsometry measurements of solar cells with large interface roughness,* European Materials Research Society (E-MRS), Strasbourg, France, May 2017
- **P.-E. Hansen, M.H. Madsen, J.S. Madsen, M. Karamehmedovic.** *Rough surface scattering for thin films and nanostructured surfaces.* SPIE Optical Metrology International Symposium, Munich, Germany, June 2017
- **H. Kerdoncuff, M.R. Pollard, P.G. Westergaard, J.C. Petersen, M. Lassen.** *Polarization-sensitive stimulated Raman spectroscopy with a compact and versatile laser system.* 9th International Conference on Advanced Vibrational Spectroscopy (ICAVS9), Victoria, Canada, June 2017
- **M.R. Pollard, H. Kerdoncuff, M. Lassen, J.C. Petersen.** *Developing fibre-enhanced Raman spectroscopy for nanoparticle concentration measurement.* Euroanalysis, Stockholm, Sweden, August 2017
- **A. Snedden, C. Thirstrup.** *Traceable High Precision Biofuel Conductivity Measurement.* 68th Annual Meeting of the international Society of Electrochemistry, Providence, USA, August 2017
- **S. B.-Figueroa.** *Environmental coefficients of the free-field sensitivity of measurement microphones.* 46th International Congress and Exposition on Noise Control Engineering, Internoise, Hong Kong, August 2017
- **S.A. Jensen, M.H. Madsen, J.S. Madsen, B. Bilenberg, D. Dwarakanath, J.F. Jørgensen, P. Boher, J. Nygård, P.-E. Hansen.** *Fast in-line characterization of nano-structures using a Fourier lens system.* International Metrology Congress (CIM2017), Paris, France, September 2017
- **H. Kerdoncuff.** *Raman enhancement techniques and their applications in biotechnology.* Drug Research Academy symposium on advanced Raman spectroscopy techniques for pharmaceuticals Faculty of Health and Medical Sciences, University of Copenhagen, Copenhagen, Denmark, November 2017
- **S. Veltzé, L.C. Deleebeeck.** *Assessment of Li-ion Batteries by Electrochemical Impedance Spectroscopy.* Electrochemical Science and Technology Conference, Kgs. Lyngby, Denmark, November 2017

INCOME STATEMENT AND BALANCE SHEET

INCOME STATEMENT (1000 DKK)	2017	2016
Commercial revenue	4 047	4 536
Project revenue	8 446	6 547
Government funding	22 510	20 474
Total revenue	**35 003**	**31 557**
Travel and out-of-pocket expenses	12 120	10 358
Total out-of-pocket expenses	**12 120**	**10 358**
Gross profit	**22 883**	**21 199**
Staff costs	19 809	17 759
Total costs	**19 809**	**17 759**
Operating profit before depreciation and impairment losses	**3 074**	**3 440**
Depreciation and impairment losses on property, plant and equipment	2 567	3 018
Operating profit before financial income and expenses	**507**	**422**
Financial income	45	2
Financial expenses	48	35
Profit before tax	**504**	**389**
Tax on profit for the year	103	42
Profit for the year	**401**	**347**
Profit for the year to be carried forward		

BALANCE SHEET AT 31 DECEMBER (1000 DKK)

ASSETS	2017	2016
Deposits	876	657
Total investments	**876**	**657**
Equipment	6 215	8 369
Leasehold improvements	15 356	247
Total property, plant and equipment	**21 571**	**8 616**
Total non-current assets	**22 447**	**9 273**
Contract work in progress	**6 918**	**3 762**
Trade receivables	894	695
Prepayments	134	144
Other receivables	3 025	289
Total receivables	**4 053**	**1 128**
Cash at bank and in hand	**7 704**	**21 255**
Total current assets	**18 675**	**26 145**
Total assets	**41 122**	**35 418**

EQUITY AND LIABILITIES	2017	2016
Share capital	1 000	1 000
Retained earnings	16 654	16 253
Total equity	**17 654**	**17 253**
Prepayments from customers and of funding	15 723	15 465
Trade payables	3 491	1 061
Other payables	4 254	1 639
Total current liabilities	**23 468**	**18 165**
Total equity and liabilities	**41 122**	**35 418**

KEY FIGURES

KEY FIGURES IN MILLION DKK	2013	2014	2015	2016	2017
Net sales	25.4	27.3	27.2	31.5	35
Gross balance	21.6	23.9	23.7	35.4	41.1
Profit or loss for the financial year [1])	0.5	0.7	0.4	0.4	0.5
Net capital	15.8	16.5	16.9	17.2	17.7
Commercial sale	3	3.6	5.3	4.6	4.0
- to small enterprises (less than 50 employees)	0.4	0.6	0.4	0.6	0.5
- to medium size enterprises (50-250 employees)	0.7	0.7	0.8	0.9	0.9
- to large enterprises (more than 250 employees)	0.8	0.8	1.3	1.1	0.9
- to Danish public institutions	0	0.1	0.4	0.5	0.2
- to foreign enterprises and institutions	1.1	1.4	2.4	1.5	1.5
Foreign net sales	6.5	5.9	7.1	3.8	3.3
RESEARCH AND DEVELOPMENT					
Number of collaborative projects	21	23	23	29	29
- thereof innovation consortia	0	2	2	2	2
- thereof international projects	12	16	17	21	24
R&D activities (million DKK)	25.4	26.2	23.2	26.9	30.6
- thereof self-funded	3.1	1.8	2.1	1.8	3.0
R&D work (man-year)	16.2	19	17.5	17.3	17.6
NUMBER OF CUSTOMERS					
Danish private enterprises	31	33	25	53	54
- thereof small enterprises (less than 50 employees)	14	15	11	21	24
- thereof medium size enterprises (50-250 employees)	6	9	6	11	12
- thereof large enterprises (more than 250 employees)	11	9	8	21	18
Danish public institutions	5	3	5	8	3
Foreign enterprises and institutions	18	17	19	28	33
Total customer base	54	53	49	89	90
NUMBER OF STAFF CATEGORIZED BY EDUCATION (MAN-YEAR)					
Dr & PhD	17	18	19	21	25
MSc	3	4	4	3	3
Other technical staff	3	3	2	2	2
Administrative staff	2	2	3	3	4
Average number of staff	25	27	28	29	32
NUMBER OF PUBLICATIONS					
Refereed publications	12	14	23	19	21
PhD and Master theses	1	0	0	3	0
Other reports	15	14	14	15	7
Conference papers	18	22	15	18	17
Calibration certificates and measurement reports	417	495	521	582	717
Press cuttings	9	27	28	15	11
EDUCATION					
DFM courses (number of days)	2	2	2	3	4
DFM courses (number of participants)	4	25	22	18	28
Supervision/teaching at universities (number of students/courses)	0	6	3	3	6
Co-supervision of master thesis students (number of theses)	4	5	4	3	0
Contribution to teaching at universities (number of days)	5	6	4	3	6
Committee work (number of committees)	24	32	29	29	29
- thereof international committee work	21	27	23	23	25
EFFICIENCY					
Turnover per employee (1000 DKK)	1011	1004	994	1011	1129
Profit per employee (1000 DKK)	20	26	15	13	16
Commercial turnover per DKK of governmental funding	0.2	0.3	0.4	0.2	0.2
R&D turnover per DKK of governmental funding	1.5	1.6	1.5	1.3	1.4

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.

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
Kogle Allé 5, DK 2970 Hørsholm
Contact: Jan Hald
Phone: +45 7730 5800
jha@dfm.dk

FORCE

FORCE Technology
Navervej 1, DK 6600 Vejen
Contact: Mogens Simonsen
Phone: +45 4325 0000
mss@force.dk

DTI

Danish Technological Institute
Kongsvang Allé 29, DK 8000 Århus C
Contact: Jan Nielsen
Phone: +45 7220 2000
jnn@teknologisk.dk

TRESCAL

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

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
(1989, 1997, 2008)	ln@dfm.dk	Force and Pressure	FORCE
		Volume and Density	FORCE
ELECTRICITY AND MAGNETISM	Carsten Thirstrup, DFM	DC electricity	DFM
(1989, 1994, 2002, 2011)	cth@dfm.dk	AC electricity	TRESCAL
		HF electricity	TRESCAL
LENGTH	Jan Hald, DFM	Basic length measurements	DFM
(1989, 1998, 2007)	jha@dfm.dk	Dimensional metrology	DFM & DTI
		Micro/Nano	DFM
TIME AND FREQUENCY	Jan Hald, DFM	Time measurement	
(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	FORCE
IONISING RADIATION	Arne Miller, DTU	Absorbed radiation dose – Industrial products	DTU
(1992, 2000)	armi@dtu.dk	Absorbed radiation dose – Medical products	
		Radiation protection	
		Radioactivity	
PHOTOMETRY AND RADIOMETRY	Anders Brusch, DFM	Optical radiometry	DFM
(1990, 1996, 2004, 2014)	ab@dfm.dk	Photometry	
		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	
METROLOGY IN CHEMISTRY	Lisa Carol DeLeebeeck	Electrochemistry	DFM
(1992, 1995, 2004)	ldl@dfm.dk	Laboratory medicine	
		Products and materials	
		Food chemistry	
		Pharmaceutical chemistry	
		Microbiology	
		Environmental chemistry	
INTERDISCIPLINARY METROLOGY	David Balslev-Harder	No subdivisions	
	dbh@dfm.dk		
QUALITY	Kai Dirscherl, DFM	No subdivisions	
	kdi@dfm.dk		

DETAILS OF PERSONNEL

BOARD OF DIRECTORS

Bjarne Fjeldsted (Chairman)
Group Director, Product Compliance and Validation
Grundfos Holding A/S

Niels Axel Nielsen (Vice Chairman) (until March 29, 2017)
Senior Vice President
Technical University of Denmark

Katrine Krogh Andersen (Vice Chairman) (from March 29, 2017)
Dean of Research, Senior Vice President
Technical University of Denmark

Marlene Haugaard
Senior Vice President, Engineering at NCC Building

Torben Jacobsen
CEO, NESBI ApS

Jan Hald
Team Leader, DFM A/S

Kai Dirscherl
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MANAGEMENT

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