DFM
Danish National Metrology Institute

# ANNUAL REPORT 2018

## 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 2018 EDITED BY
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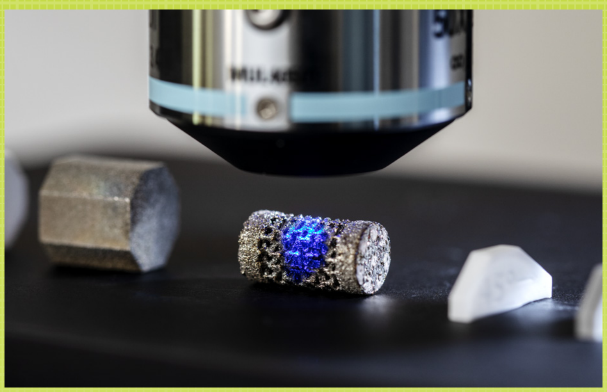
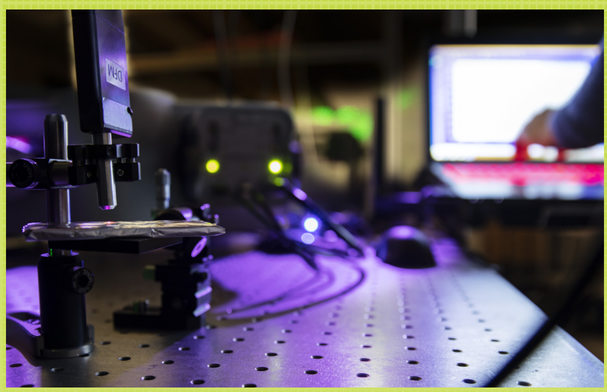
# TABLE OF CONTENTS

# WHY DO WE NEED METROLOGY?







**Imagine a society in which there are no common measurement standards. Consumers would not be able to trust that they paid the right amount for food, gas, electricity, petrol, water and other consumables. Manufacturers would not be able to trust that parts bought from several suppliers could actually be assembled, and we would not be able to monitor the change in pollution of our environment and evaluate their effects on global warming.**

Metrology has played an important role in all civilisations. In the earliest civilisations, metrology was used to regulate trade by establishing local standards for weights and measures, but as the world trade expanded, the demand for international standards for weights and measures increased. In parallel, the technological revolution created a demand for other standards than just mass and length: The steam engines required standards for temperature and pressure, the electrical machines required measurement standard for voltage, current and resistance, and other technological inventions spurred the demand for further measurement standards.

Today we live in a global and high technology society. This demands a wide range of international measurement standards of high quality and a system to make sure that all measurements performed in society are traceable to those standards. DFM is part of an international network of national measurement institutes, which work closely together to ensure that the necessary measurement standards are available to the local society and that the measurements performed in different parts of the world are equivalent. These include measurements of physical and chemical quantities that are encountered on a daily basis, measurements that industries rely on to foster innovation and to develop efficient manufacturing methods, measurements that secure fair trade, consumer protection, health and safety, law and order, and environment monitoring. Measurement are of increasing importance in connection with financial transactions, particularly to secure accurate time stamp of such transactions.

The situation is not static. New technologies continues to appear and the demand for addressing new fields, such as quantum technologies and life sciences, only increases. If the national measurement institutes were not able to meet these demands, the technological development would fade out. So not only do we need metrology in order to run a society, we also need to improve continuously our metrological capabilities!

# MANAGEMENT REPORT 2018



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

**DFM's total revenue grew to 37.1 million DKK from 35.0 million DKK a year ago, while the profit grew to 0.7 million DKK from 0.5 million DKK. The management considers both revenue and profit as satisfactory. DFM increased its field of NMI activities to include non-contact thermometry and acquired an accredited laboratory for contact thermometry.**

DFM's government contract was renewed in 2018 for the period 2019-2020. DFM received funding to continue core scientific and development activities and to maintain the critical National metrology infrastructure. In addition, new funding was received for activities within quantum metrology and surface metrology, areas that are expected to be of increasing importance for Danish industry in coming years.

DFM would like to thank the Ministry of Higher Education and Science for its continued support of our activities. The board and management developed a new strategy plan for the period 2019-2020. DFM continues its efforts to maximize the impact of metrology for Danish industry from our research, project and commercial activities.

DFM has significantly increased its NMI activities in recent years. In 2018 non-contact thermometry was added to the portfolio. This activity is well aligned with current activities in radiometry and will be conducted in close collaboration with the Technical University of Denmark, who has a strong record of accomplishments in the field.

DFM also completed its first acquisition in 2018, taking over an accredited contact thermometry laboratory. The laboratory will improve our ability to service Danish industry providing a more complete set of metrology services.

DFM is currently expanding its facilities to accommodate the new activities. The expansion includes 480 $m^2$ of office and laboratory space and will be completed by May 1, 2019.

We are pleased that the number of customers, DFM provides services, reference materials and products to, continues to increase. In 2018 the increase was 10 % (excl. thermometry) showing the continuing rise in demand for advanced metrology services among many industry sectors.

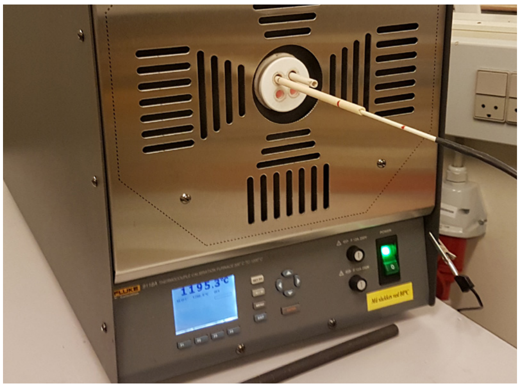
**Bjarne Fjeldsted**
Chairman of the Board

**Michael Kjær**
CEO

# INTRODUCING CONTACT AND NON-CONTACT TEMPERATURE CALIBRATION



Calibration using liquid nitrogen up to - 90 °C.



Calibration of thermocouples up to 1600 °C.

Non-contact temperature sensors calibrations using black bodies.

**In 2018, DFM acquired the Thermometry Laboratory at Risø, including both contact and non-contact thermometry. In August 2018, DFM was appointed the NMI within the area of non-contact thermometry.**

Materials, chemical processes, and electronics are all influenced by temperature. For this reason, accurate temperature measurements are of vital importance in production of pharmaceuticals, food and beverages, plastics, and to certified measurement laboratories, e.g. biomedical and calibration laboratories. DFM now offers temperature calibration services for Industry, including calibration of a wide range of temperature sensors, thermometers, data loggers, and dry-block calibrators. Presently, contact thermometry covers a temperature range from -196 °C to +1600 °C, the widest in Denmark. Calibrations can be performed in liquid baths. This large temperature range is achieved using baths containing compounds that are liquid at different temperatures. These include a liquid nitrogen-based system for the range -196 °C, and -155 °C to -90 °C, alcohol baths for the range -89 °C to 5 °C, water baths (0 °C to 90 °C), oil baths (30 °C to 300 °C), and a molten salt bath (250 °C to 550 °C). For the higher temperature range (500 °C to 1600 °C), electric ovens are used. In addition, DFM has several dry-block calibrators, which cover the temperature range from -24 °C to 700 °C and can be used for off-site calibrations.

Traceability is achieved through a standard platinum resistance thermometer, which is calibrated between -196 °C to 660 °C and thermocouples, which are calibrated between 400 °C to 1600 °C, against fixed-point standards.

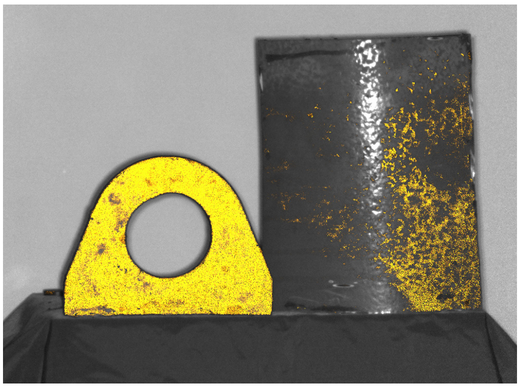
Temperature measurements are made by measuring the resistance across the thermometer. The resistance measurements are based on DFM's highly accurate resistance measurements with direct traceability to the BIPM. Computer hardware and software have been renewed in 2018.

Contact thermometry is complemented by non-contact thermometry, where infrared radiation measurements, combined with Planck's Law of radiation, are used to quantify the temperature of an object. Excitingly, in August 2018, the Danish Safety Technology Authority (Sikkerhedsstyrelsen) appointed DFM as NMI within non-contact thermometry. DFM now offers accredited non-contact thermometry calibrations of pyrometers and blackbody sources in the temperature range from -80 °C to 1600 °C, and IR equipment between -12 °C to 1100 °C. Calibration of emissivity is also provided with uncertainties down to 0.005 °C. These services are provided in collaboration with DTU Kemiteknik, and traceability of the non-contact thermometry is verified through other NMIs via the contact Thermometry Lab and participation in international comparisons. With the upcoming redefinition of the SI, new methods of traceability will be explored.

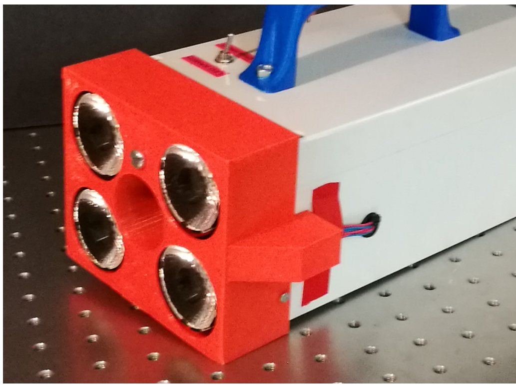
# HUNTING CORROSION USING DRONES



A drone platform that can be used to carry the sensor in the future.



Two steel samples showing corrosion from their use at sea. Detected corrosion is colored yellow.



Portable corrosion sensor prepared for mounting on a drone.

**Corrosion presents one of the great monitoring challenges of offshore structures. DFM is developing a novel sensor to allow for reliable quantification of corrosion. By using drones to carry the sensor, the inspection costs for offshore wind turbines could be dramatically reduced.**

Besides the aesthetic impact on publicly visible structures, corrosion causes huge economic loss to society every year. The amount lost is estimated to be around 4% of the worldwide gross domestic product and besides huge financial interests in cost reduction; corrosion poses a number of safety issues that need to be addressed.

State-of-the-art rating of surfaces are done manually by trained inspectors. Comparing printed example conditions with the item under inspection, the inspector has to estimate the level of corrosion. While experienced inspectors can achieve remarkable results, the day-to-day and inspector-to-inspector variations ultimately lead to inconsistency between different inspection campaigns. In addition, access to the surface in question can be very costly and involve safety concerns. When it comes to offshore structures like wind turbine towers and oilrigs, the work often requires rope access to be executed. Using a drone based sensor, both of these challenges can be solved efficiently.

DFM entered a collaboration with SEMCO Maritime, LIC Engineering, Svendborg Measurement Service and Energy Innovation Cluster with the aim to develop a novel monitoring technique that aimed to provide an innovative solution for the monitoring of corrosion on offshore wind turbine towers using drones.

As part of the project, DFM developed a novel sensor. A spectroscopic approach allows remote detection of corroded surfaces and the rating of the surface state in a reliable and reproducible way. The proprietary sensor technology is currently under final development for commercialization as a full monitoring and rating solution.

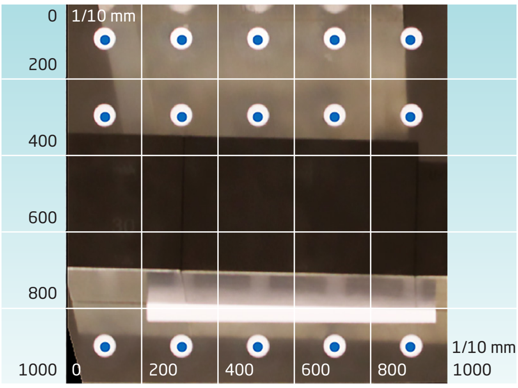
The next steps will be to mount the sensor on a drone and test it at an offshore facility. Moreover, considerable work is required for converting the highly nuanced sensor output to the coarse categories of current international standards. The further aim is to prove the potential of the sensing solution and find new applications. This may include its use on onshore structures; assessment of lifetime extension and to use the recorded high precision data for advanced maintenance prediction. Ultimately, the goal is to lower the costs for maintenance and inspection of offshore structures. It is estimated that this type of sensor will result in a cost saving potential of at least 50 million DKK per year for Danish offshore installations, which in the end will translate to reducing the price for renewable energy for both the commercial as well the private end user.

The project received funding from the EU Regional Development Fund.

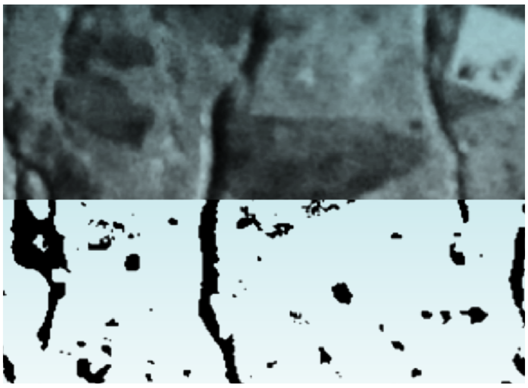
# CAMERA CALIBRATION FOR ACCURATE IMAGE-BASED MEASUREMENTS



Perspective image corrected for lens imperfections. Straight lines appear straight.




From the perfect central perspective an ortho-image can be created allowing for reliable distance measurements on a surface.



DFM has utilized this to characterize the with and length of cracks on a concrete surface.

**DFM has developed calibration facilities for a range of cameras, both in terms of spatial accuracy and color recognition. Calibration of cameras is a prerequisite for accurate measurements in areas such as production and land surveying.**

### Beyond pretty pictures

Mass production for integration into a variety of everyday applications has made cameras so inexpensive, that we sometimes forget that they are advanced measuring devises. The camera calibration services developed by DFM ensures correct measurements by determining the camera characteristics in advance.

### Camera calibration - geometrical measurement

Conventional 2D cameras and 3D stereo cameras can be used for geometrical measurements of objects by combining multiple images. The images are generally distorted due to imperfections in the lens, which compromise the accuracy of the measurement. DFM can determine the imaging error of the cameras using reference objects measured with traceable methods. A report is issued to the customer with image correction parameters and uncertainties. With this information, traceable reconstruction of distinct features in the images can be obtained.

### Calibration of hyperspectral cameras

Hyperspectral cameras are cameras with superior color resolution compared to the conventional RGB (Red Green Blue) color cameras. Such cameras are used in areas like quality control in production lines, where the high spectral resolution can yield superior color information. DFM has developed a spectral calibration procedure to ensure correct color recognition for hyperspectral cameras and other color sensors such as conventional RGB cameras. The spectral calibration at DFM involves an integrating sphere, spectral filtering, and an absolute measurement of light intensity. It is therefore also possible to measure the absolute color sensitivity of cameras and other color sensors.

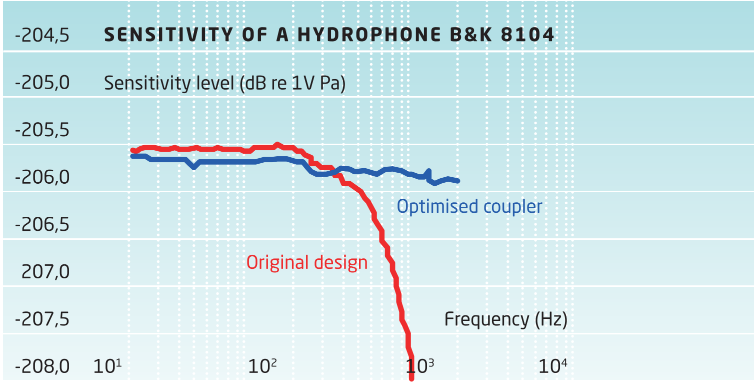
### Applications

DFM's services increase the value of measurements obtained with simple or advanced cameras. For example, cameras are by far the most used sensor on inspection drones and other autonomous vehicles. DFM has demonstrated how an inexpensive lightweight stereo camera suitable for mounting on drones can characterize the width and length of cracks on a concrete surface. Drone based hyperspectral cameras are used in areas such as forestry and agriculture, where the spectral information can yield insight into the general health of plants, as well as droughts and fire hazards. Drones equipped with cameras are expected to streamline inspection operations in many areas in the future leading to significant savings in e.g. the agricultural and construction sectors.

# THE FISH OUT OF THE WATER, OR THE CALIBRATION OF HYDROPHONES IN AIR




Measurement setup with optimised coupler.




Results of the sensitivity of a hydrophone Brüel & Kjær type 8104 obtained from measurements in the original coupler design, and in the optimized coupler design. The optimized coupler provides reliable results up to 1 to 2 kHz.

**Improved measurements for monitoring the effect of human activity in the sea will help to protect marine life. DFM is participating in a European project devoted to provide traceable calibration of underwater sound transducers at low frequencies.**

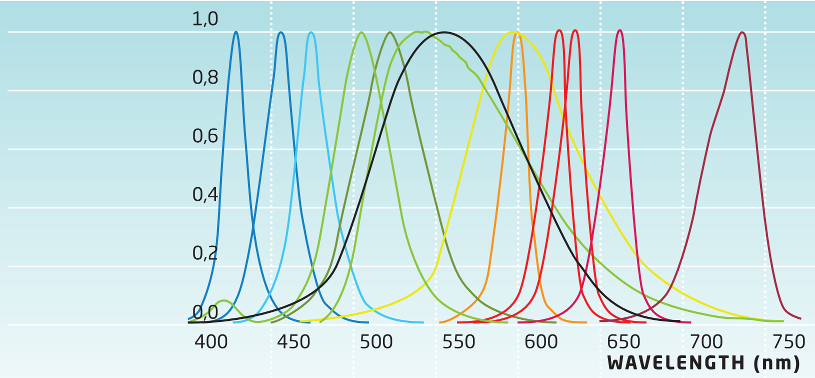
Marine life is undeniably affected by human activity in marine environments, whether for shipping products around the world or the development of offshore infra-structure. The negative influence of these activities may include physiological effects such as hearing loss or behavioural effects such as displacement from habitats due to acoustic noise. An increase in background noise level may also have chronic effects, for instance masking of biologically produced sound vital for communication and foraging. The need to monitor the marine acoustic environment has been clearly stated in the Guidelines for Monitoring Undersea Noise under the EU Marine Strategy Framework Directive.

One of the key elements in the Guidelines is the measurement of acoustic noise at frequencies under 1 kHz because most human sound sources radiate high intensity waves at these frequencies. Despite this fact, the availability of traceable measurement standards has been historically limited. Mainly due to the challenge of reproducing reliable acoustic underwater environments for these measurements.

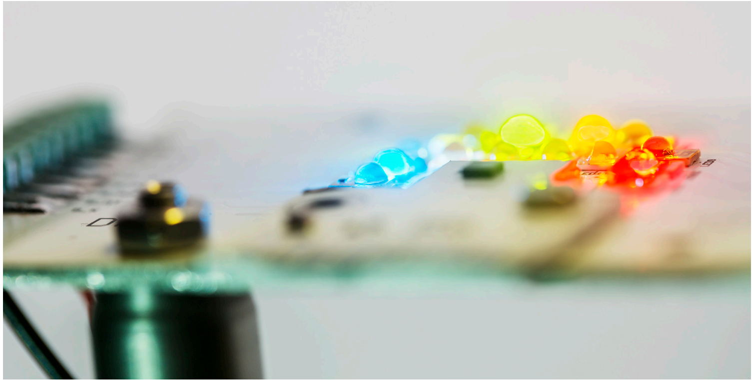
The EMPIR project *Underwater acoustic calibration standards for frequencies below 1 kHz* (UNAC-LOW) that started in 2016 has as goal to develop traceable measurement capabilities to meet the need for calibration of hydrophones at frequencies between 20 Hz and 1 kHz as required by the Guidelines. Furthermore, the partners of the project (three National Metrology Institutes and three external partners) must develop an individual strategy for the long-term operation of the developed measurement capabilities including regulatory support, research collaborations, quality schemes and accreditation, aimed at developing a coherent metrology strategy for Europe within this field.

DFM is well known in the field of calibration of acoustic devices in air, and is a valued partner in projects for this field. However, leaping into underwater acoustics is not trivial. The wavelength of soundwaves at 20 Hz is 75 meters, making standard calibration techniques for hydrophones unworkable. DFM has developed new methods for determining the sensitivity of hydrophones using air-filled comparison couplers. In an optimised coupler, the same sound pressure acts upon the hydrophone and reference microphones that are traceable to the SI units.

During this development, DFM has cooperated with a small Danish-owned company. Knowledge transfer of the project results will be made to other main Danish actors in the acoustic field.




Spectral distributions of LEDs for testing. Overlaid in black is the luminosity function that describes the eye's sensitivity to different colors of light.



Multi LED board for color testing and source optimization.

**The world of lighting is rapidly transforming due to the emergence of LEDs. The ability to characterize them correctly are an important competition parameter. In the project LEDMET, DFM together with research and commercial partners, have addressed these issues for the benefit of the prolific Danish lighting industry.**

LED is on the verge of replacing traditional light sources in virtually all lighting applications. The transition to LED presents a number of challenges for the many Danish companies working with lighting. The LEDMET consortium was formed with support from Innovation Fund Denmark with the goal of supporting Danish industry in the development of the light sources of the future. In collaboration with DTU FOTONIK, Delta (now a part of Force) and with the support of Danish Lighting Center, the partners have developed solutions addressing the calibration and measurement needs of the lighting industry. DFM has particularly focused on three aspects.

The most widely used light measurement instrument is the lux-meter that measures the amount of light per area. The response of these instruments must mimic the spec-tral sensitivity of the eye, a challenge that is solved using a complex filter. Even small variations in the filter can cause large measurement errors, due to the spectral properties of LEDs. To address this issue DFM, has developed a multi-LED device that allows characterization of the filter error. The resulting correction is applicable when measuring different LED sources.

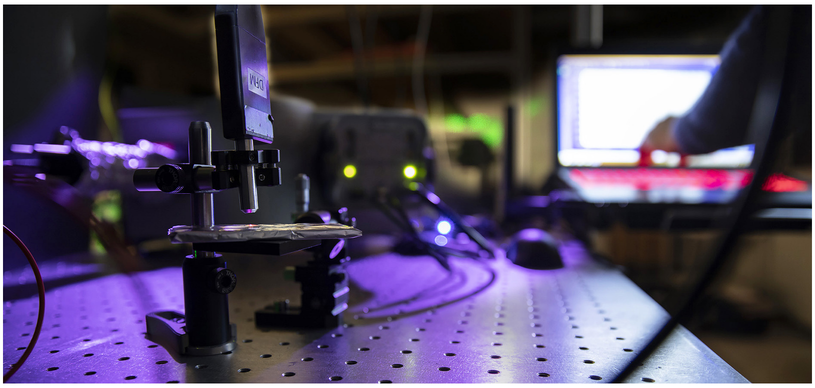
Recently, circadian stimulus that describes the effect of light on the daily rhythm / our body's internal clock is gaining interest. Actively controlling the circadian response with light can be useful in many situations i.e. better medical treatment or lessen the negative impact of shift work. In collaboration with one of the LEDMET partners, DFM developed a software tool that makes it possible to optimize the circadian response of a light source while preserving other desirable light properties such as color temperature and color rendering. The implementations of these types of light sources in hospitals and nursing homes can help both patients and personnel.

The energy efficiency of LEDs in the deep ultraviolet (UV) spectral region have increased dramatically (from below 0.5% to above 5%) in recent years. The deep UV is characterized by the photon energy being high enough to break chemical bonds which makes it biologically dangerous. Replacing traditional deep UV light sources, such as deuterium lamps, with more compact and efficient alternatives is attractive for a number of industrial applications. In this process, it is important to be able to control the exact dosage of UV light to prevent detrimental effects. In LEDMET, DFM has improved its measurement capabilities in the UV-region to meet industrial demands for high power UV applications.

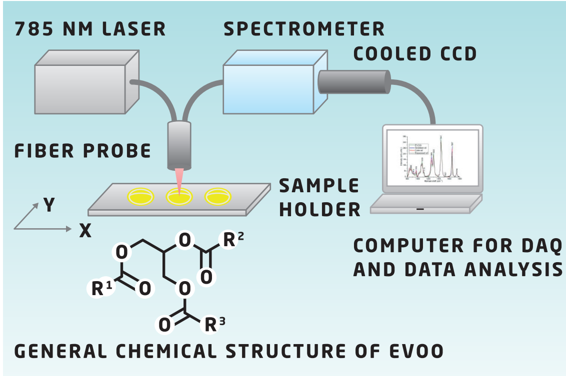
The LEDMET project was funded by Innovation Fund Denmark.

# RAMAN SPECTROSCOPY: RAPID AUTHENTICATION TOOL FOR EXTRA VIRGIN OLIVE OIL

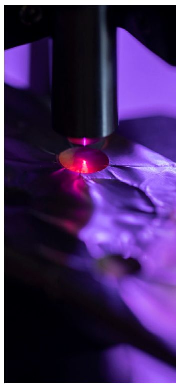




Experimental setup.




Experimental setup.



**Raman spectroscopy has a huge potential for testing the purity and authenticity of food, medicine, and other substances. DFM has exemplified this by quantifying the impurity of authentic extra virgin olive oil (EVOO) spiked with one or more adulterants, such as oils from rapeseed, corn and soybean.**

Olive oil (EVOO) is one of the main ingredients in the Mediterranean diet and its consumption has spread worldwide due to its nutritional properties and health benefits. The ability to deliver safe and authentic food is of high priority for manufactures. However, unintentional contamination, deliberate mislabeling and contamination, market competition, expanding consumers demand exists considerably. As a result, the vulnerability of products and the risks inherent to food fraud is of considerable concern. Recently counterfeit olive oil was sold in Denmark, which greatly concerns the Danish olive oil industry and the health safety of the public. Hence, investigation of the quality of EVOO using non-destructive optical methods is in demand.

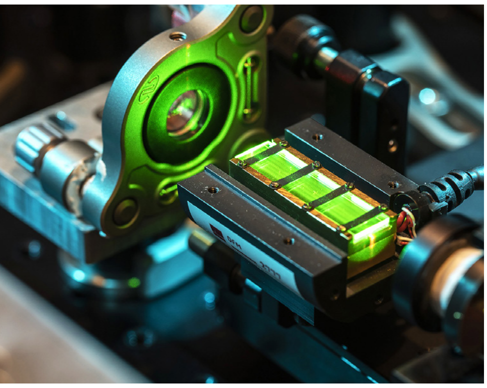
Traditionally a panel of trained tasters makes evaluation of the quality of EVOO. This evaluation may not be sensitive enough to detect the presence of sophisticated adulterations such as cheaper oils of similar composition to EVOO and dyes to simulate the color of EVOO. Several well-known techniques including mass spectrometry, gas chromatography, and nuclear magnetic resonance spectroscopy are utilized to detect the authenticity of EVOO. These methods are powerful and provide very low detection limits; however, they are time consuming, expensive, requiring dedicated laboratories and trained professionals.

EVOO is composed mainly of monounsaturated fatty acids and small amount of polyunsaturated fatty acids, which all can be identified with vibrational spectroscopy techniques. Raman spectroscopy has increasingly been recognized as a reliable quality control tool due to its ability to non-destructively probe adulteration-related changes in olive oil with high chemical specificity, without requiring any reagents or sample preparation. DFM has investigated the potential of Raman spectroscopy combined with multivariate statistics for evaluating the authenticity (or purity) and concentration of EVOO.

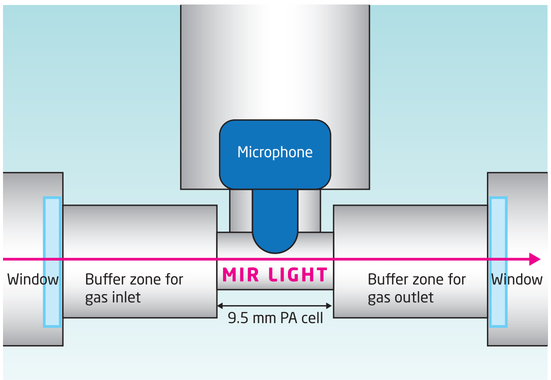
In a real-world scenario, there can be more than one adulterant in EVOO and the labelled EVOO has to be investigated without having any prior knowledge about how many adulterants have been added, or the nature of the adulterants. It is much easier and practical to quantify the amount of EVOO rather than quantifying the unknown adulterants. At DFM, we investigated the ability of Raman spectroscopy in conjunction with a simple PLS model for determining the purity of EVOO in binary mixtures (EVOO + rapeseed oil), ternary mixtures (EVOO + rapeseed + corn oil), and quaternary mixtures (EVOO + rapeseed + corn + soybean oil). The developed method is very promising for the detection of EVOO authenticity and this method is not limited to only EVOO, but can be applied to other types of food.

This work was supported by the EUROSTARS project PASOCA.

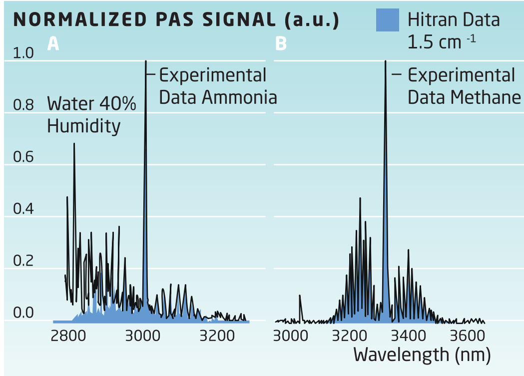
# MIR LIGHT SOURCES FOR TRACE GAS MEASUREMENTS



Homebuilt MIR OPO.




PA cell design.




Photoacoustic measured spectra of water, ammonia and methane using a MIR OPO as pump source.

**There is a growing demand for improved and reliable trace gas measurements, due to global warming and increased emissions of pollutant gases. DFM has developed different types of optical parametric oscillators to address the challenge of measuring several gas species simultaneously, to perform photoacoustic imaging for diagnostics and atomic force microscope-infrared spectroscopy.**

A number of different mid-infrared (MIR) light sources and technologies are currently commercially available; including optical parametric oscillators (OPOs) based sources. Although the OPO technology dates back to 1965, it is still an excellent choice as a MIR light source. The emission wavelengths depend on the configuration of the nonlinear crystal and the accessible wavelength span is ultimately limited only by the transmission window of the nonlinear crystal. This very broad spectral selectivity and tuning capability is a considerable advantage over other commercially available MIR light sources.

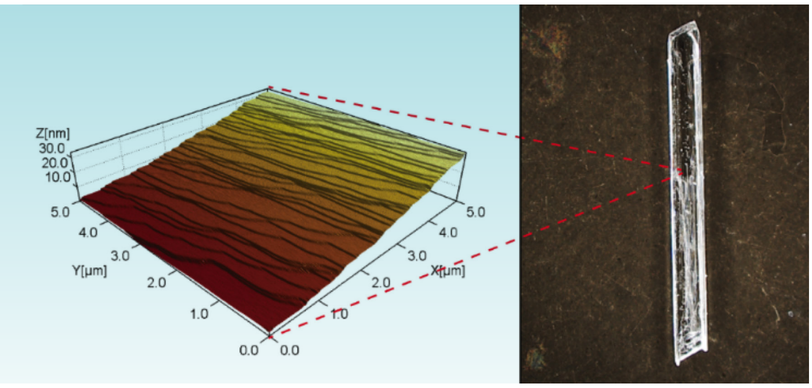
As an application of such a light source, DFM has constructed a multi-gas detection system based on the integration of a MIR OPO with a photoacoustic (PA) cell, which permits the monitoring of several trace gas components handled by common signal processing and data analysis. The system was demonstrated by monitoring three gases as shown in the figure above. The PA measurements of water, ammonia and methane shows that parts per billion (ppb) sensitivity can be achieved using the new MIR OPO. Thus, the OPO/PA sensor is an excellent choice for environmental gas sensing and exhaled breath gas monitoring for diagnostics. The emission of NOx and SOx gases is of particular concern due to their toxicity and danger to human health. Methane and CO2 are well-known greenhouse gasses. These molecules all have strong absorption lines in mid-infrared spectral region. The sensor will be capable of measuring all four species simultaneously with a sensitivity sufficient to determine if there is compliance with regulations with respect to emission levels of the four species. The sensor is characterized by ease of use, compactness, fast response time, and capability of allowing trace-gas measurements at the sub-parts per billion levels. The figure clearly shows that OPOs can provide molecular selectivity and multi-gas sensing due to large wavelength tunability (2.8 µm-4.2 µm). A similar tuneability based on other light sources would require a number of sources to cover the same wavelength range thus increase the complexity and cost of the system.

DFM is developing compact and robust OPOs for a number of sensing applications, including the generation of non-classical light (squeezing and entanglement) for quantum metrology, ultrasensitive bio-optical sensing, photoacoustic imaging for medical diagnostics, non-contact photoacoustic measurements of glucose in blood, LIDAR (Light Detection and Ranging) for wide area environmental measurements and atomic force microscope - infrared spectroscopy for nanostructured bio-films, showing the diversity of these systems for various applications.

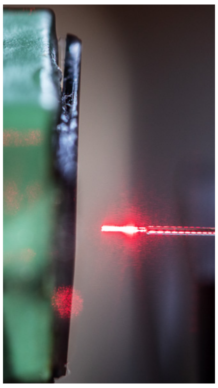
This work was partly funded by the EUROSTARS project PIRMAH.

# DFM SUPPORTS DANISH INDUSTRY

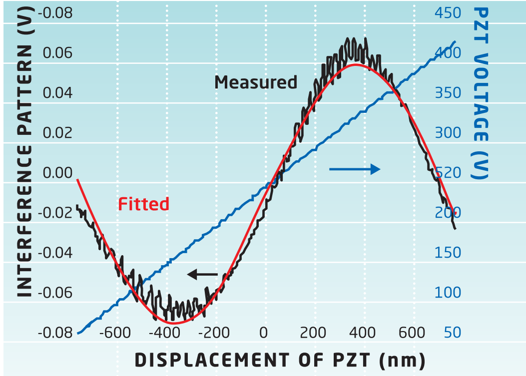





Nanoscale imaging of drug microcrystals.



A simple Fabry-Perot optical fiber based interferometer (2-3mm).




Interference pattern measured (black curve), when applying a linear voltage ramp (blue curve) with slope 1000 volt/second to the piezo-electric sample.

## 1. Surface characterization of microcrystal and drug delivery systems

DFM has developed new measurement and calibration services that can assist pharmaceutical companies in the process of drug formulations as well as in quality assurance of products in order to fulfill regulatory requirements and in support of safer pharmaceutical products.

A new service for surface characterization of pharmaceuticals based on atomic force microscopy (AFM) addresses "microcrystal measurements", which allows pharmaceutical companies to monitor the stability of micro-sized drug crystals under controlled environmental conditions (temperature and humidity). The characterization method provide nanoscale imaging of small crystals with masses down to a few microgram. This measurement capability is particularly beneficial during the screening process in drug development, where the amount of candidate crystalline drugs is typically limited as only small amounts are used for numerous quick pharmacological tests. The measurements assess the structural stability of the drug crystals, which is critical for their functionality and approval by regulatory bodies.

Another service addresses multicomponent drug delivery systems based on e.g. polymers and hydrogels, where surface mechanical mapping of these systems are performed, so that the distribution and size of different components can be visualized and quantified. These measurements assess the distribution of the active pharmaceutical ingredient in the multicomponent delivery system to secure the correct drug dose, which is critical to patients' safety.

## 2. Measurement of nanometer displacement of small objects

DFM has developed a compact interferometric technique for measurement of movements of very small objects with nm accuracy. A specific assignment was to characterize the displacement of new types of piezo-electrical (PZT) samples in response to slowly varying applied voltages.

Interference was created by light reflected from two parallel surfaces, a so-called Fabry-Perot interferometer, which result in a measurable pattern. A polished and plane optical fiber tip is used as one surface while the other is one of the surfaces of the PZT. The fiber tip surface is non-coated and creates approximately 4% back reflection. A linear voltage ramp with slope 1000 volt/second is applied to PZT material. The black curve shows the observed interference pattern as a function of PZT displacement. The distance between the location of the two extrema is 771 nm, corresponding to half the wavelength of the laser wavelength. This pattern is used for calibration of the PZT displacement. The calibration is traceable to the Danish primary standard for length, the meter. The blue curve indicate the voltage ramp applied to the PZT. The red curve is a sinusoidal fit to the experimental data and used for locating the two extreme points of the interference pattern. In the specific case the displacement as function of voltage is 2.59 nm/V ± 0.26 nm/V. The fiber interferometer is highly flexible tool for the measurement of movements and can be adapted for measurements in less easy accessible places; however, an important requirement is that the polished fiber surface is parallel to the sample surface. The interferometer is capable of measure interference from a number of different samples including PZTs, polymers, membranes and biological samples as long as an amplitude is observed.

# 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)
- Consultative Committee for Mass and Related Quantities
- EURAMET General Assembly
- 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)
- CCM Task Group on the Phases for the Dissemination of the kilogram following redefinition (CCM-TGPfD-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

- Center for LED metrology (Cap LEDMET), IF
- 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
- 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
- Metrology for nitrogen dioxide (MetNO2), SIU/EMPIR
- Realization of a Unified pH scale (UnipHied), SIU/EMPIR
- Light-matter interplay for optical metrology beyond the classical spatial resolution limits (BeCOMe), SIU/EMPIR
- High Accuracy High Flow Optical Aerosol Spectrometer for improved Cleanroom Quality Assurance (HILAS), IF/Eurostars

## DFM SPECIAL REPORTS

- **A. Brusch.**
  *Solariemåling. Forskelle og sammenhænge imellem måling af solarier efter dansk lov og DS/EN 60335-2-27:2014.*
- **S. A. Jensen, S. R. Kynde, M. S. Nielsen, J. Garnæs.**
  *Good practice guide for large scale drone based measurements.*

## CALIBRATION CERTIFICATES AND MEASUREMENT REPORTS

| | |
|---|---|
| DC Electricity | 3 |
| Electrochemistry | 483 |
| Mass | 16 |
| Length | 35 |
| Optical Radiometry | 47 |
| Nano Structures | 6 |
| Acoustics | 66 |
| Particle Metrology | 31 |
| Thermometry | 826 |
| Pressure | 30 |
| **Total** | **1543** |

## PUBLICATIONS IN REFEREED JOURNALS

- **M. Winther, D. Balslev-Harder, S. Christensen, A. Priemé, B. Elberling, E. Crosson, T. Blunier.**
  *Continuous measurements of nitrous oxide isotopomers during incubation experiments.*
  Biogeosciences **15,** 767-780, 2018.
- **M. Edinger, M.M. Knopp, H. Kerdoncuff, J. Rantanen, T. Rades, K. Löbmann.**
  *Quantification of microwave-induced amorphization of celecoxib in PVP tablets using transmission Raman spectroscopy.*
  European Journal of Pharmaceutical Sciences. **117,** 62-67, 2018.
- **M. Lassen, D. Balslev-Harder, A. Brusch, N. Pelevic, S. Persijn, J.C. Petersen.**
  *Design and experimental verification of a photoacoustic flow sensor using computational fluid dynamics.*
  Applied Optics **57,** 802-806, 2018.
- **P. Singh, S. Pandit, J. Garnæs, S. Tunjic, V.R.S.S. Mokkapati, A. Sultan, A. Thygesen, A. Mackevica, R.V. Mateiu, A.E. Daugaard, A. Baun, I. Mijakovic.**
  *Green Synthesis of Gold and Silver Nanoparticles from Cannabis sativa (Industrial Hemp) and their capacity for Biofilm Inhibition, DFM-2018-P05.*
  International Journal of Nanomedicine **13,** 3571-3591, 2018.
- **M. Lassen, L. Lamard, D. Balslev-Harder, A. Peremans, J.C. Petersen.**
  *Mid-infrared photoacoustic spectroscopy for atmospheric NO2 measurements.*
  Proc. of SPIE **10539,** 105390J-1, 2018.
- **M. Lassen, D. Balslev-Harder, J.C. Petersen, N. Pelevic, A. Brusch, S. Persijn.**
  *Flow immune photoacoustic sensor for real-time and fast sampling of trace gases.*
  Proc. of SPIE **10539,** 105390G-1, 2018.
- **K.L. Lee, N.B. Jørgensen, L.J. Wacker, M.G. Skou, K.T. Skalmstang, J.J. Arlt, N.P. Proukakis.**
  *Time-of-flight expansion of binary Bose-Einstein condensates at finite temperature.*
  New Journal of Physics **20,** 053004, 2018.

- **J.S. Madsen, S.A. Jensen, L. Nakotte, A. Vogelsang, L.H. Thamdrup, I. Czolkos, A. Johansson, J. Garnæs, T. Nielsen, J. Nygård, P.E. Hansen.** *Scatterometry for optimization of Injected molded nanostructures at the fabrication line.* The International Journal of Advanced Manufacturing Technology **99,** 2669-2676, 2018.
- **Q. Huang, J. Madsen, L. Yu, A. Borger, S. R. Johannsen, K. Mortensen, O. Hassager.** *Highly Anisotropic Glassy Polystyrenes Are Flexible.* ACS Macro Letters **7,** 1126-1130, 2018.
- **S. Duraipandian, M. M. Knopp, M. R. Pollard, H. Kerdoncuff, J. C. Petersen, A. Müllertz.** *Fast and novel internal calibration method for quantitative Raman measurements on aqueous solutions.* Analytical Methods **10,** 3589-3593, 2018.
- **A. Biber, A. C. Korakci, A. Golick, S. Robinson, G. Hayman, J. Ablitt, S. Barrera-Figueroa, S. Buogo, S. Mauro, F. Borsani, S. Curcuruto, M. Linné, P. Sigray, P. Davidsson.** *Calibration standards for hydrophones and autonomous underwater noise recorders for frequencies below 1 kHz: current activities of EMPIR "UNAC-LOW" project.* Acta Imeko **7,** 32-38, 2018.
- **E. Shekarforoush, F. Ajalloueian, G. Zeng, A.C. Mendes, I.S. Chronakis.** *Electrospun Xanthan gum-Chitosan nanofibers as delivery carrier of hydrophobic bioactives.* Materials Letters **228,** 322-326, 2018.
- **L.J. Wacker, N.B. Jørgensen, K.T. Skalmstang, M.G. Skou, A.G. Volosniev, J.J. Arlt.** *Temperature dependence of an Efimov resonance in 39K.* Physical Review A **98,** 052706, 2018.
- **G. Zeng, K. Dirscherl, J. Garnæs.** *Toward Accurate Quantitative Elasticity Mapping of Rigid Nanomaterials by Atomic Force Microscopy: Effect of Acquisition Frequency, Loading Force, and Tip Geometry.* Nanomaterials **8,** 616, 2018.
- **P.E. Hansen, J.S. Madsen.** *Thickness and refractive index analysis of ellipsometry data of ultra-thin semi-transparent films.* Proc. of Imaging and Applied Optics **JM4A.24.pd,** 2018.
- **S. Duraipandian, D. Traynor, P. Kearney, C. Martin, J.J. O'Leary, F.M. Lyng.** *Raman spectroscopic detection of high-grade cervical cytology: Using morphologically normal appearing cells.* Scientific Reports **8,** 15048, 2018.
- **J.S. Madsen, S.A. Jensen, J. Nygård, P.E. Hansen.** *Replacing libraries in scatterometry.* Optics Express **26,** 34622, 2018.
- **P. Singh, S. Pandit, M. Beshay, V.R.S.S. Mokkapati, J. Garnaes, M E. Olsson, A. Sultan, A. Mackevica, R.V. Mateiu, H. Lutken, A.E. Daugaard, A. Baun, I. Mijakovic**. *Anti-biofilm effects of gold and silver nanoparticles synthesized by the Rhodiola rosea rhizome extracts.* Artificial Cells, Nanomedicine, and Biotechnology **46:sup3,** 886-899, 2018.
- **S. Barrera-Figueroa,** *Free-field reciprocity calibration of measurement microphones at frequencies up to 150 kHz,* Journal of the Acoustical Society of America **144**, 2575-2583, 2018.

## CONTRIBUTION AT CONFERENCES

- **S. Barrera-Figueroa**. *Establishing traceability for airborne ultrasound measurements.* EURONOISE 2018 – Measurement of Airborne Ultrasound: Methods and Standards.
- **P.E. Hansen, J.S. Madsen, S.A. Jensen, M. Karamehmedovic.** *The effect of surface and substrate roughness on scatterometry.* European Optical Society Annual Meeting (EOSAM) 2018 – Frontiers in Optical Metrology, Delft, The Netherlands.
- **J. S. Madsen, S. A. Jensen, L. Nakotte, A. Vogelsang, L. H. Thamdrup, I. Czolkos, A. Johansson, J. Garnæs, J. Nygård, P. E. Hansen.** *In-line scatterometry for Injection molded nanostructures.* European Optical Society Annual Meeting (EOSAM) 2018 – Frontiers in Optical Metrology, Delft, The Netherlands.

- **P. E. Hansen, S. R. Johannsen, J. S. Madsen, S. A. Jensen.**
  *Optical Surface Roughness Measurements for High Accuracy and High Speed.*
  Metrology day 2018, Danish Technological Institute, Aarhus, Denmark.
- **L. J. Wacker.**
  *Quantification of corrosion on offshore structures.*
  Innovationsforum for Offshore Droner, Droner & Sensorer, DFM, Hørsholm.
- **L. J. Wacker.**
  *Quantitative measurements of corrosion, gasses and dimensions using drones.*
  Innodrone conference 4: The final conference, Spor 2 – Offshore, Odense Denmark.
- **H. Kerdoncuff, M. R. Pollard, K. Sparnacci, L. J. Wacker, M. Lassen, J. C. Petersen.**
  *Applying hollow core photonic crystal fibre for optical characterization of nanoparticles.*
  EMPIR Innanopart project Open Day, London, UK.
- **F. Li, V. Verdingovas, K. Dirscherl, B. Medgyes, G. Harsanyi, R. Ambat.**
  *Corrosion Reliability and Microstructure Investigation of Sn-Ag-Cu based Lead-free Solder Alloys.*
  European Symposium on Reliability of Electron Devices, (ESREF 2018), Aalborg, Denmark.
- **F. Li, V. Verdingovas, K. Dirscherl, B. Medgyes, G. Harsanyi, R. Ambat.**
  *Corrosion Reliability and Microstructure Investigation of Sn-Ag-Cu based Lead-free Solder Alloys.*
  Nordic Conference on Microelectronics Packaging (IMAPS Nordic 2018), Oulu, Finland.
- **J. Garnæs, S. R. Johannsen, P. E. Hansen, J. S. Madsen, M. S. Nielsen and G. Zeng.**
  *Surface roughness measured by different instrument – how can it be best used?*
  Surface Characterization Conference, Danish Technological Institute, arranged by ATV-SEMAPP.dk and Danish Technological Institute, Taastrup, Denmark.
- **J. Garnæs, G. Zeng.**
  *Imaging of material properties of the very surface – nanoindentation by atomic force.* Surface Characterization Conference, Danish Technological Institute, arranged by ATV-SEMAPP.dk and Danish Technological Institute, Taastrup, Denmark.
- **J. Garnæs, S. R. Johansen, J. S. Madsen, M. S. Nielsen, G. Zeng, S. A. Jensen, S. R. Kynde, K. Dirscherl, P. E. Hansen & J. Hald.**
  *Metrology for additively manufactured medical implants (Metrologi til 3D printede medicinske implantater).*
  Metrology day 2018, Danish Technological Institute, Aarhus, Denmark.
- **J. Garnæs, G. Zeng.**
  *Surface characterisation of materials to 3D print of medical implants.*
  Surfaces with texture and bio applications, Brøndby, Denmark.
- **G. Zeng.**
  *The role of surface properties in bacterial adhesion and biofilm development.*
  ATV-SEMAPP Antibacterial surfaces.
- **S. Duraipandian, M. M. Knopp, M. R. Pollard, H. Kerdoncuff, J. C. Petersen and A. Müllertz.**
  *Quantitative Raman Spectroscopy For Pharmaceuticals In Solution.*
  40th International Conference on Environmental & Food Monitoring (ISEAC-40), Santiago de Compostela, Spain.
- **S. Barrera-Figueroa.**
  *Pressure calibration of WS3 microphones.*
  25th International Congress on Sound and Vibration.
- **M. Lassen, L. Lamard, D. Balslev-Harder, A. Peremans, J. C. Petersen.**
  *Mid-infrared photoacoustic spectroscopy for atmospheric NO2 measurements.*
  SPIE OPTO Photonics West 2018, San Francisco, USA.
- **J. C. Petersen, D. Balslev-Harder, N. Pelevic, A. Brusch, S. Persijn, M. Lassen.**
  *Flow immune photoacoustic sensor for real-time and fast sampling of trace gases.*
  SPIE OPTO Photonics West 2018, San Francisco, USA.

# INCOME STATEMENT AND BALANCE SHEET



| INCOME STATEMENT (1000 DKK) | 2018 | 2017 |
|---|---|---|
| Commercial revenue | 7 099 | 4 047 |
| Project revenue | 7 312 | 8 446 |
| Government funding | 22 738 | 22 510 |
| **Total revenue** | **37 149** | **35 003** |
| Travel and out-of-pocket expenses | 10 330 | 12 120 |
| **Total out-of-pocket expenses** | **10 330** | **12 120** |
| **Gross profit** | **26 819** | **22 883** |
| Staff costs | 22 322 | 19 809 |
| **Total costs** | **22 322** | **19 809** |
| **Operating profit before depreciation and impairment losses** | **4 497** | **3 074** |
| Depreciation and impairment losses on property, plant and equipment | 3 796 | 2 567 |
| **Operating profit before financial income and expenses** | **701** | **507** |
| Financial income | 24 | 45 |
| Financial expenses | 55 | 48 |
| **Profit before tax** | **670** | **504** |
| Tax on profit for the year | 144 | 103 |
| | | |
| **Profit for the year** | **525** | **401** |
| Profit for the year to be carried forward | | |

## BALANCE SHEET AT 31 DECEMBER (1000 DKK)

| ASSETS | 2018 | 2017 |
|---|---|---|
| Deposits | 502 | 876 |
| **Total investments** | **502** | **876** |
| Equipment | 8 206 | 6 215 |
| Leasehold improvements | 15 455 | 15 356 |
| **Total property, plant and equipment** | **23 660** | **21 571** |
| **Total non-current assets** | **24 162** | **22 447** |
| **Contract work in progress** | **6 077** | **6 918** |
| Trade receivables | 1 372 | 894 |
| Prepayments | 45 | 134 |
| Other receivables | 156 | 3 025 |
| **Total receivables** | **1 573** | **4 053** |
| **Cash at bank and in hand** | **10 243** | **7 704** |
| **Total current assets** | **17 893** | **18 675** |
| **Total assets** | **42 055** | **41 122** |

| EQUITY AND LIABILITIES | 2018 | 2017 |
|---|---|---|
| Share capital | 1 000 | 1 000 |
| Retained earnings | 17 179 | 16 654 |
| **Total equity** | **18 179** | **17 654** |
| Prepayments from customers and of funding | 12 927 | 15 723 |
| Trade payables | 1 705 | 3 491 |
| Other payables | 9 244 | 4 254 |
| **Total current liabilities** | **23 876** | **23 468** |
| **Total equity and liabilities** | **42 055** | **41 122** |

# KEY FIGURES



| KEY FIGURES IN MILLION DKK | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|
| Net sales | 27.3 | 27.2 | 31.5 | 35 | 37.1 |
| Gross balance | 23.9 | 23.7 | 35.4 | 41.1 | 42.1 |
| Profit or loss for the financial year [1]) | 0.7 | 0.4 | 0.4 | 0.5 | 0.7 |
| Net capital | 16.5 | 16.9 | 17.2 | 17.7 | 18.2 |
| Commercial sale | 3.6 | 5.3 | 4.6 | 4.0 | 7.1 |
| - to small enterprises (less than 50 employees) | 0.6 | 0.4 | 0.6 | 0.5 | 0.9 |
| - to medium size enterprises (50-250 employees) | 0.7 | 0.8 | 0.9 | 0.9 | 1.5 |
| - to large enterprises (more than 250 employees) | 0.8 | 1.3 | 1.1 | 0.9 | 2 |
| - to Danish public institutions | 0.1 | 0.4 | 0.5 | 0.2 | 0.3 |
| - to foreign enterprises and institutions | 1.4 | 2.4 | 1.5 | 1.5 | 2.4 |
| Foreign net sales | 5.9 | 7.1 | 3.8 | 3.3 | 4.3 |
| **RESEARCH AND DEVELOPMENT** | | | | | |
| Number of collaborative projects | 23 | 23 | 29 | 29 | 23 |
| - thereof innovation consortia | 2 | 2 | 2 | 2 | 1 |
| - thereof international projects | 16 | 17 | 21 | 27 | 20 |
| R&D activities (million DKK) | 26.2 | 23.2 | 26.9 | 30.6 | 29.6 |
| - thereof self-funded | 1.8 | 2.1 | 1.8 | 3.0 | 2.6 |
| R&D work (man-year) | 19 | 17.5 | 17.3 | 17.6 | 19.7 |
| **NUMBER OF CUSTOMERS** | | | | | |
| Danish private enterprises | 33 | 25 | 59 | 57 | 146 |
| - thereof small enterprises (less than 50 employees) | 15 | 11 | 29 | 3 | 67 |
| - thereof medium size enterprises (50-250 employees) | 9 | 6 | 10 | 7 | 32 |
| - thereof large enterprises (more than 250 employees) | 9 | 8 | 20 | 17 | 47 |
| Danish public institutions | 3 | 5 | 10 | 3 | 20 |
| Foreign enterprises and institutions | 17 | 19 | 20 | 33 | 44 |
| Total customer base | 53 | 49 | 89 | 90 | 210 |
| **NUMBER OF STAFF CATEGORIZED BY EDUCATION (MAN-YEAR)** | | | | | |
| Dr & PhD | 18 | 18 | 20 | 25 | 26 |
| MSc | 4 | 4 | 2 | 3 | 1 |
| Other technical staff | 3 | 2 | 2 | 2 | 2 |
| Administrative staff | 2 | 3 | 4 | 4 | 4 |
| Average number of staff | 27 | 27 | 27 | 34 | 33 |
| **NUMBER OF PUBLICATIONS** | | | | | |
| Refereed publications | 14 | 23 | 19 | 21 | 19 |
| PhD and Master theses | 0 | 0 | 3 | 0 | 0 |
| Other reports | 14 | 14 | 15 | 7 | 2 |
| Conference papers | 22 | 15 | 18 | 17 | 17 |
| Calibration certificates and measurement reports | 495 | 521 | 582 | 717 | 1543 |
| Press cuttings | 27 | 28 | 15 | 11 | 35 |
| **EDUCATION** | | | | | |
| DFM courses (number of days) | 2 | 2 | 3 | 3 | 4 |
| DFM courses (number of participants) | 25 | 22 | 18 | 21 | 28 |
| Supervision/teaching at universities (number of students/courses) | 6 | 3 | 3 | 6 | 3 |
| Co-supervision of master thesis students (number of theses) | 5 | 4 | 3 | 0 | 0 |
| Contribution to teaching at universities (number of days) | 6 | 4 | 3 | 6 | 3 |
| Committee work (number of committees) | 32 | 29 | 29 | 29 | 29 |
| - thereof international committee work | 27 | 23 | 23 | 25 | 25 |
| **EFFICIENCY** | | | | | |
| Turnover per employee (1000 DKK) | 1004 | 994 | 1066 | 1129 | 1126 |
| Profit per employee (1000 DKK) | 26 | 15 | 14 | 16 | 17 |
| Commercial turnover per DKK of governmental funding | 0.3 | 0.4 | 0.2 | 0.2 | 0.3 |
| R&D turnover per DKK of governmental funding | 1.6 | 1.5 | 1.3 | 1.4 | 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.**

## DFM

DFM A/S, Danish National Metrology Institute
Kogle Allé 5
DK 2970 Hørsholm

Contact: Jan Hald
Phone: +45 7730 5800
jha@dfm.dk

## 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

## FORCE

FORCE Technology
Park Allé 345, DK-2605 Brøndbyvester
Contact: Peter Bo Mortensen
Phone: +45 4325 0457
pbm@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

## DTU

Technical University of Denmark
Frederiksborgvej 399, Building 201, room S41,
DK-4000 Roskilde
Contact: Jens-Peter Lynov
Phone: +45 46 77 46 67
jply@dtu.dk

# 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 | DFM |
| | | Humidity | FORCE |
| | | Moisture in materials | DTI |
| **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 | |
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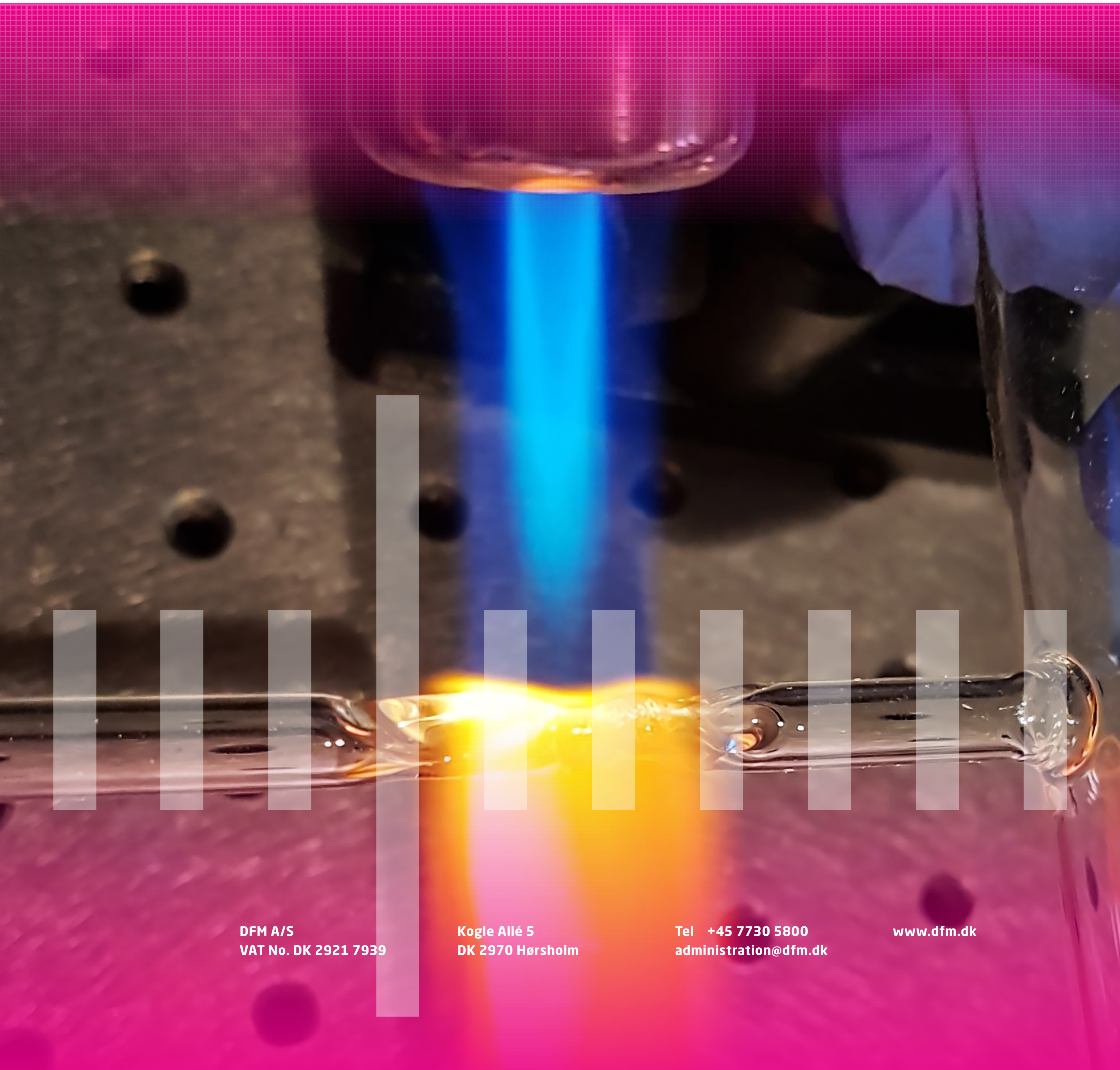


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