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IMM

FRAUNHOFER INSTITUTE FOR MICROENGINEERING AND MICROSYSTEMS IMM

MAKING THE DIFFERENCE

2020/21
ANNUAL REPORT

MAKING THE DIFFERENCE

2020/21
ANNUAL REPORT

EDITORIAL NOTES

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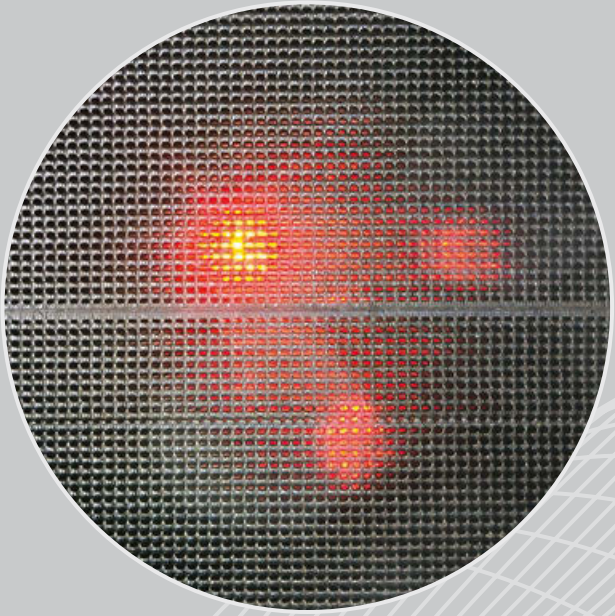
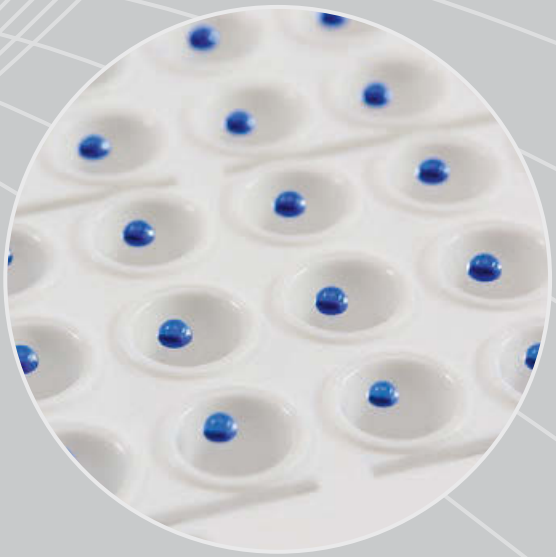




DEAR READERS

The last 12 months have been enormously challenging for all of us. The balancing act between absolutely necessary health care and maintaining operations in known quality was a major effort. This is a place where I would just like to say: thank you. Thank you to my entire team for their thoughtfulness and tireless dedication and thank you to our partners and customers who met us with a lot of understanding and patience under these exceptional circumstances.

Of course, the Covid-19 pandemic has also influenced the Fraunhofer IMM project portfolio drawing a good measure of attention towards the fastest possible diagnosis achievable by reducing test duration, improving throughput and getting as close as possible to the point of need. However, it was clear from the beginning that we must not lose sight of the energy transition and that we must not lose sight of the important innovation drivers in the SME sector that perspectively might have to struggle with the effects in the long term. More than ever, science is recognized to play a major role when it comes to maintain or even speed-up progress and innovation.

In this context we were quite successful to foster our efforts towards establishing processes with increased resource efficiency and lower to no carbon dioxide emission. We have won a project combining the entire Fraunhofer expertise to help getting green chemistry off the ground and to provide some kind of a Fraunhofer "one-stop-shop" for R&D work in this field. We could improve our 360 degree hydrogen competences dealing with its production from renewable resources, its purification for different applications and its utilization in power-to-gas applications.

In all these fields we are honestly convinced that our contribution will make a difference in terms of sustainability. Let me close with a quotation from the 1987 Brundtland Report in which sustainability was defined as **"meeting the needs of the present generation without compromising the needs of future generations to meet their own needs"**. Enjoy reading!

PROF. DR. MICHAEL MASKOS
EXECUTIVE DIRECTOR FRAUNHOFER IMM

PROFILE

FRAUNHOFER INSTITUTE FOR MICROENGINEERING AND MICROSYSTEMS

Our scientists are engaged in research and development in the fields of **ENERGY, CHEMISTRY** and **DIAGNOSTICS.** The emphasis is on hydrogen-based energy supply, sustainable chemistry and process analysis as well as personalized diagnostics and liquid biopsy. With our development work we achieve an essential contribution to the societal challenges "secure, clean and efficient energy", "climate action, environment and resource efficiency" as well as "health".

ENERGY

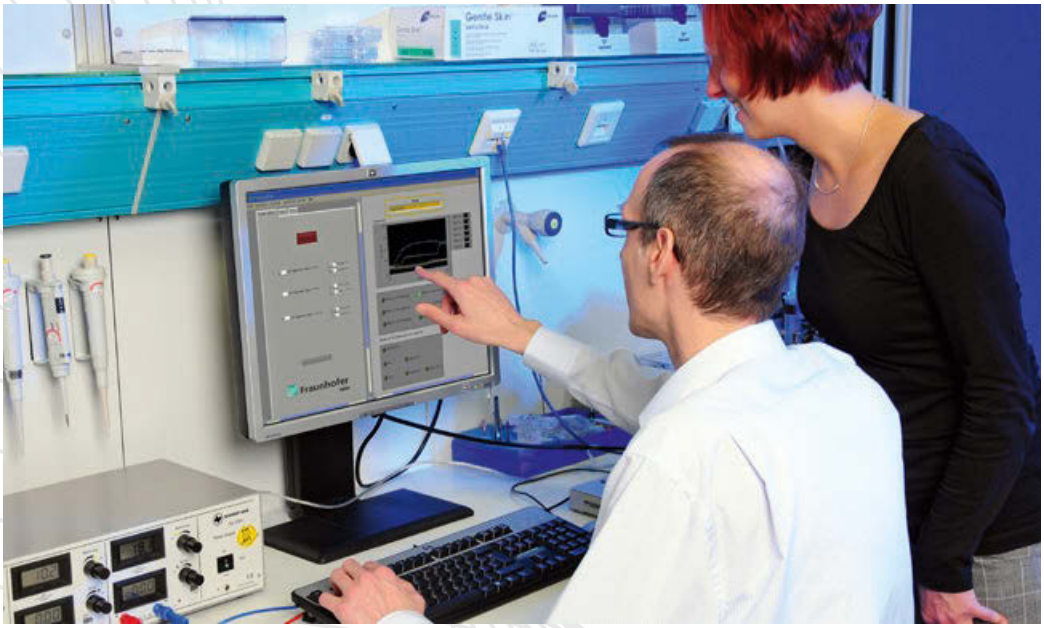
In the division **ENERGY** we deal with current and future issues concerning the mobile and decentralized provision and storage of electrical energy with a stronger focus on sustainable energy sources. Our activities are directly related to the Fraunhofer Strategic Research Field HYDROGEN TECHNOLOGIES, promote the decarbonization of industry and increasingly aim at CO_2 neutrality in processes. We build on a strong fundament, the use of our proven microstructured plate heat exchanger technology, a portfolio of highly active, long-term stable and robust catalysts as well as established manufacturing technologies, which also allow the realization of larger quantities. The development work covers the entire technology chain in the areas of system design, process simulation, catalyst development, durability tests, reactor design, development of cost-effective manufacturing technologies, system control, system integration and system testing. In addition to the development of individual components and complete reformer systems for hydrogen production for all types of fuel cells from conventional and renewable fuels, the research focuses on exhaust gas purification, power-to-gas, methanation, heating/cooling management and biofuel synthesis as well as the use of ammonia as an energy carrier.

CHEMISTRY

In the division **CHEMISTRY**, we are dealing with improving chemical production processes in terms of product properties, efficiency, sustainability and safety. In doing so, we focus on process intensification (PI) enabled by innovative devices and technologies of micro-process engineering as the central strategy for increasing the efficiency and flexibility of processes. Our activities are directly related to the Fraunhofer Strategic Research Field RESOURCE EFFICIENCY & CLIMATE TECHNOLOGIES targeting sustainable production, lower resource consumption, and the avoidance of by-products and waste products. We develop, design and manufacture milli- and microstructured flow reactors and mixers from laboratory to industrial scale, which are optimally adapted to the respective process or application. Considered processes mainly stem from the field of organic chemistry. We cover both, single and multiphase processes as well as non-catalytic and heterogeneously and homogeneously catalyzed reactions. In addition to organic chemistry in general, our research priorities comprise the synthesis of reactive intermediates, electrochemistry and photochemistry. The production and characterization of nanoparticles with various properties and possible applications in medicine, pharmacy and the consumer goods industry represent another research priority. By linking process analysis technologies and new plant concepts, such as the chemical plant infrastructure in container format, we build a bridge to the chemical industry 4.0 and open up decentralized and mobile production approaches.

DIAGNOSTICS

In the division **DIAGNOSTICS**, we focus on processes and methods that open up new ways and time scales in making diagnostic information and data available to individual patients at the point-of-use or point-of-care. In doing so, we focus on the development of previously unused diagnostic parameters for routine medical care and/or the creation of new, flexible access points for the provision of established parameters as well as the determination of individual characteristics of certain diagnostic information on a scale that has not yet been established as standard. Our activities fit directly into the Fraunhofer strategic research field DIGITAL HEALTHCARE, enhance cost-intelligent diagnostics and therapy, and increasingly take into account automation, digitalization, and a link to artificial intelligence. As one of the pioneers of microfluidics, we rely on a "microfluidic construction kit" for the development of fully integrated and automated microfluidic analytical systems with comprehensive coverage of the required functional elements. This includes successful assay modification and their microfluidic integration. Thus, we are able to develop an application idea to the proof of function and build fully functional and economic demonstrators up to pilot series within short time. We attach particular importance to optimal manageability and unrestricted usability in terms of future use as well as compatibility with relevant manufacturing methods. In addition to cancer diagnostics and liquid biopsy, infection diagnostics, pandemic prevention and antibiotic resistance, our work focuses on bioanalytics for industrial media and food safety.



QUALITY POLICY

As a contract research organization a reproducibly high quality of our research and development services is the basis for a successful business activity and customer loyalty in the long term. Quality means for us to understand the partially complex customer requirements, whether expressed or unspoken, to transfer them into workable and customer-friendly solutions and to meet or exceed our customers' expectations. The quality of our work is crucial for customers to place an order and to successfully exploit the results. We are not only developing solutions with and for industry, we as well strive for a project-oriented continued development of our capabilities. We are working together with industry, research organizations and universities in projects being co-financed by the federal government, the federal state or the European Commission in order to tackle important issues for the future. Fraunhofer IMM is a reliable partner and cultivates fair relationships to customers and suppliers. Without doing so the provision of our services would not be possible. To openly communicate with all stakeholders is the absolute precondition for any constructive collaboration. Our employees are the backbone of our institute. Their skills, willingness and subjective well-being determine our target achievement. Our employees feel fully committed to our standards of quality and are being encouraged to further expand our high standards in project work and quality of service by continuous training. Essential prerequisites for professional operation, such as adequate communication structures, training and qualification opportunities as well as a positive and productive working environment are created. Quality-determining process flows are clearly defined, documented and are continuously adapted to changing requirements and improved. Novel quality-determining processes are documented immediately. All related documents are clearly guided and controlled in order to guarantee a sustainable quality in all areas.

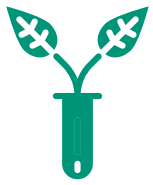
Our quality awareness and understanding as well as the attitude of all employees towards quality are essential to achieving the project objectives and, by this, the satisfaction of our customers. Our management stipulates the quality policy and ensures a consequent implementation of the quality management system. We are currently certified according to DIN EN ISO 9001:2015 and review the effectiveness of our quality management system by regular internal audits and quality meetings.

FRAUNHOFER IMM IN NUMBERS (2020)

94 %
OPERATIONAL SPENDING

6.1
MILLION EURO CONTRACT RESEARCH

6 %
CAPITAL SPENDING



122 PROJECTS

> 61 %
INDUSTRIAL

< 39 %
PUBLIC

77.4 %
PUBLICLY FINANCED R&D PROJECTS

REVENUES FROM EXTERNAL FUNDING SOURCES

22.6 %
INDUSTRIALLY FINANCED R&D PROJECTS

FRAUNHOFER IMM NETWORK

In order to secure our competitiveness and scientific excellence, a close cooperation with research institutes and multipliers is of particular importance to us. Our scientists and engineers therefore cooperate with universities, institutes and companies both nationally and internationally in development projects with a short-term and long-term focus. Close connections to partners in the region are of special relevance in this process.

RESEARCH NETWORKS

BMBF Project Partners // TU Eindhoven // European Technology Platforms // EU Project Partners // BAM Bundesanstalt für Materialforschung und -Prüfung // Dechema // Process-Net // DWV // DGO // Microtec Südwest // N.ERGHY

COOPERATIONS AND STAFF EXCHANGE

University of Mainz // MaxPlanck Institute for Polymer Research Mainz

REGIONAL NETWORK

STUDENT RESEARCH PROJECTS AND DISSERTATIONS

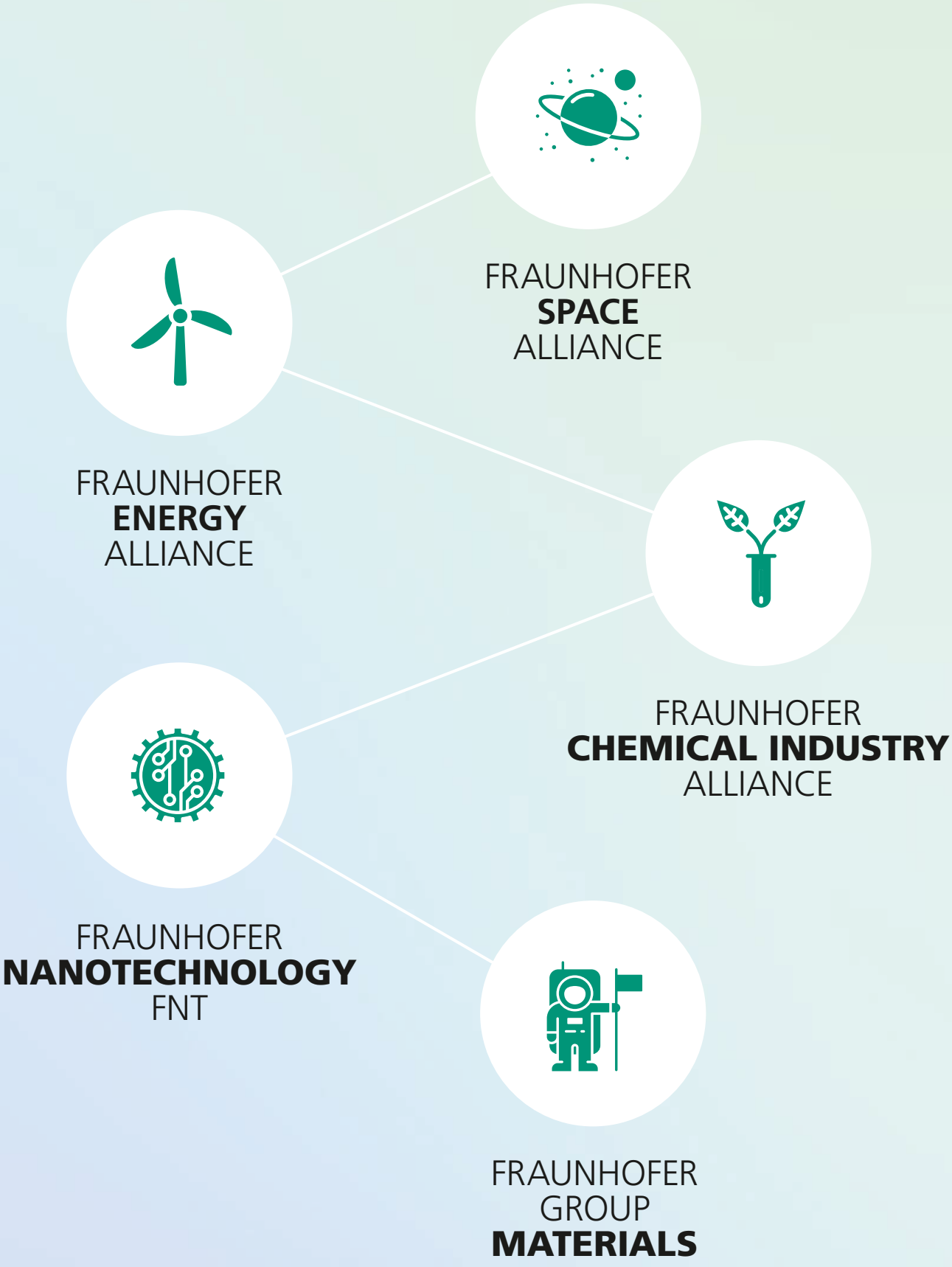
University of Mainz // University of Applied Sciences Mainz // TU Darmstadt // TU Kaiserslautern // RheinMain University of Applied Sciences // Frankfurt University of Applied Sciences // Kaiserslautern University of Applied Sciences // Bingen University of Applied Sciences // Darmstadt University of Applied Sciences // University of Stuttgart // University of Duisburg-Essen // Karlsruhe Institute of Technology // University of Ulm

NETWORKS

AMA // IVAM // Dual Career Network Rheinmain // Mainz Research Alliance e.V. // Cluster Indiviualized Immuneintervention (CI3) e.V. // INNOMAG // Kompetenznetz Verfahrenstechnik Pro3 e.V. //Transferinitiative Rheinland-Pfalz // Cluster Nanotechnology – Netzwerk NanoAnalytik und -Messtechnik in der Produktion

ASSOCIATIONS AND ALLIANCES

WITHIN FRAUNHOFER



Joseph von Fraunhofer

FRAUNHOFER-GESELLSCHAFT

The Fraunhofer-Gesellschaft is the world's leading applied research organization. With its focus on developing key technologies that are vital for the future and enabling the commercial exploitation of this work by business and industry, Fraunhofer plays a central role in the innovation process. Based in Germany, Fraunhofer is an innovator and catalyst for groundbreaking developments and a model of scientific excellence. By generating inspirational ideas and spearheading sustainable scientific and technological solutions, Fraunhofer provides science and industry with a vital base and helps shape society now and in the future.

At the Fraunhofer-Gesellschaft, interdisciplinary research teams work together with partners from industry and government in order to transform novel ideas into innovative technologies, to coordinate and realize key research projects with a systematic relevance, and to strengthen the German and the European economy with a commitment to creating value that is based on human values. International collaboration with outstanding research partners and companies from around the world brings Fraunhofer into direct contact with the key regions that drive scientific progress and economic development. Founded in 1949, the Fraunhofer-Gesellschaft currently operates 75 institutes and research institutions. The majority of our 29,000 staff are qualified scientists and engineers who work with an annual research budget of 2.8 billion euros. Of this sum, 2.4 billion euros are generated through contract research. Around two thirds of Fraunhofer's contract research revenue is derived from contracts with industry and publicly funded research projects. The remaining third comes from the German federal and state governments in the form of base funding.

This enables the institutes to work on solutions to problems that are likely to become crucial for industry and society within the not-too-distant future. Applied research also has a knock-on effect that is felt way beyond the direct benefits experienced by the customer: Our institutes boost industry's performance and efficiency, promote the acceptance of new technologies within society and help train the future generation of scientists and engineers that the economy so urgently requires.

Our highly motivated staff, working at the cutting edge of research, are the key factor in our success as a scientific organization. Fraunhofer offers researchers the opportunity for independent, creative and, at the same time, targeted work. We therefore provide our employees with the chance to develop the professional and personal skills that will enable them to take up positions of responsibility at Fraunhofer, at universities, in industry and within society. Students who work on projects at Fraunhofer Institutes have excellent career prospects in industry by virtue of the practical training they enjoy and the early experience they acquire of dealing with contract partners. The Fraunhofer-Gesellschaft is a recognized non-profit organization that takes its name from Joseph von Fraunhofer (1787–1826), the illustrious Munich researcher, inventor and entrepreneur.

FRAUNHOFER-GESELLSCHAFT IN NUMBERS (2020)

75
INSTITUTES AND RESEARCH UNITS IN GERMANY

2.8
BILLION EURO RESEARCH BUDGET

29,000
STAFF

≈ 2/3
INDUSTRY AND PUBLICLY FINANCED RESEARCH PROJECTS

2.4
BILLION EURO CONTRACT RESEARCH

≈ 1/3
CONTRIBUTED BY THE GERMAN FEDERAL AND STATE GOVERNMENTS

BUSINESS FIELDS

Our society faces an increasing number of challenges that require both, targeted investment in research and innovation and top-notch organizations that are able to create a tangible benefit for society from it. No single player can be ubiquitous. But in our business fields we strive for making the difference, dealing with sustainable and efficient energy supply, green and sustainable chemistry as well as rapid and personalized diagnostics.

ENERGY

What makes us unique?

// The availability of a **mature scalable reactor concept** based on microstructured plate heat exchangers that can easily be coated with catalysts

// A portfolio of **highly active and long-term stable, robust catalysts** for the special application area of fuel processing technology for fuel cells

// A reliable **manufacturing technology** for the cost-effective production of large numbers of reactors

// All **R&D services** up to the complete system including the fuel cell from a single source

Transforming the global energy sector from fossil-based to zero-carbon by the second half of this century will be essential to limit climate change. Due to the fluctuating availability of renewable sources energy storage will become even more important in near future. The capacity of chemical energy storage is orders of magnitude higher than that of batteries. Hydrogen is such a storage medium while hydrogen carriers such as methanol and ethanol, synthetic hydrocarbons such as methane (natural gas), higher molecular weight liquid hydrocarbon mixtures as a substitute for kerosene or diesel and ammonia have significant advantages concerning power density and storage conditions. Nonetheless the extraction of hydrogen from different hydrogen carriers through catalytic conversion, called fuel processing technology, will foreseeably become one of the central processes of future energy technology.

Since the beginning of the millennium, Fraunhofer IMM has evolved to be the most powerful non-university research unit worldwide working in the field of fuel processing. Projects based on industrial contract research or public funding are arranged along the entire technology chain: system design, process simulation, catalyst development, durability tests, reactor design, development of cost-effective manufacturing technologies, system control, system integration and system testing. Dynamic hydrogen supply for fuel cells, including the reforming of natural gas, LPG, methanol, ethanol, propylene glycol, gasoline, kerosene, diesel and ammonia decomposition for stationary as well as mobile applications in the field of aerospace, shipping, transport, leisure, automotive, combined heat and power units form outstanding project examples in the Fraunhofer IMM portfolio. Besides the production of hydrogen, its utilization in power-to-gas applications and the purification of reformate or exhaust gases are part of the core competencies. The construction, realization and testing of highly compact microstructured reformer reactors, the associated catalyst technology, the construction of complete fuel processor systems and their coupling with fuel cells and finally the automation of systems with and without fuel cells complete the expertise.

CHEMISTRY

What makes us unique?

// A wide range of **microstructured mixers, heat exchangers and reactors** allowing to precisely control chemical processes

// **Scalability and modularity** of the reactor concept as a premise for flexible production and reduced time-to-market

// A **profound knowledge and experience** base in the transfer of batch to continuous processes including the perspective towards pilot and production scale

// **Industry relevant process know-how** for special reaction classes like electro- and photochemical syntheses, syntheses of reactive intermediates and polymers, nanoparticle synthesis and encapsulation

The chemical and pharmaceutical industry need to evolve and adapt themselves to the changing market conditions constantly. These include an increasing commoditization of chemical products, a changing raw material base and climate change directly linked to the context of energy transition. Moreover, society increasingly voices the expectation that production and consumption need to become more resource-saving, environmental friendly, socially acceptable, in total, more sustainable.

Chemical industry is the base of many value chains and often the most important driving force for innovations in other fields. As Europe's most important chemical producer, Germany especially faces the public as well as competitive pressure to establish a sustainable chemistry.

The business field Chemistry deals with the improvement and sustainable design of chemical production processes and process analytics using in-house technologies. These technologies enable precisely controlled continuous chemical processes with increased resource and energy efficiency and foster modular and flexible production concepts, e.g., facilitating the adaptation to a raw material base changing towards more renewables. Moreover, regeneratively produced excess electricity can be used to produce valuable chemicals with a high efficiency and selectivity applying electrochemical microreactors. Photochemical microreactors with optimized use of light allow for green paths in organic synthesis and material use of CO_2.

Services provided for our customers and partners cover lab chemical process development in the area of flow chemistry, the development and realization of specialized flow reactors (with an increasing use of additive manufacturing technologies) up to production scale, and further support in transferring the results in chemical production and application, e.g., by the establishment of demonstrators at pilot scale level.

DIAGNOSTICS

What makes us unique?

// The breadth and depth of our **microfluidic system competence** for the automated preparation and analysis of human samples

// Extensive experience in the miniaturization of lab preparation methods, their integration with microsystems, including measurement methods for sample analysis, such as PCR, nucleic acid extraction and purification, immunoassays or ELISAs and flow cytometry

// The capability **to isolate and position single cells** directly from billions of other cells

// A technique for the dispensing of single cells guaranteeing a good morphological quality and allowing a further cultivation of these cells

The cause, course and treatment of a disease such as cancer, autoimmune disorders, diseases of the central nervous and the respiratory system, are significantly influenced by individual genetic attributes and living conditions. Modern medicine increasingly recognizes and addresses these differences between human individuals and terms this concept "personalized medicine". Due to the tumor heterogeneity personalized approaches are especially relevant for cancer therapy. This is as well reflected in the "national decade against cancer" proclaimed by the German federal government to set the focus on the uniqueness of every human individual. Patients are expected to significantly benefit from precisely targeted therapies based on a personalized initial and companion diagnosis and a quasi-continuous monitoring of disease progression.

For more than two decades Fraunhofer IMM develops technical solutions for microfluidic-based analysis systems to be applied in life sciences, medical research and diagnosis, comprising the detection of pathogens in natural body fluids (such as whole blood, plasma, serum, sputum and urine) as well as the analysis of organic samples. Microfluidics enable robust solutions with new functionality and offer opportunities for significantly saving costs and time in (diagnostic) analysis processes. Our microfluidic processes and techniques allow to overcome limitations with respect to fast, locally available and precise diagnostic tests that still exist for near patient, on-site testing, operating inside and outside the established large central laboratories. The approaches enable the provision of in-depth diagnostic parameters that are so far unused. The importance for such an improved, fast and flexible diagnostic testing became directly obvious during the Corona crisis. Sample preparation is a vital part of our activities when developing the corresponding microfluidic cartridges and functional systems. Besides, we also use microfluidics to enable automated on-line quality control of cell based processes. Among others, this is required for the future automated production of advanced therapy medical products, which is a precondition to make such personalized medical products applicable and affordable on a large scale.

FLAGSHIP PROJECTS

Last year we introduced a series of flagship projects, one for each of the business fields. We do not necessarily base this terminology on the financial volume of these projects. It is more a question of the importance and character as a prominent technology ambassador that the respective developments will take. They represent the power of microsystems technology and are all predestined to make a significant difference in real-world applications.

FUEL CELL BASED COMBINED HEAT AND POWER UNIT

THE GOAL
CO_2 neutral electrical energy and heat supply with power equivalents allowing to address large scale application scenarios in a variety of areas in work and life.

(Substantially financed by the Ministry of Science, Education and Culture of the State of Rhineland-Palatinate)

THE STATUS Our prototype fuel cell combined heat and power (CHP) unit for methane / natural gas with 50 kW_{el} power equivalent has been put into operation. Both the fuel processor (hydrogen generation) and fuel cell parts of the system are now running fully automated through the different steps of the start-up procedure up to the normal operation mode. This means that all about 30 control loops of the system have been optimized and the control of the balance-of-plant (i.e. pumps, compressors and other periphery) has been put into operation. Possible system failures have been minimized. The control system processes more than 800 measured values in real time. Depending on the requirements, the system reacts after about a second or faster, e.g., on changes of the fuel cell voltage within less than 10 ms. In addition, there are values calculated from these signals, such as gas compositions, temperature gradients and mean values. Most of these values are monitored in real time by the system for plausibility and some also for limit value violations. In this way, many critical operating states can be recognized and classified by the system much faster than a person could recognize and evaluate the relationships. A total of almost 300 warnings, alarm, event and fault messages are defined in text form, all of which are also archived.

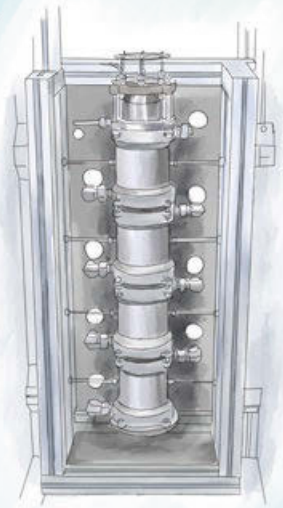
THE GOAL
Flexible provision and processing of reactive intermediates in a resource efficient way and at a scale that allows to address chemical and pharmaceutical production.

PILOT PLANT
FOR THE CONTINUOUS GRIGNARD SYNTHESIS

THE STATUS Within the last twelve months, we have focused the efforts on improving and optimizing our modular pilot plant and, thus, paving the way to get the first pilot plant installed at an industrial partner's site within a year.

This included a significant amount of trial runs, varying compositions, throughput and operating time to be prepared to address the 100+ tons annual production range in good time.

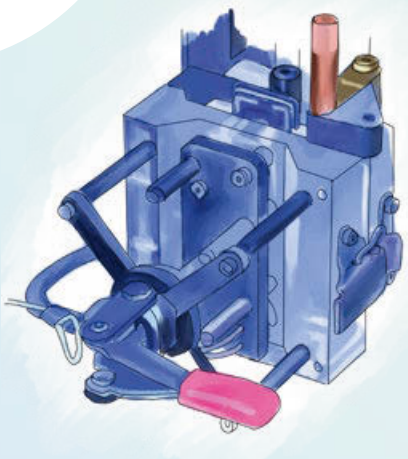
High impact papers have been published and a number of seminars have been given to disseminate the results of our work. Additionally, the use of the innovative reactor concept is extended to other chemistries. So, systematic investigations of the synthesis of organometallic compounds of zinc on the lab scale have been performed.

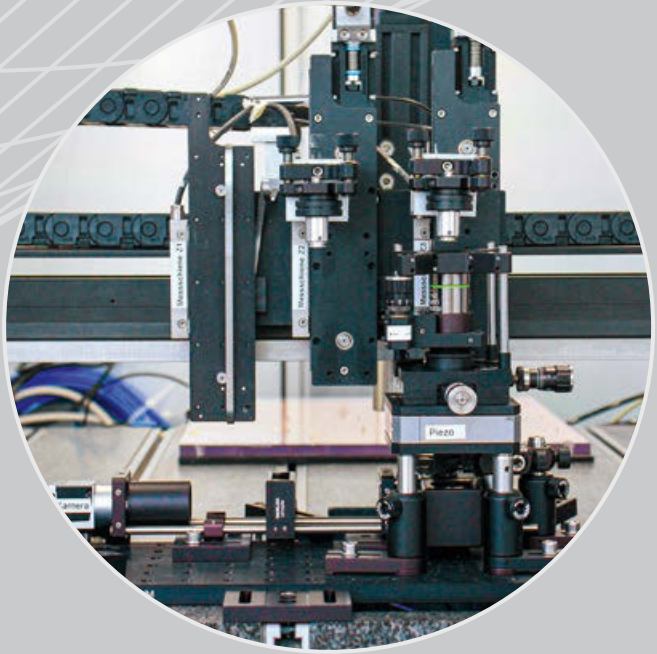


THE GOAL
Analyzing a variety of relevant biomarkers from one single standard blood sample giving access to novel diagnostic procedures.

LIQUID BIOPSY

THE STATUS The initial prototype has been turned into a robust and user-friendly demonstrator for research in personalized cancer therapy. Using preclinical models, morphologically intact cells could be reliably isolated from real patient samples. Subsequent molecular analyses of the individual cells confirmed that they were indeed tumor cells. Thus, completely new insights into the heterogeneity of tumors become possible, which have the potential to explain the response or failure of therapies, which is often difficult to predict. In addition to the research market, the additional direct use in diagnostics without radical changes to the system is possible and naturally envisaged in the next steps.



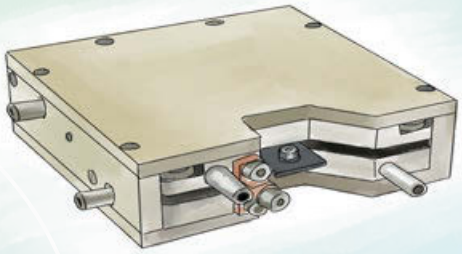


PROJECT HIGHLIGHTS

In many ways the past 12 months have been remarkable. This includes a remarkable number of new projects that allow(ed) us to enter new paths and further develop old ones. There was one constant though, we devote most of our efforts to health, environment and energy supply. The following pages are as usual a cross-section of our activities.

FRAUNHOFER IMM VS. CORONA

Fraunhofer IMM leads and participates in projects on Covid-19, addressing different targets to contain the pandemic: early detection, rapid and reliable testing at lab scale and on-site as well as infection prevention and drug production.



AVATOR

Development of an electrochemical reactor for the on-site production of a novel virucide as well as an innovative air monitoring system for online monitoring of the virus concentration in room air.

Funding: Fraunhofer Anti-Corona-Program;
Status: active; Grant no. 840265

CoV-2-KomET

Mobile laboratory, Point-of-Care analysis and high-throughput diagnostic strategies to complement SARS-CoV-2 testing.

Funding: Fraunhofer Anti-Corona-Program;
Status: active; Grant no. 840268

FhVT

Development of a scalable continuous manufacturing technology for mRNA nanodrugs, designing GMP-capable micromixers that enable controlled formulation of vaccines.

Funding: Fraunhofer Innovations Program;
Status: active; Grant no. 800092

CaZe

Prevalidation of a point-of-care (POC) system prototype for the rapid detection of SARS-CoV-2 to be used even by untrained personnel thanks to full automation of the processes.

Funding: Carl-Zeiss Foundation;
Status: closed

MICRO-DETECT

Optimization of an existing microfluidic moving plug PCR system with regard to the analysis of viral RNA for the automated detection of viral infectious agents, such as SARS-CoV-2.

Funding: Rhineland-Palatinate;
Status: closed;
Grant no. 724-0032#2020 /
0004-1501 15402

CODECT

Establishment of a rapid test method for the early detection of undetected or asymptomatic covid-19 patients based on routine laboratory tests applying artificial intelligence.

Funding: Fraunhofer Anti-Corona-Program;
Status: closed; Grant no. 840237

OPEN-POCT

Establishment of an administrative and regulatory ecosystem for a scalable, intelligent, and digitized open-access rapid test platform for the detection of pandemic infectious agents.

Funding: EU-EFRE, (REACT-EU)
Rhineland-Palatinate;
Status: active;
Grant no. 84009429

SHAPING THE FUTURE OF GREEN CHEMISTRY

BY PROCESS INTENSIFICATION AND DIGITALIZATION

Global challenges in the areas of climate protection, energy and resource efficiency, coupled with demands from society and politics for green, sustainable chemistry, have led the chemical industry to set itself ambitious goals for defossilizing its production processes and establishing circular, greenhouse gas-neutral material and energy conversion. Nine Fraunhofer Institutes cooperating in the lighthouse project ShaPID want to provide targeted support to chemical industry in R&D efforts by pooling their applied research to achieve the challenging sustainability goals and, at the same time, intensifying their R&D relationships with one of the most innovative industries.

This project aims to demonstrate that sustainable, green chemistry can be achieved through practical technological innovations based on process intensification and digitalization. So, technology developments are pursued in the four following technology fields:

// Synthesis, reaction and catalysis technology,
// continuous process technology and process engineering,
// modeling, simulation and process optimization,
// and digitalization and automation.

These innovations are demonstrated in a practical manner using three reference processes:
// "Green Plastics" – from CO_2 and biogenic raw material sources to new polymers,
// "Green Monomers" – energy-efficient syntheses of monomers from non-fossil raw materials, and
// "Efficient Building Blocks" – use of highly reactive molecules for atom-efficient synthesis.

Fraunhofer Lighthouse projects:
https://s.fhg.de/lighthouse-projects

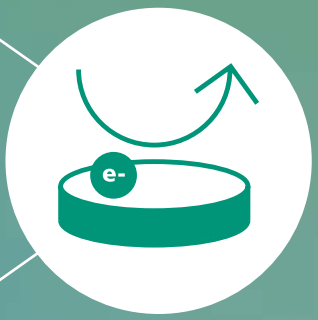
ShaPID:
https://s.fhg.de/shapid

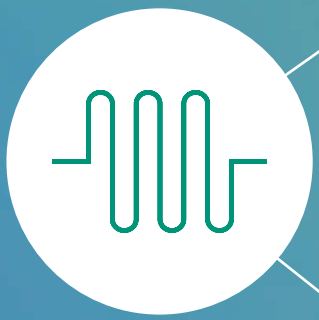
FRAUNHOFER IMM CONTRIBUTION

We play a key role in the reference processes when it comes to the development of the continuous process steps for the demonstrators, the development and realization of the process modules and the plant engineering. This includes modular reactor concepts, process scaling and downstream processing as well as modular or container based plant concepts for multistep processes.

GREEN PLASTICS DEMONSTRATOR

We are involved in implementing and adapting the individual modular processes in order to create an overall continuous and modular process. We contribute to the electro catalytic intermediate production with a newly developed scalable electrolysis cell and to the integrated downstream processing.





EFFICIENT BUILDING BLOCK DEMONSTRATOR

We are involved in safety concepts guaranteeing that toxic and explosive substances are formed only briefly in small quantities as intermediates. We contribute to the goal that all synthesis steps for the production of different diazo compounds are developed on a laboratory scale in continuous mode of operation while varying reaction conditions to define suitable process windows. Single-step downstream processes for the in-situ conversion of diazo intermediates will be developed.

GREEN AND EFFICIENT CHEMISTRY TECHNOLOGY PLATFORM

The Fraunhofer Green Efficient Chemistry (GEC) technology platform will be established in a joint effort of all involved Fraunhofer Institutes as a central exploitation. So, the project results achieved, including hardware, software, processes, tools, concepts as well as the expert knowledge will be the basis for future R&D with the chemical industry.

Viking Energy, the first ship in the world to be equipped with an ammonia-based fuel cell

THE WORLD'S FIRST HIGH-TEMPERATURE AMMONIA-POWERED FUEL CELL FOR SHIPPING

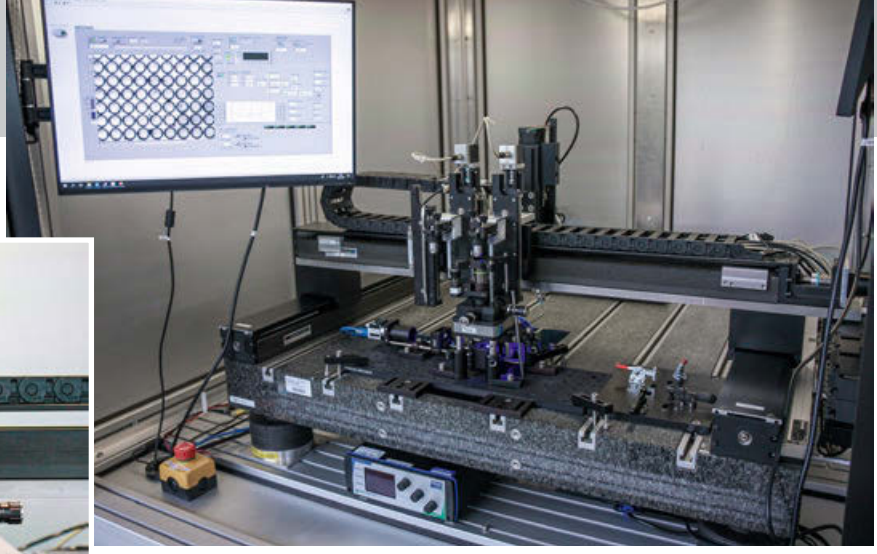
Maritime transport emits hundreds of millions of tons of carbon dioxide annually and is responsible for about 2.5% of global greenhouse gas emissions. As scientists and engineers around the world are working towards propulsion methods capable of replacing fuel oil in ships, Fraunhofer IMM researchers are part of an international consortium aiming to develop ammonia-based fuel cells. When used as fuel for ships with electric engines, ammonia is a high-quality energy carrier, is as eco-friendly as hydrogen but easier and safer to handle in transport and storage. Though toxic, well-established regulations are in place to allow safe handling. Today ammonia is primarily known for its use as a fertilizer in the agricultural sector.

Ammonia can directly be fed into a Solid Oxide Fuel Cell in which the hydrogen from the ammonia together with oxygen from the air is generating electricity, emitting water and nitrogen. About 12 percent of the hydrogen and some residual ammonia leave the fuel cell uncombusted. This residue is then fed a catalytic converter in which the residue together with air gets into contact with a corrugated metal foil coated with a powdered layer of catalytic particles. In a chemical reaction the residue is converted into water and nitrogen. An optimal reaction process will not even produce environmentally harmful nitrogen oxides. In the second half of 2023, the first ship with an ammonia-powered fuel cell will put out to sea – the Viking Energy, a supply vessel owned by the Norwegian shipping company Eidesvik.

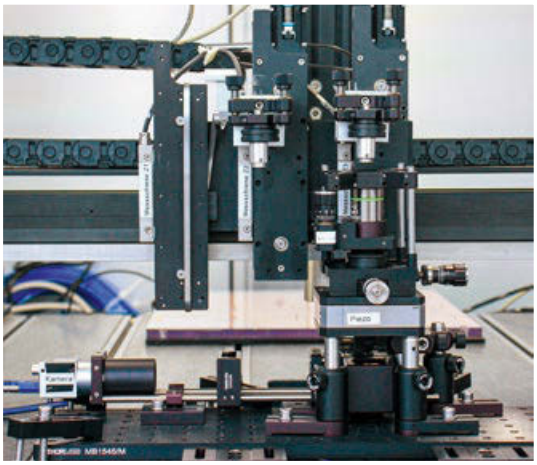
FRAUNHOFER IMM CONTRIBUTION

// Development of a catalytic converter for the residue of hydrogen and ammonia coming out of the fuel cell
// Development of the suitable catalyst for use in the converter
// Building a first small prototype by the end of 2021
// Building an actual-size prototype by the end of 2022

The ShipFC project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 875156. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation program, Hydrogen Europe and Hydrogen Europe research.



Multi-axis micropositioning system with integrated microscope



Close-up of the robotic positioning head, with piezo sample holder for fine positioning

QUANTUM MAGNETOMETRY

Magnetometry has two general aims: measuring magnetic fields as precisely as possible and on the smallest length scale. Magnetometers have been used intensively for a long time – as compasses to measure the earth's magnetic field, for geological studies or to analyze nanostructured magnetic layers in hard drives for data storage. There have been numerous breakthroughs in the scientific and technological use of magnetic fields during the past decades. However, quantum technology will stimulate disruptive innovation when magnetic fields can be measured with nanoscale spatial resolution and with the highest sensitivity, using quantum sensors at room temperature.

Using quantum technology, the Fraunhofer lighthouse project QMag will further develop magnetometers including the respective application testing. For that purpose, nitrogen vacancy centers in diamond will be used turning a single atomic system into a highly sensitive sensor that can already be operated at room temperature. As a second approach, so called optically pumped alkali magnetometers, OPM, will be applied exploiting the magnetic field dependence of the optical properties of alkali atoms. Thus, innovations like the insight into the magnetic fields of the brain come within reach.

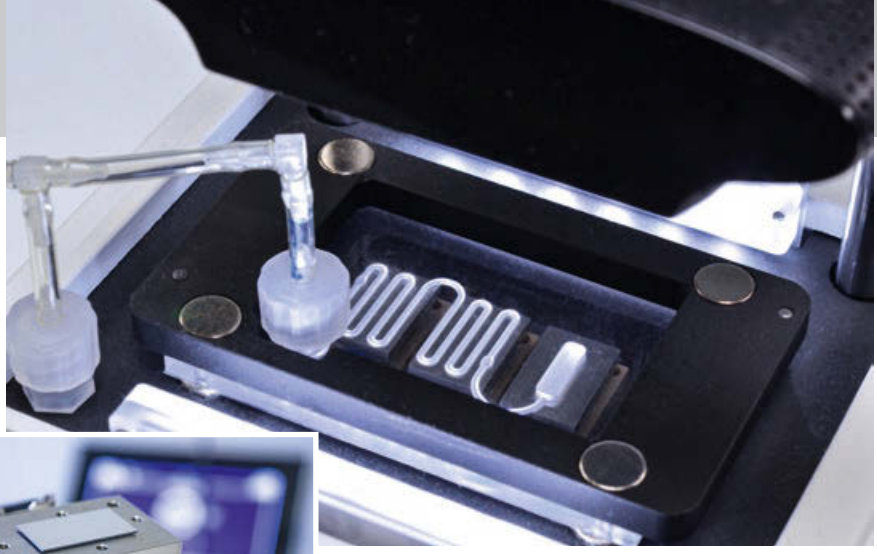
Based on prototypes of such magnetometers, application-specific, cost-effective, complete measuring systems are to be developed. The two measuring methods are complementary with regard to highest spatial resolution and extreme sensitivity, so that different new applications can be developed as a result. With such novel quantum magnetometers, micro- and nanoelectronic components, for example, can be non-destructively tested and then optimized. Potentially, even individual bits in storage media could be visualized. In addition, process nuclear magnetic resonance for chemical process analysis as well as scattered magnetic field measurement for contactless material testing will be tested and established.

FRAUNHOFER IMM CONTRIBUTION

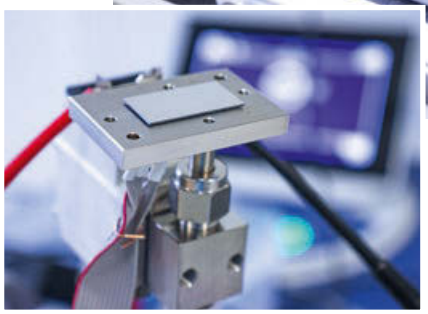
// Production and characterization of magnetic nanoparticles, which are attached to diamond tips containing NV centers and are intended to increase the sensitivity of the quantum magnetometers.

Partners:
Fraunhofer IAF
Fraunhofer IPM
Fraunhofer IWM
Fraunhofer IISB
Fraunhofer IMM
Fraunhofer CAP, UK Research Limited

Funding source: Fraunhofer LIGHTHOUSE PROJECT
Grant no. 838527



Polycarbonate chip inside a real-time PCR module



New Hydrogen sensor test set up with silicon-based thin hydrogen selective membrane

FIGHTING CORONA WITH "ULTRAFAST PATHOGEN DETECTION" AND SUPPORTING THE HYDROGEN STRATEGY WITH "MEMS-BASED HYDROGEN SENSING"

The SARS-CoV-2 virus emerged at the end of 2019 has caused the COVID-19 pandemic, with over 3.7 million deaths worldwide, more than 1 million deaths in Europe and about 90.000 deaths in Germany. New variants of the virus that are constantly developing due to mutations continue to spread around the world and lead to severe outbreaks. To control, contain and manage the situation, we need technologies that are fast, sensitive, compact and indispensable from laboratory equipment or –personnel to facilitate a detection wherever needed.

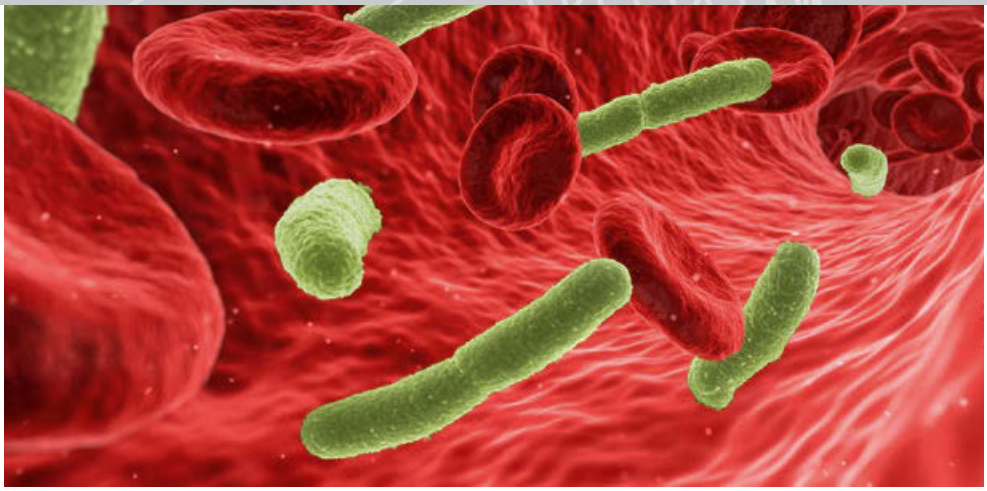
MIKRO-DETECT aims to improve the sensitivity and efficiency of analytical systems by optimizing microstructured components and to demonstrate the potential of such systems for two core innovations. One is the fast and automated detection of viral infectious agents (e.g., SARS-CoV-2) via rapid PCR to fight pandemic threats, and the other is the reliable detection of hydrogen as a future energy carrier to meet safety requirements for its transport and storage. It is more than obvious to use microtechnology and microsystems in the two subprojects of MIKRO-DETECT to demonstrate a way to make both a direct contribution to pandemic control and thus an indirect contribution to economic recovery, as well as a direct contribution to establishing hydrogen as a safe energy carrier.

In subproject 1, Fraunhofer IMM utilizes the existing 6-min-PCR-moving-plug technology to develop a molecular method that will detect SARS-CoV-2 as fast as an antigen rapid test, but with significantly higher sensitivity and specifity. In subproject 2, Fraunhofer IMM transfers the functional principle for an existing helium sensor into a miniaturized hydrogen-sensitive sensor with a detection principle based on thermal conduction instead of electrical ionization capability.

FRAUNHOFER IMM CONTRIBUTION

// Optimization of the existing microfluidic moving plug PCR system with regard to the analysis of genomic viral RNA for the automated detection of viral infectious agents such as SARS-CoV-2 including a prototype system and testing of an automated sample supply
// Fabrication and measurement of a hybrid sensor cell consisting of a base body with micro-engineered membrane and a commercial thermal conductivity pressure gauge as readout instrument

The project MIKRO-DETECT is partially supported by Ministry of Science, Education and Culture of Rhineland-Palatinate Grant no. 724-0032#2020 / 0004-1501 15402



Bacteria in a bloodstream as cause of a sepsis

EARLY DETECTION OF SEPSIS

Sepsis describes a strong systemic inflammatory reaction to pathogens such as bacteria, viruses, fungi or parasites. With an estimated 18 million deaths worldwide per year, sepsis is one of the leading causes of death. The mortality rate depends largely on the severity and progression of the disease. Since sepsis can lead to death within a few days, diagnosis as early as possible is essential. Especially in physically impaired collectives (sick, elderly, newborn), sepsis represents a serious and life-threatening health risk for the patients. Even if sepsis is survived, long-term consequences of a psychological or physical nature may occur.

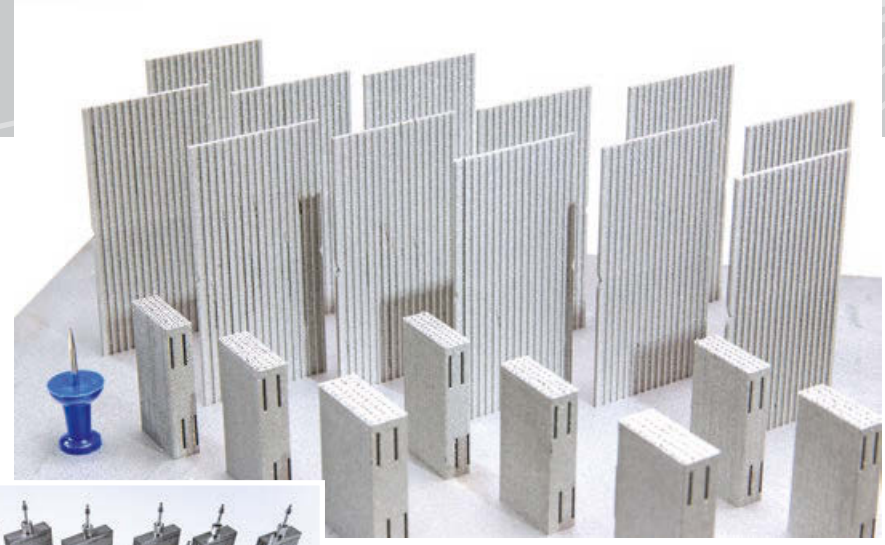
The current standard clinical procedure is still based on the time-consuming central laboratory blood analysis for inflammatory markers and bacterial culture of blood samples. Results commonly take hours to days. During this time, the patient is administered a broad-spectrum antibiotic drug. However, this is associated with systemic side effects, whereas the therapeutic success often remains very limited due to prevalent microbial resistances. It is therefore not surprising that most deaths related to sepsis occur within the first 48 hours.

The aim of the project RESCUE-SEPS is to develop an automated overall system, consisting of an analyzer demonstrator and a disposable microfluidic cartridge, for an early and patient-near detection of sepsis. The system will improve medical information quality and allow for a significantly faster diagnosis and thus a precise therapeutic start. In addition, by short time interval measurements, a progress-monitoring will be feasible too. The research and development approach is based on the use of rapid, microfluidic amplification and detection of cell-free DNA (cfDNA), which is present in the patient's blood in increased concentrations upon sepsis. The advantages of the system include shortened detection times, a high analytical sensitivity and reduced amounts of blood of only 100 µl per test. Moreover, disposable cartridges, an automated analyzing process, a stable and thus reliable quantitative assay adapted to the system and an intuitive user interface will allow for an application at the point-of-care.

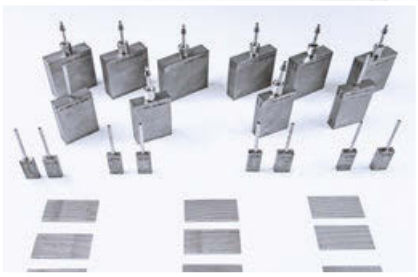
FRAUNHOFER IMM CONTRIBUTION

// Development of an automated system for a fast detection of sepsis with a high sensitivity and an easy to use interface
// Development of a suitable assay adapted to the system
// Design of a disposable polymer cartridge suitable for the assay

The project RESCUE-SEPS is carried out together with the JGU Mainz and funded by Ministry for Economy, Transport, Agriculture and Viniculture of the State of Rhineland-Palatinate Grant no. 7200-0007#2020 / 0001-0801 8401



Exploring selective laser melting for reactor realization: microstructured test blocks



Microreactor test blocks ready for tightness and pressure stability measurements

INNOVATIVELY MANUFACTURED REACTORS AND INTELLIGENTLY CONTROLLED MODULAR PLANTS

The European process industry needs to change to persist in the growing competition especially from Asia, e.g., by moving to more customer specific products. But these are related to smaller production lots and shorter product life cycles. In consequence, there is a need for flexible production concepts allowing high efficiency and low costs. Modular plants for continuous chemical and energy conversion processes represent a solution approach here with high potential to address these challenges. Ideally a modular plant is assembled from already engineered single modules. Re-use of the former corresponding engineering efforts or even re-use of physical equipment will lead to a reduction of efforts and costs in plant engineering. Furthermore, plant realization is accelerated and a faster time-to-market enabled.

The project InnoModA "Innovatively fabricated reactors and intelligently controlled modular plants for tomorrow´s industry" bundles and further develops the competences of Fraunhofer IMM in the field of energy and chemical technology in view of modular production. The target is to pave the way for a broader industrial uptake and implementation of the corresponding technology.

PROJECT WORKS FOCUS ON

// Innovatively manufactured reactors: Micro- and millistructured reactors form the core of Fraunhofer IMM´s technology basis for improving chemical and energy conversion processes. More and more, additive manufacturing like selective laser melting is used for their manufacturing due to high design freedom and fast realization times. Realizing larger reactors and getting exemplary regulatory approval is followed to remove obstacles for an industrial implementation.

// Module and plant automation: Plant modularization means also modularization of the automation concept. Exemplary, one of its modules will be automated reflecting the so called Module Type Package (MTP) approach. Furthermore, for a fast gas phase process an AI-based automation approach to improve process control compared to a conventional automation approach will be followed.

// Economic considerations of modular plant concepts: In national and international discussions the term "modular plants" is broadly used ranging from package units up to complete plants. Aside from plants assembled from single modules, Fraunhofer IMM also follows the concept of a mobile, container based plant as module.

The project achievements will be implemented and operated in two demonstration plants from the area of energy and chemistry to narrow the gap for an industrial implementation of the new technology approaches.

InnoModA funded by Ministry of Science, Education and Culture of Rhineland-Palatinate
Funding reference: Europäischer Strukturfond für die regionale Entwicklung (EFRE) – "Investitionen in Wachstum und Beschäftigung (IWB) – Rheinland-Pfalz", Funding period 2014–2020. Proposal no.: 84004713.

NMRplusX synthesis plant including all analytic units: thermostat, pumps, UV-Vis spectrometer (left), synthesis platform with thermal reactor, photoreactor and IR sensor (middle), UV-Vis light source, IR and NMR spectrometer with flow cells (right)

ORTHOGONAL SPECTROSCOPY FOR CHEMOMETRICS AND AUTOMATED PROCESS OPTIMIZATION

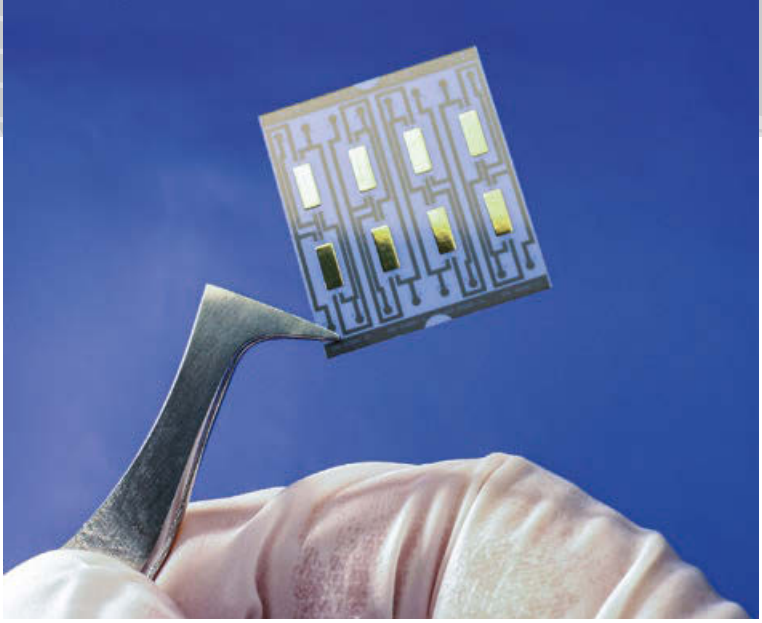
Recent developments in process analytical technology have become a major driving force for the digitalization of the chemical industry with regard to Industry 4.0. Smart analytical tools based on commonly known analytical methods allow the rapid development of novel control technology for chemical processes. Even more important is the communication between the analytical tools and the meaningful interpretation of the accumulated data derived from highly resolving analysis tools. Such detailed information maps on every physical and chemical change during a chemical process are the base for an in-depth investigation using available software tools for big data analysis and machine learning (ML).

The overall goal of the project NMRplusX is the development of a hardware- and software-based synthesis- and analysis platform, which will enable an automated, self-regulating and self-optimizing synthesis and analysis of chemical products. NMR spectroscopy will be used in conjunction with FTIR and UV-Vis spectroscopy as central process analytical unit. All available spectroscopic information can be used for chemometrics or vice-versa calibration, and will prove the synergy from three orthogonal spectroscopic tools. Continuously operated reactor systems will be provided for thermal and photochemical syntheses. A central process control unit will harmonize data transfer between each of the spectrometers and all communication to the continuous flow synthesis plant.
Big data amounts derived from each spectroscopic tool are analyzed and assessed as base for machine learning approaches. Minimal or systematic changes in spectroscopic data can be disclosed and verified by three analytical methods, hence, associated with physical and chemical changes in the synthesis protocol. Results from routine learning with normalized spectroscopic data sets can then be transferred from the model compound synthesis to its derivatives allowing a faster and more reliable process development.

FRAUNHOFER IMM CONTRIBUTION

// Development of a continuously operated laboratory synthesis plant for model compound synthesis
// Development and construction of a customized spectroscopic module for the online analysis of continuous flow chemical processes
// Enhancement of the spectrometer hardware together with Nanalysis Corporation
// Development of the suitable ML software together with TROUT GmbH
// Process control unit with implemented spectroscopic module to control a continuous flow synthesis plant

Funded by: German Federal Ministry of Education and Research (BMBF), funding code 01DM19004A



New bolometer sensor made on flexible ceramic substrate with gold surface (rear view)

RADIATION MONITORING IN FUSION EXPERIMENTS

The finite nature of fossil energy sources as well as the emission of vast amounts of the greenhouse gas CO_2 when fossil fuels are combusted pose a major challenge for the field of energy supply. By means of nuclear fusion, i.e. the fusion of two light atomic nuclei, a considerable amount of energy can be gained from only very small quantities of "combustion material" such as deuterium and tritium. However, the fusion reaction demands substantial technical effort to generate an extremely hot, magnetically confined plasma as well as precise monitoring and control of the respective processes. For the determination of the plasma-radiated power at different points of the plasma, special radiation sensors known as bolometers are used. They convert incoming radiation into heat, which can then be measured by a temperature-dependent resistor (platinum). Bolometry in a fusion experiment is not only used for process control, it also allows to measure if more energy is generated than supplied and it facilitates the calculation of cross-sectional profiles of engergy densities within the plasma.

The goal of the CALORI04 project series is to contribute to the advancement of bolometry for the ITER project, the biggest international collaboration in the field of fusion energy, to the point where bolometer sensors can be procured through commercial contracts. Apart from needing to be sensitive to electromagnetic radiation (from IR-light to X-rays), another challenge for the bolometer sensors is resilience against extreme conditions, such as neutrons emitted from the plasma and alternating temperatures up to 400°C. In particular, the resilience against alternating temperature loads has been found to be a critical aspect of previous bolometer designs used in many fusion experiments in the past.

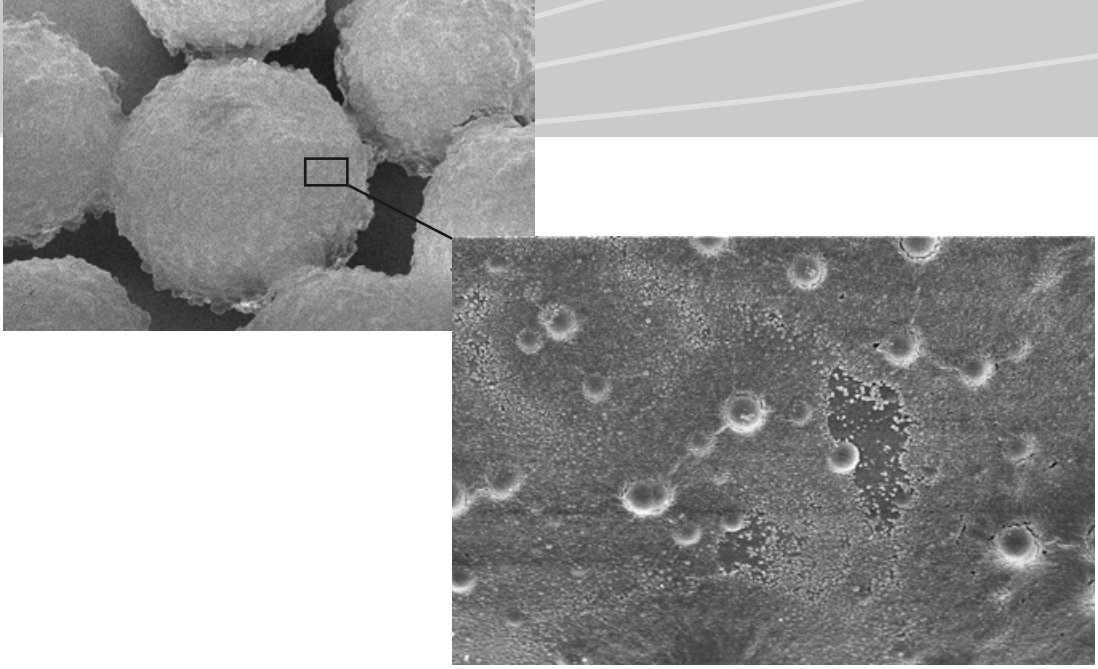
RECENT PROGRESS ACHIEVED BY FRAUNHOFER IMM

The action plan consisted of pursuit of two approaches.

// Development of a process for the electrodeposition of gold absorbers on thin SiN membranes and additionally blackening of the gold surface to reduce the reflection of visible light: The switch from platinum to gold absorbers has contributed significantly to the resilience against alternating thermal loads.
// A second type of sensor that uses zirconia as base material, which is also used for other high-temperature-resistant electronic components. The zirconia has many excellent properties and replaced the less-reproducible natural mica that was used in earlier generations of bolometer sensors. However, its brittleness required the development of special handling and processing techniques.

After overcoming various technical challenges encountered, both approaches have resulted in functional bolometer-sensor prototypes that meet the specifications and withstand thermal cycles. The prototypes produced will undergo further testing to determine the best sensor approach for ITER.

The CALORI04 Project series is co-financed by Fusion for Energy (F4E), the EU organization responsible for Europe's contribution to ITER, through grant F4E-FPA-384-04 (DG).



Scanning electron microscopy images of microcapsules with adsorbed PLGA nanocapsules at pH 7

FRAUNHOFER CLUSTER OF EXCELLENCE PROGRAMMABLE MATERIALS – CAPSULE MEMBRANE

Video showcasing the continuous formation of polymeric particles and capsules through emulsification, solvent evaportaion

https://youtu.be/2d0h-C4HONs

Global challenges such as climate change, the energy transition or access to clean water require political and social rethinking but as well technological innovations that enable the intelligent and sustainable use of resources. One of the main research areas of the Fraunhofer Cluster of Excellence Programmable Materials (CPM) is programmable mass transport. This includes the production of intelligent, programmable materials that can independently cope with the challenges that arise in the application process. In any form of industrial filtration, there are two fundamental interrelated challenges: removing filtered material and minimizing fouling on the surface of the filter.

The experts from the Fraunhofer Institutes IAP, IKTS, ITWM, IFAM and IMM are joining efforts in order to find a solution and efficiently prevent the complex problem of membrane fouling. The project idea comprises the strong fixation of microcapsules to the surface of polymer membranes in order to generate a turbulent flow on the membrane surface. The surface of microcapsules is additionally coated with biodegradable nanocapsules. The microcapsules and nanocapsules both contain active ingredient / biocide inside and are "programmed" for different release profiles in order to prevent the deposition of organic materials on the membrane surface.

As the nanocapsules can be reversibly attached to the microcapsules, the "used" nanocapsules can be removed during the cleaning process of the membrane (at low pH value), and afterwards the surface of microcapsules (123 µm) is additionally coated with biodegradable nanocapsules (145 nm). The life cycle of a capsule membrane should be able to last for several years, so that subsequent loading of the capsules with an active ingredient will be necessary. The newly developed capsule membrane was identified as a promising structure, as it influences the formation of aggregates and layers through the targeted structuring of the surface and at the same time can release antifouling agents locally.

Fraunhofer IMM is involved in development of a continuous synthesis process for the production of polymer-based nanocapsules in the size range from 0.1 to 1 µm, which are loaded with hydrophilic / hydrophobic active agents and can change their surface properties in response to external stimulus. The pH-responsive adsorption/desorption of the eucalyptus oil-loaded poly(lactide-co-glycolide) nanocapsules on the surface of microcapsules has been successfully implemented.

Funding Source: Fraunhofer Cluster of Excellence Programmable Materials; Grant no. 800130

First table assembly of the mobile detection device

MOBILE SYSTEM FOR MONITORING MICROPLASTICS

The determination of microplastics in environmental compartments will be necessary in the future for monitoring of the status quo as well as local changes in the environment. In particular, discharges into water systems (sewage treatment plants, large laundries and industrial complexes) as well as soil monitoring of selected areas and the monitoring of anthropogenic microplastic sources (tires / paint wear) can be defined as target applications. Target industries are therefore service providers in the field of environmental analysis, wastewater monitoring and equipment manufacturers.

Detection of microplastic in environment compartments is a longterm challenge for society. Sample preparation and measurement is complex, lengthy and expensive. Commercially suitable detection systems are fragile and / or bulky and not acceptable for widespread use outside of laboratories. The sampling density of environmental compartments is therefore low and sampling is usually only carried out for a characterization afterwards. Samples need a complex preparation and a high level of analysis.

The precautionary and after-care screening of soils and water bodies for plastic pollution is currently not part of environmental analysis due to the lack of suitable equipment. New approaches to microplastic analysis on site are therefore in demand.

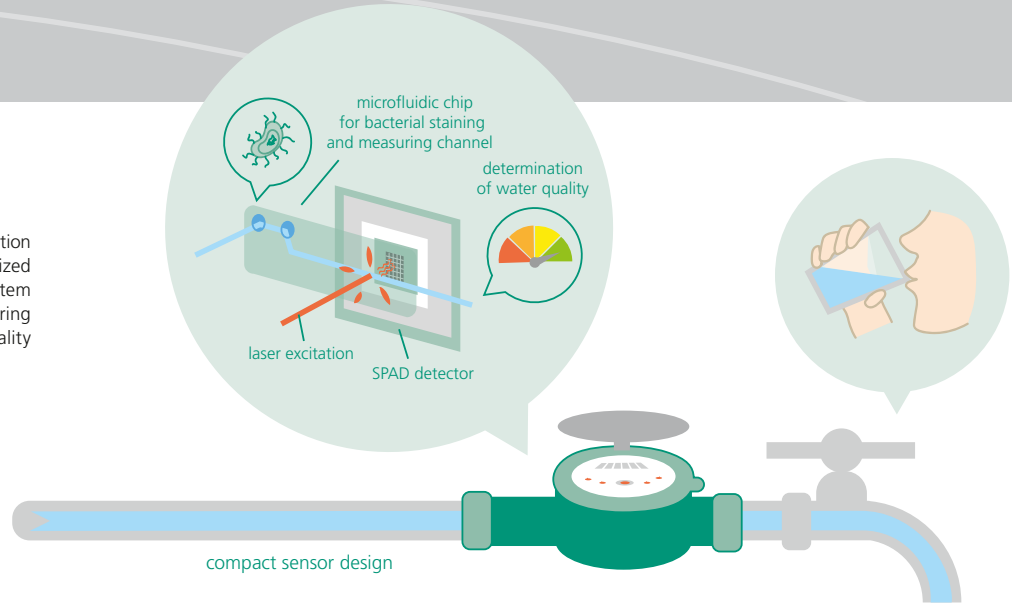
The solution to be developed will be a mobile system for the detection of microplastic particles in the environmental compartments of soil and water. The sample preparation takes place with an automated, computer-controlled miniaturized sieve / filter / enrichment cascade to an analyte suspended in water, which will be analyzed by modules integrated in the system in regard to size distribution and material composition.

The demonstrator to be developed will be suitable for a sufficiently precise on-site analysis for microplastics. Within the project, the complexity of the sample should initially be limited to a few types of plastics, which are analytically recorded with regard to the number of particles in size classes and the type of material based on chemometric evaluation of the Raman signal. Particular attention is paid to the economic efficiency and robustness of this measuring system in comparison with devices currently available on the market or in research.

FRAUNHOFER IMM CONTRIBUTION

// Development of a demonstrator for the analysis of a sample of microplastic consisting of some exemplary plastics

Funding Souce: Fraunhofer Internal Programs
Grant no. SME 840217



Functionality illustration of a miniaturized flow cytometer system for monitoring drinking water quality

DETECTION OF GERMS IN DRINKING WATER

Germs can occur anywhere in the drinking water network. Central monitoring in the treatment plants only is often insufficient to prevent contaminated drinking water from reaching the end user. A comprehensive monitoring of microbial contamination in the drinking water network and in industrial process water requires fully automated, cost-efficient and compact sensor systems with which the microorganisms can be detected quickly and sensitively directly at the point of sampling. For years, IMM has been receiving an increasing number of requests from SMEs for automated sensor solutions that can reliably detect the number of germs in drinking water and are suitable for widespread on-site use, especially directly at the end user site.

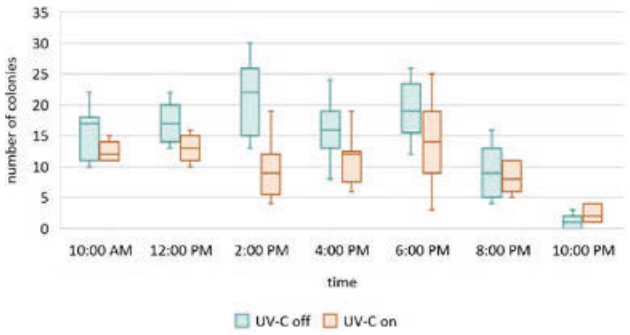
One promising detection method is fluorescence-based flow cytometry. However, current systems are still too large and require expensive optical components to separate the weak fluorescence signals from the noise background. Thus, these systems have mostly been limited to laboratory use and have not been suitable for widespread use. In the "IMFLUSS" project, a miniaturized flow cytometer is therefore being developed for rapid on-site water monitoring. This is achieved by combining microfluidic techniques of the Fraunhofer IMM with the single photon sensor technology (SPAD) of the Fraunhofer IMS. To achieve the goal of a miniaturized flow cytometer, sample processing is performed entirely using microfluidic methods. Germs are thereby automatically stained on a microfluidic chip. Their time-dependent fluorescence is excited by pulsed laser and detected by SPADs in sub-ns time resolution.

FRAUNHOFER IMM CONTRIBUTION

// Development of a miniaturized detection unit for fluorescence lifetime detection without requiring optical emission filters
// Implementation of automated fluorescence staining by using micromixers
// Set-up and validation of a demonstrator for the cost-effective, automated on-site determination of the total bacterial count in drinking water

Funding Source: Fraunhofer Internal Programs
Grant no. SME 840 063

Bacterial Count
Box-and-whisker plot of bacterial counts over the course of a day, where each dataset from a blue and red box represents data of three days. A reduction of airborne bacteria through the use of UV-C irradiation is clearly visible. Since the mall closes at 8:00 pm the number of colonies is greatly reduced. This leads to statistical uncertainties so that data after this time are of little significance.



Air sampler located in an area covered by UV-C irradiation in a shopping mall.

STUDY ON THE EVALUATION OF THE EFFICIENCY OF UV-C RADIATION AS AN AIR DISINFECTANT DURING OPERATING HOURS IN PUBLIC SPACES

During the current pandemic the risk of particles and aerosols containing infectious SARS-CoV-2 (severe acute respiratory syndrome coronavirus type 2) particles in public spaces became apparent. UV-C irradiation (Upper-Room Ultraviolet Germicidal Irradiation, UVGI) can be used to inactivate pathogenic particles in the air and on surfaces. UVGI targets primarily nucleic acids such as deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) encoding the genetic information in living cells and virus particles. Due to mutagenic and cytotoxic damages, the nucleic acid replication of cells treated with UV-C irradiation is obstructed. This leads to contagious germs being no longer infectious. However, the effectiveness of UVGI has primarily been studied under laboratory conditions.

Thus, the aim of this overview study was to demonstrate the efficiency of UVGI under operating conditions in a supermarket and in a shopping mall together with our partner from Fraunhofer IBP. Air samplers were placed in areas covered by the UV-C irradiation and used to collect airborne germ counts (see right figure).

For obvious reasons, a release of potentially infectious SARS-CoV-2 is not possible in public spaces. Thus, the results were based on airborne fungal and bacterial counts. The filters used for collecting the air samples were transferred under sterile conditions onto plate count agar and cultured for 3 days in an incubator at 25 °C to determine airborne germ counts. Covering different customer frequencies, the measurements were performed every two hours, where activated and deactivated UV-C irradiation were alternated every other day for six consecutive days. Hence, the efficiency of the installed UVGI devices as air disinfectant at different customer frequencies over the course of a day were analyzed.

We found a reduction of total viable aerobic count of 36 % and a reduction of total viable bacteria count by up to 59 % through the use of UV-C irradiation. An analytical model allows for an estimation of the UVGI inactivation rate of SARS-CoV-2 by comparing the inactivation rates of bacteria and fungi to the 10- to 20-fold higher ones of SARS-CoV-2 as mentioned in the literature. We determined an expected reduction of infectious SARS-CoV-2 particles by 99,987 %. In conclusion, the employment of UVGI-devices causes significant decontamination, which helps mitigating infection risks in indoor public spaces.

FRAUNHOFER IMM CONTRIBUTION

// Development of measurement schedule
// Measurement of airborne germ count
// Development of protocol for data processing

Automated extraction system for inorganic nanomaterials

STUDYING THE DYNAMIC SOLUBILITY OF INORGANIC NANOMATERIALS

Silicon dioxide, also known as silica, is an inorganic material which is widely used in many applications and consumer products, for instance as filler, abrasive material or rheological additive. Under normal environmental conditions, such as on beaches, silica is very poorly soluble in water. Of course, there is nevertheless a certain low solubility, i.e. saturation concentration, which can be determined quite easily using static solubility, e.g., under OECD Testguide 105. However, in biological systems, e.g., the human body, static conditions do not prevail. In the lungs, for example, fluid is continuously produced to maintain function and flush out any foreign bodies. The question to be answered is to what extent inorganic particles that end up in the lungs may dissolve slowly if they are repeatedly exposed to fresh medium and, hence, they never reach the saturation concentration. Usually, for human safety, animal experiments are required for the finding of these answers.

Within the BIOSIMP project, Fraunhofer IMM has developed an automated system allowing to perform long-term dynamic solubility studies of powdered materials in vitro suitable for replacing animal experiments almost completely. The materials can be exposed to constantly renewed media to mimic, for instance, the situation in the lung, where lung fluid is continuously produced and exchanged. The material under investigation can be loaded into a column and exposed to a stream of fluid, similar to an extraction experiment. Thus, material data can be acquired under controlled and reproducible conditions that are relevant to the fate and potential toxicity of materials. A parallel processing of different extraction experiments is possible. Afterwards, the eluate fractions can be automatically collected and analyzed with state-of-the-art offline spectroscopic methods such as ICP-OES or ICP-MS.

The developed system can be flexibly adapted to a wide range of materials and media. In the future, further questions with a particular relevance in everyday life can be addressed, for instance whether certain ingredients are potentially extracted from a product, possibly also nanoparticles, which are contained, for example, as fillers or excipients. The system is currently being upgraded for a flexible choice between up to four different liquid media and will be used for studies ordered by industrial customers as well as in interlaboratory round-robin studies in the frame of European and international standardization efforts.

FRAUNHOFER IMM CONTRIBUTION

// Development of a system for studying the solubility of inorganic nanomaterials to replace animal experiments

FEATURED RESEARCH GROUPS

The targeted career development of female researchers is a central issue at the Fraunhofer-Gesellschaft. Two years ago we started to report about our rising stars and we are proud to say that funding received in the course of Fraunhofer internal programs is an important pillar to either pave the way for an industrial career path or to finally establish a distinct research group. Currently three of our female researchers receive funding from the TALENTA program.

In this report, however, we are focusing on two new research groups that are currently being established, receiving funding from the Fraunhofer ATTRACT program and the Federal Ministry of Education and Research.

FUNDING BODY

Fraunhofer ATTRACT program,
2.5 M € from November 2020
to October 2025

Project "InBaDtec" – Enable real-time media monitoring for early detection of microbiological hazards in industry
Project number 600009

THE MIND BEHIND

Dr. Sisi Li joined Fraunhofer IMM in November 2020 with the Fraunhofer ATTRACT program funding (2.5 M €) to build up and lead the group of Bioanalysis for Industrial Media. She got the Bachelor's degree of Engineering from Xiamen University in 2009, and then she received her Ph.D. degree from Ecole Normale Supérieure de Paris in 2013. Her Ph.D research direction was micro- and nanoengineering of cell microenvironment. Afterwards, her interest turned to application-oriented research, especially combining advanced microfluidic technology and polymerase chain reaction (PCR) for point-of-care diagnostics. She first spent two years as a research fellow in Singapore Institute of Manufacturing Technology (SIMTech), and then she worked for a French company Elveflow /BforCure as the product manager for more than three years. Dr. Sisi Li has been awarded Marie-Curie individual fellowship to support her research interest and career development. Her current main interest is to apply the technology portfolio of advanced microfluidics for point-of-care diagnostics to applications of microbiological hazards detections in environment and industry.

POINT-OF-USE DETECTION OF MICROBIOLOGICAL HAZARDS IN ENVIRONMENT AND INDUSTRY

Timeline

11/2020: Project starts
05/2021: All core team members are on board
10/2022: Proof-of-concept of the missing technology gap to extract microorganisms directly from industrial sample is validated.
10/2023: Demonstrators of individual functional modules are delivered:
(1) sample pre-cleaning module,
(2) concentration module,
(3) lysis module,
(4) mixing module and
(5) PCR analysis module.
10/2025: Project ends, collaborative projects with industries start.

Biological hazards can be prevented by identifying target microorganisms and timely applying decontamination actions. A real-time response to health hazards and biological threats that spoil industrial products or infrastructures are eagerly demanded. Desired solutions must provide high specificity to detect microorganisms in due time (typically < 1 hour), and at the same time, must be cost-effective, possible to be implemented on-site and fully automated. PCR reactions can be controlled in fully automated microfluidic systems with minimized reagent consumption and there is a clear trend that PCR-based analytics will be accepted as an industrial bio-detection standard. The missing link that hinders PCR-based applications to penetrate industrial markets is the tedious sample preparation process to extract microorganisms. The mission of the ATTRACT group is to fill the technology gap by enabling automated microorganism extraction directly from industrial sample. This will be done by connecting the IMM existing technological portfolio of point-of-care medical diagnostic platform, based on microfluidics and PCR technology, to various industrial applications not yet addressed, such as microorganism detection in cooling water, house warming water, bathing/swimming water, waste water and drinking water. The technology developed can be also applied for the biosafety control in a wide range of industries including pharmaceuticals, agriculture, food and beverage, algae and fish farming, bioreactors and bioprocessing, cosmetics, defense and biosecurity, chemical industries such as painting and coating, glue, cooling lubricants as well as fuels such as kerosene and diesel.

(R)EVOLUTIONIZING CANCER THERAPY

Timeline

2020

// Development and synthesis of a functional polymer system
// Characterization of polymers and investigation of self-assembly behavior
// Encapsulation and release of model substances and test drugs
// Characterization of polymer particles in the biological environment

2025

// Novel, highly functional, water-soluble, thermoresponsive polymer material and microtechnical processes for the production and formulation thereof.

The goal of the 5 year project is to make drug delivery to cancer cells safer and more targeted, and to realize controllable drug release in tumor tissue. On the way to this goal, the research group will take advantage of a common property of all tumors, which exhibit a slightly increased temperature compared to healthy tissue due to the increased cell division rate. The active ingredients will be packaged in shells made of a temperature-controllable material.

Once the target site is reached the disintegration of the shell and thus the release of the active ingredient is triggered following a biomimetic concept analogous to the reading of genetic information in the DNA double helix. The interactions between the polymer chains forming the shell will change depending on the temperature in such a way that a controllable release process can be achieved. Thus, conventional chemotherapy will become more tolerable and innovative but sensitive substances can also expand the therapy spectrum thanks to the protective coating. Even an interlocking of chemotherapy and hyperthermia with diagnostics will be possible in the future, if active substance and contrast agent, such as magnetic iron oxide nanoparticles, are encapsulated.

FUNDING BODY

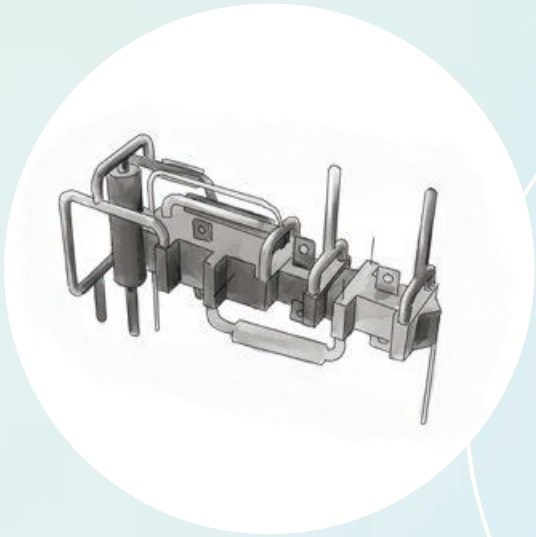
The German Federal Ministry of Education and Research (BMBF) is funding the project for five years as part of the "BMBF Young Scientists Competition – NanoMatFutur". Funding reference: 13XP5113

THE MIND BEHIND

Dr. Regina Bleul first graduated as a biotechnology engineer at the University of Applied Sciences in Darmstadt. After receiving her diploma, she successfully completed her doctorate in chemistry at the Freie Universität Berlin and the Bundesanstalt für Materialforschung und -prüfung (BAM). During her doctorate, she spent a six-month research stay at the University of British Columbia in Vancouver, Canada. Since 2014, she has been conducting research at Fraunhofer IMM on nanoparticle systems and their synthesis based on micro process engineering. The developments of new nanoparticulate systems and formulations include diagnostic and therapeutic application areas predominantly in cancer medicine. Since October 2020, she has been setting up the "NanoMatFutur" junior research group "Nanomaterials for Cancer Therapies" at Fraunhofer IMM.

WHAT'S NEXT

Understanding complex correlations, an orderly performing of experiments and, sometimes, trying to be smarter than nature itself is part of the daily business of a researcher. But being a scientist specially goes along with the commitment to go beyond the state-of-the-art and to tackle the society's needs of tomorrow already today, to always be one step ahead. In this section we will continue to present activities and topics where we want to make the decisive difference in the nearer or distant future!



AMMONPAKTOR

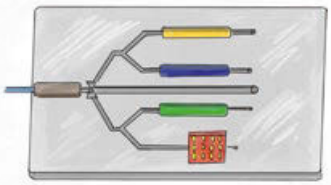
Ammonia is particularly suitable as a storage medium for hydrogen, as it can be liquefied at moderate temperatures or pressure and is therefore easier to transport to the point of demand. We are developing a refueling module based on innovative catalyst and microstructured reactor technology that produces pure hydrogen from green ammonia. The hydrogen can then be provided at fuelling stations to be used in fuel cell vehicles. A demonstration unit consisting of hydrogen production, gas processing and conversion to electricity in a fuel cell is going to be developed until the end of 2022.

Activities funded by the state of Rhineland-Palatinate in the framework of the EFRE REACT program.

EMPOLSENS

As a result of industrial activities continuously increasing wastewaters containing toxic heavy metals, antibiotics, hormones, etc., being harmful to humans' health already at ppb level, are released into the environment. Thus, drinking water quality and safety is a very sensitive issue even in countries with high standards of water treatment technologies. The project aims, together with Russian and Belgian partners, to develop a novel microfluidic based, miniaturized and portable sensor with several detection modules for the determination of most toxic metal ions, antibiotics and hormones in water.

Activities funded by
the BMBF, ERA.Net RUS Plus



BIOLIGHT

Fine chemicals are an essential building block for the simple, fast, cost-effective and flexible synthesis of drugs and vaccines. The overall objective of the project is the establishment of a new, modular and continuous flow synthesis platform for selected fine chemicals under noble metal-free, biologically mild and (stereo)selective conditions. Thus, restrictions of the classic homogeneous batch synthesis will be overcome by means of new catalyst concepts including photochemical processes.

Activities funded by
Fraunhofer internal program

OPEN-POCT

In order to increase resilience in pandemic crises and to adequately balance individual freedom and protection, instant and area wide testing is needed that sensitively detects infections in minutes and transmits test results immediately to decision-makers. The aim of the project is to develop a holistic concept for nationwide and both financially and organizationally realistic mass testing of the population in pandemic events using a sensitive, scalable, intelligent, open and digitized POC-PCR rapid testing system to contain the spread of infectious pathogens as quickly as possible.

Activities funded by the state of
Rhineland-Palatinate in the framework of
the EFRE REACT program.

PEOPLE MAKE THE DIFFERENCE

Our employees are the backbone of our institute – they make the difference. Their experience, knowledge, collective responsibility and subjective well-being determine our scientific and economic success. We believe that success best comes from interdisciplinary teams working together at eye level with perception and appreciation. For this reason, we focus on diversity, the creative potential of all genders, different ages, cultures and disciplines. To protect the health of our team members, we are setting high standards for occupational safety and the quality of the working environment and workplaces – especially in times of COVID-19.

Dr. Thomas Rehm

"I introduced flow photochemistry as a novel branch in sustainable organic synthesis to our institute. Due to the mild reaction conditions in photocatalysis with visible light, such processes can be coupled with other, sensitive catalyst systems in parallel to enhance the over-all sustainable character while yielding very high chemical selectivity for, e.g., active pharmaceutical ingredients or precursors for important industrial compounds.

On the one hand, I am very enthusiastic in understanding and using or mimicking natural systems. Hence, flow photochemistry is one pathway to high-level chemistry and technology. On the other hand, I highly appreciate the easy and interdisciplinary collaboration with my colleagues, internal and external, to speed up R&D for a sustainable future in chemical processing.

Peter Spang

I am doing the R&D work for lab-on-a-chip systems and components up to the automated lab demonstrator. Besides, I am in charge of various experimental setups, I take care of a cobot handling system as well as a hot embossing and injection molding lab machine. In my everyday work I provide proof that the latest equipment is not necessarily required for the best results.

My motivation is to put thoughts and ideas on paper, digitize them, bring them into the production, the assembly and finally into the lab to my colleagues and put them into application for my customers. Taking into account all standards and regulations, what matters most to me, is working together with colleagues in an interdisciplinary team at eye level with perception and appreciation.

Ute Müller

Heading the human resources group, my team and I take care of the entire human resources work, from personnel acquisition and employment contracts, to personnel development including the organization of training courses, daily support up to leaving the company with references. The organization of Corona-related measures and the participation in occupational health and safety is currently very important.

I have been at IMM for a very long time now and still enjoy the varying everyday tasks. This is due to the broad spectrum of activities and the constantly changing requirements from both internal and external sources. As an HR specialist, I always bring together in one person the best of very different worlds, from employment law expert to creative recruiter to – sometimes – psychologist.

Dr. Patrick Löb

I am the Deputy Head of Division Chemistry, Group Leader Flow Chemistry and Sustainable Chemical Syntheses. One of my main tasks is to cooperate with our partners and customers mainly from chemical industry to improve their chemical production processes based on our technology approach of using flow reactors and continuous processing.

Working more than 20 years now at the institute, I still like the manifoldness of tasks and the jobs to be done with an interdisciplinary team. Moreover, I am happy to accompany the shift of chemical industry to a more sustainable one.

Eva Deitmann

I am currently doing my doctoral thesis in the field of "Reactive Intermediates" focusing on continuous scalable Grignard reagent formation and Grignard reaction aiming at enhancing the understanding of reaction and process engineering of both synthesis steps. My motivation is to see the high potential and the benefits of an on-demand continuous process using the advantages of micro technology especially for the pharmaceutical industry.

What I really like about working at Fraunhofer IMM is the interdisciplinary nature of my colleagues and the fact that I am constantly learning something new, expanding my knowledge base and gaining experience through scientific exchanges with colleagues from other departments.

Christian Brucker

I am a mechanical engineer for micro analysis devices, so I design them in a CAD program and the workshop will produce most of the parts. In this role I am responsible for the 3D printers. The 3D printers can be used for many test parts in our research, but also functional parts. 3D printing enables a new way of thinking and designing.

This results in a very exciting and varied field of work. Through our interdisciplinary collaboration approach, I gain new insights every day. I love variety and therefore enjoy constantly facing and overcoming new challenges as it is typical for working in research.

Dr. Christian Bidart

I make my contribution towards the analysis of the processes developed by IMM from an economic and sustainability perspective. Life cycle analysis and economic assessments are necessary for the further commercialization of IMM developments.

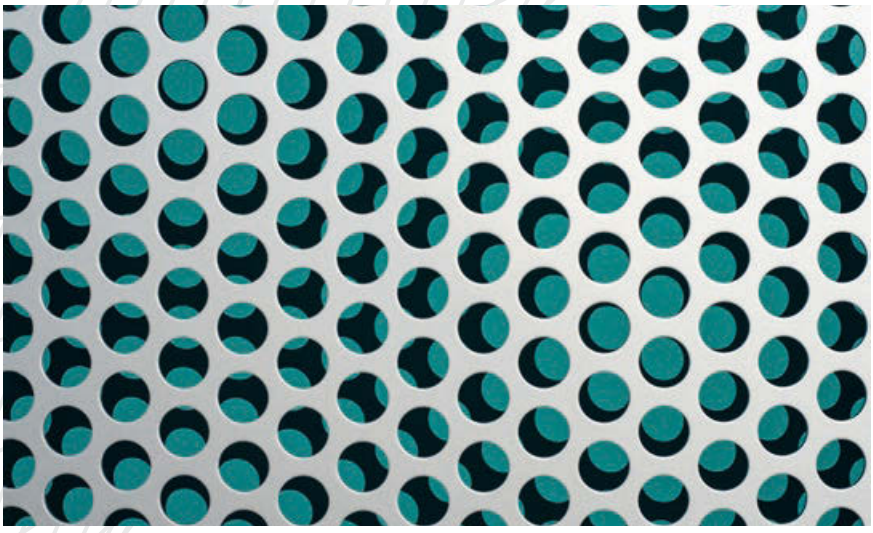
What fascinates me about IMM's work is to see, in concrete terms, the integration of numerous engineering disciplines in such small processes: chemical kinetics, catalysis, reactor design, process simulation, dynamics & control, economic and environmental analysis for the development of a reformer, for instance. All that brought together in just one device developed at just one institute.

EXTENSION BUILDING

Good things come to those who wait. Almost 5 years ago we first reported on our planned extension building. At that time it was not more than a vision, a plan and a sketch we could provide. Now, in July 2021, the building was handed over to us and we can begin to gradually bring the new laboratory areas and the technical center to life. A giant step for us that will enhance our project capacities especially with respect to coverable size ranges but also with respect to manageable throughputs. Follow us on a little picture journey and discover the new possibilities.

Sketch presented in the annual report 2015

Entrance view of the building



Detail of the facade structure

Chemical lab with walkable fume hood

View from office to lab area

Technical center

Building technology

Building technology

Area with work places

Meeting rooms

Foyer first upper floor

Staircase

Foyer ground level

West view of the building

Rear view into the technical center

North east view of the building

APPENDIX

FAIRS, EVENTS AND CONFERENCES

FAIR/EVENT/CONFERENCE	DATE	TYPE OF EVENT
ProcessNet 2020 – 10. ProcessNet Annual Conference	21.–24.9.2020	Virtual conference
Young Scientists' Workshop at IMM	30.9.2020	Virtual conference
Hydrogen Online Conference	8.10.2020	Virtual conference with booth
Webinar SelectBIO – Flow Chemistry Webinar Series: Fraunhofer IMM Webinar	23.10.2020	Virtual conference
Fraunhofer Solution Days	26.–29.10.2020	Virtual fair
Fraunhofer IMM Virtual Open House	10.–12.10.2020	Virtual conference with booth
InnoHealth China German R&D Tour	2.12.2020	Virtual presentation
Fraunhofer IMM Online Seminar: Microfluidics “decoded” – why, what, how?	3.3.2021	Virtual presentation
Hydrogen Online Workshop	25.3.2021	Virtual conference
Fraunhofer IMM Online Seminar: IMM reactor and fuel processor technology – hydrogen from hydrogen carriers	7.4.2021	Virtual presentation
Fraunhofer IMM Online Seminar: Effective encapsulation of liquids and solids: from batch to continuous flow production	5.5.2021	Virtual presentation
ACHEMA Pulse	15.–16.6.2021	Virtual fair

PUBLICATIONS 2020/2021

Publications in refereed journals

Hoogendijk, E.; Swider, E.; Staal, A.H.J.; White, P.B.; van Riessen, N.K.; Glaßer, G.; Lieberwirth, I.; Musyanovych, A.; Serra, C.A.; Srinivas, M.; Koshkina, O.:
Continuous-flow production of perfluorocarbon-loaded polymeric nanoparticles: From the bench to clinic
In: Applied Materials & Interfaces 12 (2020) 44, 49335–49345

Neuberg, S.; Pennemann, H.; Shanmugam, V.; Zapf, R.; Kolb, G.:
Promoting effect of Rh on the activity and stability of Pt-based methane combustion catalyst in microreactors
In: Catalysis Communications 149 (2021), 106202

Gac, W.; Zawadzki, W.; Rotko, M.; Greluk, M.; Slowik, G.; Kolb, G.:
Effects of support composition on the performance of nickel catalysts in CO_2 methanation reaction
In: Catalysis Today 357 (2020), 468–482

Shanmugam, V.; Neuberg, S.; Zapf, R.; Pennemann, H.; Kolb, G.:
Effect of support and chelating ligand on the synthesis of Ni catalysts with high activity and stability for CO_2 methanation
In: Catalysts 10 (2020) 5, 493

Divins, N.J.; López, Eduardo; Angurell; Inmaculada; Neuberg, S.; Zapf, R.; Kolb, G.; Llorca, Jordi:
CO Total and preferential oxidation over stable Au/TiO_2 catalysts derived from preformed Au nanoparticles
In: Catalysts 10 (2020) 9, 1028

Engelbrecht, N.; Everson, R.C.; Bessarabov, D.; Kolb, G.:
Microchannel reactor heat-exchangers: A review of design strategies for the effective thermal coupling of gas phase reactions
In: Chemical Engineering and Processing – Process Intensification 157 (2020) 108164

Danilov, V.A.; Kolb, G.:
Tanks-in-series model for an auto-thermal reforming reactor with a channeled monolith
In: Chemical Engineering Science 231 (2021), 116269

Rehm, T.H.:
Flow photochemistry as a tool in organic synthesis
In: Chemistry – A European Journal 26 (2020) 71, 16952–16974

Wegner, C.; Schlett, P.; Höth, J.; Buckert, T.; Klotzbücher, T.; Hofmann, U.G.; Krüger, T.B.:
Neurophotonic scanning system – towards automatic infrared neurostimulation
In: Current Directions in Biomedical Engineering 6 (2020) 3, 20203069

Ziogas, A.; Pennemann, H.; Kolb, G.:
Electrochemical synthesis of tailor-made hydrocarbons from organic solvent free aqueous fatty acid mixtures in a micro flow reactor
In: Electrocatalysis 11 (2020) 4, 432–442

Meister, H.; Schmitt, S.; Szenthe, I.; Szakál, A.; Albrecht, H.; Gillemot, F.:
Irradiation tests of bolometer sensor prototypes for ITER
In: Fusion Engineering and Design 161 (2020), 111995

Gül, G.:
Minimax robust decentralized hypothesis testing for parallel sensor networks
In: IEEE Transactions on Information Theory 67 (2021) 1, 538–548

Danilov, V.A.; Kolb, G.; Cremers, C.:
Tanks-in-series model for high-temperature electrochemical hydrogen pump
In: International Journal of Hydrogen Energy (2021) 21, 11536–11543

Nickel, C.; Scherer, C.; Noskov, S.; Bantz, C.; Berger, M.; Schupp, W.; Maskos, M.:
Observation of interaction forces by investigation of the influence of eluent additives on the retention behavior of aqueous nanoparticle dispersions in asymmetrical flow field-flow fractionation
In: Journal of Chromatography A 1637 (2021), 461840

Berger, M.; Scherer, C.; Noskov, S.; Bantz, C.; Nickel, C.; Schupp, W.; Maskos, M.:
Influence of oscillating main flow on separation efficiency in asymmetrical flow field-flow fractionation
In: Journal of Chromatography A 1640 (2021), 461941

Baki, A.; Löwa, N.; Remmo, A.; Wiekhorst, F.; Bleul, R.:
Micromixer synthesis platform for a tuneable production of magnetic single-core iron oxide nanoparticles
In: Nanomaterials 10 (2020) 9, 1845

Löwa, N.; Gutkelch, N.; Welge, E.-A.; Welz, R.; Meier, F.; Baki, A.; Bleul, R.; Klein, T.; Wiekhorst, F.:
Novel benchtop magnetic particle spectrometer for process monitoring of magnetic nanoparticle synthesis
In: Nanomaterials 10 (2020) 11, 2277

Fuhrmann, M.; Musyanovych, A.; Thoelen, R.; von Bomhard, S.; Möbius, H.:
Magnetic imaging of encapsulated superparamagnetic nanoparticles by data fusion of magnetic force microscopy and atomic force microscopy signals for correction of topographic crosstalk
In: Nanomaterials 10 (2020) 12, 2486

Bleul, R.; Baki, A.; Freese, C.; Paysen, H.; Kosch, O.; Wiekhorst, F.:
Continuously manufactured single-core iron oxide nanoparticles for cancer theranostics as valuable contribution in translational research
In: Nanoscale Advances 2 (2020) 10, 4510–4521

Menges, G.; Deitmann, E.; Gössl, L.; Hofmann, C.; Löb, P.:
Scalable continuous synthesis of organozinc reagents and their immediate subsequent coupling reactions
In: Organic Process Research & Development 25 (2021) 3, 427–433; Open Access

Onyema, Helen; Freese, Christian; Musyanovych, Anna; Bantz, Christoph; Maskos, Michael; Baßler, Michael:
Uptake of polymeric nanoparticles in a human iPSC-based blood-brain barrier model: Influence of size, material and protein corona
In: Biointerphases 16 (2021) 2, 021004

Kolb, Gunther; Keller, Steffen; Neuberg, Stefan; Schürer, Jochen; Tiemann, David; Valenteijn, Heike; Wichert, Martin; Zapf, Ralf:
A complete fuel processor for propylene glycol as hydrogen supply for a 5 kw low temperature pem fuel cell – Interim report on single reactors and system performance
In: Catalysis Today (2021); inPress

Neumann, Christian; Bacher, Lisa; Musyanovych, Anna; Tutus, Murat; Latnikova, Alexandra:
Formulation of next generation multi-compartment microcapsules by reversible electrostatic attraction
In: Chemistry – A European Journal (2021); Accepted Manuscript

Danilov, Valery A.; Kolb, Gunther:
2D model of the transfer processes in S-traps with wash-coated monolith channels and fixed bed for the application of H2S chemisorption in a fuel processor/fuel cell system
In: Chemical Engineering Journal 419 (2021), 129508

Gac, Wojciech; Zawadzki, Witold; Rotko, Marek; Greluk, Magdalena; Slowik, Grzegorz; Pennemann, Helmut; Neuberg, Stefan; Zapf, Ralf; Kolb, Gunther:
Direct conversion of carbon dioxide to methane over ceria- and alumina-supported nickel catalysts for biogas valorization
In: ChemPlusChem 86 (2021) 6, 889–903

Baki, Abdulkader; Remmo, Amani; Löwa, Norbert; Wiekhorst, Frank; Bleul, Regina:
Albumin-coated single-core iron oxide nanoparticles for enhanced molecular magnetic imaging (MRI/MPI)
In: International Journal of Molecular Sciences 22 (2021) 12, 6235

Articles in other journals

Baßler, M.; Freese, C.; Gransee, R.; Winkler, A.:
Die Sechs-Minuten-PCR
In: Laborpraxis (2020) 10, 18–21

Kunz, S.; Winkler, A.:
Funkenerosive Mikrobohrungen mit der Plug & Play Sonodrive300 (Verbessertes Verfahren zur Mikrostrukturierung von Bauteilen)
In: wt Werkstattstechnik online 110 (2020) 11–12, 784–786

Bidart, Christian:
Verfahren zur Methanisierung von Kohlendioxid; Beitrag zur Energiewende
In: Verfahrenstechnik (2021) 4, 10

Menges-Flanagan, Gabriele:
Damit nichts explodiert – Grignard-Reagenzien sicher nutzen
In: Nachrichten aus der Chemie 69 (2021) 5, 46–47

Publications in proceedings

Gül, G.; Baßler, M.:
Fast multilevel quantization for distributed detection based on Gaussian approximation
In: 28th European Signal Processing Conference (EUSIPCO); Heusdens R.; Richard C.(Ed.). – Amsterdam, Netherlands: IEEE, 2020, 2433–2437

Scientific lectures

Baki, A.; Thiermann, R.; Freese, C.; Kosch, O.; Remmo, A.; Wiekhorst, F.; Bleul, R.:
Continuously manufactured single core iron oxide nanoparticles for cancer theranostics
In: NALS – International Conference on Nanomaterials Applied to Life Sciences , 2: IMDEA Nanociencia, 29.01.–31.01.2020. – Madrid, Spain

Kögler, K.U.:
4-OrganPrint – Rapid and Parallel "Single-Cell-Dispensing" for 3D-Organ-Printing
In: YSW – Young Scientists' Workshop IMM, 14, 30.09.2020 – Mainz

Stiefel, J.H.:
Fully-automated single cell isolation of circulating tumor cells for liquid biopsies
In: YSW – Young Scientists' Workshop IMM, 14, 30.09.2020 – Mainz

Gimmler, U.:
Development of a miniaturized flow cytometric sensor
In: YSW – Young Scientists' Workshop IMM, 14, 30.09.2020 – Mainz

Deitmann, E.:
Continuous grignard reagent formation in lab and pilot scale
In: YSW – Young Scientists' Workshop IMM, 14, 30.09.2020 – Mainz

Gössl, L.:
Continuous formation of organolithium compounds
In: YSW – Young Scientists' Workshop IMM, 14, 30.09.2020 – Mainz

Baki, A.:
Continuous synthesis of iron oxide nanoparticles for biomedical applications
In: YSW – Young Scientists' Workshop IMM, 14, 30.09.2020 – Mainz

Mettang, K.-V.:
MEMS based nondispersive infrared spectroscopy for process analytical technology
In: YSW – Young Scientists' Workshop IMM, 14, 30.09.2020 – Mainz

Baumgarten, N.; Ziogas, A.:
Electrochemical synthesis in flow using a flexible, microstructured electrochemical reactor
In: YSW – Young Scientists' Workshop IMM, 14, 30.09.2020 – Mainz

Fröhlich, J.:
Microfluidic chips for on-line analysis
In: YSW – Young Scientists' Workshop IMM, 14, 30.09.2020 – Mainz

Lüdicke, M.:
Continuous synthesis and purification of fluorescent nanoparticles
In: YSW – Young Scientists' Workshop IMM, 14, 30.09.2020 – Mainz

Bacher, L.:
Continuous flow encapsulation of different agents by microfluidic devices
In: YSW – Young Scientists' Workshop IMM, 14, 30.09.2020 – Mainz

Schwarz, N.:
Fabrication of 3D nanostructures by laser direct writing / Direct laser-writing of metal nanostructures from the gas phase by two-photon absorption process
In: YSW – Young Scientists' Workshop IMM, 14, 30.09.2020 – Mainz

Deckers, C.:
Synthesis of functionalized biphenyls via photochemical reaction in versatile micro reactors
In: YSW – Young Scientists' Workshop IMM, 14, 30.09.2020 – Mainz

Kolb, G.:
Wasserstoffbereitstellung für Brennstoffzellen – Mehanol, Ammoniak und andere alternative Energieträger / Hydrogen supply for fuel fells – methanol, ammonia and other alternative energy carriers
In: Fraunhofer Solution Days (digitales Fraunhofer-Event): Fraunhofer Gesellschaft zur Förderung der angewandten Forschung e.V., 26.10.–29.10.2020

Baßler, M.:
Liquid Biopsy: Automatisierung für zukunftsweisende Krebsforschung
In: Fraunhofer Solution Days (digitales Fraunhofer-Event): Fraunhofer Gesellschaft zur Förderung der angewandten Forschung e.V., 26.10.–29.10.2020

Posters

Menges-Flanagan, G.; Deitmann, E.; Gössl, L.; Hofmann, C.; Kost, H.-J.; Reinhard, D.; Löb, P.:
Skalierbare kontinuierliche Grignard Reagenz Bildung
In: ProcessNet-Jahrestagung und 34. DECHEMA-Jahrestagung der Biotechnologen, 10, 21.09.–24.09.2020. – Web-Konferenz

Deckers, C.; Rehm, T.H.:
Synthesis of functionalized biphenyls via heterogeneous photocatalysis in versatile microreactors
In: ProcessNet-Jahrestagung und 34. DECHEMA-Jahrestagung der Biotechnologen, 10 , 21.09.–24.09.2020. – Web-Konferenz

Metzke, L.:
Weiterentwicklung eines Lab-on-a-chip Systems zur Diagnostik von Alzheimer
In: YSW – Young Scientists' Workshop IMM, 14, 01.10.2020. – Mainz

Khajehamiri, R.:
Plattform zur Automatisierten Anreicherung von Exosomen und die Etablierung einer PCR auf einer mikrofluidischen Kartusche
In: YSW – Young Scientists' Workshop IMM, 14, 01.10.2020. – Mainz

Best, F.:
SARS-CoV-2 Testung am point of need
In: YSW – Young Scientists' Workshop IMM, 14, 01.10.2020. – Mainz

Kiehn, C.:
Examination of microplastic particles in suspension with Raman spectroscopy
In: YSW – Young Scientists' Workshop IMM, 14, 01.10.2020. – Mainz

Zapf, R.; Neuberg, S.; Pennemann, H.; Shanmugam, V.; Thiermann, R.; Ziogas, A.; Kolb, G.:
Improvement of the low-temperature activity of Ni/CeO_2 catalysts for CO_2 methanation by applying additives for impregnation
In: Jahrestreffen Deutscher Katalytiker, 54 16.03.–19.03.2021. – Online Event

Stiefel, J.H.; Freese, C.; Alebrand, S.; Baßler, M.:
Fully-automated isolation of circulating tumor cells to enable microfluidic single cell analysis from patient blood
In: TECH DAY 2021, Online Meeting on Single Cell Analysis 20.04.2021

Research and development reports

Sperling, R.A.:
Erforschung und Aufbau einer enzymatischen Signalamplifikation für multiparametrische Lateral Flow Tests auf Basis von Quantum Dots. Verbundprojekt: Quantum Dot-gestützte, bildgebende Fluoreszenzdetektion mit enzymatischer Signal-Amplifikation für multiparametrische Lateral Flow Tests der nächsten Generation
Project duration: 01.07.2016–30.06.2020, funding reference: 13N13866, grant by: BMBF, 2020

Gransee, R.:
Integriertes mikrofluidisches Einwegsystem zur automatisierten Probenprozessierung und Nukleinsäureamplifikation für die Patienten-nahe MRSA Diagnostik
Project duration: 01.09.2016–30.11.2020, funding reference: 13GW0154, grant by: BMBF. – executing agency: VDI Technologie-zentrum GmbH. – Mainz, 2020

Klotzbücher, T.:
Optisch ortsaufgelöste Stimulation von Nervenbahnen mittels Laser für die Visualisierung mit Scannersystemen. Verbundvorhaben: "Neurophotonisches Scannersystem zur intraoperativen Visualisierung von Nervenbahnen"
Project duration: 01.07.2016–30.06.2020, funding reference: 13GW0155D, grant by: BMBF, 2020

PhD theses

Bacher, L.:
Kontinuierliche Prozessentwicklung für die mikrofluidische Verkapselung von festen, flüssigen und leichtflüchtigen Substanzen als Kernmaterial
Dissertation. Fachbereich Chemie, Pharmazie und Geowissenschaften der Johannes Gutenberg-Universität Mainz. Carried out at Fraunhofer IMM, 2020

Bachelor theses

Drauth, J.:
Aufbau und Charakterisierung eines mikrofluidischen Mehrkanal-Systems für die chipbasierte Durchfluss-Titration
Bachelor thesis. Fachbereich Chemie- und Biotechnologie, Studienbereich Chemische Technologie der Hochschule Darmstadt. Carried out at Fraunhofer IMM, 2020

El Bouch, B.:
Elektrische und automatisierungstechnische Charakterisierung sowie Optimierung der Funktionsweise eines mit Reformat betriebenen Brennstoffzellensystems mit Einspeisung in das öffentliche Netz
Bachelor thesis. Fachbereich Elektrotechnik und Informationstechnik der Hochschule Darmstadt. Carried out at Fraunhofer IMM, 2020

Heßling, L.:
Kontinuierliche Verkapselung von hydrophoben Stoffen mittels Polymerisation an der Tropfengrenzfläche unter Nutzung von Mikroreaktionstechnik
Bachelor thesis. Fachbereich Chemie- und Biotechnologie, Studiengang Chemische Technologie der Hochschule Darmstadt. Carried out at Fraunhofer IMM, 2020

Glaser, M.:
Entwicklung eines photovoltaischen MIR Mehrkanalsensors zur parallelen Messung von Gasen unter Berücksichtigung der Feuchtigkeit
Bachelor thesis. Fachbereich Verfahrens- und Chemietechnik, Studiengang Verfahrenstechnik der Hochschule Mannheim. Carried out at Fraunhofer IMM, 2020

Dovoda, M.:
Untersuchung und Optimierung des Rücklöseverhaltens gefriergetrockneter Reagenzien in mikrofluidischen Systemen
Bachelor thesis. Studienbereich Physik, Fachbereich Ingenieurswissenschaften der Hochschule RheinMain. Carried out at Fraunhofer IMM, 2020

Fritsch, S.:
Entwicklung eines photovoltaischen MIR H2O-Sensors zur Berücksichtigung der Feuchtigkeit bei der Gasmessung
Bachelor thesis. Studienbereich Angewandte Physik und Medizintechnik der Hochschule RheinMain. Carried out at Fraunhofer IMM, 2020

Geyer, T.:
Auslegung und Aufbau eines faserbasierten Refraktometers und eines faserbasierten Trübungssensors
Bachelor thesis. Fachbereich Ingenieurwissenschaften, Studienbereich Physik der Hochschule RheinMain. Carried out at Fraunhofer IMM, 2020

Kraft, P.:
Entwicklung einer chemometrischen Methode zur Materialerkennung in gemischten Mikroplastiksuspensionen basierend auf Raman-Spektrometrie
Bachelor thesis. Fachbereich Ingenieurwissenschaften, Studiengang Angewandte Physik der Hochschule RheinMain. Carried out at Fraunhofer IMM, 2020

Schmitt, M.:
Entwicklung eines miniaturisierten photovoltaischen MIR CO-Sensors für die Gasmessung für die Prozessanalytik
Bachelor thesis. Fachbereich Ingenieurwissenschaften, Studiengang Umwelttechnik der Hochschule RheinMain. Carried out at Fraunhofer IMM, 2020

Ingenhorst, A.:
Charakterisierung von Mikromischern bei heterogenen fluidischen Betriebsbedingungen für die chemische Analytik
Bachelor thesis. Gottfried Wilhelm Leibniz Universität Hannover. Carried out at Fraunhofer IMM, 2020

Bachiri, I.:
Hochgeschwindigkeits-Dispensieren von monodispersen Mikrotropfen aus biokompatibler Flüssigkeit
Bachelorarbeit. Fachbereich Ingenieurwissenschaften, Studiengang Interdisziplinäre Ingenieurwissenschaften an der Hochschule RheinMain. Durchgeführt am Fraunhofer IMM, 2021

Master Theses

Gössl, L.:
Kontinuierliche Darstellung von lithiumorganischen Verbindungen
Master thesis. Fachbereich Chemie- und Biotechnologie im Studiengang Chemie- und Biotechnologie der Hochschule Darmstadt. Carried out at Fraunhofer IMM., 2020

Kohlmann, L.:
Entwicklung eines nicht-dispersiven Raman-Detektors zur Identifizierung von Mikroplastik in Wasser
Master thesis. Studienbereich Physik, Fachbereich Ingenieurwissenschaften der Hochschule RheinMain. Carried out at Fraunhofer IMM, 2020

Leinweber, S.:
Aufbau eines Mikro- und Nanopositioniersystems
Master thesis. Fachbereich: Ingenieurwissenschaften, Studiengang: Angewandte Physik der Hochschule RheinMain. Carried out at Fraunhofer IMM, 2020

Khajehamiri, R.:
Automatisierte Anreicherung von Exosomen und die Etablierung einer PCR für den Nachweis von miRNA auf einer mikrofluidischen Kartusche
Master thesis. Studiengang Biotechnologie/Biopharmazeutische Technologie, Fachbereich 04 – LSE, Technische Hochschule Mittelhessen, Standort Gießen. Carried out at Fraunhofer IMM, 2020

Best, F.:
SARS-CoV-2 Testung am Point-of-Care
Master thesis. Fachbereich Biologie, Johannes Gutenberg-Universität Mainz. Carried out at Fraunhofer IMM, 2020

Kiehn, C.:
Entwicklung einer Raman-Spektometrie-basierten Analysemethode für Mikroplastik in Suspension
Masterarbeit. Fakultät für Physik, Karlsruher Institut für Technologie KIT. Durchgeführt am Fraunhofer IMM, 2021

Internship reports

Dörr, M.-J.:
Aufbau und Charakterisierung eines Testgeräts zur Detektion von Cat Fines
Internship report. Studiengang Angewandte Physik an der Hochschule RheinMain. Carried out at Fraunhofer IMM, 2020

Drauth, J.:
Charakterisierung von statischen Mischern in mikrofluidischen Chips
Internship report. Studiengang Chemische Technologie, Fachbereich Chemie- und Biotechnologie an der Hochschule Darmstadt. Carried out at Fraunhofer IMM, 2020

Geyer, T.:
Konzeption und optische Simulation eines Faser-Refraktometers
Internship report. Studiengang Angewandte Physik an der Hochschule RheinMain. Carried out at Fraunhofer IMM, 2020

Nguyen, T.V.M.:
Voruntersuchung zur Silbernanopartikel-Detektion in der Muschel Corbicula fluminea und deren Auswirkung mit Hilfe von in vitro Versuchen
Internship report. Studiengang Bioverfahrenstechnik der Frankfurt University of Applied Sciences. Carried out at Fraunhofer IMM, 2020

Heßling, L.:
Nanopartikelsynthese und Verkapselung
Internship report. Fachbereich Chemie- und Biotechnologie im Studiengang Chemische Technologie, Hochschule Darmstadt. Carried out at Fraunhofer IMM, 2020

Metzke, L.:
Aufbau und Charakterisierung eines optischen Detektionsmoduls zum Nachweis Alzheimer spezifischer Biomarker im Blut
Internship report. Fachbereich Ingenieurwissenschaften, Studiengang Medizintechnik an der Hochschule RheinMain. Carried out at Fraunhofer IMM, 2020

Patents

Baßler, M.; Breitruck, A.; Holzki, M.; Latta, D.; Schunck, T.; Spang, P.:
Verfahren zum Vereinigen zweier Flüssigkeitsvolumina, Fluidikstruktur und mikrofluidischer Chip zum Ausführen des Verfahrens
Patent document: CN 107427832 B Priority date: 10.03.2016
Date of grant: 02.10.2020

Baßler, M.; Quint, S.:
Apparatuses, cytometer, method and computer program for providing information about at least one sequence
Patent document: CN 107771278 B Priority date: 23.06.2016
Date of grant: 20.11.2020

Bleul, R.; Thiermann, R.:
Verfahren zur Herstellung von stabil dispergierbaren magnetischen Eisenoxid-Einkern-Nanopartikel, stabil dispergierbare magnetische Eisenoxid-Einkern-Nanopartikel und Verwendungen hiervon
Patent document: CN 108349746 B Priority date: 05.08.2016
Date of grant: 10.11.2020

Baßler, M.; Quint, S.; Sommer, C.; Spang, P.:
Verfahren zur Bestimmung von ungelösten Teilchen in einem Fluid
Patent document: DE 10 2013 210 952B4 Priority date: 12.06.2013
Date of grant: 19.03.2020

Höbel, P.; Maskos, M.:
Verfahren zur Bestimmung der mittleren Partikelgröße von Partikeln, die in einem flüssigen und fließenden Medium suspendiert sind, über dynamische Lichtstreuung und Vorrichtung hierzu
Patent document: EP 3 479 096 B1 Priority date: 03.07.2017
Date of grant: 09.09.2020

Höbel, P.; Maskos, M.:
Method for determining the average particle size of particles which are suspended in a liquid and flowing medium, by means of dynamic light scattering, and a device therefore
Patent document: US 10,768,086 B2 Priority date: 03.07.2017
Date of grant: 08.09.2020

Hofmann, C.; Pennemann, H.:
Heat exchanger and reactor
Patent document: US 10,737,232 B2 Priority date: 23.02.2018
Date of grant: 11.08.2020

Himmelreich, R.; Schunck, T.; Sperling, R.A.; Thiermann, R.:
Stationary phase for detecting a specific analyte in a mixture, uses thereof and method for detecting a specific analyte in a mixture
Patent document: US 10,775,374 B2 Priority date: 07.11.2017
Date of grant: 15.09.2020

Published patent applications

Krüger, A.; Rehm, T.H.:
Microreactor for photocatalytic reactions
Disclosure document: CN 112154026 A Priority date: 02.04.2019
Date of publication: 29.12.2020

Himmelreich, R.; Simon, P.:
In-vitro-Verfahren zum Nachweis von mindestens einer Nukleinsäure, die sich bei einem Lebewesen im Vollblut außerhalb der Blutzellen befindet und Vorrichtung und Kit hierzu
Disclosure document: DE 10 2018 222 357 A1 Priority date: 19.12.2018
Date of publication: 25.06.2020

Baßler, M.; Schunck, T.; Spang, P.:
Mikrofluidikeinrichtung und Verfahren zum Abtrennen von Blutserum
Disclosure document: DE 10 2019 102 822 A1 Priority date: 05.02.2019
Date of publication: 06.08.2020

Frese, I.; Maskos, M.:
Verfahren, Vorrichtung und System zum Detektieren von Raman-Streulicht
Disclosure document: DE 10 2019 114 252 A1 Priority date: 28.05.2019
Date of publication: 03.12.2020

Kolb, G.; Neuberg, S.; Pennemann, H.; Thiele, R.; Wernig, P.; Wichert, M.:
Device and method for in-situ production of a sterilisation gas and sterilisation of objects and their use
Disclosure document: US 2020/0230276 A1 Priority date: 19.07.2018
Date of publication: 23.07.2020

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