DIFFER

ANNUAL REPORT 2016

WE ARE DIFFER. **SCIENCE FOR FUTURE ENERGY**

Colophon

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Managementteam Marco de Baar, Richard van de Sanden, Wim Koppers

DIFFER SCIENCE FOR FUTURE ENERGY

FROM THE DIRECTOR

It is a great pleasure to present to you the DIFFER annual report 2016. The first full year in our new building has been intense and productive. A lot of hard work has been done on the construction of the laboratories for both Fusion Energy and Solar Fuels. With good progress! Several laboratories came on-line already and have been generating results that whet the appetite for more.

A major milestone was the delivery of the superconducting magnet for the Magnum-PSI facility in October 2016. After years of hard work, and great uncertainty, the construction was successfully finalized by the supplier Bruker. The magnet was quickly up and running and at the time of writing, Magnum-PSI is generating exciting results for the development of novel materials and concepts for fusion reactor walls.

Many new people have joined DIFFER in 2016: new tenure track group leaders, post-doc researchers, PhD students and support staff. People are highly motivated to make the new scientific groups a success and to establish fruitful links within and outside the institute. Exciting initiatives have been started which cross-cut the two research themes and which will certainly lead to strong, novel approaches in fundamental energy research.

The high quality of the institute's people and facilities is underlined by the new research programs that have been acquired in 2016. As an example, in the Fusion Energy theme the strategic program "Taming the Flame" was granted by NWO, and a joint program with the materials institute M2i was granted on Extreme materials, a public-private partnership in which companies such as ASML, Research Instruments and NRG are involved. A total of sixteen PhDs and post-docs will work within these programs to further boost the Dutch efforts on nuclear fusion materials research. Solar Fuels has also been successful in acquiring funds for many new projects and programs. DIFFER embarks on a Chemical Industrial Partnership Program with our in-house industrial partner Syngaschem. With Shell and HoSt, we will start two projects as part of the NWO program Solar to Products.

Fitting our national role in bringing together the community for fundamental energy research, DIFFER organized workshops and conferences to prepare for joint research and explore collaborations, and was instrumental in setting up an Energy Transition route within the National Science Agenda. With the shared appointment of a lector between DIFFER and Fontys polytechnical school, we have set up the first collaboration between fundamental and applied research in the Dutch research environment. This joint activity will help accelerate the transfer of fundamental insights to applied research and practical application.

While DIFFER has finished its own transition, the Dutch research landscape is busily reshaping itself as well. The FOM foundation, DIFFER's parent organization since 1959, has stopped to exist. The four FOM institutes have become part of a new organization: the foundation NWO-Institutes, which will eventually consist of nine institutes. The new NWO-I organization will take further shape in the coming years with a strong role for DIFFER as NWO's foremost strategic instrument for fundamental energy research.

From new talent, top research and research facilities to a prominent national and international role in energy research, DIFFER is filled with energy. The interviews with eager young researchers in this report speak for themselves. I wish you pleasant reading.

Richard van de Sanden,
Director

ABOUT **DIFFER**

DIFFER is the Dutch Institute for Fundamental Energy Research, with the mission to conduct leading fundamental research in the fields of Fusion and Solar Fuels Energy. In our research we work closely together with science and industry. On the national level, we are actively building a community for energy research to help transfer fundamental scientific results to society at large.

Science for future energy

Climate change and rising energy demand require us to transform our current fossil-dominated infrastructure into a fully sustainable system by the end of the century. Scientific research plays a key role in developing the solutions to this grand challenge. As national institute for fundamental energy research, DIFFER seeks to build the interdisciplinary networks capable of solving the score of scientific questions involved. Our own research efforts are focused on two themes: Solar Fuels for renewable energy storage and transport, and Fusion Energy as a clean, safe and inexhaustible power source.

Fusion Energy has the potential to provide concentrated, safe and clean energy from the process which powers the sun and stars. The international fusion reactor ITER aims to demonstrate the technical feasibility of fusion as an energy source. DIFFER is part of the EUROfusion consortium which supports the development of the ITER project. Our fusion research program addresses high priority topics in EUROfusion's European Fusion Roadmap. With our unique high flux plasma generator Magnum-PSI, we explore plasma surface interactions under the extreme conditions near the reactor wall, to validate solutions for the reactor walls of ITER and its successors. Our program on control in burning plasmas develops the understanding and tools to control the highly non-linear plasma dynamics in ITER. Both research lines contribute to understanding and control of the extreme conditions in the fusion environment, with the aim to develop robust solutions that ensure optimal fusion performance.

Solar Fuels tackles the efficient conversion of sustainable energy into chemical bonds. Our program on Solar Fuels addresses the global challenge of energy storage and transport by converting intermittent sustainable energy into fuels. The research theme also develops insights applicable to the broader topic of electrification of the chemical industry, which is currently heavily reliant on fossil feedstock. DIFFER investigates both the indirect conversion of sustainable electricity into hydrocarbon fuels, and a direct 'artificial leaf' approach to convert solar energy into chemical bonds, using so-called photo-electrochemical cells.

DIFFER's cross-disciplinary research naturally involves societal partners and adresses the synthesis and design of novel materials and processes to obtain scalable, efficient and cost-effective systems.

A superconducting Magnum-PSI

After the successful delivery of Magnum-PSI's new superconducting magnet in October 2016, DIFFER's main research facility for Plasma Surface Interactions studies (PSI) is being commissioned for its first experimental campaign in its new location.

Magnum-PSI is the first laboratory experiment capable of reaching and even exceeding the intense plasma conditions expected at the exhaust wall of the ITER fusion reactor. The superconducting magnet allows for hours-long exposures to these conditions and will lead to the first detailed studies of how materials will evolve during their entire lifetime in ITER. These unique capabilities will enable DIFFER to play a leading role in designing and validating wall materials for future fusion power plants.

At the time of writing, Magnum-PSI and the magnet are fully operational and are already setting records for exposure of materials to ITER-relevant plasmas. Pages 14-15 describe the world-class infrastructure being set up in DIFFER's PSI-lab and the exciting results already realized in 2016 in more detail.

Visit by EU commissioner Šefčovič

On 24 May, DIFFER welcomed Mr. Maroš Šefčovič (commissioner) of the European Commission in charge of the Energy Union) for a lab tour and discussion on Solar Fuels and Fusion Energy research. Together with regional government representative Mrs. Anne-Marie Spierings, Mr. Šefčovič toured the Eindhoven region to explore its high-tech collaborations tackling the energy transition. Visits to Solliance and the TU/e's Stella solar car and Storm electric motorcycle rounded out the EU commissioner's visit.

Foto: Wiki creative commons

PERSONALIA

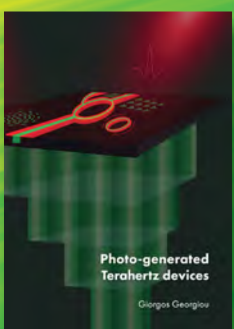
CSER grants for new group leaders Süleyman Er and Shuxia Tao

In 2016, four new tenure track researchers started in the Shell/NWO/FOM-program on Computational Sciences for Energy Research (CSER). Two of these researchers will be stationed at DIFFER. YES!-fellow Dr. Süleyman Er will use his CSER grant to set up a research group on computational design of new hybrid photocatalysts for solar fuel generation. He will develop computational techniques to accelerate the development of advanced materials for fuel production out of sunlight that are optimally matched to the solar spectrum. Transitioning from the world of high energy particle physics, Dr. Shuxia Tao will use her CSER grant to design a multi-scale simulation tool that can investigate new materials for third-generation PV. Formally stationed at TU/e, Shuxia Tao's group works in-house at DIFFER and is the first element of the joint Center for Computational Energy Research that TU/e and DIFFER are setting up.

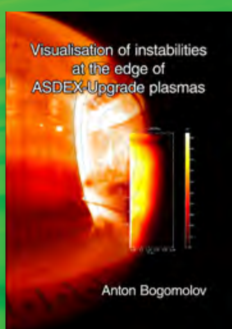
Aafke Bronneberg wins Marie-Curie grant

Physicist Dr. Aafke Bronneberg (Helmholtz-Zentrum Berlin and DIFFER) received one of the prestigious Marie Curie grants in the European Horizon2020 program to start a post-doc position at DIFFER. Bronneberg's research will tackle materials that use direct energy from sunlight to produce hydrogen. Her aim is to perform live measurements and generate new insights in the conversion of this reaction. This will generate new insights in the conversion of sustainable energy into efficient fuels.

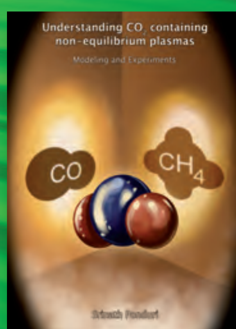
PhD theses 2016



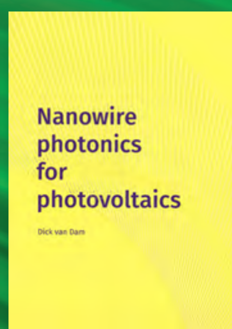
Giorgos Georgiou



Anton Bogomolov



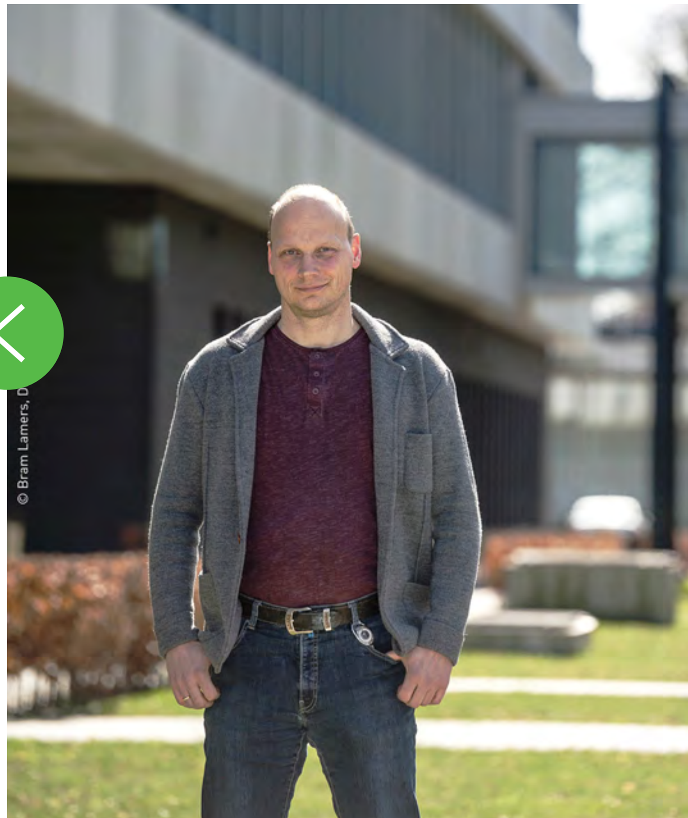
Srinath Ponduri



Dik van Dam

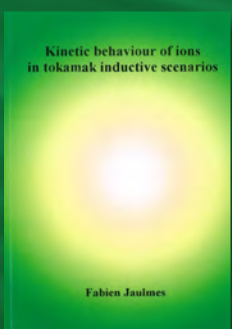
Jonathan Citrin starts up integrated modelling group

After a four year post-doc on transport processes in fusion plasmas at CEA in Cadarache (Fr), YES!-fellow Dr. Jonathan Citrin joins DIFFER as a new group leader in the DIFFER research theme on fusion energy. Citrin leads the strong effort on integrated modeling of the many processes that are at play in the plasma of a fusion reactor. With these physics-based models, Citrin and his group want to contribute to predictive control of the reactor performance.

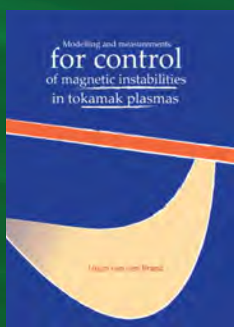


Peter Thüne starts joint lectorate at Fontys and DIFFER

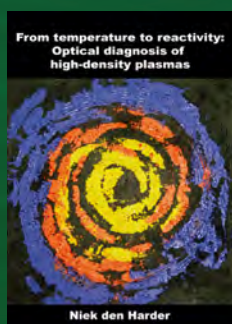
Solar fuels researcher Dr. Peter Thüne has been appointed the first lector with a joint research appointment at a Dutch polytech and national research institute. His group at Fontys Hogescholen and DIFFER will work closely together with the research company Syngaschem (in-house at DIFFER), and is the first in a national program to build bridges between applied and fundamental research. Peter Thüne and his students will deploy techniques from catalysis, materials and surface science to develop experiments and diagnostics for solar fuels research.



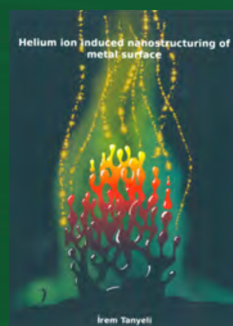
Fabien Jaulmes



Hugo van den Brand



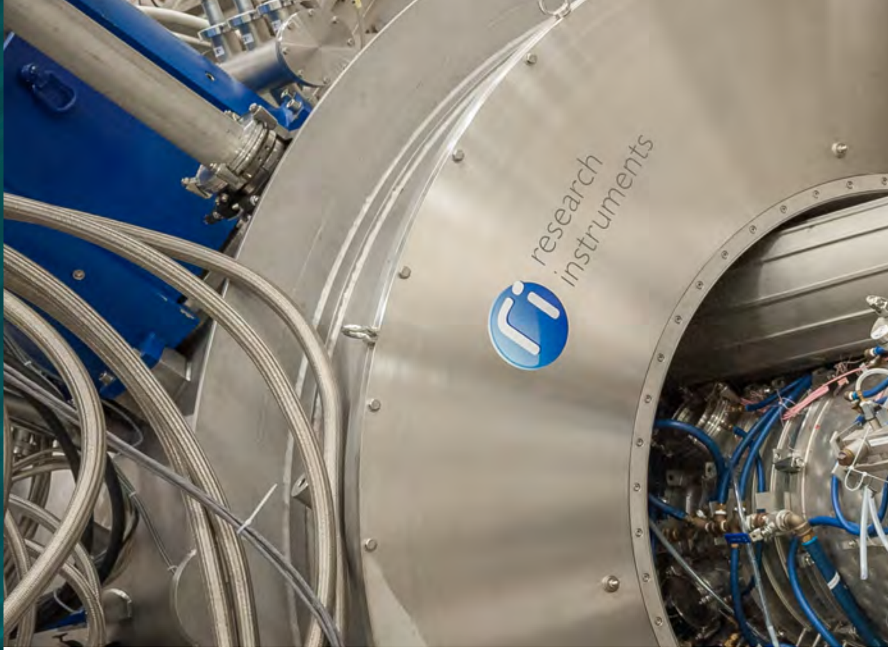
Niek den Harder



Irem Tanyeli

RESEARCH

THEME **FUSION ENERGY**



Theme leader:
Marco de Baar

Research groups: 6

Science staff:

permanent staff	10
post-docs	7
PhD students	8
research engineers	11

Peer reviewed publications	64
PhD theses	4
Invited talks	24

Personal grants:
EUROfusion Engineering Grant:
Matthijs van Berkel

Industrial collaborations:
NL: ASML, HIT
EU: Research Instruments

The process of nuclear fusion powers the sun and has great potential as a concentrated, safe and clean energy source on earth. The research at DIFFER addresses two of fusion's grand challenges: developing tools to control the hot, turbulent fuel of charged particles (plasma) in a fusion reactor, and learning how wall materials for fusion reactors will interact with the extreme plasma conditions at the reactor exhaust.

The international fusion project ITER aims to demonstrate the technical feasibility of fusion energy. ITER is the first ever experiment where the power from the fusion reaction will be larger than the power of the reactor's control systems; a fundamentally new regime for control engineering. DIFFER develops techniques to sense, predict and control the many possible instabilities in the hot, magnetized plasma. This is crucial to optimize the reactor performance.

At the ITER exhaust, (divertor) wall materials face extreme plasma surface interactions in an environment similar to the surface of the sun or a spacecraft's re-entry heat shield. DIFFER's linear plasma device Magnum-PSI is the only laboratory facility in the world capable of exposing materials to such extreme conditions. Our researchers study the effect of wall materials and develop new concepts for reactor components.

European connection

The research at DIFFER addresses two high priority topics in the European Fusion Roadmap. As the Dutch partner in the European Horizon2020 research program EUROfusion, DIFFER is the linking pin between Dutch researchers and companies and the international fusion community.

Boost for fusion materials research

In 2016, two research programs with industrial and academic partners were granted which strengthen DIFFER's leading role in developing solutions for materials under extreme conditions. A total of sixteen new PhD and post-doc researchers work on topics from the exhaust of fusion reactors to designing materials for EUV lithography.

Taming the Flame

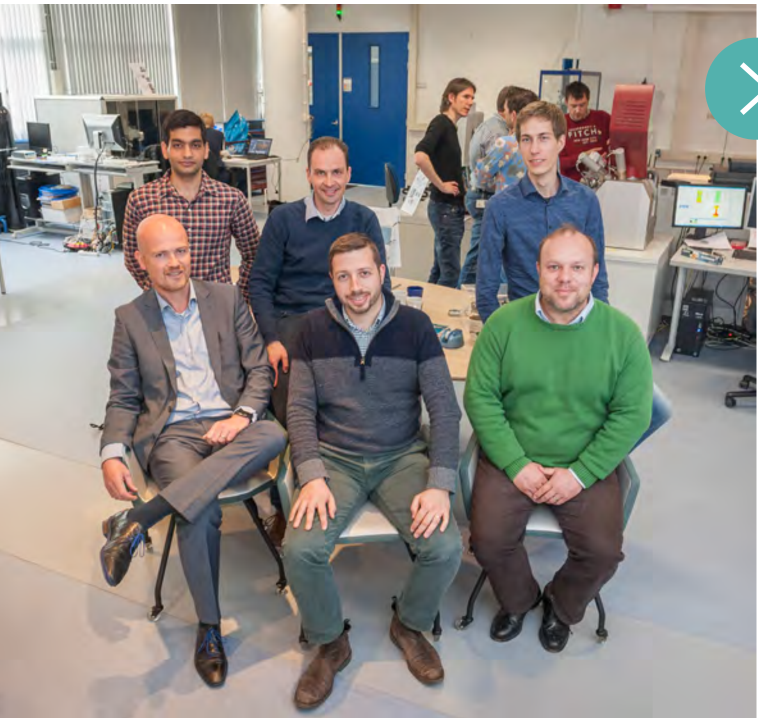
The Taming the Flame program tackles one of the great challenges to realising commercially attractive fusion energy. Control engineers, physicists and materials scientists will team up to remove heat and fast particles exhausted by the fusion reactor in a controlled way, before they can damage the surrounding wall. The research will focus on controlling and diluting the hot, dense plasma before it reaches the reactor wall, and on the novel concept of a self-repairing reactor wall, with a liquid metal layer flowing over and protecting solid material underneath. This program is supported by strategic funding from NWO.

PhD positions	7
Post-doc positions	2

Extreme materials

This Public-Private research program brings together academic researchers, technological institutes and industrial partners to work on materials behaviour under extreme particle and radiation loading. The partners will investigate how advanced materials respond to exposure to extreme plasma environments. This knowledge will be applied to cases from 3D printing of Eurofer metal for fusion and fission power plants, to materials research for advanced EUV lithography. This program is partly funded by Materials Research Institute M2i.

PhD positions	7
Research partners	TU/e, TUD
Technology institutes	ECN, NRG
Industrial partners	ASML, Research Instruments



Research team *Materials behaviour under extreme particle and radiation loading*, TU/e, DIFFER and M2i

THE CREATIVE **CHALLENGE**

Interview Stein van Eden

"I keep finding myself being amazed about the mysteries of the universe", says PhD Stein van Eden. "It would be exciting if we could use exotic phenomena like nuclear fusion to tackle societal challenges such as for instance the energy crisis."

In his research, Van Eden investigated how a layer of liquid tin can protect the exhaust (divertor) of a fusion reactor against the enormous heat flux from the fusion plasma. His results show that a thin layer of vapor above the liquid wall has self-regulating properties. "What's really cool is that we finally could understand the origins of this effect, which we summarized in a new publication."

Van Eden wants to continue his career in research, as long as there are opportunities to be creatively challenged while working in an inspiring team. Ideally, he wants to perform societally relevant research, for instance in the context of the energy transition. "Of course global warming concerns me", says the physicist. "And at the same time I am fascinated by humanity's capability to again and again solve such major challenges. That is what I want to be a part of."

Self-regulating heat flux by vapor layer above liquid tin

Fusion edge plasma reveals its true colors - Wouter Vijvers

New data on the distribution of radiation in the edge of the TCV tokamak plasma lays the foundation for unraveling the physics of detachment.

In fusion reactors, tremendous energy fluxes flow along the plasma boundary towards the machine walls. At the power level expected in a fusion power station, this energy needs to be dissipated (e.g. by radiation) before it reaches the walls. A plasma that thereby completely decouples from the walls is called detached. The physics underlying this highly desired state is not yet fully understood, preventing reliable extrapolations to future machines. An international team investigated detachment on the Swiss TCV tokamak. A DIFFER-operated multi-spectral imaging system provided uniquely detailed data into detachment physics.

Detachment evolution on the TCV tokamak, J.Nucl.Materials and Energy, https://doi.org/10.1016/j.nme.2016.10.020

Above: Multi-spectral imaging provided high-resolution 2D radiation distributions for four spectral line intensities. Fast interpretative modelling, constrained by this data, was employed to reconstruct the main plasma parameters in high resolution for the whole edge plasma at once.

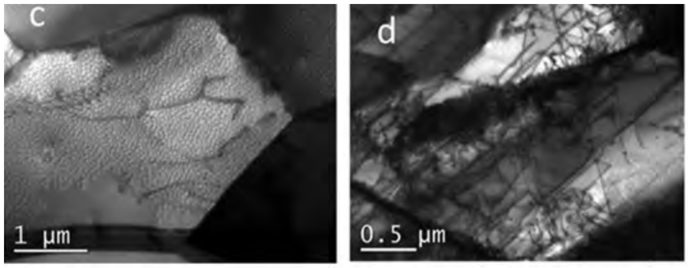
A TRILLION TIMES FASTER

INTERVIEW AARON HO

"Working to understand fusion plasmas gives me the same sense of excitement I had as a six-year-old, when I first learned that electricity is tamed lightning." Nuclear engineer Aaron Ho brings a great deal of enthusiasm to his PhD research at DIFFER. He works with MSc student Karel van de Plassche to massively accelerate predictions of which experimental settings provide the best fusion performance. "From detailed but slow non-linear models, we develop more pragmatic reduced models and train our neural networks to emulate their results." A neural network can run a trillion times faster than the original models, and could be a way to explore optimum discharge settings before running an experiment. "I love the idea of helping prepare the best possible experiments and accelerate the research", says Aaron, who is also actively setting up energy debates with fellow PhD students. "Fusion has so much potential, I want to help realize it."

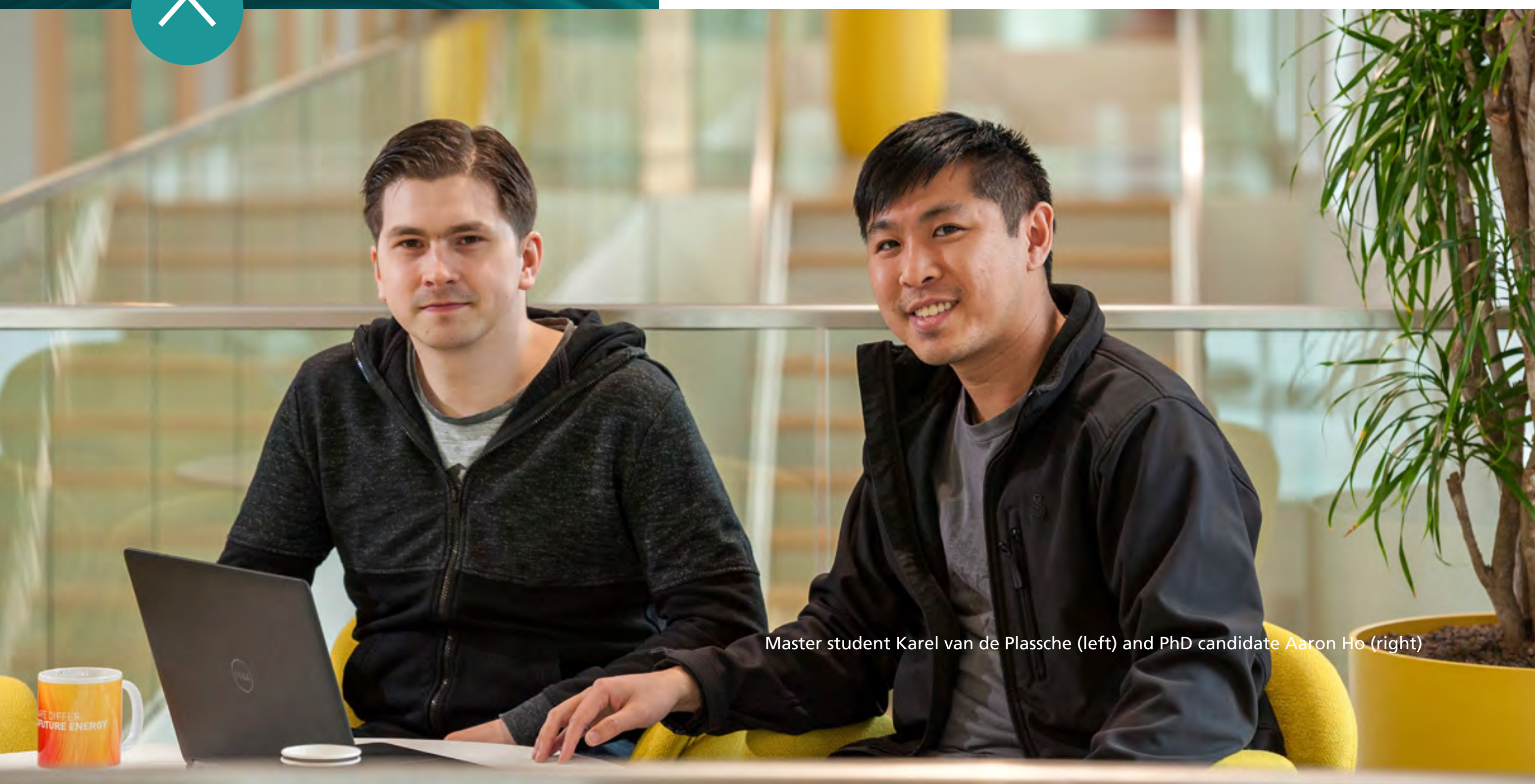
Hydrogen prisons in tungsten are formed by imperfections - Thomas Morgan

For the tungsten used in the ITER divertor it is important that unburnt fuel is not locked up in the material but can be reinjected into the plasma. Two recent papers explore this problem from different angles using DIFFER's linear devices.
Anastasiia Bakaeva et al. found that dislocations (imperfections in the crystal structure of the material) act as trapping sites for hydrogen close to the surface at low temperatures, but start to act as highways for deep diffusion as the temperature is increased. When impurity ions used to cool the divertor plasma are included in the mix, Long Cheng et al. identified that they act like defects, making extra traps for the hydrogen. Using this information we can start to extrapolate how tungsten will perform in ITER.



TEM images of a normal (left) and deformed (right) W targets. The dark lines inside the grains are dislocations.

Dislocation-mediated trapping of deuterium in tungsten under high-flux high-temperature exposures, J. Nucl. Mater. 479 (2016) 307-315.
Effect of noble gas ion pre-irradiation on deuterium retention in tungsten, Phys. Scr. 2016 (2016) 014001

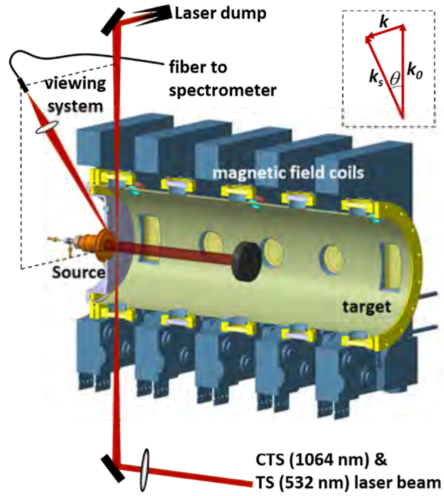


Master student Karel van de Plassche (left) and PhD candidate Aaron Ho (right)

Measuring collective electron behavior
Hennie van der Meiden

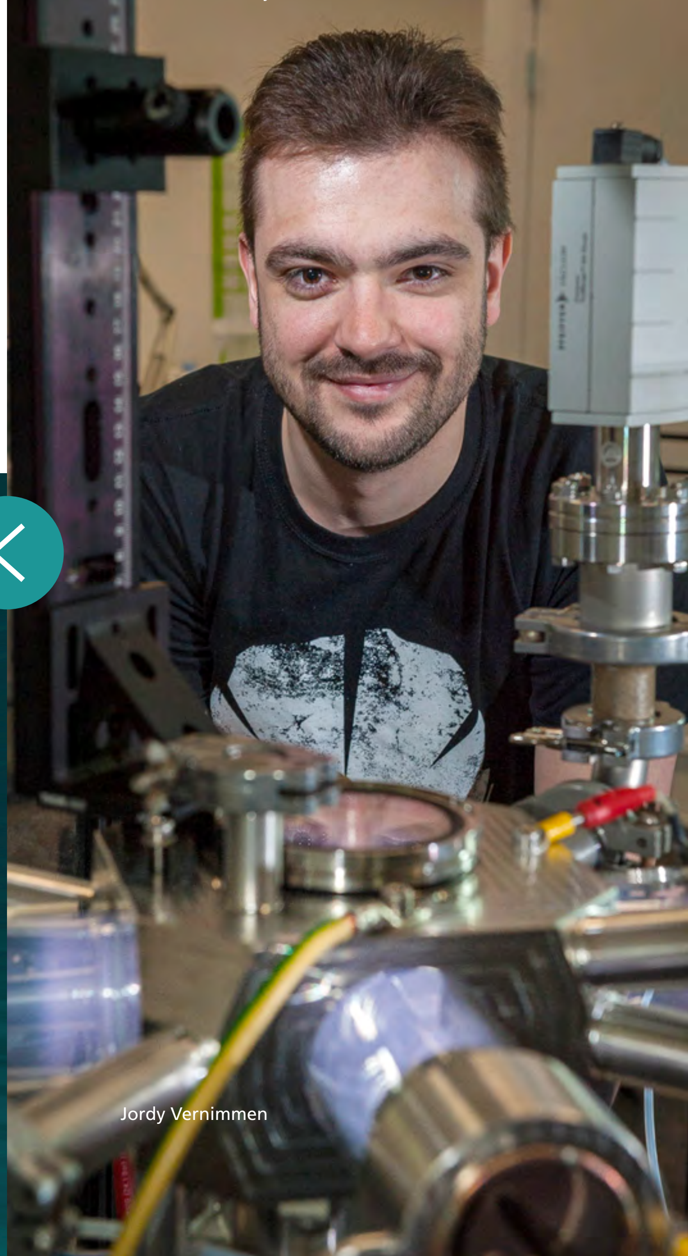
Understanding the behavior of the hot, charged particles in plasmas is crucial to realize fusion energy and for many other technologies.

Ways exist to measure the properties of the light electrons in a plasma, but not for the heavier ions. With a new Collective Thomson Scattering diagnostic (CTS), Hennie van der Meiden and Jordy Vernimmen managed to determine ion properties such as temperature, plasma velocity and impurity concentrations from the signature cloud of electrons massing around each ion. The CTS system was tested succesfully at the Pilot-PSI experiment. An upgraded CTS system together with all available diagnostics will be deployed to provide a full picture of the near-surface plasma under ITER-divertor relevant conditions in front of the target of Magnum-PSI.



H.J. van der Meiden, J.W.M. Vernimmen, K. Bystrov, K. Jesko, M.Y. Kantor, G. De Temmerman, T.W. Morgan, Collective Thomson scattering system for determination of ion properties in a high flux plasma beam, Appl. Phys. Lett. 109 (2016)

BABE – a brush cathode discharge for thermal fluctuation measurements, J. Plasma Phys. 81, 345810202 (2015)



Jordy Vernimmen

BABE - A device for plasma fluctuation measurements - Jordy Vernimmen

The presence of dust particles in plasmas will invoke electron density fluctuations. Characterization of these induced fluctuations is a valuable diagnostic for the normally invisible dust particles in space plasmas. However, most laboratory plasmas are not stable enough, meaning that these induced fluctuations will be masked. For this purpose BAri Brush Electrode (BABE) is developed, a combination of two concepts proposed in the ‘60s. The plasma in the central part of BABE is unprecedentedly stable and the electric field is essentially zero. This plasma will be seeded with small dust particles to experimentally validate the theory of dusty plasmas. Understanding this interaction is essential for space plasmas, fusion energy and solar fuels, but also for industrially produced plasmas.

RESEARCH FACILITIES

FUSION ENERGY FACILITIES

Surface of the sun

One of the main challenges to developing commercial fusion energy is finding a material which can stand up to the extreme plasma conditions in the fusion reactor. The exhaust (divertor) of a reactor experiment is the only component which comes into direct contact with the hot, dense plasma.

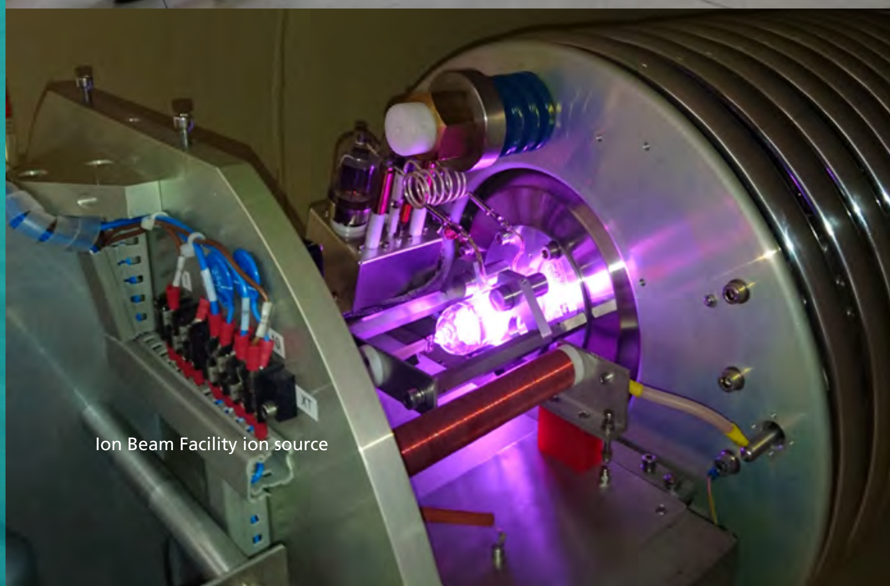
In the ITER experiment, divertor materials will face plasma conditions similar to those at the surface of the sun for minutes up to an hour at a time. In ITER's power plant successor DEMO, conditions will be even more intense, and will last for hours at a time.

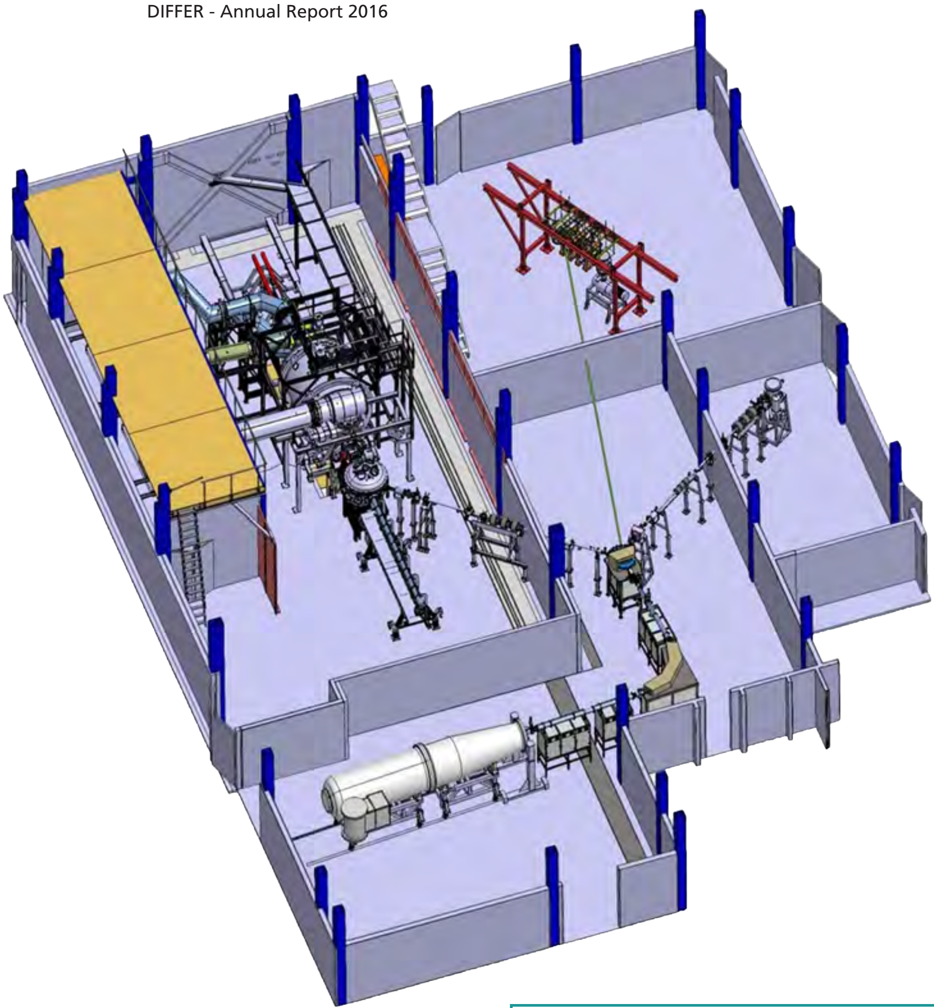
DIFFER's PSI-lab consists of three facilities which together explore how materials evolve under ITER-relevant plasma conditions: the linear devices Magnum-PSI and Pilot-PSI Upgrade, and the newly installed Ion Beam Facility.

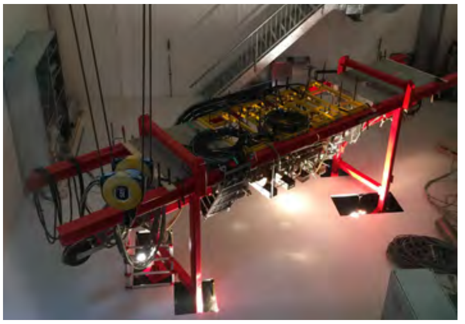
Commissioning Magnum-PSI

DIFFER's linear plasma generator Magnum-PSI is the only laboratory facility in the world capable of mimicking and even exceeding the divertor conditions in ITER and DEMO. In 2016, rebuilding and commissioning proceeded smoothly after Magnum-PSI's relocation from its original location in Nieuwegein to DIFFER's new building. On Saturday 8 October, the PSI team received their custom designed superconducting magnet for Magnum-PSI. It will enable hours-long plasma discharges and will allow the team to perform unique long duration tests of wall materials under realistic fusion reactor conditions. Magnum-PSI produced its first magnetized plasma in the new location in December 2016.


New superconducting magnet brought in through the roof


Ion Beam Facility ion source





The Upgraded Pilot-PSI project: enabling simultaneous plasma exposure and ion beam analysis.

Superconducting magnet installed.

Magnum-PSI and ITER divertor plasma conditions

Parameter	Magnum-PSI	ITER divertor
electron density (m^{-3})	10^{19} - 10^{21}	10^{19} - 10^{21}
ion flux density (m^{-2} s^{-1})	10^{23} - 10^{25}	10^{24} - 10^{25}
magnetic field (T)	2.5	~5
energy flux density (MW m^{-2})	>10	>10
transient energy flux density* (GW m^{-2})	2	2-4

* during Edge Localized Modes - sudden energy bursts from the fusion plasma

Work starts on Pilot-PSI Upgrade

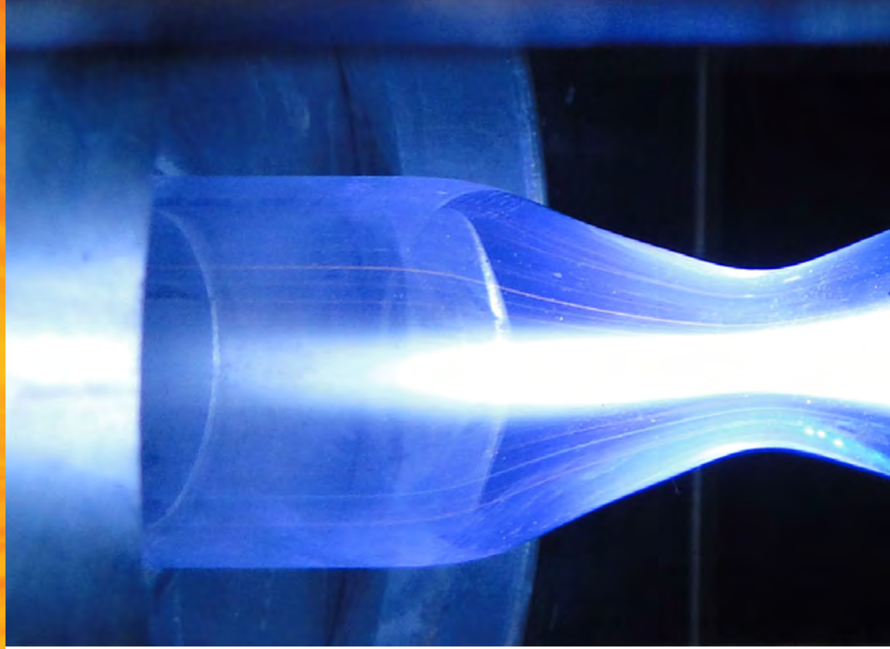
DIFFER has started the assembly of an upgraded version of its successful Pilot-PSI project. By connecting the device with its powerful plasma source and steady state magnets to a beamline of the Ion Beam Facility, Pilot-PSI Upgrade will deliver new insights in the dynamics of how materials evolve under the bombardment of particles and heat in a dense plasma. Offering a lower magnetic field and a less intense plasma than Magnum-PSI, Pilot-PSI Upgrade's unique feature is its capability to perform ion beam analysis of how materials evolve during exposure to intense plasmas.

First measurements in Ion Beam Facility

The new Ion Beam Facility (IBF) uses a 3.5 MV accelerator to investigate properties and processes at and below a material's surface. A switch magnet in the IBF allows for the installation of multiple experiments. In 2016, the IBF was already connected to Magnum-PSI's vacuum chamber for materials analysis, where it will enable detailed studies of how wall materials will evolve during their lifetime in future fusion reactors. The IBF will also connect to Pilot-PSI Upgrade and to dedicated user stations for Solar Fuels experiments and for external users. Possible research includes live analysis of the energy and materials streams at a catalyst that converts sunlight into fuels.

RESEARCH

THEME
SOLAR FUELS



Theme leader:
Richard van de Sanden

Research groups:	**10**
Science staff:	
permanent staff	11
post-docs	15
PhD students	15
research engineers	7
Peer reviewed publications	39
PhD theses	4
Invited talks	39
Patents	1

Personal grants:
CSER Tenure Track - Shuxia Tao
CSER Tenure Track - Süleyman Er
L.INT polytech/institute lectorate - Peter Thüne
Marie Curie Grant - Aafke Bronneberg

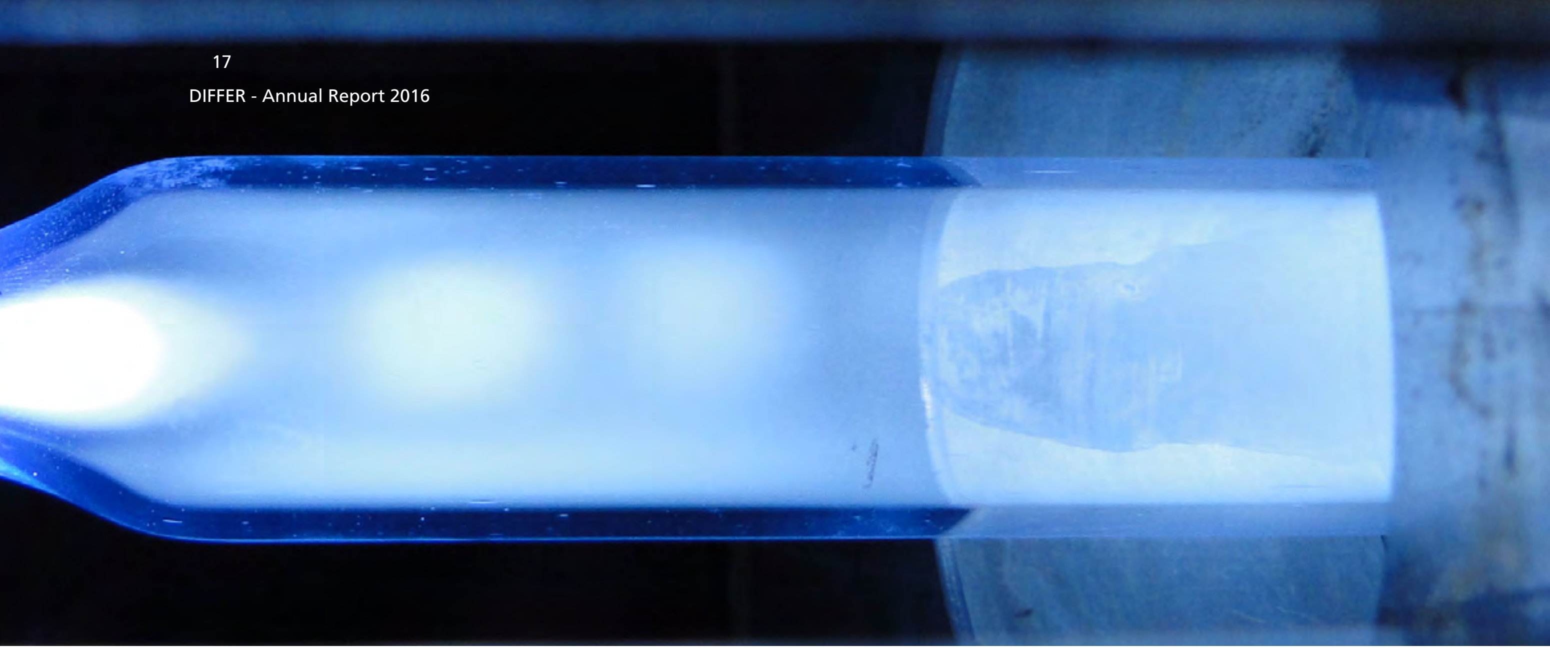
Industrial collaborations:
NL Alliander, Fujifilm Research, Philips Research, Shell, Syngaschem
EU Evonik, Protemics GmbH (D)
World Atlantic Hydrogen (Ca), Facebook (US), Sasol (SA)

The worldwide energy transition requires solutions to efficiently store and transport sustainable energy to where and when it is needed. The solar fuels research at DIFFER addresses the global challenge of efficiently converting and storing sustainable energy into chemicals. These offer the highest energy densities and are ideal for long-term storage and long-distance transport of sustainable energy.

The Solar Fuels research and development program at DIFFER is driven by the need for cost effective and energy efficient production of solar fuels and products through the use of abundantly available materials.

In particular, DIFFER investigates using direct or indirect renewable energy for splitting of water into hydrogen and oxygen, and the reduction of carbon dioxide (CO_2) to carbon monoxide, as an important starting point for the synthesis of CO_2-neutral chemical fuels. Our research involves the synthesis and design of novel materials and processes to obtain scalable, efficient and cost-effective systems.

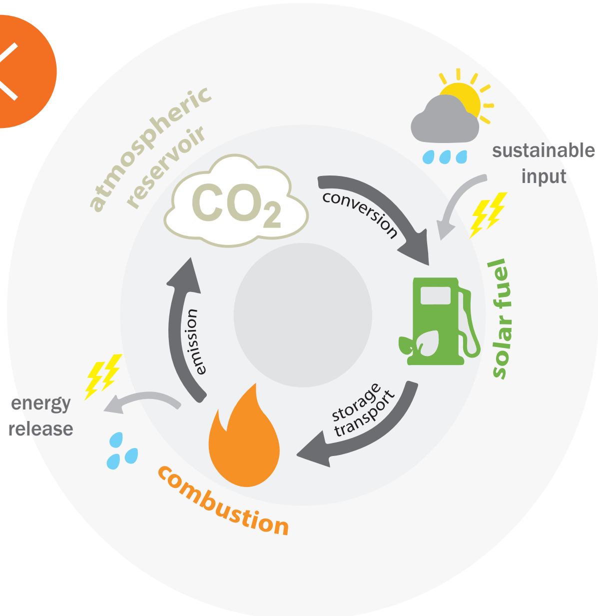
The concrete research areas are plasmolysis, where non-equilibrium plasma is used to efficiently dissociate CO_2 and H_2O, the artificial leaf approach, and novel materials synthesis, preparation, and characterisation for the production of solar fuels and chemicals.

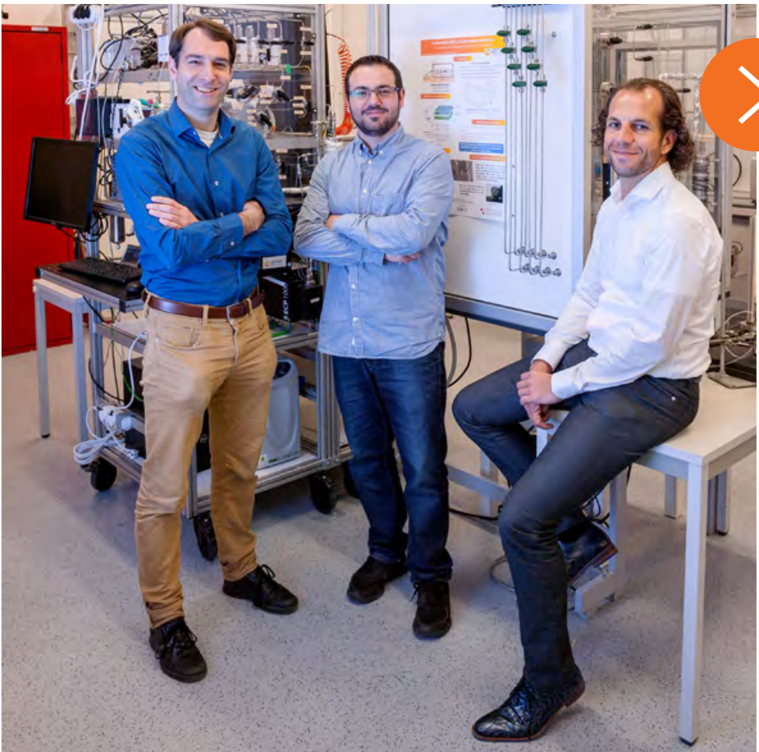


Solar to Products

DIFFER prepared the NWO program Solar to Products and scored two out of eight projects in this cross-disciplinary program. This program covers both biological and non-biological approaches and fits in three of the Dutch Government's public-private Topsector collaboration schemes - Energy, Chemistry and AgroFood. DIFFER will partner with Shell and HoSt BioEnergy to investigate plasma reforming of biogas and integration of plasma and membrane technologies in electrolysis.

Total program budget: M€ 4.2
Partners: Shell, HoSt





In-house industrial collaboration

Together with TU/e's PMP group, lead by Erwin Kessels, and the research company Syngaschem BV, DIFFER embarks on a Chemical Industrial Partnership Program (CHIPP) to make liquid fuels from green electricity, water and carbon dioxide. The research has both chemical and physical aspects: partners are active in the area of electrochemistry, catalysis, surface reactions, spectroscopy and plasma physics.

Budget: M€ 1.6
(50% FOM/NWO CHIPP; 25% Synchaschem BV;
25% TKI-fund from Top sectors Chemistry,
and research Partners, TU/e, Synchaschem BV)

CHIPP partners Kees-Jan Weststrate (Syngaschem), Mihalis Tsampas (DIFFER), Erwin Kessels (TU/e)

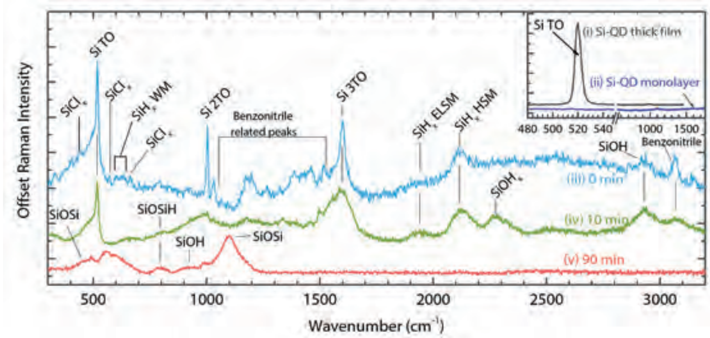
ABUNDANT BATTERY MATERIALS

INTERVIEW WITH ILKER DOGAN

Tracking single molecules on a surface

Ilker Dogan

Surface-enhanced Raman scattering (SERS) is a powerful technique that enables detection of single molecules by virtue of the enhancement of the Raman signal from specially designed surfaces. Here, we used SERS for the first time to monitor the surface chemistry of quantum-dots (QDs) at single molecule level. We have succesfully revealed the real-time oxidation mechanism of chlorine terminated silicon-QDs using SERS. This unique method can be used as an in-situ real-time tool to monitor the chemical processes taking place on the surface of silicon-QDs when they are involved in chemical/electrochemical processes. For instance, surface processes on silicon-QDs can be real-time monitored when they actively take part in batteries, or solar cells, and the performance limiting phenomena can be revealed. This research is partly funded by the Topsector Energy.



Detecting single molecules on a substrate. Surface-Enhanced Raman Scattering (SERS) analyses of silicium quantum dots on silver/silver20 thin films as a function of air exposure time. The inset shows a measurement from silicium quantum dots on glass substrates in the form of a thick film and with the same quantum dot density as SERS analyses.

Analysis of temporal evolution of quantum dot surface chemistry by surface-enhanced Raman scattering, Sci.Rep. 2016; 6: 29508

Since childhood, Ilker Dogan has been curious to know how science can explain the world. As a physicist, the process of 'free' photons from the Sun streaming down on Earth all day long continues to fascinate him. "Now that we are realizing the technology to generate electricity from sunlight, I feel challenged to find a way to store this in an efficient way." In his current research, Ilker revisits the original rechargeable batteries concept based on sodium and sulphur, focussing on the aluminium membrane between both substances. The appeal of sodium-sulphur batteries: high energy density, low leakage storage, based on abundant resources. "In my work, I take >>

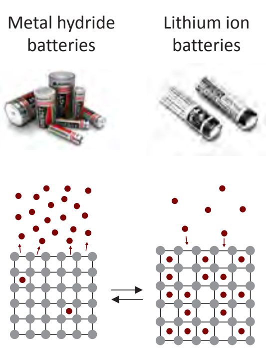
Phase transitions in nanobatteries
Andrea Baldi

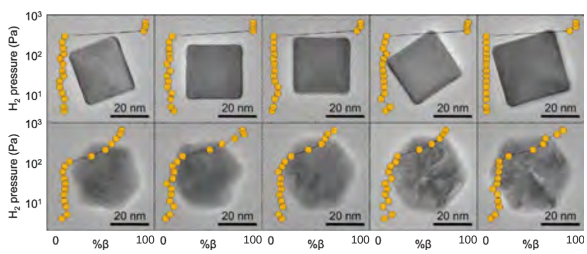
The Nanomaterials for Energy Application (NEA) group of Andrea Baldi explores fundamental aspects of energy conversion and storage in nanomaterials. In collaboration with the group of prof. Jennifer Dionne at Stanford University, they have developed novel experimental techniques to study in-situ how individual nanoparticles undergo phase transformations in reactive environments. The work, featured in a recent issue of Nature Materials, can lead to new ways of studying nanomaterials used in a wide range of applications, from energy and information storage, to chemical synthesis.

Compared to their bulk counterpart, nanostructured materials used in battery applications show faster charging and extended durability. Characterizing their performance at the single nanoparticle level is a daunting task due to their extremely small dimensions. In the present study researchers at Stanford University and DIFFER developed new techniques that allow them to "look inside" individual nanostructured particles during their charging process. As a model energy storage system they investigated the absorption of hydrogen atoms inside single nanoparticles of palladium, using an advanced transmission electron microscope that allows studying specimens under a reactive gas pressure. By combining different in-situ imaging and spectroscopic techniques, they have been able to reconstruct the mechanism of hydrogen absorption inside individual nanoparticles of different shapes and structures. Their study highlights the role of elastic strain and crystallographic defects in the charging mechanism of nanostructured materials. Furthermore, their techniques can be extended to the study of a wide range of structural transformations in nanoscale processes, from energy storage in nanostructured battery electrodes, to information storage in volatile memories and chemical reactions on metal nanoparticle catalysts.

While their study has so far been limited to equilibrium conditions, in the future the researchers want to extend their in-situ approach to visualize the hydrogen absorption process in real time and with nanometer spatial resolution.

Reconstructing solute-induced phase transformations within individual nanocrystals, Nature Materials 15, 768-774 (2016)



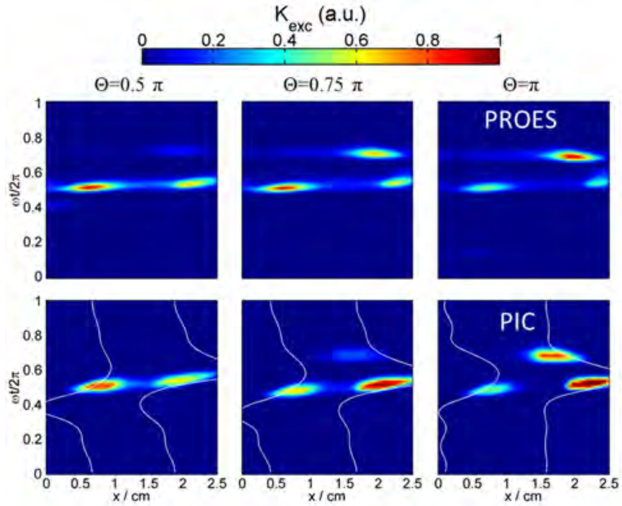


full advantage from the knowledge, experience and tools that I discovered in different fields of science, including a short stay in industry. Combining insights from different fields helps accelerate research", says the physicist. "The challenges are great, transfering scientific knowledge to applications does not happen overnight, but I'm not pessimistic. We can make this work."


First authors Tarun Narayan and Andrea Baldi

Effect of Tailored Voltage Waveforms on hydrogen discharges - Paola Diomede

Production of plasmas via waveforms consisting of a sum of harmonics has recently been proposed as an efficient way to break the link between the plasma density (process rate) and the ion energy flux to a surface (substrate damage). These waveforms produce unexpected spatio-temporal trends in the physics and the chemistry of the reactor. In the framework of an international collaboration a combined computational-experimental study of a geometrically symmetric capacitively coupled plasma was performed in hydrogen, the main component in mixtures for deposition of silicon thin films for solar cells fabrication. The excellent agreement of simulations and experiments provided an improved understanding of the effect of these novel voltage waveforms on the plasma dynamics and on the electrical asymmetry of the discharge.



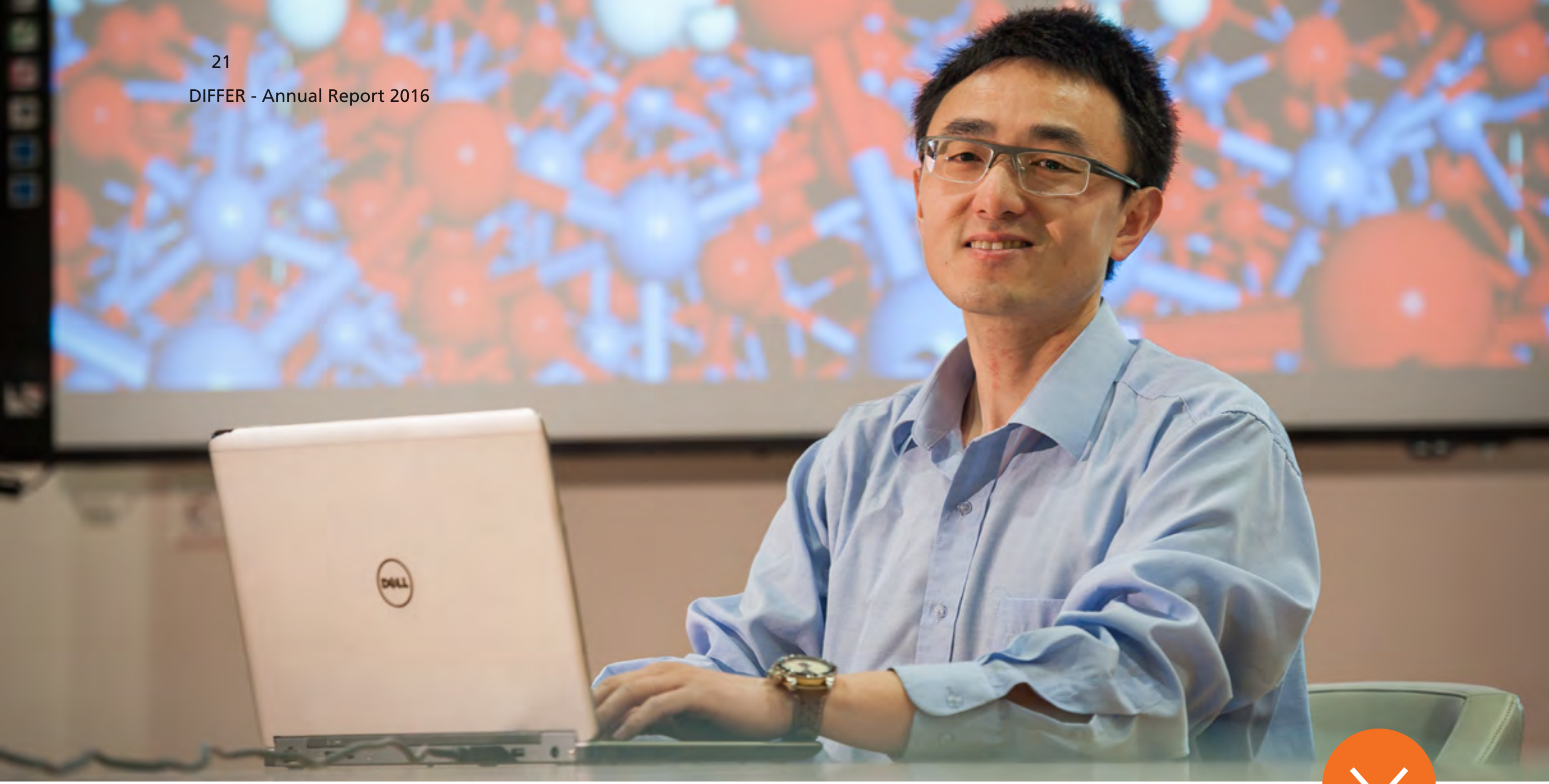
Spatio-temporal excitation rates derived from measurement of the emission line at 656 nm using Phase Resolved Optical Emission Spectroscopy (PROES, top row), and from Particle in Cell (PIC) simulations (bottom row) for different phase shifts for the harmonics in the voltage waveforms.

Capacitively coupled hydrogen plasmas sustained by tailored voltage waveforms: excitation dynamics and ion flux asymmetry, Plasma Sources Science and Technology, 25 (2016) 045019

Moving electrons
Interview with Thibaut Stoll

“Much technology that uses sunlight as an energy source is mainly based on photovoltaic systems, which are of course very interesting. However, when there is no sun, there is no electricity.’ Postdoc Thibaut Stoll explains why his own research focuses on using sunlight to generate electron movement, but not electricity. “We turn solar energy into mobile electrical charges and move those to a catalyst that can promote the formation of a fuel like hydrogen.” The concept is that such solar fuels can be stored and used to produce energy when there is no sunlight available.

“At first, we were able to build a system that allows analytic gas phase photo electrochemistry, which is really new. Now we search for materials with more suitable properties for the catalytical reaction.” With his fellow researchers, Thibaut wants to also develop electrodes that are optimized for the entire visible range of sunlight. Stoll really likes the idea of contributing to the worldwide energy challenges with his research. “But it has nothing to do with pride. I just like solving problems.”



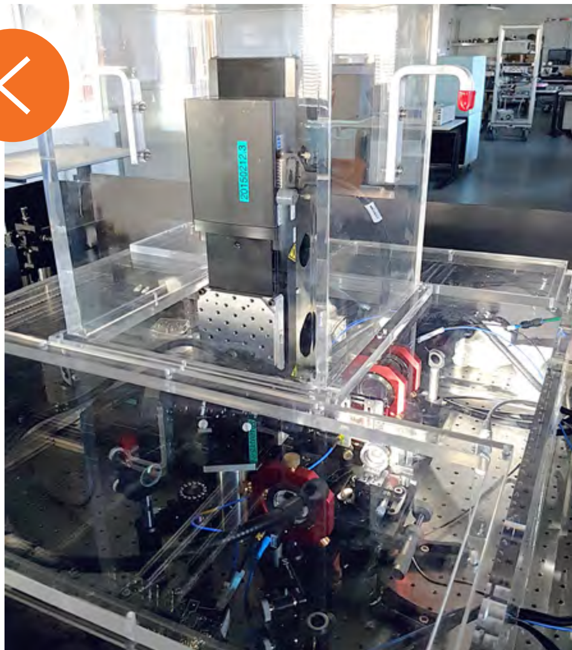
Speeding up water splitting - Interview with Xueqing Zhang

From a casual conversation with his group leader-to-be, a new idea sprang up which turned into a full research project. Together with his international colleagues, this young researcher sees a bright future for the efficient storage of sustainable energy. As postdoc at DIFFER, Xueqing Zhang currently works on speeding up the process of using light to directly split water into hydrogen and oxygen. He focuses on the oxygen evolution reaction as the slower step in the process. "I truly believe that converting sustainable energy into 'solar fuels' holds great opportunities", he explains. "Our aim is to increase the efficiency of this conversion." Together with his colleagues, Xueqing's target is to understand the exact processes involved in water splitting, and the limiting factors at the interface between semiconductor and water, through modeling and simulations. "It is very exciting to me that our review paper on our multi-scale modeling approach kicked off promising international collaborations this year. We see this as a promising way to improve the oxygen evolution reaction and realize a more efficient water splitting process."

Modeling and Simulations in Photo-electrochemical Water Oxidation: From Single Level to Multiscale Modeling, ChemSusChem 9 (2016) 1223-1242.

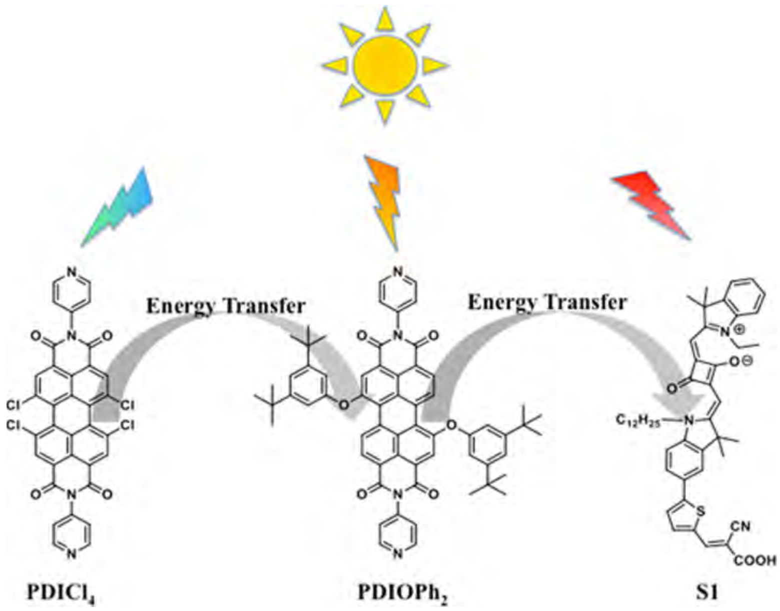
High resolution terahertz sensing - Jaime Gómez-Rivas

Far infrared (THz) electromagnetic radiation represents a valuable probe for material characterisation. Free charges in materials will react to THz radiation, giving rise to absorption that can be used to determine their conductivity. A main limitation of electromagnetic radiation is that it cannot be focused below the diffraction limit, which constrains the spatial resolution of measurements. In this patent, we disclose a near-field measuring method that can be used to determine the photo-conductivity of materials relevant for energy conversion with a high spatial resolution (well below the diffraction limit). We have also developed a demonstrator (shown in the photo) that is now being tested for commercialisation. This patent and research is done in the framework of the ERC proof-of-concept project MICROMAP, led by Jaime Gómez Rivas.



Directional energy transfer in a rudimentary artificial leaf - **Süleyman Er**

Photosynthesis is the process by which plants and some bacteria use the energy from sunlight to produce useful chemicals, such as glucose, from basic and abundant chemicals, such as carbon dioxide and water. Photosynthesis starts with the absorption of photons and the generation of charge-carriers. In a series of radiationless transfers these charge-carriers move from one molecular antenna to another, until they reach a reaction center and drive the chemical reactions to produce glucose.

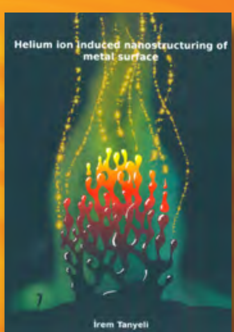


The building blocks used to generate the Metal Organic Frameworks (MOFs) that absorb across the visible light region and facilitate directional energy transfer.

Discovery of new materials that would show efficient and directional energy transfers, similar to the biological systems, has great promise to significantly advance the existing material and energy landscapes. Metal Organic Frameworks (MOFs) are crystalline materials that are assembled together from interesting chemical building blocks. Together with our collaborators from the USA, we computationally modeled and experimentally demonstrated that our artificial MOFs can be produced with nanoscale precision to enable the controlled photon absorption and the directional energy transfer similar to the antennas in natural photosynthesis. Our work elucidates the important effects of the structural and electronic properties of the generated MOFs on their light absorption and energy transfer properties. These insights may help in developing new, nature-inspired solar energy utilization devices.

Layer-by-Layer Assembled Films of Perylene Diimide- and Squaraine-Containing Metal–Organic Framework-like Materials: Solar Energy Capture and Directional Energy Transfer, ACS Appl. Mater. Interfaces 8, 24983 (2016)

First PhDs awarded in the Solar Fuels theme



Irem Tanyeli

The rapid advancement that DIFFER has made initiating its new Solar Fuels research theme is highlighted by the first two PhD theses that were completed in 2016. In both cases the research developed out of the fusion context.

Irem Tanyeli (thesis defence January 2016) has used the specialized plasma devices developed within DIFFER's fusion related plasma-surface interaction studies to investigate nanostructure fabrication for advanced electrodes in solar fuels applications. For example, she has discovered how these nanostructures can be grown in a controlled manner by bombarding metals with helium particles.

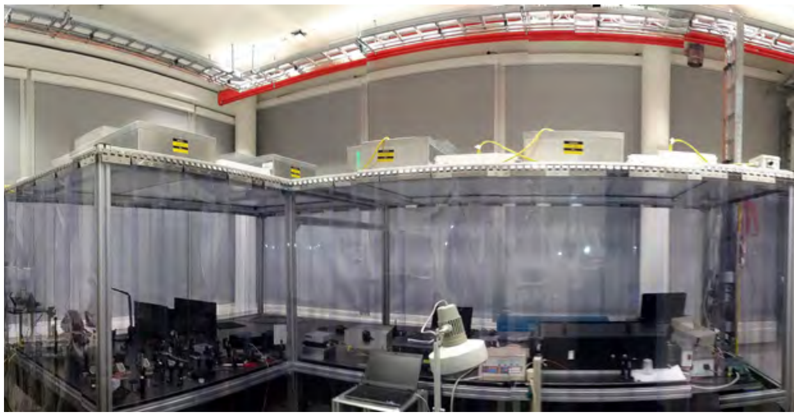
Solar Fuels laboratories - Stefan Welzel

When the new DIFFER building was designed, the research labs for the Solar Fuels theme were deliberately equipped with (only) basic means. In this way, we kept the freedom to make these labs suitable for the specific research in the individual Solar Fuels groups that were just being shaped at that moment. In March/April 2016 the first two labs of some 40 m^2 each were furnished as multipurpose laboratories.

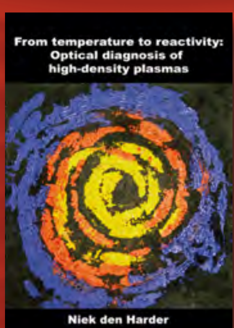
While these “FlexLabs” are accommodating at the moment setups and laser-based diagnostics for plasmas-assisted fuel conversion processes, they will serve in the future as flexible environment for new, short-running projects. In December 2016 a similar lab for partnership with Syngaschem B.V. became available. In October, after 3 months of reconstruction, the Photonic for Energy group could merge their activities in one dedicated laser lab. Up till that time, the group was being spread over several temporary locations within DIFFER and AMOLF.

Throughout the entire year preparations of the backbone infrastructure for four big experimental labs of some 150 m^2 went on which will successively become available before the summer of 2017.

Installation of optical tables in a compartment of the Photonics-for-Energy-lab just after the reconstruction (September 2016)



A “FlexLab” in use for plasma-assisted CO_2 conversion.



Niek den Harder

Niek den Harder (thesis defence April 2016) started with benchmarking tungsten erosion under fusion conditions in the JET ITER-like Wall project and in DIFFER’s Magnum-PSI. Subsequently, he projected the diagnostic methodologies used in the fusion context to a microwave plasma reactor for CO_2 activation in the solar fuels context. It enabled him to achieve the thermodynamic sweet spot performance of over 50% energy efficiency.

NETWORK BUILDING

WORKING TOGETHER ON ENERGY RESEARCH

Collaboration is key to seriously accelerate the transition to a renewable energy society; an acceleration essential to reach the COP21 UN Climate Conference target to limit global warming to preferably 1.5 °C, but maximum 2 °C, as laid out in the Paris agreement in 2015.

At DIFFER, we invest in an active community on energy research in the Netherlands and beyond, where we focus on connecting different disciplines and innovation actors, from fundamental and applied research, development and prototyping, to enterprises and industry. The main goal is to foster a scientific collaboration that will lead to the necessary breakthroughs for the short, mid and long term.

Science across disciplines

The multidisciplinary network that DIFFER is establishing is based on openly sharing information and insights between various scientific disciplines and actors. In this way, it strengthens the Dutch position in European and international energy initiatives. To further this goal, DIFFER organizes workshops on fundamental energy research and participates in (inter)national consortia and networks.

Over the years, DIFFER has been building and structuring the national energy research network, for instance by actively organizing workshops and conferences to bring disciplines together.

www.scienceandtheenergychallenge.nl

NWO conference "Science for Circular Economy"

As an activity from the scientific community during the Dutch Presidency of the European Union in the first half of 2016 and in view of the strategy on Circular Economy of the European Commission, DIFFER and NWO Social Sciences took the initiative to organize the NWO conference "Science for Circular Economy" on June 16th. The conference was attended by almost 200 people, of which a group of 40 joined the network dinner on the evening prior at DIFFER. During the day and in workshop break-out sessions the audience, from scientists to entrepreneurs and policymakers, got an insight into the diversity of the topic and the role of scientific research therein.

EU 2016

Connecting basic to applied research

This year the 2015 Memorandum of Understanding between DIFFER and polytechnic school Fontys University of Applied Sciences was followed-up by successfully acquiring funding for the appointment of a shared lector. Dr. Peter Thüne will start on this position in February 2017 and will strengthen the research collaboration between both Fontys and DIFFER.

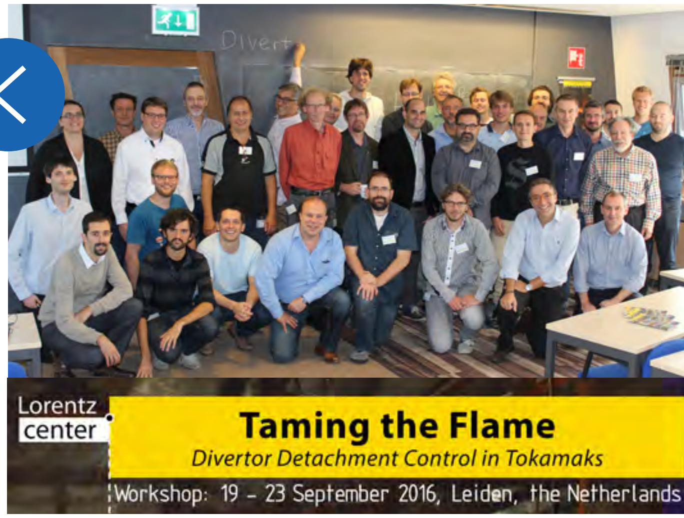
For Fontys, the theme Solar Fuel will become a new branch in the successful lectorate Thin Films and Functional Materials. Besides better connecting Fontys students to the DIFFER research and incorporating the topic in educational courses, Dr. Thüne will develop research activities on the cutting edge of fundamental and applied research in close collaboration with DIFFER's in-house industrial partner Syngaschem BV.

syngaschem BV
synthesis gas chemistry
fundamental research projects

Fontys

Lorentz workshop "Taming the Flame"

In September, Marco de Baar and Tony Donné (EUROfusion program manager) organized the Lorentz workshop "Taming the Flame" together with international top scientists. The workshop focused on methods for control of divertor detachment to prevent damage to the reactor components during the power exhaust of a fusion plasma. Almost 40 experts from different communities, like materials, plasma and fusion physics, control engineering, worked together in trying to tackle this important challenge. One of the envisaged outcomes of the workshop is a white paper to be published in one of the leading scientific journals of the field.



International Conference SCOM16 - Strongly Coupled Organic Molecules

Group leader Jaime Gómez-Rivas co-organized the SCOM16 conference in October to discuss the latest developments in the study of the strong coupling involving organic molecules and optical cavities. Leaders in the fields of photonics, quantum optics, materials, chemistry and condensed matter physics came together in Spain to discuss recent results on phenomena that involve polaritonic states, molecular excitations, molecular vibrations and their complex interactions. These phenomena give rise to a plethora of fascinating effects of both scientific and technological interest. The meeting was aimed to act as a catalyst in this emerging field, encouraging discussion of the underlying concepts and promoting new directions and collaborations.

The NWA route Energy Transition

We aim to position the institute as a natural national point for contact on (fundamental) energy research, both for academia and other research institutes as well as the technological institutes, enterprises and industries. This role was appreciated by the Netherlands Energy Research Alliance (NERA, www.nera.nl), who asked DIFFER to chair the process to consult all stakeholders in the energy community to formulate the route Energy Transition for the Dutch National Research Agenda (NWA).

Director Richard van de Sanden co-chaired the process together with Wim Sinke (ECN, UvA) and Kornelis Blok (TUD, Ecofys). The experience of DIFFER in bringing together disciplines, connecting people and taking a broad perspective, was key and led to a clear route description of the scientific needs and challenges regarding (the acceleration of) the transition towards a sustainable and secure energy supply and a strong green knowledge-based economy. Supported by ten transition-related challenges as building blocks, the game changer message was to take an integrated approach to technical, social, economic, legal and spatial aspects. Together with other NWA exemplary routes, the route Energy Transition was handed to the Minister of Economic Affairs and Minster of Education, Culture and Science to make a strong case for a structural impulse for scientific research.

OUTREACH

KNOWLEDGE TRANSFER TO SOCIETY

One of DIFFER's goals is transferring knowledge to society at large. DIFFER pursues strong contacts with high-tech SME's and industry, both as an inspiration for research questions and to translate our fundamental research into practical applications. The institute welcomes young talent for research projects in the upper levels of high school, in the bachelor and master phase, and as technical apprentices. Finally, DIFFER runs a strong outreach program to the general public, either via the media or directly in the form of open days.

Activities and reach

Lab tours	**295**
Students (high school, university)	100
UU Honours Program	25
Dutch Physics Olympiad	40
Brainport Summer School	40
TU/e physics teachers day	30
Dutch Technology Week	40
Plasma Lab practicum	20
General outreach	**1020**
Fusion Road Show	370
Open House Day	650

Plasma Academy with ASML

In September and October 2016, DIFFER organized a three day Plasma Academy for employees of the Dutch high-tech company ASML. The Academy revolved around fundamental plasma physics, a key area of expertise in the ASML scanners that work with Extreme Ultra Violet (EUV) lithography. "Working on EUV lithography means working on exciting scientific and engineering challenges. To tackle those challenges, we rely on a network of over 700 partners across the world", said Hans Franken, Principal Architect at ASML. "Collaborating closely with fundamental research institutes like DIFFER means everything."

ASML

Regional council members for energy

The Eindhoven region boasts the Netherlands largest concentration of high-tech industry and SMEs, with a great focus on sustainable energy technology. Supporting close collaboration between knowledge partners and local government, is the Metropolitan Region Eindhoven (MRE). On October 5th, DIFFER was the host for the regular MRE meeting of council members for energy. As a short introduction, DIFFER director Richard van de Sanden presented a vision on closer collaboration between knowledge institutes and manufacturing industry in the topic of sustainable chemistry.

METROPOOL
REGIO
EINDHOVEN

Young Brainport Summer School

Forty international high school students visited DIFFER on August 30th as part of the Young Brainport Summer School. The group toured the fusion and solar fuels laboratories and saw the Fusion Road Show with live experiments about fusion energy. The Young Brainport Summer School branches off the successful summer school by the Perimeter Institute and welcomes top physics students from around the world to the Eindhoven area. During the week-long event they visited research institutes, Eindhoven University of Technology and cutting-edge technological companies in the area, such as ASML and Philips.

DIFFER postdoc Tiny Verreyken (*right*) welcomes students to the DIFFER plasmolysis lab during the Young Brainport Summer School 2015.

Niels van Hoof in BNN's Proefkonijnen

PhD student Niels van Hoof (Photonics for Energy group) had a guest appearance in the popular scientific TV program 'Proefkonijnen' broadcasted on national television (BNN/NPO3).

Watch the full item here:
http://proefkonijnen.bnn.nl/media/363317

New website and newsletter

In 2016 DIFFER launched its new website. The layered design ensures that visitors can quickly find their desired information, while contact information, calls-to-action and social media links on every page help them to get in contact with the DIFFER staff to explore joint activities. In October 2016 we also sent out the first edition of our quarterly newsletter EXPLORE, with news about the people, research, projects and events at DIFFER.

Subscribe to our newsletter EXPLORE:
https://www.differ.nl/newsletter

OPEN HOUSE DAY 2016

DIFFER's annual open house day on Sunday October 2 , drew 650 visitors from the Eindhoven region to the institute. Visitors could explore research activities in the fusion energy and solar fuels themes and attend a number of special activities:

Energy Q&A with theme leaders Richard van de Sanden and Marco de Baar, moderated by Belgian science comedian and TV-personality Lieven Scheire;

Interactive Energy Quiz on all the facts you should really know or would be surprised to discover about energy and climate change, with Erik Langereis and Gieljan de Vries;

Fusion Road Show, a science theater performance on fusion energy and on how to build a tokamak, with Arian Visser.

Belgian TV-personality Lieven Scheire

Another special activity was the GirlsOnly Workshop with Techniekpact Ambassador Ans Hekkenberg, where girls were taught how to make their own BrushBot: a robot from a toothbrush.

FACTS & FIGURES

- **8** PhD theses
- **103** Publications
- **63** Invited talks
- **5** Editorships
- **56** Other talks
- **109** Posters
- **1** Patent
- **1** Book chapter

Organizational chart

Director
Theme leader
M.C.M. van de Sanden

Theme leader
M.R. de Baar

Institute Manager
W.R. Koppers

Theme Fusion Energy

- Integrated Modelling and Transport – J. Citrin
- Integrated Modelling and MHD – E. Westerhof
- Plasma Edge Physics and Diagnostics – I.G.J. Classen
- Plasma Material Interactions – T.W. Morgan
- Computational Plasma Physics and Chemistry – P. Diomede
- Fusion Facilities & Instrumentation – H. van Eck

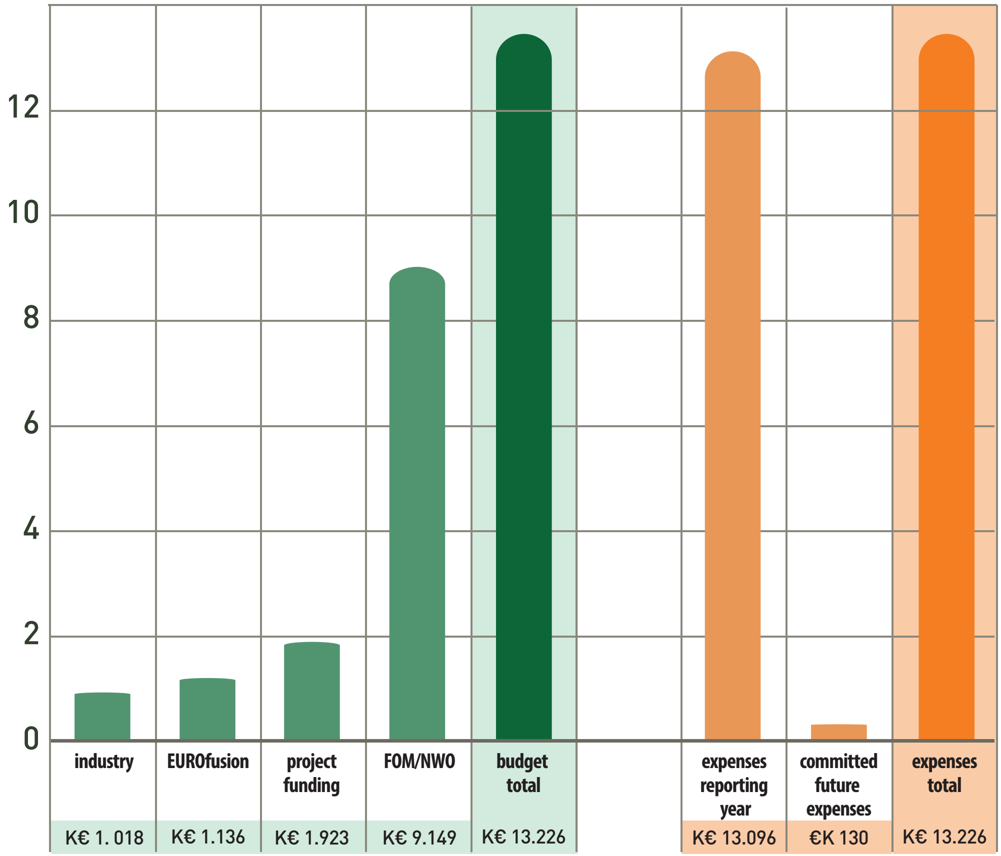
Theme Solar Fuels

- Atmospheric Plasma Processing of Functional Films – H.W. de Vries
- Electrochemical Materials and Interfaces – A. Bieberle
- Catalytic and Electrochemical Processes for Energy Applications – M. Tsampas
- Materials and Surface Science – M.A. Gleeson
- Nonequilibrium Fuel Conversion – G.J. van Rooij
- Nanomaterials for Energy Applications – A. Baldi
- Plasma Solar Fuel Devices – W.A. Bongers
- Photonics for Energy – J. Goméz Rivas
- Storing Solar Energy (DIFFER - TU/e) – R.A.J. Janssen
- Solar Fuels Facilities & Instrumentation – S. Welzel

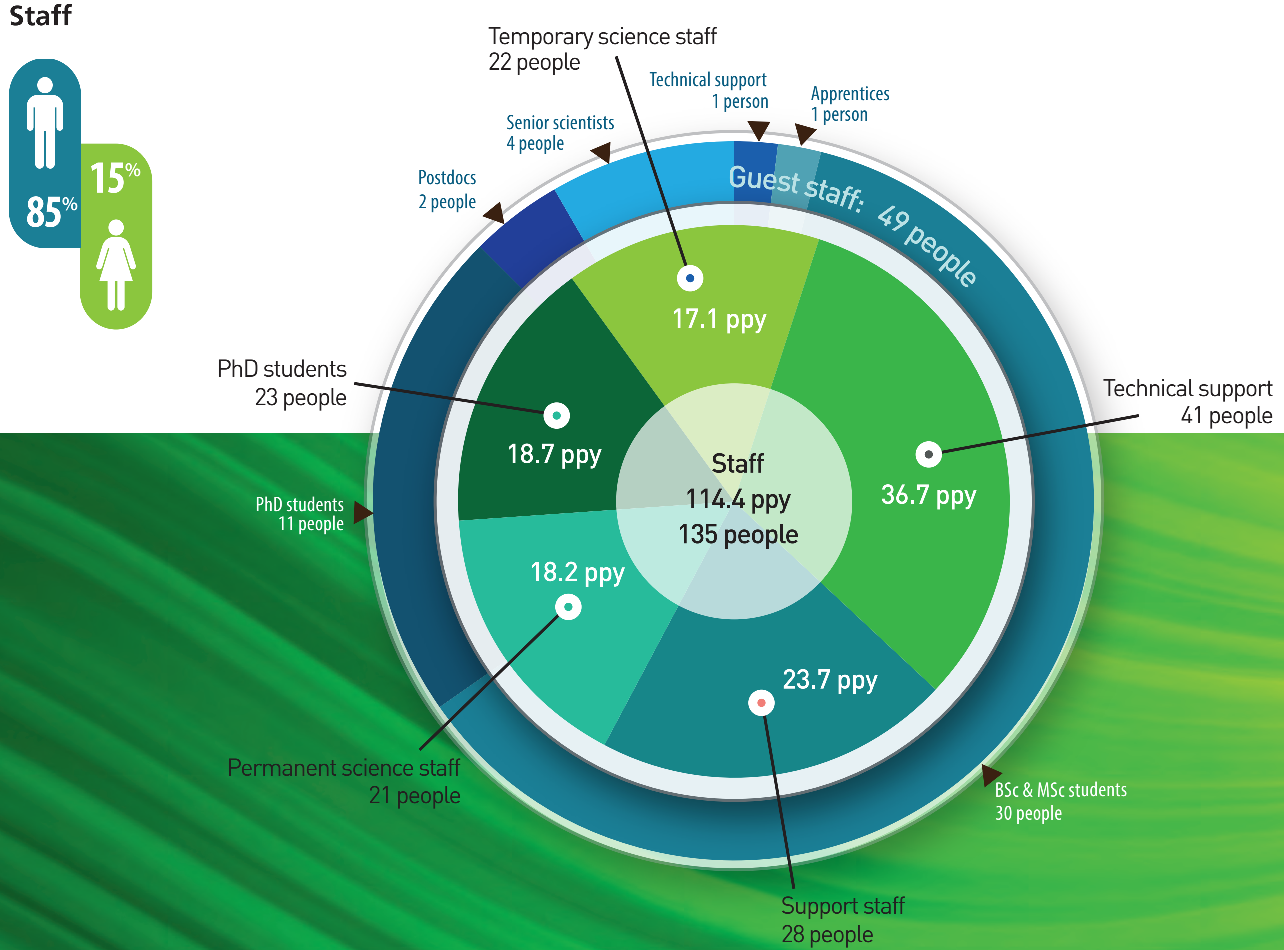
Support Facilities

- Occupational Health & Safety – A.M.M. Arends
- Communication – F.T.M.E. de Vries
- Electronics & ICT – A. Broekema
- Financial Administration – M.P.M. Schoonen
- Management Support – W.R. Koppers
- Mechanical Techniques – F.J. van Amerongen
- Personnel & Organization – H. Tamsma
- Technical Service – K. Grootkarzijn
- Facility Management – J.E. Kragten

Funding and expenses 2016



Staff



Committees

Management Team

M.C.M. van de Sanden (institute director; theme leader solar fuels)
W.R. Koppers (institute manager)
M.R. de Baar (theme leader fusion)

Scientific Advisory Committee

G. van der Steenhoven (KNAW)
C. Bourdelle (CEA)
D.J. Campbell (ITER)
U. Fantz (IPP MPG)
R. van de Krol (Helmholtz)
D. Lincot (Institut de Recherche et Développement sur l'Energie)
E. Stechel (ASU)
H. Werij (TNO)

Employees Council

E. Langereis
B.S.Q. Elzendoorn
J.W. Genuit
J.G. Stroet
A. Tamminga
A.G.A. Verhoeven
W.A. Bongers

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