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FOM

NWO
Netherlands Organisation for Scientific Research

DIFFER

Annual Report 2012

Dutch Institute for Fundamental Energy Research

DIFFER

Annual Report 2012

Dutch Institute for Fundamental Energy Research

Colophon

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Cover image	CO_2 dissociation for solar fuels research in a plasma reactor (photo Waldo Bongers)

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Annual report and online appendix

DIFFER's annual report presents the highlights of the scientific work in our research institute.
The full list of the institute's output and an overview of the employees is given in the online appendix,
http://www.differ.nl/en/annual_reports

Preface
A flying start

It is our great pleasure to present to you the first annual report of DIFFER, the Dutch Institute for Fundamental Energy Research. We believe that a focused and well-coordinated research effort is essential to meeting the challenge of creating a fully sustainable energy infrastructure. To that end, and bolstered by the support of our external evaluation panel, we broadened our mission to 'Science for Future Energy' in 2012. Reflecting our new focus, we changed our name from the Institute for Plasma Physics Rijnhuizen to DIFFER.

Our drive is to perform exciting use-inspired basic research that enables new, sustainable energy technologies. We also aim to catalyze cooperation between Dutch researchers and sustainable energy industries, in accordance with the Dutch government's Topsector policy. To support new research activities and expand existing activities, we will move to a new building on the campus of Eindhoven University of Technology in 2015.

Science-wise, 2012 has been a rewarding year for DIFFER. While our programme on control of burning plasmas continues to deliver robust tools and theory to stabilise turbulent fusion plasmas, we have also obtained the first scientific results of our flagship experiment, Magnum-PSI. We are very excited by the progress in our new programme on solar fuels, with results that will whet your appetite for further developments. The flying start on energy storage research is especially gratifying, driven as it is by the plasma physics and chemistry experience originally developed within the fusion programme.

Given the new focus on energy research, two successful research activities have relocated to fertile grounds. After producing its 'last photon' in March, the free electron laser user facility FELIX is in the process of moving to Nijmegen to become part of the Radboud University's free electron laser facility, a unique national facility with international prominence. Meanwhile, the nanolayer surface and interface physics-division is preparing for a new role as an industrial focus group on XUV Optics at Twente University from 2014 onwards.

These are exciting times for DIFFER and, as its director, I am proud of the way our staff is rising to meet new challenges. Whether developing the science of future energy, connecting with external partners, or helping design DIFFER's new home in Eindhoven, they are creating a bright new future for the institute.

Richard van de Sanden,
Director DIFFER

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About DIFFER

The mission of the Dutch Institute for Fundamental Energy Research (DIFFER) is to undertake and stimulate basic research aimed at developing a sustainable energy infrastructure. DIFFER performs leading fundamental research in the fields of fusion energy and solar fuels, in close partnership with academia and industry. In accordance with Dutch Topsector policy, DIFFER seeks to adopt a national coordinating role in fundamental energy research.

Science for Future Energy

Providing breakthrough solutions to the global energy and climate change issues is one of the biggest challenges facing mankind in this century, presenting a wealth of scientific questions. The newly started institute DIFFER focuses its efforts on this exciting science for future energy.

To help join together the existing research initiatives in the Netherlands into one coherent national research programme, DIFFER will set up strategic collaborations and joint research programs with universities, Large Technological Institutes (LTIs) and industry.

DIFFER considers knowledge transfer to society of paramount importance. Apart from training graduate and undergraduate students and technicians, the institute strives for potential industrial applications and increased valorisation of energy research.

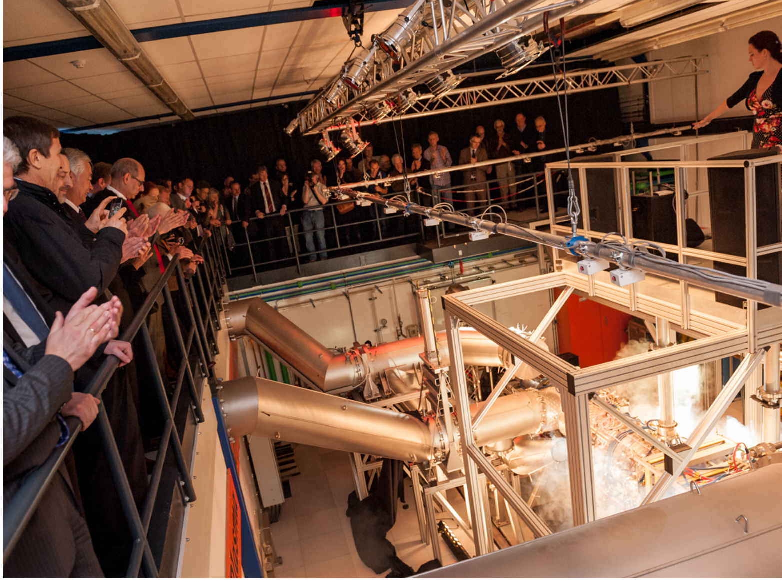
DIFFER is one of the three research institutes of the Foundation for Fundamental Research on Matter (FOM), part of the Netherlands Organisation for Scientific Research (NWO) and has emerged from the FOM Institute for Plasma Physics Rijnhuizen. To support new research activities and expand existing activities, a new building is being constructed on the campus of Eindhoven University of Technology, with DIFFER moving to its new location in 2015.

Research at DIFFER

The energy research at DIFFER focuses on two research themes: solar fuels and fusion.

Solar fuels address the global challenge of energy storage and transport by converting intermittent sustainable energy into carbon containing chemical fuels. This constitutes the splitting of water in hydrogen and oxygen or the activation

Opening DIFFER in April 2012, with State Secretary Halbe Zijlstra and Niek Lopes Cardozo, Chairman of the FOM Governing Board



Magnum-PSI ,
official opening in March 2012

of carbon dioxide into carbon monoxide and oxygen and the processing of these products into a hydrocarbon fuel. This research area of artificial photosynthesis, utilizing earth abundant materials, focuses on the synthesis and design of novel materials and processes to obtain scalable solutions for energy- and cost-efficient production of carbon containing fuels. The institute has started its first experiments in this by investigating activation of carbon dioxide via a plasma-chemical route and is exploring novel processing methods to create photocatalytic materials for photo-electrochemical water splitting with its linear plasma generators.

Fusion has the potential to provide concentrated, safe and clean energy from the process powering the sun and stars. DIFFER's two fusion research programs are both high priority areas within the international ITER program. With the unique high-flux plasma generator Magnum-PSI, DIFFER explores plasma surface interactions under future fusion reactor conditions. Research into the control of burning plasmas, in particular of magnetohydrodynamic (MHD) modes, aims at developing pertinent physics, diagnostics and technologies for ITER.

In 2012, the division operating and exploiting the infrared free electron laser and user facility FELIX / FELICE relocated to the Radboud University Nijmegen. Starting 2013, it is part of the greater user facility Free Electron Lasers for Infrared Experiments (FELIX) together with the university's FLARE laser.

Finally, DIFFER's division nanolayer Surface and Interface Physics will become part of Twente University's MESA+ institute as the Industrial Focus Group XUV Optics in 2014. The group will continue its highly successful work on multilayer mirrors for 13.5 nm and shorter wavelengths photolithography and other applications such as smart, adaptive optics for this wavelength. At Twente University, the division will become the heart of an extended group of scientific and industrial partners, including ASML and Carl Zeiss.

Events

DIFFER opening symposium

On 16 April, the new Dutch Institute for Fundamental Energy Research DIFFER formally started its mission of Science for Future Energy with a symposium on the politics, industry and science of sustainable energy. During the DIFFER opening symposium, leading international speakers from these fields shared their views on the importance of fundamental energy research. Steven E. Koonin, former Under Secretary for Science in the U.S. Department of Energy opened the symposium and State Secretary Halbe Zijlstra for Education, Culture and Science performed DIFFER's opening ceremony.

Starting Magnum-PSI

In the future fusion reactor ITER, the plasma-surface interaction will be more intense than in any previous experiment. DIFFER's linear plasma generator Magnum-PSI is the first laboratory experiment in the world capable of exposing proposed wall materials to the plasma conditions near the ITER exhaust. On Thursday 22 March, Director-General Osamu Motojima of the ITER International Organization opened the scientific symposium celebrating the start of Magnum-PSI's experimental campaign: "This installation will enable us to anticipate the way materials behave - and fatigue - when in prolonged contact with a fusion plasma. The work accomplished here will be of the utmost importance for ITER and for what lies beyond."

DIFFER opening symposium

On 16 April Halbe Zijlstra, the Dutch State Secretary for Education, Culture and Science, opened the new Institute DIFFER in Nieuwegein. DIFFER's predecessor, the FOM Institute for Plasma Physics Rijnhuizen, was founded in 1959 as the Dutch center for fusion research. In 2011, the institute decided to broaden its mission to fundamental energy research, in line with the research agendas of its parent organisations FOM and NWO.

During the DIFFER opening symposium, leading international speakers from politics, industry and science shared their views on the importance of fundamental energy research. In his opening address, former Under Secretary for Science in the U.S. Department of Energy Steven E. Koonin expressed his support for DIFFER's new research mission.

The morning programme continued with speeches by Dirk Smit (Member of the FOM Governing Board and Chief Scientist Geophysics at Shell), Bert Hesselink (Stanford University) and DIFFER's director Richard van de Sanden. The afternoon programme gave an overview of fundamental energy research with talks on, amongst others, organic solar cells, fusion energy and solar fuels.

Speakers Steven E. Koonin (top) and Dirk Smit (bottom)

"The research themes of solar fuels and fusion physics are well chosen and are very likely to have novel synergies." -Steven E. Koonin

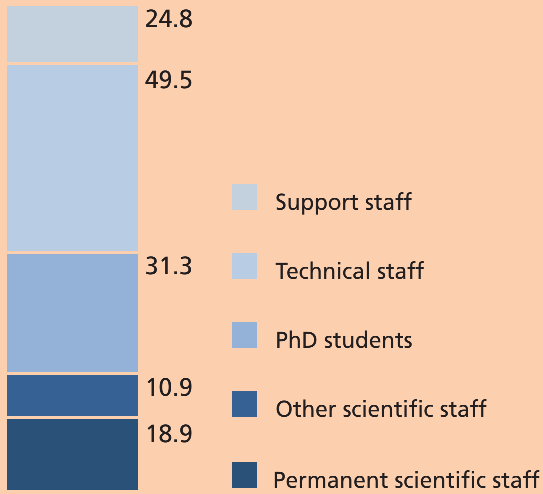
Stakeholder visits

In 2012 DIFFER welcomed two Members of Parliament for a visit to the institute. On 13 January Carola Schouten (ChristenUnie - spokesperson higher education, economy and innovation) spoke to young researchers at the lab to hear about their ambitions and concerns. Anne-Wil Lucas (VVD - spokesperson higher education) visited DIFFER together with representatives of the top sector High Tech Systems and Materials on 10 June. Both MPs toured the institute for a visit to Magnum-PSI, the nSI facilities, the FELIX free electron laser and the Remote Handling Study Centre.

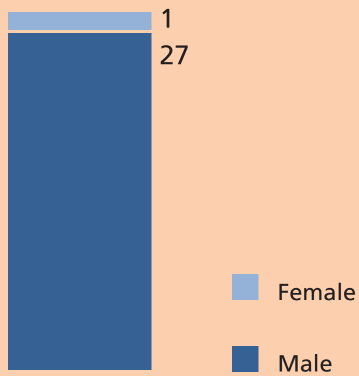
Anne-Wil Lucas (VVD)

Carola Schouten (ChristenUnie)

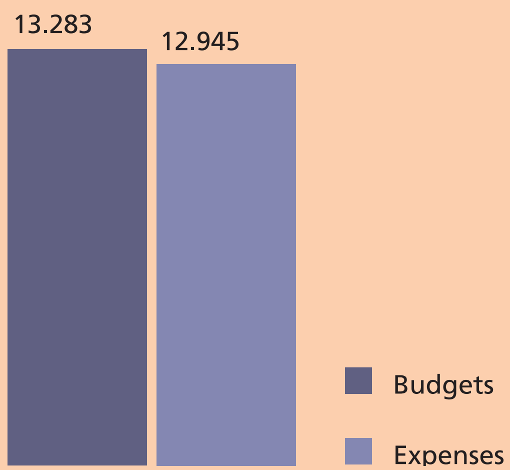
Staff overview (ppy)



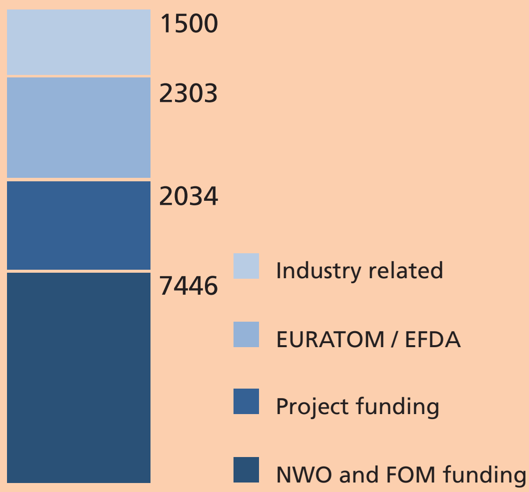
Top level gender balance (people)



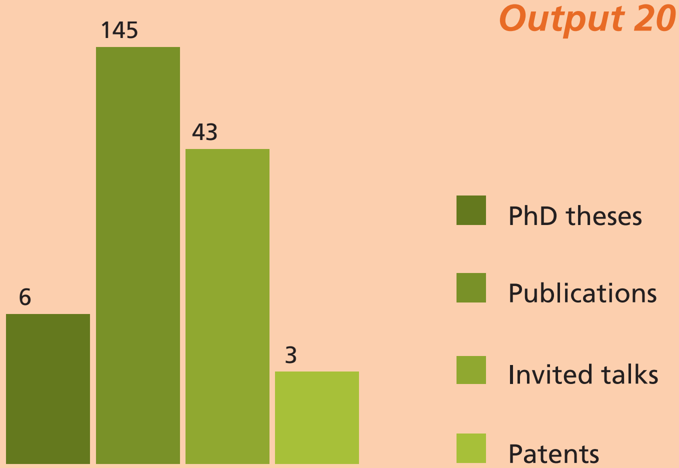
Funding vs expenses (k€)



Running budget (k€)



Output 2012



2

2.1 Fusion

Control of burning plasma

Fusion research aims to develop a clean, safe and sustainable energy source based on the process powering the sun and stars. With the construction of the ITER experiment in Cadarache, a global effort is underway to build the first ever fusion reactor to produce more power from fusion than the device requires: a so-called burning plasma. Three of DIFFER's fusion groups study the physics underlying the active control of magnetohydrodynamic (MHD) instabilities in burning plasmas and are directly involved in work on the design of ITER components.

Research

In the burning ITER plasma, which will be the first reactor dominated by alpha particle heating, magnetohydrodynamic (MHD) instabilities arise which can both enhance and decrease the reactor performance. Active control of the MHD instabilities will allow tuning of the plasma and reaching the planned tenfold greater power output from the fusion process than is injected via the reactor's heating and control systems.

The research groups in the program Control of burning plasmas study the physics underlying the active control of instabilities in burning plasmas and are directly involved in work on the design of ITER components. The development of high resolution multi-channel diagnostics allows the measurement of small scale structures in hot magnetized plasmas.

These novel diagnostics concepts lead to new insights in plasma physics, which feed into the development of sensors, actuators and models for the control of MHD instabilities. The diagnostics and control work are supported and inspired by mathematical and numerical modelling of MHD instabilities and their real-time control.

Partners

The experimental work of the division is largely focused on the ASDEX-Upgrade tokamak in Garching (Germany) and the Joint European Torus (UK). The instrumental work for ITER in Plasma Diagnostics and Tokamak Physics is organized within the framework of ITER-NL, a consortium consisting of four Dutch research institutes: TNO, DIFFER, NRG and Eindhoven University of Technology. ITER-NL aims to facilitate front-line participation of Dutch researchers in the scientific exploitation of ITER and additionally to enable Dutch companies to have strong participation in ITER.

Division leader

A.J.H. Donné

Funding

Main program: FP-120 - Advanced Control of Magnetohydrodynamic Modes in Burning Plasmas

Supporting funding

ITER-NL2, EURATOM, EFDA, EFP, NWO, NWO-RFBR CoE, TU/e, US-DOE

Collaborations

ASIPP, Hefei, China; CCFE, Culham, UK; CEA Cadarache, France; CWI, Amsterdam, the Netherlands; DTU Risø, Denmark; FZJ, Jülich, Germany; IAP, Nizhny Novgorod, Russia; Ioffe Institute, St. Petersburg, Russia; IPP Garching, Germany; ITER IO, Cadarache, France; Kurchatov Institute, Moscow, Russia; KU Leuven, Belgium; SWIP Chengdu, China; TNO, the Netherlands; TU/e, Eindhoven, the Netherlands; UC-Davis, US; University of Pohang, Korea

Awards

B.A. Hennen - Thesis Prize 2012, European Physical Society's Plasma Physics Division

H. van den Brand - Shell Master thesis prize for Physics 2012

> *"The group focuses on modelling the effects of MHD instabilities and their real-time control."*

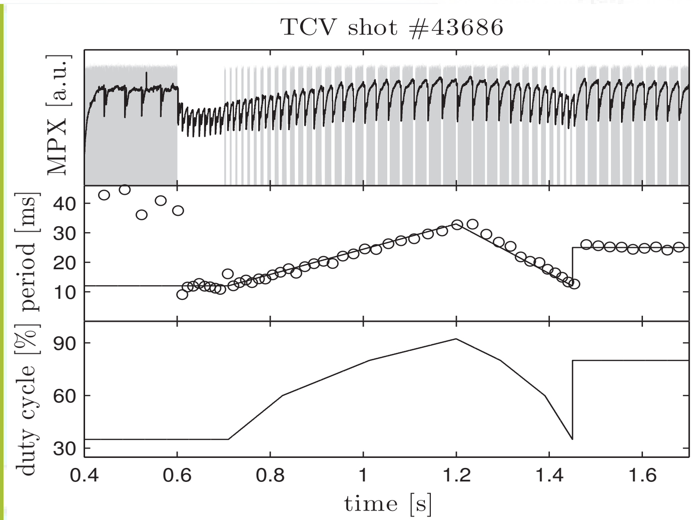
Highlights

Locking the sawtooth

A repetitive magnetohydrodynamic instability is observed in the core of nuclear fusion plasmas. This instability has two phases. On a slow timescale, the distribution of the current peaks, while on a fast time-scale, the core current distribution is flattened. Due to this two-timescale behaviour the instability is often referred to as the sawtooth crash. The crash is associated with mixing of the core-plasma (desired) but large sawteeth can trigger unwanted secondary instabilities.

Researchers of DIFFER and the Eindhoven University of Technology (TU/e) have used simulations to show that the non-linearity of the sawtooth instability can be used: The sawtooth can be phase-locked using modulated high power μ-waves. The modulation parameters (frequency, power and duty cycle) determine if the sawtooth will 'march the beat.' The modulation-range for a specific tokamak, TCV of the École Polytechnique Féderale de Lausanne, was determined, and successful locking experiments were carried-out.

Demonstration of sawtooth period locking with power modulation in TCV plasmas, 2012 Nucl. Fusion 52 062002



A pacemaker for the sawtooth instability (top trace). High power microwaves are injected in to the TCV tokamak. Due to phase locking, the sawtooth period is forced to the microwave beating period.

Study contracts for remote handling centre

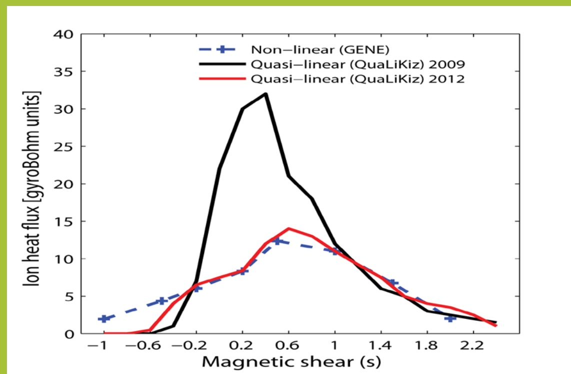
The maintainability of ITER components is studied in the Remote Maintenance Study Centre. A four operator control room is connected with a virtual reality Hot Cell (the location where the maintenance is carried out). Object movements as well as forces and moments are evaluated and provided in real-time to a haptic master station. In 2012, the remote handling group obtained both a grant from F4E and contracts from ITER for the maintenance analysis of heating and diagnostic systems.

Analysis of ITER upper port plug remote handling maintenance scenarios, Fusion Engineering and Design Volume: 87, Issue: 5-6, Pages: 515-519

Highlights

Understanding the low turbulence in tokamak hybrid operation

In the advanced 'hybrid' mode of fusion reactor operation, detrimental turbulence is reduced and the plasma stays confined longer than simple scaling laws suggest. In his PhD thesis Turbulent transport in tokamak advanced scenarios, awarded cum laude at TU/e, Jonathan Citrin successfully applied and improved detailed models of the plasma in hybrid operation and showed how the hybrid's particular distribution of current helps mitigate turbulence and heat loss. Experiments at JET and ASDEX-Upgrade validated these predictions, which can now help optimise the hybrid operation of ITER.

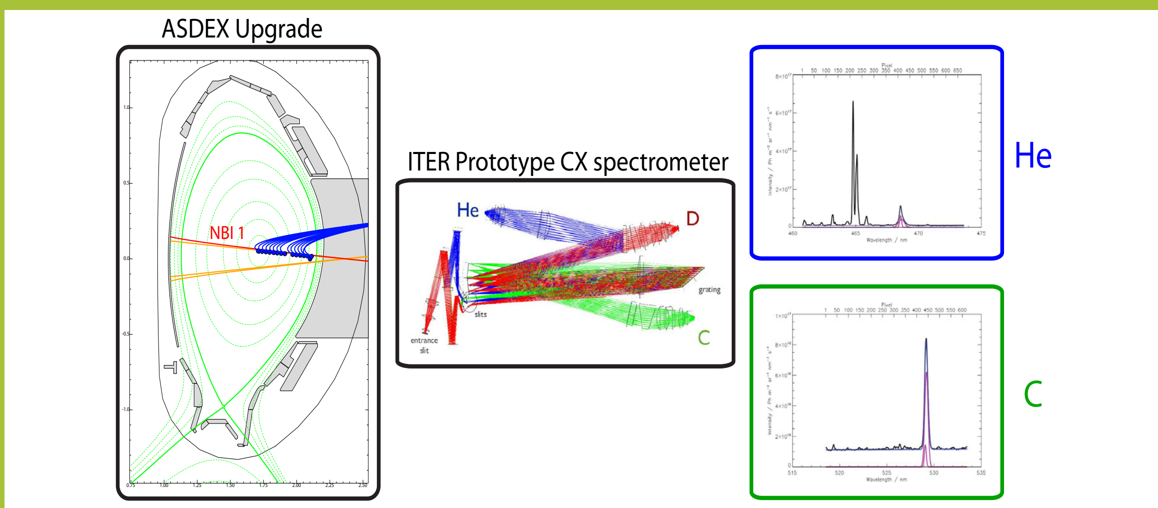


Predictive analysis of q-profile influence on transport in JET and ASDEX Upgrade hybrid scenarios, 2012 Plasma Phys. Control. Fusion 54 065008

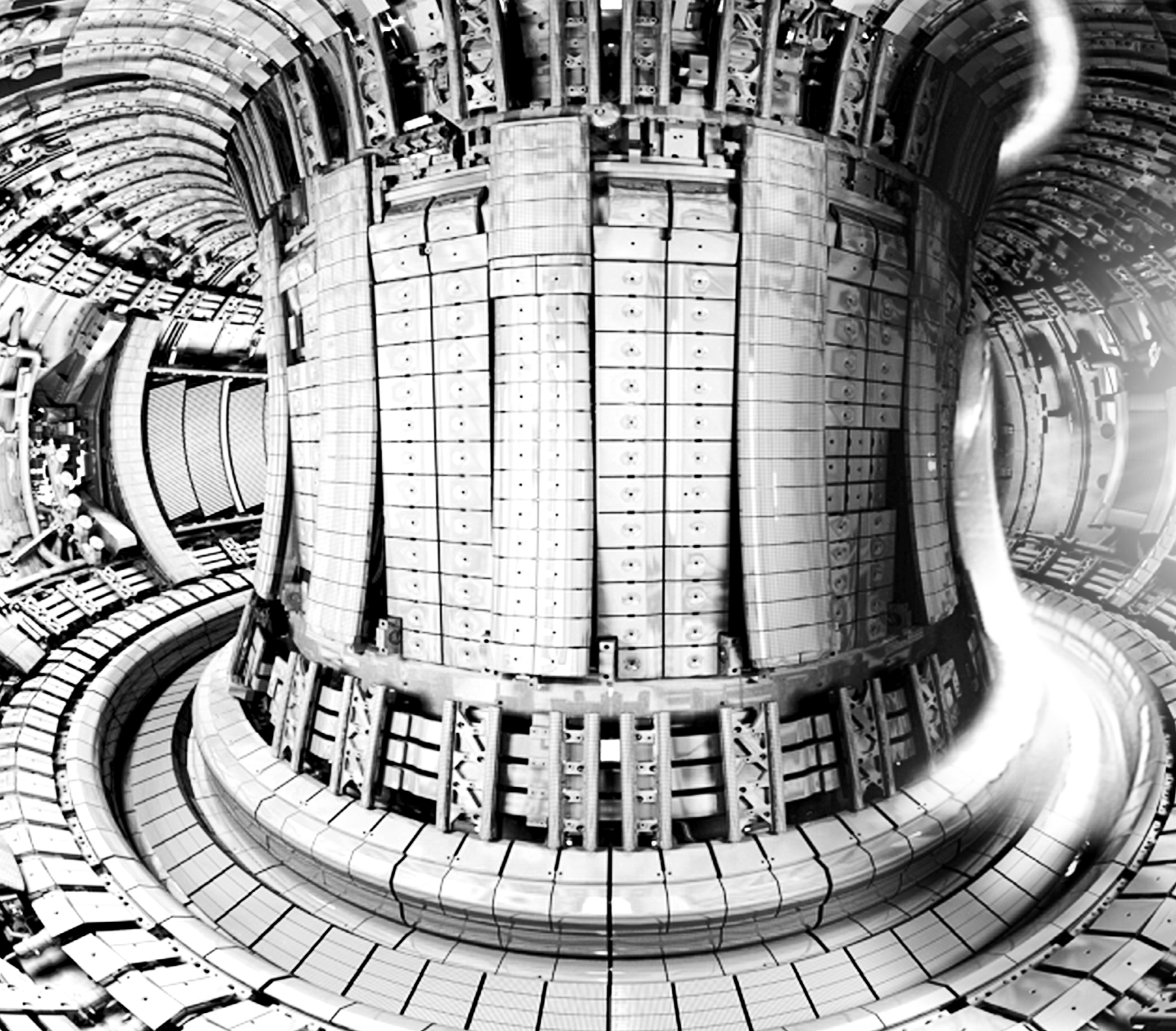
ITER prototype charge exchange spectrometer installed on ASDEX Upgrade

ITER requires a high optical throughput spectrometer for the measurement of the helium content, ion temperature and rotation using charge exchange recombination spectroscopy (CXRS). To this end, in 2012 the ITER prototype charge exchange spectrometer has been installed on ASDEX Upgrade (in close collaboration with the TU/e and ITER-NL). This spectrometer allows for high quality CXRS measurements and can simultaneously measure carbon, helium and deuterium. The figure shows the optical setup and some of the first (simultaneously measured) spectra.

Feasibility of non-thermal helium measurements with charge exchange spectroscopy on ITER, 2012 Nucl. Fusion 52 043007



The ITER Prototype Charge Exchange spectrometer on ASDEX Upgrade. Left: layout of the line of sights crossing the neutral beam. Middle: Optical beam paths of the carbon (C), deuterium (D) and helium (He) branches. Right: Some of the first measured helium and carbon spectra.



Inside the JET tokamak

Publications

In 2012 a special issue of Nuclear Fusion on MHD Control on Burning Plasmas was published, with five scientific papers and the editorial emerging from the DIFFER-lead programme on control of burning plasmas.

Nuclear Fusion -
Volume 52, Number 7, July 2012

2.2 Fusion

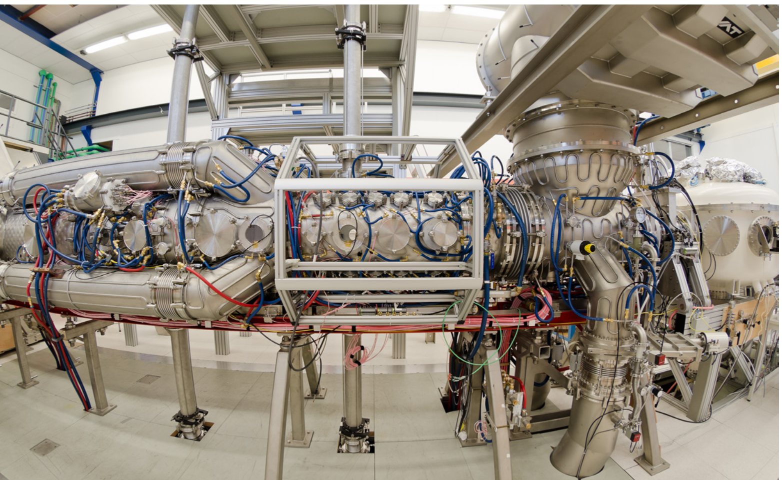
Plasma surface interactions

The development of materials which survive the intense plasma conditions at the exhaust of future fusion reactors is critical to the success of this future energy source. The PSI research aims at bringing a fundamental understanding to plasma-material research in modern fusion devices and helping numerical code benchmarking.

Research

DIFFER's two linear plasma generators Magnum-PSI and Pilot-PSI are uniquely capable of producing the relevant plasma parameters in a laboratory setting. With these two setups, the institute aims at exploring, understanding and controling material modification under the intense plasma conditions expected at the exhaust of the fusion reactor ITER. Research topics in the division include surface modification and dust formation under extremely high plasma flux conditions. Numerical models developed in-house allow for a translation of the results obtained in the linear plasma generators to modern-day fusion devices.

In addition to the work described above, one exciting new area of research is the development of plasma assisted surface modification, a novel synthesis technique for nano-structured catalyst materials.
These materials find applications in the conversion of sustainably produced electrical energy into fuels, a natural link to the work in the institute's Solar Fuels theme.
The PSI division of DIFFER is actively involved in the European activities organized under the European Fusion Development Agreement (EFDA). In particular, the engagement in the EFDA Plasma Wall Interaction Task Force should be mentioned, which is defining most of the work within the PSI division.



Magnum-PSI facility

Division leader

A.J.H. Donné a.i.

Funding

Main program: FP-75, PSI-lab, an integrated laboratory on Plasma Interaction

Supporting Funding

EFP, EFDA, NWO-Groot, NWO-RFBR CoE

Awards

M.H.J. 't Hoen - Popular choice award Dance your PhD-contest

Collaborations

ASIPP, Hefei, China; Australian National University, Canberra, Australia; Beihang University, Beijing, China; CEA Cadarache, France; CIEMAT, Madrid, Spain; Dalian University of Technology, China; Element6, UK; FZJ Jülich, Germany; German University Cairo, Egypt; Heriot-Watt University, Edinburgh, UK; IPP Garching, Germany; Jefferson Laboratory, Newport, US; MIT, Boston, USA; Nagoya University, Japan; National Institute for Fusion Science, Toki, Japan; National Institute for Laser, Plasma and Radiation Physics, Bukarest, Romania; Oak Ridge National Laboratory, Oak Ridge, USA; Osaka University, Japan; Princeton Plasma Physics Lab, Princeton, USA; Purdue University, West Lafayette, USA; SCKCEN, Mol, Belgium; TKK, Helsinki, Finland; TEKES, Finland; Tsinghua University, Beijing, China; TU/e Eindhoven, the Netherlands; University of Basel, Switzerland; UCSD San Diego, USA, Universitatea Alexandru Ioan Cuza, Iaşi, Romania

Director-General Osamu Motojima of the ITER International Organization inspecting Magnum-PSI after its opening ceremony in March 2012

Magnum-PSI starts experimental campaign

Creating hotter, denser plasmas than ever before: that is the goal of the new Magnum-PSI facility at DIFFER. On Thursday 22 March 2012, the institute celebrated the start of Magnum-PSI's experimental campaign with a scientific symposium, opened by Director-General Osamu Motojima of the ITER International Organization. Magnum-PSI is designed to investigate the interplay between the hot plasma in a fusion reactor and the reactor wall materials and a recent publication shows that it indeed reaches the ITER-divertor relevant strongly coupled regime. In 2012, several international collaborators visited DIFFER for experimental campaigns with Magnum-PSI.

Highlights

Self-shielding during extreme transient heat loads

Future fusion reactors require wall materials in their exhaust region which can withstand interaction with high energy fluxes from highly energetic particles emanating from the core plasma. As well as a steady state load these materials must also withstand repetitive pulses from transient instabilities called edge localised modes (ELMs). This is an extreme environment and no tokamak existing today currently produces ELM fluxes at the same energy as is expected in future devices. Therefore to investigate how materials perform under those conditions requires a specialized laboratory experiment.

At the linear plasma device Pilot-PSI a unique pulsed plasma source has been developed which can produce high density and temperature plasmas, which are superimposed on a steady background plasma. This produces the most realistic replication of the relevant conditions of future fusion reactors thus far and permits the effect of combined transient and steady state heating and particle loads on wall materials to be successfully investigated.

While studying the heat transfer from the plasma to the tungsten surface, a singular behaviour was observed. A non-linear relationship between the upstream plasma parameters and the measured energy density to the target has been observed to occur at high discharge currents. Both the magnitude of the energy density to the target and the temporal evolution of the heat pulse are modified. This results in a decreased energy transfer to the surface despite the increased power flux from the plasma source. This self-shielding effect is attributed to the release of neutrals from the plasma-exposed target due to particle backscattering and outgassing. The plasma conditions in the present study is such that the mean free path for ionization is shorter than the plasma size, so that neutrals released from the target are ionized in the very vicinity of the target and this protects the plasma-exposed surface from the intense plasma flow.

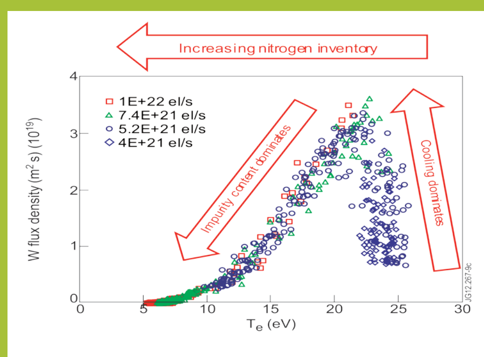
J.J. Zielinski, A high power pulsed plasma system for material testing under simultaneous continuous and transient loads, (2013) PhD thesis at Eindhoven University of Technology

Edge Localised Modes in the MAST tokamak produce high transient heat loads on plasma facing materials

Nitrogen seeding in JET to control tungsten sputtering

Cooling of the fusion boundary plasma reduces wall erosion and can be achieved by introducing radiators such as nitrogen and neon. Their beneficial effect via plasma cooling is compromised by their higher sputtering efficiency compared to hydrogen. The plot shows an experimental example of this delicate balance for the ITER like wall configuration of JET. Here, nitrogen is increasingly seeded to cool the plasma, which initially increases sputtering until the effect of plasma cooling dominates.

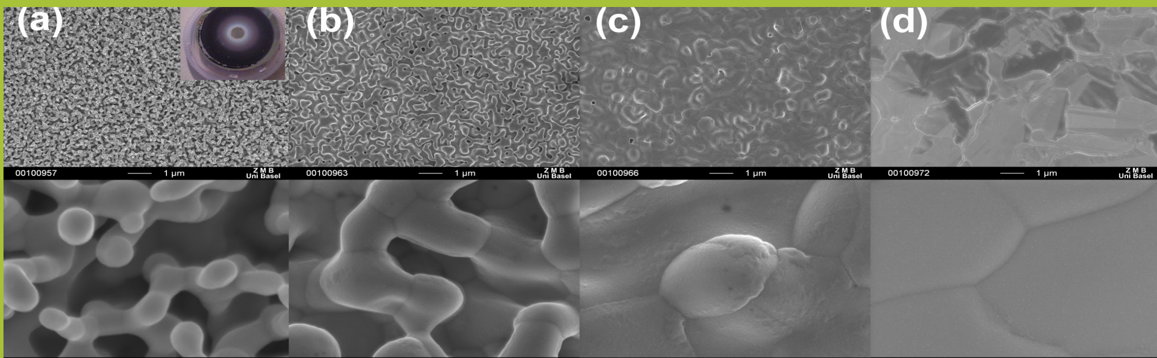
Tungsten divertor erosion in all metal devices: lessons from the ITER Like Wall of JET, Journal of Nuclear Materials, (2013) In Press



Helium-modified surfaces under transient heat loads

A fibre shaped nanostructure forms on tungsten under irradiation by helium ions. As the nanostructure is relatively fragile, its formation raises the concern of dust generation during transient events such as Edge-Localized Modes (ELMs). The pulsed plasma source of Pilot-PSI allowed to observe the complete disappearance of the nanostructure for energy densities higher than $0.5 MJ.m^{-2}$ with no detrimental effect (dust formation for example) observed when the nanostructure was exposed to the ELM-like events.

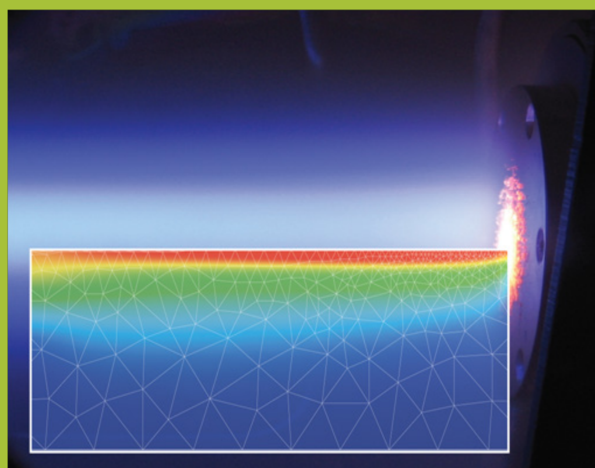
Helium effects on tungsten under fusion-relevant plasma loading conditions, J.Nucl.Mater. (2013)



Evolution of the helium-induced nanostructures after exposure to ELM-like heat loads in Pilot-PSI

In-house Monte Carlo code successfully models Pilot-PSI

Proper validation of the plasma surface interactions experiments in the devices Pilot-PSI and Magnum-PSI and translating them to fusion reactors such as ITER require a computer model capable of handling both the kinetics of single particles and plasma fluid behaviour. The new Monte Carlo code Eunomia was created in-house to describe the kinetic behaviour of test particles against the backdrop of a dense plasma. Designed to work together with the existing B2.5 code for collective plasma behaviour, the Eunomia-B2.5 coupled codes have been successfully benchmarked and are now ready to translate results from DIFFER's linear plasma experiments to tokamaks.



The coupled B2.5-Eunomia code successfully models the electron temperature (inset) in the Pilot-PSI plasma beam

R.C. Wieggers, B2.5-Eunomia simulations of Pilot-PSI, (2012) PhD thesis at Eindhoven University of Technology

2.3 Solar Fuels

Sustainable energy storage

Large scale implementation of renewable energy sources in our current energy infrastructure requires efficient storage and transportation in order to overcome the ill-matched supply-demand character of wind and solar energy. One solution to this requirement is energy storage in chemical bonds, for example by using CO_2 and H_2O as feedstock for the production of synthetic fuels: so-called solar fuels.

The DIFFER solar fuels research and development program is driven by the need for cost-effective production of solar fuels and the use of abundantly available materials. The challenge will be to achieve power efficient dissociation of CO_2 or H_2O or both, after which traditional chemical conversion (Fisher-Tropsch, Sabatier, etc.) towards fuels can take place. A high dissociation efficiency is made possible by preferentially exciting vibrational states in the CO_2 molecule, exploiting the nonequilibrium state of the plasma medium. This is the crucial first step in forming syngas, a mixture of H_2 and CO, which can then be further processed chemically using the conventional Fischer-Tropsch process.

Most of the worldwide research efforts in solar fuels are directed at the splitting of water into hydrogen and oxygen. However, no efficient catalytic or traditional chemical alternative is yet available. A promising route is the dissociation or activation of CO_2 by means of plasma, possible combined with catalysis.

Research

Taking advantage of non-equilibrium plasma conditions to reach optimal energy efficiency, DIFFER has started one division of its solar fuels program in 2012: Materials and materials engineering for Solar Fuels (MaSF). The institute is also investigating the application of the oxidized porous and photo-active material structures for a so-called photo-electrochemical cell utilizing the photocatalytical dissociation of water into hydrogen and oxygen, opening directly the storage of solar energy in molecular hydrogen.

In 2012, DIFFER started its solar fuels program through a collaboration contract with the Institut für Plasmaforschung (IPF) of the University of Stuttgart. The highlight 'Efficient plasma dissociation of CO_2' describes the results of this experimental campaign.

Division leader
M.C.M. van de Sanden

Funding
DIFFER mission budget

Workshop on the new national research programme on CO_2 neutral fuels

Strategic collaborations

During 2012, strategic collaborations were established at the national and European level, including the Dutch Topsector Energy and the European Energy Research Alliance (EERA). On a national level DIFFER has joined the Topsector Energy under the innovation contract Power to Gas / Gas to Energy (P2G/G2E), whilst affiliation with the Topsector Chemistry is being explored under the Topconsortium voor Kennis en Innovatie Nieuwe Chemische Innovaties (TKI-NCI).

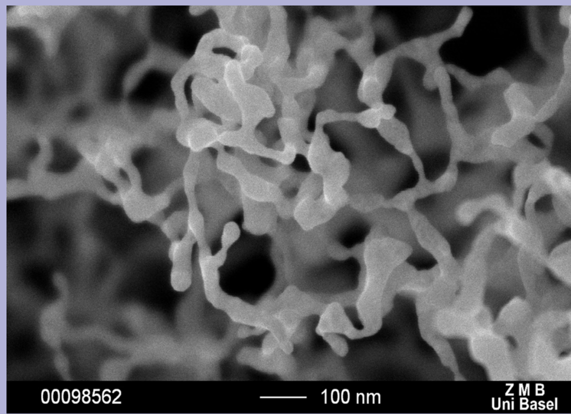
On a European level DIFFER has become a full participant of the EERA subgroups Artificial Photosynthesis (AMPEA) and Energy Storage (Chemical Storage). Several EU workshops on CO_2 reuse and renewable energy have been attended. These activities are aimed at participation in the European Framework Program Horizon 2020. In parallel, collaborations with Dutch and European industry are being established with an aim to provide the transition to the construction of an industrial scale pilot plant. Several proposals for NWO, STW and FOM funding are under preparation.

Highlights

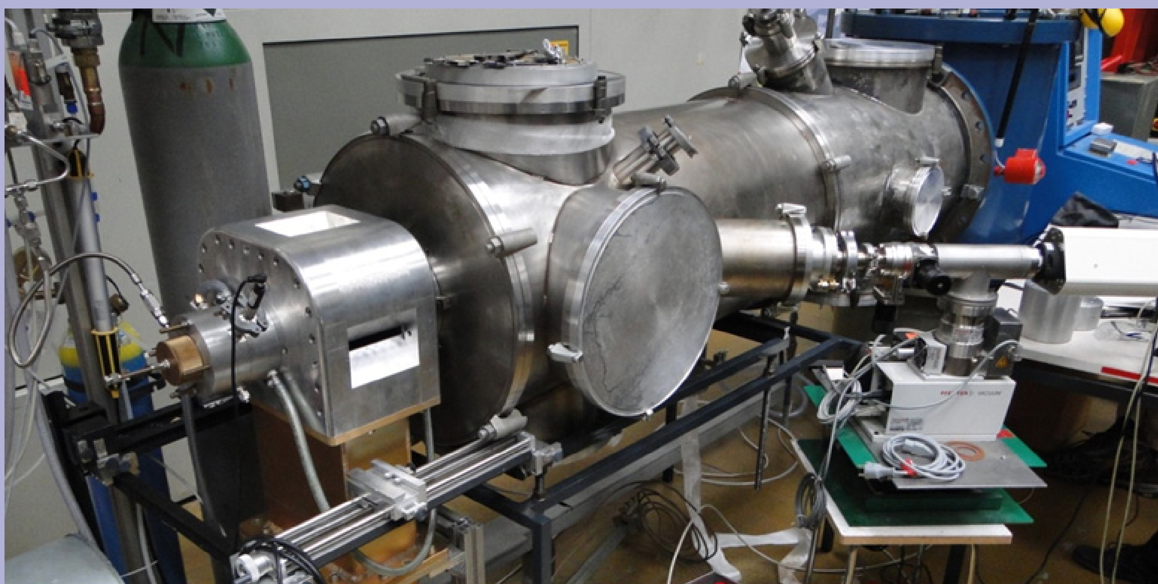
Plasma modification of metals for photocatalysts

A discovery in the institute's Plasma Surface Interaction experiments, in which extreme non-equilibrium processing of materials is investigated, is the formation of highly porous 'nano fuzz' on the surface of metals (W, Fe, Mo, etc.) exposed to the high density, low energy plasma. After an optimized two-step oxidation procedure, the measured photocurrent value in excess of 1 mA/cm^2 shows that these structures offer exciting applications as photoactive materials for water-splitting into H_2 and O_2.

I. Tanyeli et.al., to be published



Highly porous molybdenum nanostructures formed after exposure to a high density helium plasma in Pilot-PSI

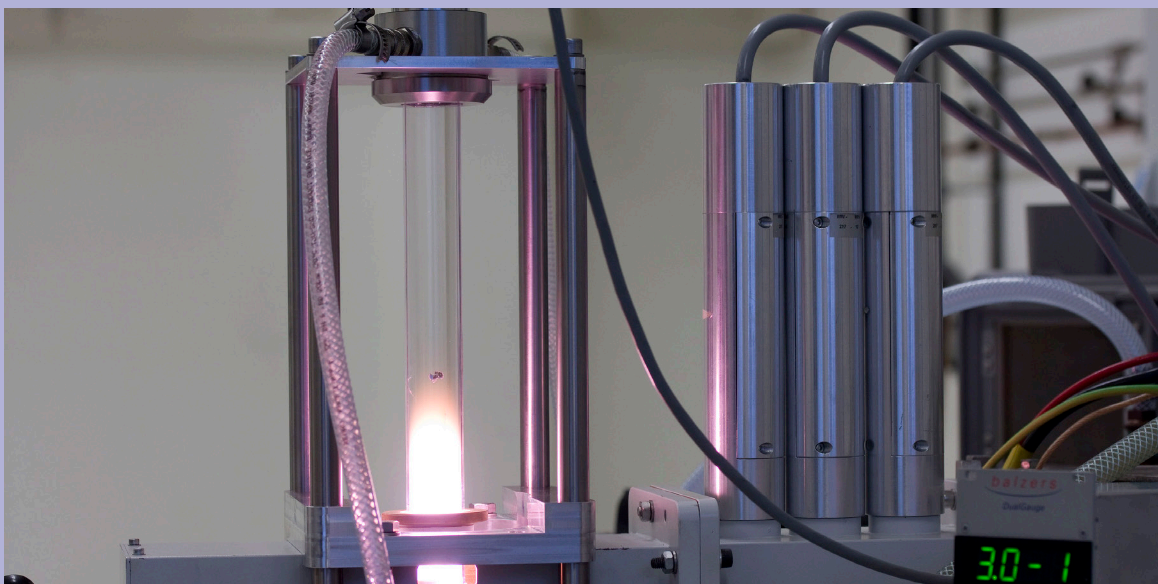


Above: Solar Fuels test facility with microwave-plasma reactor and diagnostics.
Below: Optimal CO_2 plasma configuration, reactor and diagnostics at IPF, University of Stuttgart

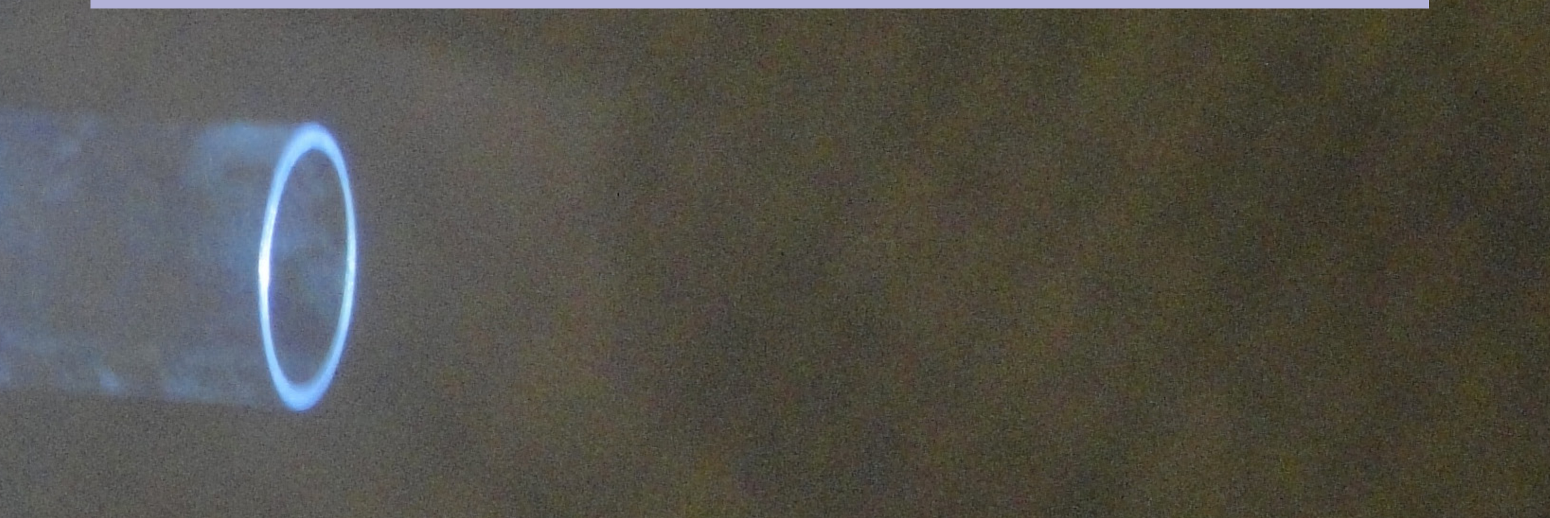
Energy efficient plasma dissociation of CO_2

In 2012 the DIFFER solar fuels program was kick-started through a collaboration contract with the Applied Plasma Technology group of the Institut für Plasmaforschung (IPF) at the University of Stuttgart. CO_2 dissociation tests into CO and O_2 were carried out and analyzed by means of mass spectroscopy and optical spectroscopy. The goal was to gain experience in microwave generated plasmas for solar fuels production and to reach high energy efficiency in CO_2 dissociation tests.
During 2012 four experimental campaigns were conducted, during which the CO_2 dissociation energy efficiency was increased from about 20% to more than 50%, achieved at 3 kW input power and a conversion of about 10%. Various nozzle shapes, sizes and positions were explored with an aim to create a vibration excited CO_2 non-equilibrium condition at low gas (< 1000K) and electron temperature (< 10000K), low ionization degree (10^{-5} and low reduced electric field conducive of high energy efficiency. A parameter scan of microwave power and CO_2 input gas flow rate revealed that the highest energy efficiency was obtained at low conversion efficiency, as expected (see graphs). Optical emission spectroscopy showed strong CO emission in several bands increasing with microwave power.

The collaboration with IPF Stuttgart has provided valuable design information to develop and realize the first full Solar Fuels facility at DIFFER, including advanced diagnostics.



In-house plasma setup for CO_2 dissociation



2.4 nSI

nanolayer Surface and Interface physics

The nSI division aims to perform high-quality scientific research in the fields of surface science and thin film and interface physics. The research includes photo-chemical phenomena, photo-conversion processes, and the solid state and interface physics of short-wavelength optics. The latter primarily concerns multilayered reflective coatings relevant for the 'XUV wavelength band' ranging from the soft X-ray to the VUV. In particular, the division studies the boundary areas between these topics: the use of XUV optics, for instance, generates exciting research questions in the field of photo-induced surface chemistry, as in Extreme UV-induced optics contamination.

A key feature of the research in the nSI division is its industrial and societal relevance: the investigations are usually motivated by application of the knowledge in plasma surface interaction phenomena as e.g. in advanced photo-lithography optics or in the utilization of multilayer reflective optics for radiation sources with highest brightness. The industrial relevance formed the basis for a new activity which has been formulated in the frame of the national innovation policy, namely the industrial-related research group XUV Optics, to be founded at the MESA+ Institute for Nanotechnology at the University of Twente.

The division's research comprises four closely related activities. Research on the behaviour of thin single and multilayered films down to atomic scale processes provides the foundation of the departments research. The development of physics and technology for XUV and soft X-ray multilayer optics for various applications builds on this basic research. Of special mention is the extramural EUV Lab research group within ASML Research, which focusses on the photochemistry at surfaces upon EUV illumination up to intensities causing non-linear processes.

Minister Henk Kamp of Economic Affairs opened the new Industrial Focus Group XUV Optics during his visit to Twente University on 25 Februari 2013

Division leader

F. Bijkerk

Funding

Main program: FOM Industrial Partnership Programmes I10, I23, AgentschapNL, ASML, Carl Zeiss SMT, CATRENE programme of the EC, FOM, M2i, NanoNext, STW

Collaborations

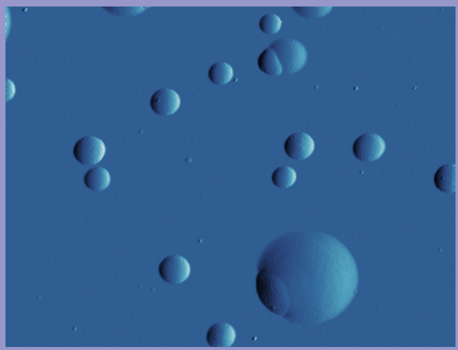
ASML Research, Veldhoven, The Netherlands; Carl Zeiss SMT GmbH, Germany; Delft University of Technology; DEMCON, Oldenzaal, The Netherlands; Eindhoven University of Technology, The Netherlands; Institute for Plasma Physics, Warsaw, Poland; Institute for Spectroscopy, Troitsk, Russia; Institute of Crystallography, Moscow, Russia; Lawrence Berkeley National Laboratory, USA; Lebedev Physical Institute, Russia; MESA+ Institute for Nanotechnology, University of Twente; Moscow State University, Russia; PANalytical, Almelo, The Netherlands; Physikalisch Technische Bundesanstalt Berlin, Germany; SolMateS, Enschede, The Netherlands; SRON Space Research, Utrecht, The Netherlands; TPD/TNO, Delft, The Netherlands

Highlight

Hydrogen-induced blistering of multilayer structures

The degradation of multilayer mirrors exposed to plasma's via blister formation is a process relevant to e.g. space telescope optics. Studies on blistering of multilayer stacks as a result of irradiation by hydrogen revealed that the type and extent of blisters formed was strongly dependent on the precise composition of the irradiation. The types of blisters formed depended on the relative fraction of energetic (> 600 eV) ions and thermal atomic hydrogen. The smaller blisters in the accompanying figure are the result of the incident ions while the larger are due to the neutral hydrogen.

Hydrogen-induced blistering mechanisms in thin film coatings, Journal of Physics: Condensed matter 24 (2012)



Top-down representation of AFM scan showing blisters on a multilayer sample

XUV OPTICS

The Industrial Focus Group for XUV Optics

Undoubtedly, the general nSI highlight in 2012 consisted of the successful formation of the Industrial Focus Group XUV Optics. This is a brand new type of organization of research, directly corresponding to the changes anticipated by the new governmental innovation policy: the Topsectorenbeleid.

The Focus Group is funded by a consortium of industrial participants, the regional government and the MESA+ Institute for Nanotechnology. Industrial parties include ASML, Carl Zeiss SMT, PANalytical, DEMCON, SolMateS, and others. Together they raised the funding for an eight year research programme with a 20M€ budget. In return, the industrial participants have aquired a right in the intellectual property developed in the Focus Group. The parties are selected based on their complementary industrial competence so that new innovations can be developed jointly right from the very initial stages of know how.

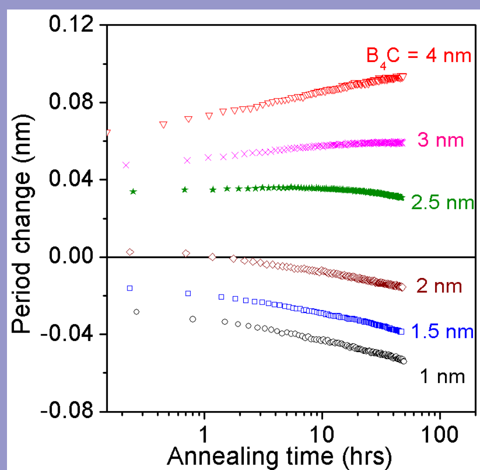
The themes in the Focus Group are selected on basic physics aspects of thin film and multilayer systems within the areas of the applications. Clever choices allow both the fundamental research and high quality scientific output as well as a high probability of industrial spin-off.

Highlights

Interlayer growth in Extreme UV Mo/B_4C multilayered structures

Multilayers having interfaces of Mo/B_4C find applications in optical coatings for e.g. free electron lasers and EUV lithography. The thermal stability of these multilayers was studied using x-ray analysis during annealing. Expansion and compaction of the multilayer period was observed, depending on film thickness, annealing temperature and time. This complex behaviour could be fully linked to diffusion induced interlayer growth, while the interlayer properties are determined by the availability of diffusing species. The observed period change was related to the density of the formed interlayer compound. With these data, a complex interdiffusion process was unraveled successfully.

Interlayer growth in Mo/B_4C multilayered structures, Journal of Applied Physics, Vol 113, Issue 14, 144310 (2013)



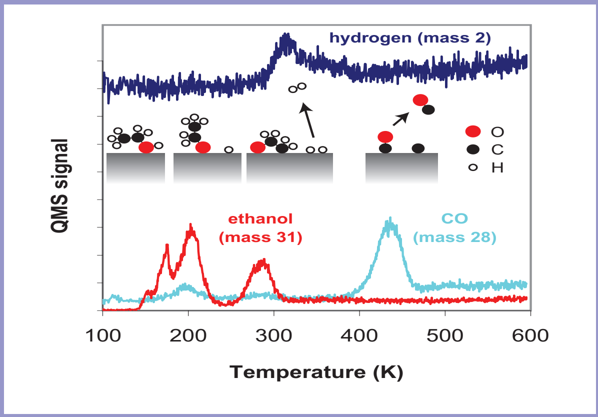
Molecular dissociation processes at Extreme UV mirror surfaces

The interactions of hydrocarbons with metal catalytic surfaces are of interest for a variety of reasons. Catalysts play a key role in many industrial processes, being required to lower the activation energy of many chemical reactions. In addition, catalytically active metals often have other favorable properties, such as oxidation resistance, mechanical hardness, and thermal stability, which make them good choices as protective layers.

To understand the catalytic behavior of such metals, we studied the dissociation of ethanol on a Ruthenium layer. The ethanol was adsorbed to the surface of a specific facet, referred to as (1000), of a ruthenium crystal held at liquid nitrogen temperatures. As the temperature of the crystal is increased, we observe the desorbed compounds with mass spectroscopy, and detect the surface products using infrared spectroscopy. As the crystal heats up, the majority of ethanol simply desorbs. At higher temperatures, a second ethanol signal is found, due to ethanol that dissociates on the surface and, subsequently, recombines during desorption. At yet higher temperatures, the ethanol breaks down more completely, resulting in carbon monoxide, and hydrogen molecules, along with carbon on the ruthenium surface.

The dissociation of ethanol provides insight into carbon contamination of EUV optics. This work shows that organic molecules do not seem to decompose into volatile hydrocarbons, such as methane. Instead, a more complete dissociation to hydrogen and carbon monoxide and carbon dioxide may be preferred. Since most organic molecules do not have sufficient oxygen groups, this leaves a substantial portion of carbon atoms to form an amorphous layer on the surface. These results, therefore, shine new light on the contamination mechanisms relevant to EUV multilayer mirrors, which have a major practical application in EUV photolithography.

Reactions of ethanol on Ru(0001), Surf. Sci. 612, 42 (2013)

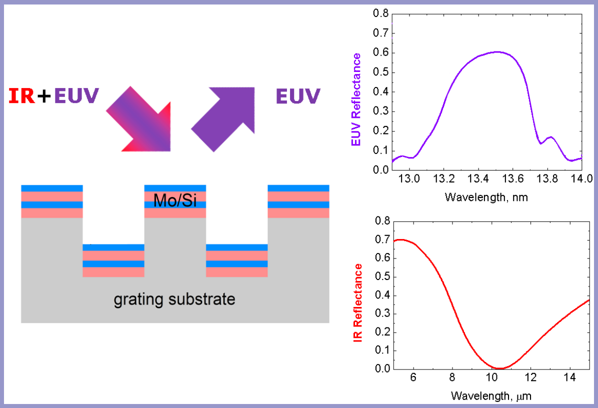


Reaction products of ethanol dissociation on Ru(0001) monitored by mass spectroscopy. The cartoon depicts the reaction pathway.

Integrated infrared spectral filter for Extreme UV mirrors

Many optical applications demand high reflectivity in a particular wavelength range while simultaneously suppressing radiation outside that range. It was found that under certain conditions a thin film layered interference structure can combine both effects acting as an EUV reflecting mirror and as a resonant infrared anti-reflecting mirror. Pilot experiments showed a suppression of the infrared radiation by several orders of magnitude while the EUV reflectivity remained nearly unaffected at 60% at 13.5 nm.

Infrared suppression by hybrid EUV multilayer - IR etalon structures, Opt. Lett. 36 (17) (2011)



2.5 GUTHz

Generation and Utilization of TeraHertz radiation

Mid- and far-infrared radiation, or Terahertz (THz)-radiation is the key element of the activities in the division GUTHz. The infrared region, commonly referred to as the molecular 'fingerprint' region, allows for identification of molecules and molecular structures by the position of the bands in the vibrational spectra. Towards longer wavelengths into the THz regime, the radiation probes structures of solids and low frequency collective modes in soft condensed matter including e.g. proteins.

The objectives of the division are:
- to operate a world-leading infrared user facility that offers the international community access to very bright, infrared radiation sources, tuneable over the spectral range from 3 μm - 250 μm;
- to run a molecular physics program focused on elucidating the structure and dynamics of (complex) molecules, ions and clusters in the gas phase, with applications to life sciences, catalysis and astrophysics;
- to create a stimulating scientific environment for visiting user groups active in various fields of research, such as solid state physics and ion spectroscopy of biomolecules.

Research

The GUTHz division operates the international infrared user facility FELIX (Free Electron Laser for Infrared eXperiments). This facility was designed and constructed to provide the scientific community with tuneable, high brightness radiation in the mid- and far-infrared. An in-house research group exploits the radiation generated by FELIX and FELICE for a variety of studies in the field of molecular sciences. The success of this in-house group attracted a large number of other user groups, and more than 50% of the beam time is nowadays devoted to this kind of action spectroscopy experiments.

The by far most important recent development for the division is the relocation of the facility and its personnel to the Institute for Materials and Molecules (IMM) of the University of Nijmegen (RU), to merge with the free electron laser FLARE into a new facility with the acronym FELIX. The FELIX facility at Nijmegen will be able to provide experimental opportunities that are worldwide unique. The possibility to combine the outputs of FELIX and FLARE in one single experiment, and the opportunity to perform studies in the very high magnetic fields of HFML in combination with infrared radiation over the entire spectral range from 3 – 1500 μm, stand out in this respect.

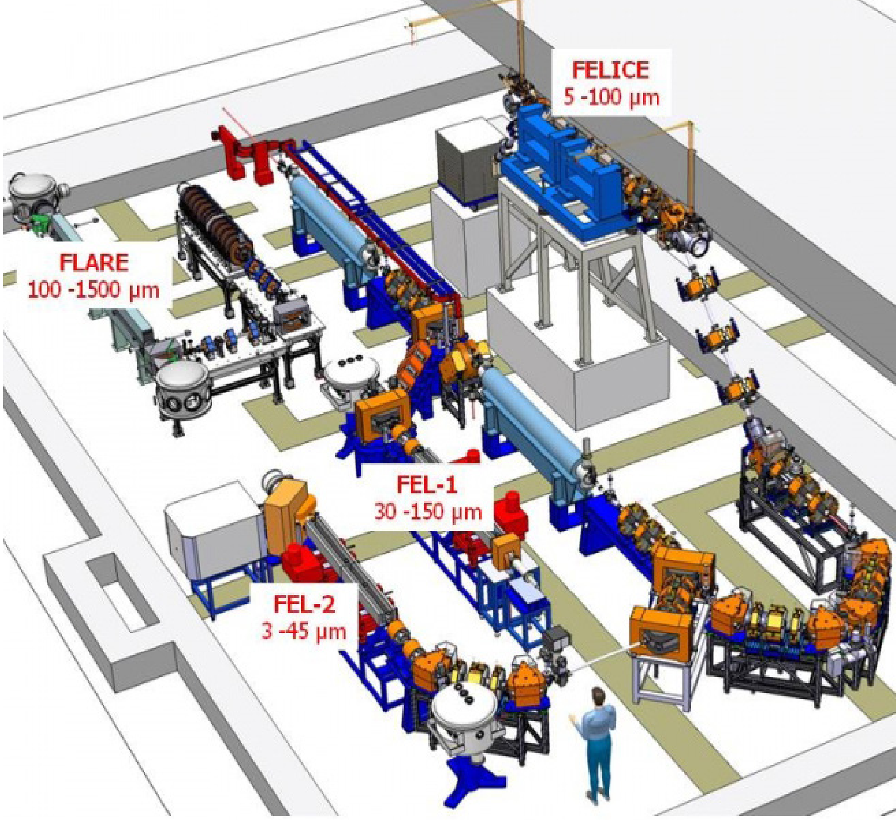
Division leader
A.F.G. van der Meer

Main funding
FP-58 - The IR user facility FELIX, expanded with FELICE

Supporting funding
EPSRC, CALIPSO, NWO-Groot

Personal grant
J. Oomens - VICI-grant (NWO-CW)

Collaborations
Cardiff University, UK; Case Western Reserve University, Cleveland, USA; CEA Saclay, France; DLR, Berlin, Germany; FHI, MPG Berlin, Germany; Radboud University, Nijmegen, The Netherlands; Technical University, Berlin, Germany; UC Berkeley, USA; UC Riverside, USA; UC Santa Barbara, USA; UCL and LCN, London, UK; University of Amsterdam, The Netherlands; University of Bilbao, Spain; University of Canterbury, UK; University of Cologne, Germany; University of Florida, Gainesville, USA; University of Leiden, The Netherlands; University of Northern Illinois, DeKalb, USA; University of Regensburg, Germany; University of Surrey, UK; University of Utah, Salt Lake City, USA; University of Würzburg, Germany; University Pablo Olivade, Seville, Spain; Wayne State University, Detroit, USA; Wichita State University, Wichita, USA; York University, Toronto, Canada



In March 2012 the FELIX facility stopped user operation and the rest of the year was devoted to the preparation of the relocation, the move of equipment of the free electron laser and the connected user experiments and the reassembly at the new location. The operation of relocation is progressing well and for the first half of 2013 the gradual recommissioning of the various systems is expected. In late summer the first beam line – FELIX-2 – is scheduled to provide 'first light' and user operation is expected to resume in the last months of 2013.

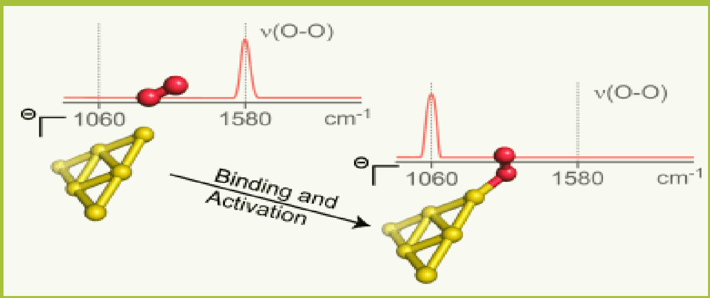
Artist's view of the FELIX free-electron laser facility in Nijmegen, combining FLARE, FELIX and FELICE. The four infrared and THz beam lines of the FELIX facility are shown: FLARE, FELIX-FEL1, FELIX-FEL2, and FELICE.

Photograph of the FELIX beam lines in the vault in Nijmegen showing the progress of the re-building of the free electron lasers.

Highlight

A golden opportunity: activation of molecular oxygen by gold

FELIX experiments have demonstrated the activation of molecular oxygen by anionic gold clusters. Molecular oxygen is found to be converted into a superoxo (O2-) species upon complexation to gold-cluster anions containing an even number of gold atoms. The frequency of the oxygen vibration, ν(O-O), serves as a measure for the extent of the activation and it is found that the latter can be approximately anticorrelated with electron affinity of the parent cluster. These results may help the future understanding of nano-sized gold catalysis.



Activation of Molecular Oxygen by Anionic Gold Clusters - Angew. Chem. Int. Ed. 2012, 51, 4444-4447

Upon binding of oxygen to a anionic gold cluster the frequency of the oxygen vibrations shifts to lower frequencies. The size of the frequency shift is a direct measure for the extent of the activation.

Highlights

Metal ion binding induces keto/enol tautomerization of the peptide bond

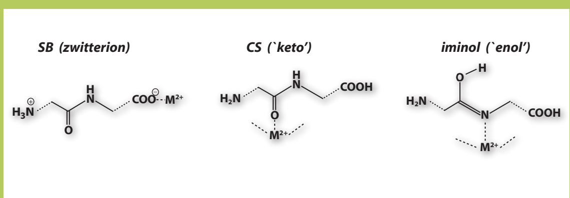
In biochemistry, the importance of metal ions and their binding to biological molecules can hardly be overestimated. Nature employs metal ions in a wide range of proteins, e.g. as oxygen transporters or photoreceptors. Not surprisingly, numerous studies have addressed the binding geometries of metal ions to peptides and proteins. In the gas phase, where the interactions between the metal and the peptide can be explored in complete isolation, mass spectrometric studies have been most influential. Recent combination of mass spectrometry with IR spectroscopy at the FELIX facility has revealed further details of the gas-phase structures.

Two general binding motifs are well known from these studies. In the salt-bridge (SB) structure, the peptide adopts a zwitterionic structure where the C-terminal carboxylic acid is usually deprotonated. This carboxylate forms a salt bridge with the metal cation. In the charge-solvated (CS) structure, the metal ion charge is solvated by binding to multiple electronegative sites in the peptide, especially the carbonyl groups. For alkali and alkaline earth metals, IR spectroscopy has been able to probe the fine balance between SB and CS structures.

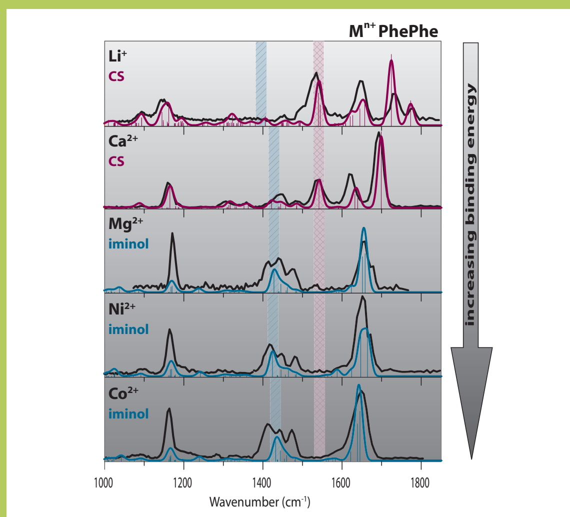
In solution, another well known motif results from deprotonation of an amide nitrogen and binding of the metal cation to this negatively charged site. We have now identified the gas-phase analog of this motif. In solution, transfer of the amide proton to the solution is efficient, but in the gas phase, removal of a proton is energetically costly. The gas-phase analogue therefore does not eliminate the amide proton, but instead relocates it to the amide carbonyl oxygen. This keto/enol tautomerization results in an imine-enol, or iminol, motif of the peptide linkage.

Experiments and quantum-chemical calculations show that the iminol binding motif can be observed for strongly binding metal ions including Ni(II) and Co(II). In addition to these active transition metals, the iminol motif has also been identified for Mg(II). This is somewhat surprising as Mg(II) does not normally engage in binding to deprotonated nitrogen sites in solution. From a spectroscopic point of view, the iminol motif is readily identified in an IR spectrum by the absence of the Amide II band around 1550 cm-1 due to the bending motion of the amide N-H moieties.

Peptide bond tautomerization induced by divalent metal ions: characterization of the iminol configuration - Angew. Chem. Int. Ed. 2012, 51, 4591
Metal ion binding: oxygen or nitrogen sites? - Int. J. Mass Spectrom. 2012, 330-332, 71



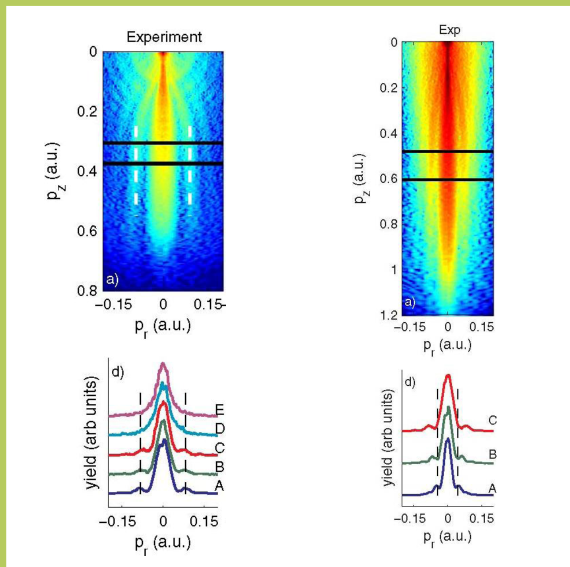
SB, CS, and iminol binding motifs of peptides to metal ions.



IR spectra of the PhePhe dipeptide bound to different metal ions, showing the transition from CS to iminol binding (black: experimental, blue/red: calculated).

Photoelectron Holography: a new tool to probe atomic or molecular dynamics?

Midinfrared strong-field laser ionization offers the promise of measuring holograms of atoms and molecules, which contain both spatial and temporal information of the ion and the photoelectron with subfemtosecond temporal and angstrom spatial resolution. Using FELICE it has been shown how the photoelectron holographic interference patterns scale with the laser pulse duration, wavelength, and intensity. The results are compared to semiclassical calculations that provide profound analytical insight. intensity. The results are compared to semiclassical calculations that provide profound analytical insight.



Scaling of the photoelectron holography with intensity (left) and with wavelength (right). The upper panel shows the experimental holographs and the lower panel lineouts at different intensities and wavelengths, respectively.

Scaling Laws for Photoelectron Holography in the Midinfrared Wavelength Regime - Phys. Rev. Lett. 109, 013002 (2012)

Last FELIX photon in Nieuwegein - FELIX operation stops on 15 March 2012

After more than 20 years of operation at the FOM Institute in Nieuwegein, FELIX, the Free Electron Laser for Infrared eXperiments, produced its last photon on 15 March 2012. The FELIX lasers as well as the user experiments and the auxiliary equipment are being relocated to the Radboud University Nijmegen where they will merge with the recently commissioned terahertz free electron laser FLARE. The future of the new FELIX facility at Nijmegen looks bright as it will offer the user community an even larger frequency range, a high resolution spectroscopic mode and the combination with the high magnetic fields available in the adjacent facility HFML.

Pictures of the moment of "Last Photon", the transportation of FELIX parts to Nijmegen and the first parts of the beamline reassembled in the vault in Nijmegen.

3

Knowledge transfer to society

One of DIFFER's strategic goals is to transfer its scientific results to society at large, via close cooperation with industry and SME's, participation of staff in university education, and outreach to the general public.

Industrial Focus Group XUV Optics

An important result in transferring knowhow to industry in 2012 was the initiation of the Industrial Focus Group XUV Optics at the University of Twente. With DIFFER as the launching base, the XUV Optics group is a novel type of joint venturing with forefront industrial research in the Netherlands. It fully meets the current government policies of catalyzing transfer of applied research to industrial activities. The new group is described in more detail in the section on page 24 (nSI Highlight).

Connecting Dutch industry to Big Science

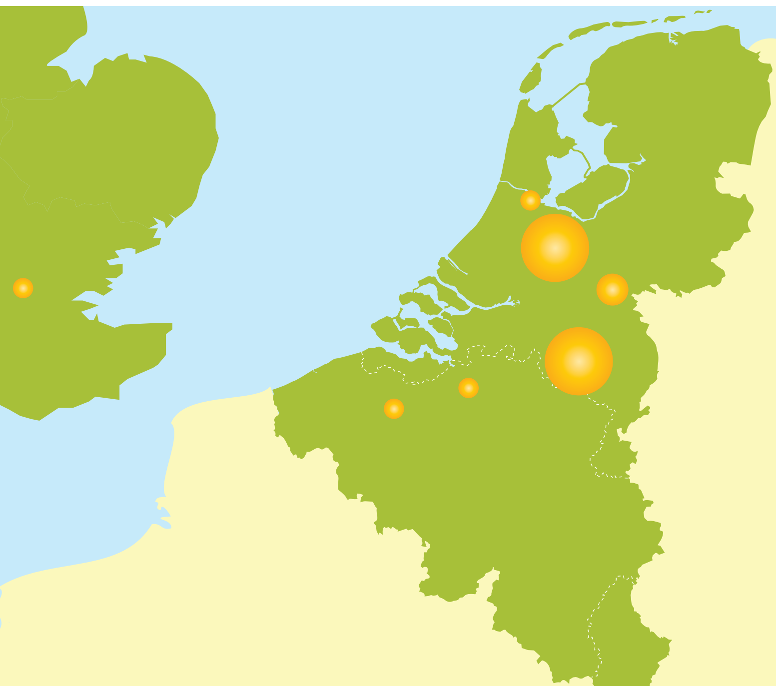
DIFFER is part of the ITER-NL consortium, which aims to optimize scientific and industrial participation of the Netherlands in the ITER project. ITER-NL maintains an online portfolio of Dutch high-tech companies with relevant expertise to the ITER work packages. Toon Verhoeven is the national ILO or Industrial Liaison Officer between Dutch companies and the European tender organization Fusion for Energy. Together with Fusion for Energy, Verhoeven works to raise awareness regarding funding schemes and ways to get involved in the ITER project.

In 2012, the Dutch ILOs involved in Big Science - e.g. LHC, ITER, ESRF, SKA - joined forces in the ILO-Net, which maintains the Big Science for Business website. DIFFER's ILO acts as secretary for this project. On 12 October 2012, the ILO-Net organised a fully booked industry day at DIFFER for companies interested in big science-related work.

To validate ITER remote handling maintenance procedures, DIFFER together with HIT and Dutch Space have established a state of the art virtual reality simulation of ITER hot cell procedures which allows up to four operators to simultaneously work on a proposed maintenance task for ITER components. In 2012, this Remote Handling Study Centre together with European partners scored a framework contract with ITER for analysis of it's diagnostics design's compatibility with remote handling procedures. The Dutch company HIT also obtained a contract to investigate use of augmented reality techniques to support remote handling operators.

Education

DIFFER is keen to play a role in educating the next generation of energy scientists. Research carried out by the 39 PhD students under supervision of the scientific staff constitutes a vital part of the research. Five PhD students



University courses

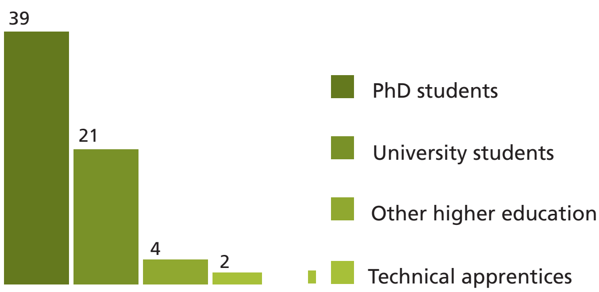
In 2012, seven of DIFFER's scientists held a part-time professorship at a Dutch university, and together with five more scientific staff they (co-)taught twenty courses at the BSc or MSc level at universities in the Netherlands, Belgium and UK (see map). In total, eleven courses were given on fusion or topics in a fusion context such as control or diagnostics, two courses on solar fuels and energy storage in general; and seven on other topics such as EUV multilayer research, electrodynamics or atom and molecule physics.

University courses taught by DIFFER staff in 2012 - dot size indicates number of courses taught at each university successfully defended their PhD thesis in 2012. The average PhD period at DIFFER is 4.5 years.

In addition to the PhD candidates, DIFFER welcomes interns from all education levels for research projects in their MSc or BSc programme or for traineeships in the workshop or electronics department.

For secondary schools, DIFFER supports the elective lessons module Kernfusie ('nuclear fusion') for the science subject NLT (nature, life and technology). For a different take on fusion, schools can invite the Fusion Road Show, DIFFER's dynamical science performance about the potential of fusion to tackle the energy challenge. In 2012, the show was performed nineteen times at schools and at the institute's general open day. Thirteen secondary school students visited DIFFER to experiment with the dedicated Paschen curve experiment.

Students trained at DIFFER



General public

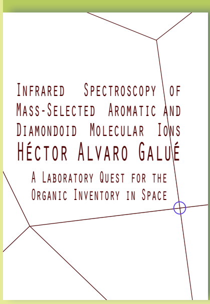
DIFFER opened its doors for visitors during two open days in October for the general public and for students from secondary school to undergraduate level. Eleven guided tours were organized for the Dutch Physics Olympiad finalists, for the International Conference of Physics Students ICPS, and for secondary schools and university students.

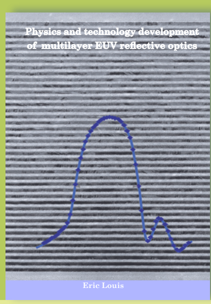
The start of the new mission of DIFFER, coupled with the start of Magnum-PSI's experimental campaign, garnered international media attention. DIFFER's new mission and the newly started research on solar fuels proved an especially attractive topic and were the topic of numerous articles in popular science magazines, websites and national newspapers. As national centre for fusion research, DIFFER facilitated articles on ITER and fusion in general in national newspapers and provided background material for articles on industrial participation in ITER.

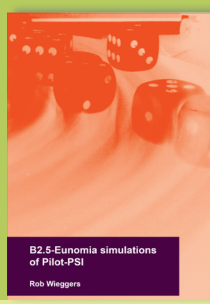
PhD Theses in 2012

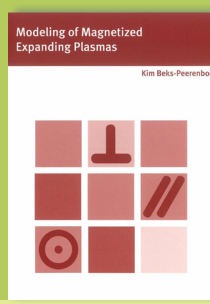
Of the six PhD students at DIFFER that graduated in 2012, two young researchers deserve special mention:

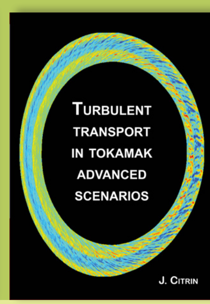
- Dr. Jonathan Citrin *(photo at right)* was awarded his doctorate cum laude for his thesis on turbulent transport in tokamak advanced scenarios;
- Dr. Héctor Alvaro Galué received the Dick Stufkens Prize 2012 for his research on Infrared Spectroscopy of Mass-Selected Aromatic and Diamandoid Molecular Ions: A Laboratory Quest for the Organic Inventory in Space.











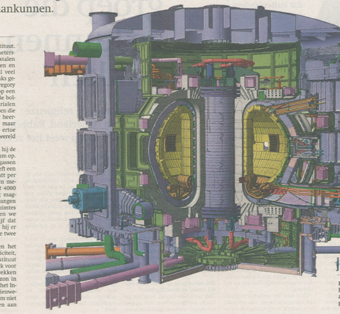
News clippings

Trouw donderdag 22 maart 2012 — deVerdieping 5

De zon in een doosje

Kernfusie is de energiebron van de toekomst. In Nieuwegein wordt materiaal voor een reactor getest. Die moet 150.000.000°C aankunnen.

Joep Engels



De ITER-kernfusiereactor. In Nieuwegein werkt men aan de 'zeilen', de bruine gedeelten in het midden.

'Een groot ongeluk met kernfusie is eigenlijk ondenkbaar'

Wat is kernfusie?

PhD student Rianne 't Hoen wins popular choice award of the international 'Dance your PhD' contest

14 Het Grote Verhaal 15

Dansen voor de wetenschap

Wetenschappers hebben er veel voor over om hun onderzoek onder de aandacht te brengen. Nu vertalen ze hun onderzoek zelfs naar dansjes. En: het werkt. Dansen rond een kernfusieapparaat.

My theorem works!

En de winnaar is...

Scènes uit het filmpje dat wiskundige Diana Davis maakte voor 'Dance your Ph.D'. Hierin bewegen dansers over twee vijfhoeken om een wiskundig theorema inzichtelijk te maken.

Scènes uit het dansfilmpje van de Australische materiaalkundige Peter Liddicoat de 'Dance your Ph.D' wedstrijd won. Een aantal mensen uit zijn lab danste mee.

ZONNE-ENERGIE OPSLAAN IN KOOLWATERSTOFFEN

Brandstofbuffer

Het Amerikaanse onderzoekslab Sandia heeft een proefinstallatie waarbij de hitte van geconcentreerd zonlicht wordt gebruikt om uit kooldioxide en water brandstoffen te maken.

WIE ZONNE-ENERGIE WIL OPSLAAN, KAN DAT VOLGENS DIFFER, HET VOORMALIGE FOM-INSTITUUT VOOR PLASMAFYSICA RIJNHUIZEN, HET BESTE DOEN IN DE VORM VAN KOOLWATERSTOFFEN. 'VAN GROENE STROOM VIA SYNGAS NAAR METHAAN, DAT IS DE UITDAGING.'

Het FOM-Instituut voor Plasmafysica Rijnhuizen, bekend om zijn bijdrage aan het wereldwijde kernfusieonderzoek, heet voortaan DIFFER, waarbij de afkorting staat voor Dutch Institute for Fundamental Energy Research. De naamsverandering houdt ook een koerswijziging in, waaraan, zo vertelt directeur prof.dr.ir. Richard van de Sanden, 'een soort van strijd' voorafging. Onderzoeksfinancier NWO en de natuurkundestichting FOM kregen vanuit de overheid de opdracht zich meer te richten op wat Van de Sanden noemt *use-inspired* onderzoek. Het leidde tot een nieuwe lijn van onderzoek naar de productie van brandstof met zonne-energie. 'Kernfusie is slechts een oplossing voor de langere termijn', stelt Van de Sanden. 'Kernfusiecentrale ITER in het Franse Cadarache gaat pas rond 2020 draaien en de eerste commerciële reactoren worden op zijn vroegst rond 2035 verwacht. Het onderzoek naar zogeheten *solar fuels* kan op kortere termijn resultaten opleveren.'

'Kernfusie is slechts een oplossing voor de lange termijn'

Zonne- en windenergie zijn bezig aan een onstuitbare opmars. Probleem is alleen dat zon en wind sterk fluctuerende energiebronnen zijn. Opslag van elektriciteit wordt de komende decennia dus steeds belangrijker. Een voor de hand liggende opslagmethode zijn accu's, maar daar heeft Van de Sanden zijn twijfels bij. 'De ontwikkeling van accu's gaat de laatste jaren een stuk langzamer dan voorheen. En het grote probleem is en blijft de energiedichtheid. Koolwaterstoffen bevatten veel meer energie per kubieke meter, of kilogram, dan accu's. Diesel bijvoorbeeld bevat 46 MJ/kg, terwijl de beste accu's niet veel verder komen dan 1 MJ/kg.' Wie energie wil opslaan, kan dat volgens hem dan ook het beste doen in de vorm van koolwaterstoffen.

Het internationale onderzoek daarnaar spitst zich toe op de productie van synthetisch methaan uit zogenoemd syngas, een mengsel van koolmonoxide en waterstofgas. 'Vervolgens zijn van methaan lange koolwaterstoffen te maken. Dat is niets bijzonders; dat is chemische industrie. Maar van groene stroom via syngas naar methaan, dát is de uitdaging.' Waarom niet direct gebruikmaken van waterstof? 'De energiedichtheid van waterstofgas is veel lager dan van methaan. Je kunt waterstofgas samenpersen, maar dat kost energie en dan nog haal je niet de dichtheid van methaan.' Het geproduceerde methaan kan vervolgens worden gebruikt als brandstof voor gasturbines, die elektriciteit opwekken wanneer wind en zon onvoldoende stroom leveren.

Waterstofgas, het eerste bestanddeel van syngas, is te verkrijgen door de elektrolytische ontleding van water in zuurstof en waterstofgas. Er zijn heel wat wetenschappelijke instituten die zich daarmee bezighouden. DIFFER wil zich vooral richten op de productie van CO uit CO_2 door middel van microgolven – bij uitstek het expertisegebied van Rijnhuizen. Dat dit haalbaar is, blijkt uit tot voor kort geheim Russisch onderzoek. 'Dat dateert uit de tijd

Dr. Waldo Bongers is als microgolfexpert betrokken bij het kernfusieonderzoek, maar houdt zich sinds kort vooral bezig met het syngasproject. Hij noemt het Russische onderzoek leerzaam, maar primitief. 'De microgolven werden opgewekt in een magnetron en dan door een golfpijp geleid. Dwars door die golfpijp liep een buis waarin aan de ene kant CO_2 werd gepompt. Aan de andere kant kwamen er CO en O_2 uit. Wat me irriteerde was dat die microgolven aan het eind van de golfpijp werden opgevangen in een *absorber*. Ik wilde alle energie gebruiken om CO_2 te dissociëren.'

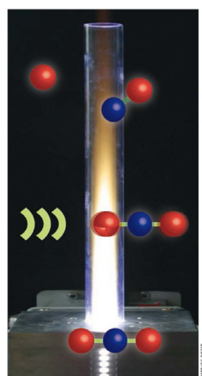
STUK TRILLEN

Niet lang nadat hij aan het syngasproject begon te werken, bezocht Bongers het Institut für Plasmaforschung in Stuttgart, waar onderzoekers met praktisch dezelfde opstelling werken aan de afbraak van gechloreerde koolwaterstoffen. Alleen laten de Duitse onderzoekers de microgolven niet verloren gaan: aan het eind van de golfpijp bevindt zich een resonator die is afgestemd op de frequentie van de microgolven, waardoor deze alleen door het plasma geabsorbeerd kunnen worden en er dus geen energie verloren gaat. 'Het was me meteen duidelijk dat we die techniek moesten gaan gebruiken', vertelt Bongers. 'Inmiddels werken we nauw samen met het Duitse instituut. We hebben de techniek aangepast en verfijnd. Zo spuiten we het CO_2-gas in met snelheden boven de geluidssnelheid.' Wanneer dat CO_2 met microgolven wordt bestookt, ontstaat een plasmavlam van enkele duizenden kelvin. Dat getal is echter misleidend: de microgolven verhitten het gas niet echt, de microgolfenergie gaat zitten in vibraties van het molecuul, zodat deze stuk trillen. Hoe hoger de inspuitsnelheid, des te hoger de efficiency. 'Het molecuul kan onder invloed van de golfenergie gaan verplaatsen, vibreren of ronddraaien. Door de snelle expansie van het plasma blijken de verplaatsing en rotatie vrijwel direct af te koelen en gaat de meeste toegevoerde energie in de vibratie zitten, een toestand die gunstig is voor het uiteenvallen van het CO_2-molecuul.'

Voordeel is dat daarbij geen katalysator van dure edelmetalen nodig is.'

Voor de CO_2-toevoer denkt Van de Sanden aan fabrieken en energiecentrales die op dit moment grote hoeveelheden de atmosfeer in blazen. 'Voor een bedrijf als Tata in IJmuiden is het een kwestie van rekenen. Als de CO_2-emissierechten goed op gang komen, dan krijgen we, hoop ik, naast elke fabriek een syngasgenerator.' Daarnaast acht hij kleinschalige installaties denkbaar. 'In principe is met de zonne-energie afkomstig van zonnecellen op het dak van een huis dagelijks genoeg methaan te produceren om een uur auto te rijden. Voorwaarde daarbij is wel dat de auto het door de motor geproduceerde CO_2 opslaat, zodat dat weer is te benutten in de syngasinstallatie thuis.'

www.differ.nl



Het instituut DIFFER gebruikt plasmatechniek: microgolven veranderen het van onder ingespoten kooldioxide in een plasma, waarbij de moleculen zo hard vibreren dat ze opbreken in een zuurstofatoom en koolmonoxide.

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Voor ITER lijkt kernfusie koud kunstje vergeleken met zoektocht naar geld

Tussen Japan en Frankrijk liggen bijna 10 duizend kilometer land en water. Toch is de aardbeving die in maart Fukushima trof ook 'gevoeld' in Saint-Paul-lès-Durance. Bij dit gehucht even ten noorden van Mar[…] moest Europa als grootste deelnemer voor dit en volgend jaar een ga[…] in zijn bijdrage dichten van liefst 1,3 miljard euro. Na achttien maanden soebatten zijn die gevonden in de begroting van 2013 – die nog niet […]

Woensdag 9 mei 2012 De Molenkruier pagina 25

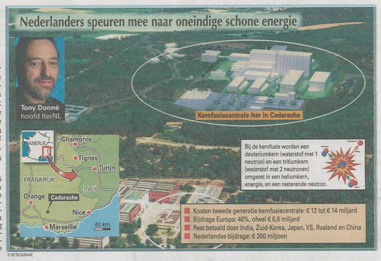
Drie dagen kunst kijken in park en kasteel Rijnhuizen

Jacqueline Tijssen en Jeroen Endeveld bij het theehuis in park Rijnhuizen: 'Groot aanbod aan kunst tijdens Pinksteren.' KARIN BEENEN

Hollandse bedrijven jagen op kernfusie

ONEINDIGE BRON VAN SCHONE ENERGIE

door EDWIN VAN DER SCHOOT



Kennis-economie kan zich bewijzen

Deal me[…] doodste[…]

door RICHARD VAN DE CROMMERT

Prof. dr. Richard van de Sanden is directeur van het FOM-Instituut voor Plasmafysica Rijnhuizen. Dit instituut wordt de komende jaren omgevormd tot een nationaal coördinerend instituut voor funderend energieonderzoek, het Dutch Institute for Fundamental Energy Research (DIFFER). 'Wij zullen er alles aan doen om ons die rol waardig te tonen', aldus Van de Sande.

64 Experiment NL wetenschap in Nederland

Wetenschappers moeten op jacht naar nieuwe energiebronnen

Zoeken naar nieuw zwart goud

Een steeds groter deel van de energie die we gebruiken is duurzaam. Dat stelt onderzoekers voor nieuwe uitdagingen. Ze moeten nieuwe energiebronnen aanboren die overal gebruikt kunnen worden. Een vliegtuig kan nu eenmaal niet vliegen op groene stroom. En als we de Sahara volbouwen met zonnepanelen, hoe komt die energie dan in het koude noorden?

Duurzame energie is in opmars en het is niet meer te stuiten. Windmolens op land en zee voorzien al in vier procent van onze elektriciteitsbehoefte. En van zonne-energie wordt verwacht dat ze over vijf jaar in prijs kan concurreren met traditionele energie en over tien jaar goedkoper zal zijn. Misschien gaat het nog sneller als de politieke instabiliteit in het Midden-Oosten de prijs van ruwe olie opdrijft. Fysicus Richard van de Sanden constateert het met tevredenheid. 'Juist het groeiend aandeel aan duurzaamheid in de totale energiemix stelt ons voor nieuwe uitdagingen', legt Van de Sanden uit. Zon en wind hebben nu eenmaal de lastige eigenschap dat ze soms voor handen zijn en soms niet. Onze energiehuishouding dreigt daarmee instabiel te worden. Tenzij we erin slagen de overtollige energie op te slaan. Dat is nog niet eens zo eenvoudig. Uit zon en wind winnen we elektriciteit en die laat

Dutch plasma facility reveals new problems for ITER

Trouw.nl

Nieuws | Opinie | Groen | Religie & filosofie | S[…]

Brandstof uit CO2, geen gebakken luch[…]

Marianne Wildschut – 10/01/12, 14:04

Een geothermische centrale bij de Blue Lagoon, een belangrijke toeristische attractie in IJsland. Bij de winning van geothermische energie komt ook koolstofdioxide vrij. © Reuters

Kernfusie in een nieuw jasje

Fusiereactor JET, de grande dame van de kernfusie, is weer helemaal bij de tijd. Een nieuwe reactorwand moet fusiereacties bij **150 miljoen graden** in goede banen leiden. *NWT Magazine* bezocht de vernieuwde reactor, die commerciële kernfusie dichterbij moet brengen. **Door Anouck Vrouwe**

DE VLOERBEDEKKING IN DE hal – een druk patroon met cirkels – is zo gedateerd, dat het bijna weer hip is. Het auditorium is een tijdmachine naar de zeventig. En zelfs in het technologische hart van het Culham Center for Fusion Energy is het moeilijk te zien dat er bijna dertig jaar is verstreken sinds het eerste plasma werd opgewekt in 1983. In een immens grote hal staat de fusiereactor Joint European Torus (JET). De stalen pijpen, het oranjekleurig transformatorjuk en de overalls van de medewerkers – het oogt tijdloos. Maar schijn bedriegt: JET is helemaal bij. De machine loopt al twee decennia in reservetijd, maar is na een onderhoudsronde van twee jaar fitter dan ooit. Dankzij een nieuwe binnenwand en extra verhitting beginnen de fysici aan een nieuw hoofdstuk in kernfusie. In augustus brandde er weer een voorzichtig plasma.

Hier bij JET moet duidelijk worden of kernfusie als energiebron haalbaar is. Bij kernfusie versmelten twee waterstofkernen (deuterium en tritium) tot helium en een neutron, waarbij veel energie vrijkomt. Dat voelen we dagelijks: de zon loopt op kernfusie.

De mensheid droomt al tijden van een eigen zonnetje op aarde. In 1955, tijdens de eerste Atoms for Peace-conferentie van de Verenigde Naties, voorspelde conferentievoorzitter Homi J. Bhabha dat er binnen twintig jaar een methode zou komen om fusie-energie gecontroleerd vrij te laten komen. 'Als dat lukt, zal het energieprobleem van de wereld voor altijd zijn opgelost,' beweerde hij optimistisch.

Bhabha zat er ver naast: JET is 'slechts' een onderzoeksreactor en ook opvolger ITER zal een onderzoeksreactor zijn. De eerste commerciële fusiereactoren kunnen pas op zijn vroegst in 2050 verschijnen – als ze al ooit haalbaar zijn. Toch riep Bhabha niet zomaar wat. Hij baseerde zijn verwachting op de ontwikkeling van kernsplijting. De wereld was in slechts tien jaar tijd van kernbom naar kerncentrale gegaan. De eerste waterstofbom ontplofte in 1952. Hoe lang kon het nou duren, van een bom naar de eerste fusiecentrale?

Afremmen

Het is inmiddels 2011. In het Engelse plaatsje Culham, in de buurt van Oxford, werken wetenschappers aan een nieuwe

24 | nwtmagazine | januari 2012

De fusiereactor van de Joint European Torus (JET) heeft een diameter van zes meter, half zo groot als die van ITER. EFDA/JET

Science NOW UP TO THE MINUTE NEWS FROM SCIENCE

How to Line a Thermonuclear Reactor

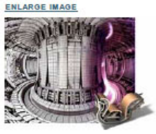
by Jim Heirbaut on 16 August 2012, 3:51 PM |

Email Print | More PREVIOUS ARTICLE NEXT ARTICLE

One of the biggest question marks hanging over the ITER fusion reactor project—a giant international collaboration currently under construction in France—is over what material to use for coating its interior wall. After all, the reactor has to withstand temperatures of 100,000°C and an intense particle bombardment.

Researchers have now answered that question by refitting the current world's largest fusion device, the Joint European Torus (JET) near Oxford, U.K., with a lining akin to the one planned for ITER. JET's new "ITER-like wall," a combination of tungsten and beryllium, is eroding more slowly and retaining less of the fuel than the lining used on earlier fusion reactors, the team reports. "This was very good news, because it means that our choice of materials for ITER was the right one," says physicist Peter de Vries, task force and session leader at JET.

ENLARGE IMAGE

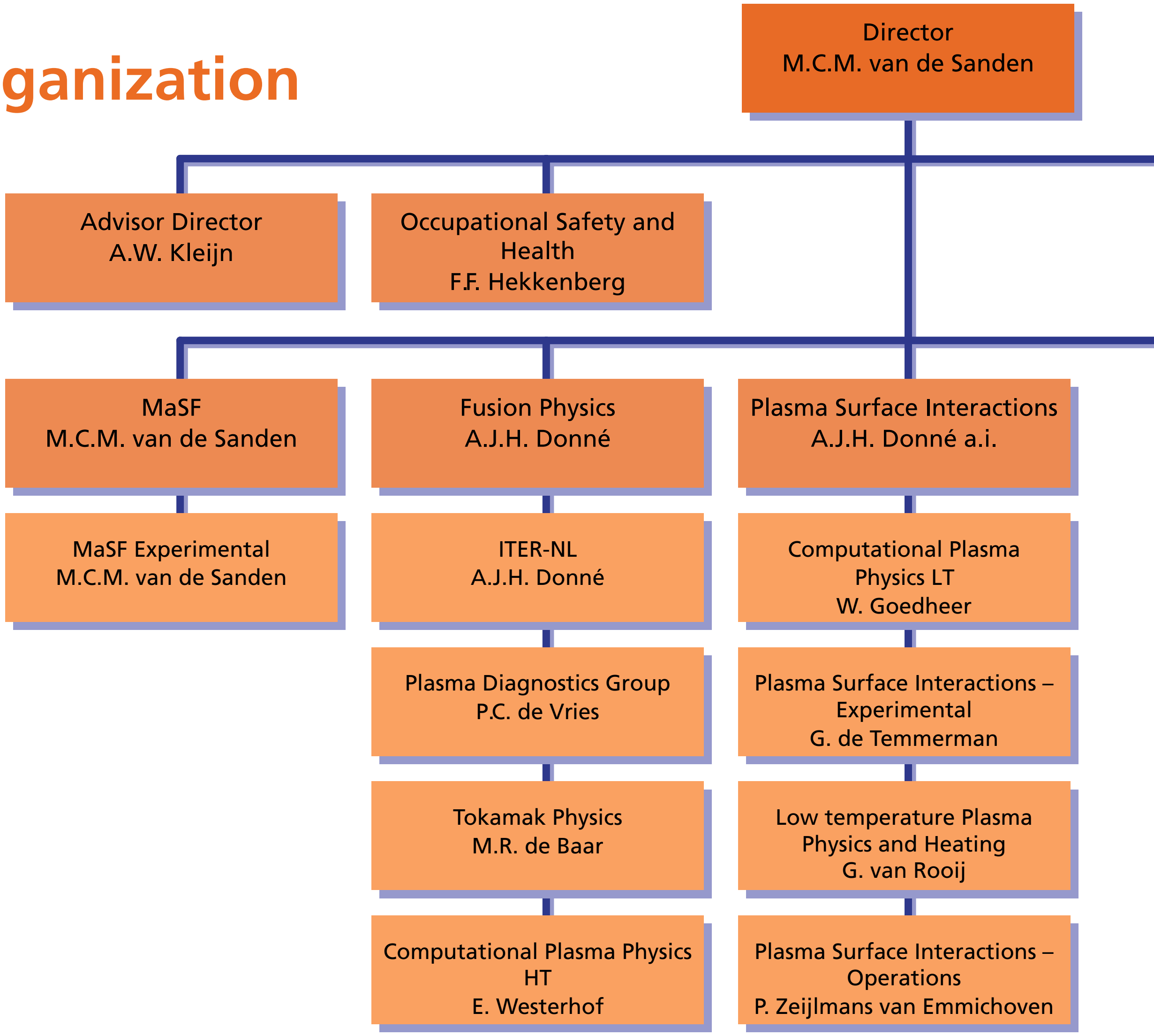


Sturdy lining. The experimental nuclear fusion device JET has successfully tested a brand new lining for the future fusion reactor ITER. A cross section of the tungsten divertor, ITER's exhaust pipe, is shown (inset).

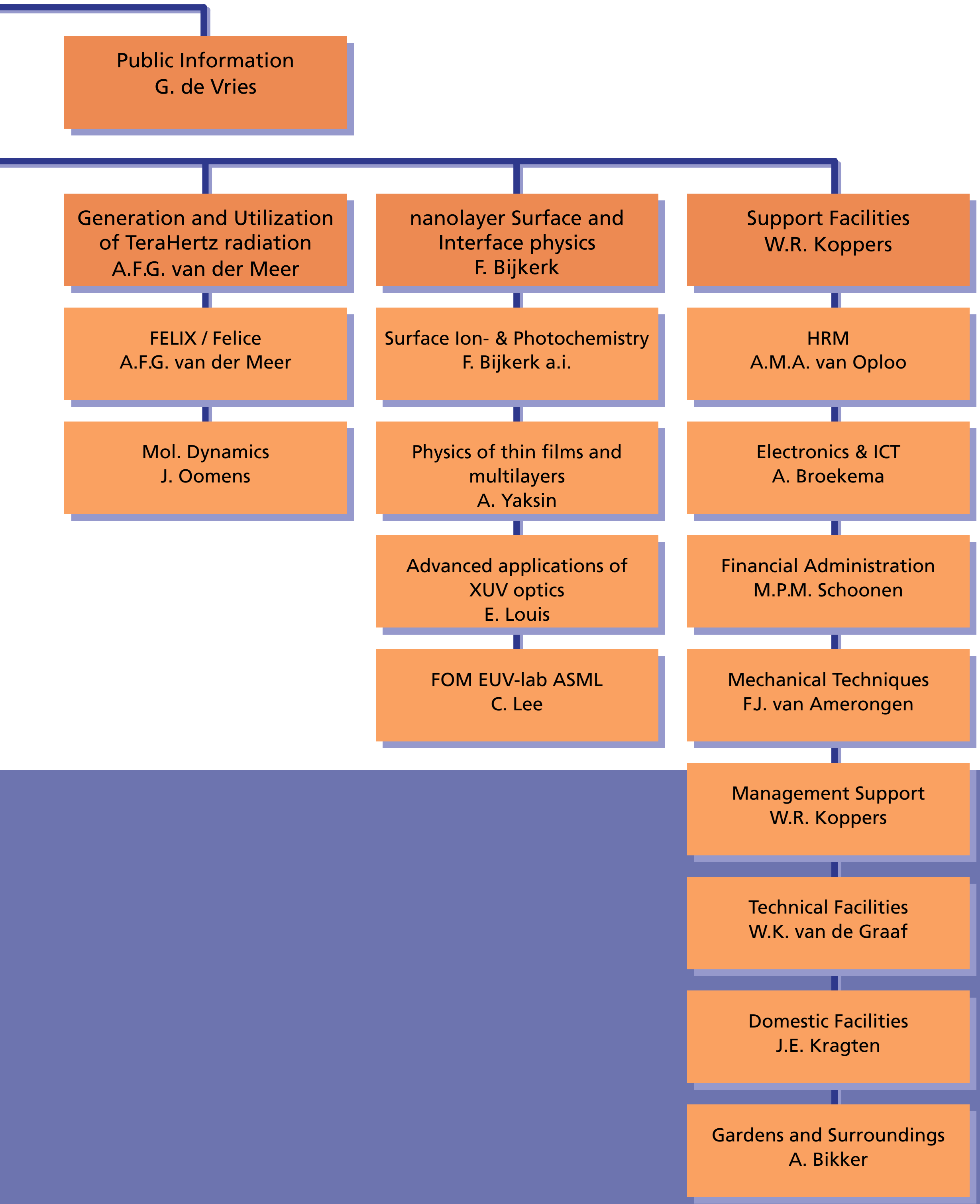
Credit: EFDA; (inset, bottom right) ITER

4

4.1 Organization



For a full list of employees per group, please see the online appendix, http://www.differ.nl/en/annual_reports


Public Information
G. de Vries
Generation and Utilization of TeraHertz radiation
A.F.G. van der Meer
FELIX / Felice
A.F.G. van der Meer
Mol. Dynamics
J. Oomens
nanolayer Surface and Interface physics
F. Bijkerk
Surface Ion- & Photochemistry
F. Bijkerk a.i.
Physics of thin films and multilayers
A. Yaksin
Advanced applications of XUV optics
E. Louis
FOM EUV-lab ASML
C. Lee
Support Facilities
W.R. Koppers
HRM
A.M.A. van Oploo
Electronics & ICT
A. Broekema
Financial Administration
M.P.M. Schoonen
Mechanical Techniques
FJ. van Amerongen
Management Support
W.R. Koppers
Technical Facilities
W.K. van de Graaf
Domestic Facilities
J.E. Kragten
Gardens and Surroundings
A. Bikker

4.2 List of committees

Management Team
M.C.M. van de Sanden (institute director, chairman)
F. Bijkerk
A.J.H. Donné
W.R. Koppers
A.F.G. van der Meer

FELIX Program Advisory Committee
M. Helm (chairman)
H. Bakker
A.J.R. Heck
A. Krier
P. Maître
W. van der Zande

Scientific Advisory Committee
G. van der Steenhoven (chairman)
D.J. Campbell
A. von Keudell
J.R. Schneider
Y. Ueda
H. Werij

Employees Council
G. Kaas (chairman)
F.J. van Amerongen
J. Citrin
J.W. Genuit
G.M.D. Hogeweij
H.J. van der Meiden
A.P. Visser