DEPARTMENT OF

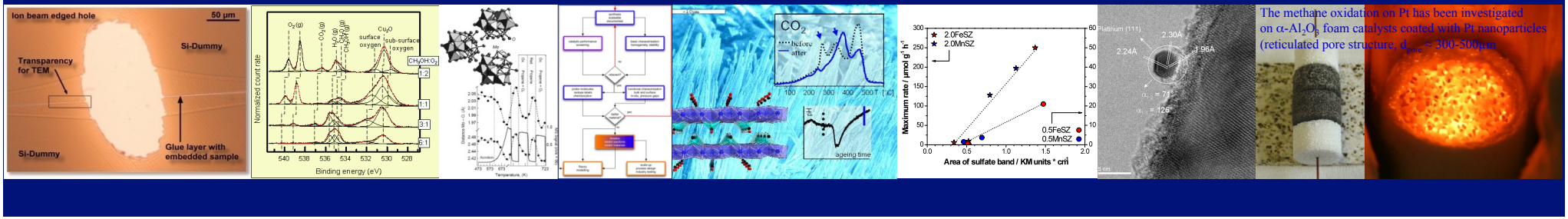
MAX-PLANCK-GESELLSCHAFT

INORGANIC CHEMISTRY

AC FHI

FRITZ-HABER-INSTITUT DER MAX-PLANCK-GESELLSCHAFT

November 2009 / 5th Edition



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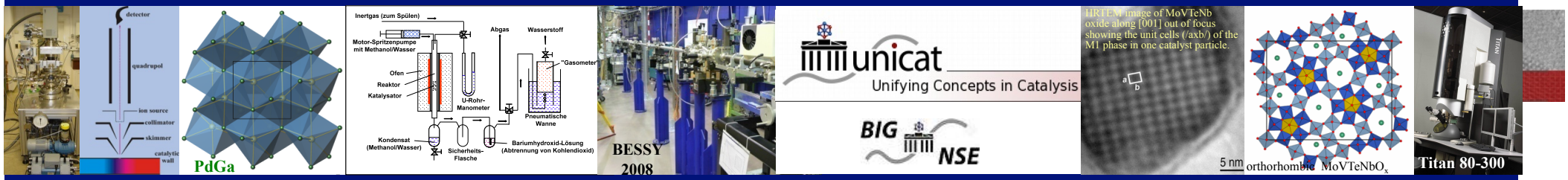

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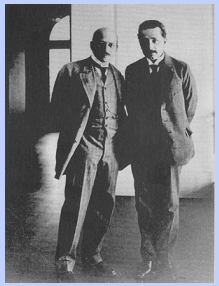
History of the Fritz-Haber-Institut

http://www.fhi-berlin.mpg.de/history

The Kaiser-Wilhelm Institutes for Chemistry (left) and for Physical Chemistry and Electrochemistry (right) --(1913).

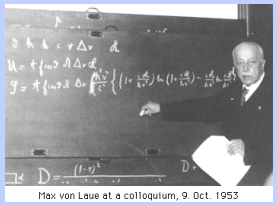
What is now called the Fritz-Haber-Institut of the Max-Planck-Gesellschaft was founded in 1911 as the Kaiser-Wilhelm-Institut for Physical Chemistry and Electrochemistry, together with the Kaiser-Wilhelm-Institut for Chemistry. These were in fact the first two institutes of the Kaiser-Wilhelm Society (Kaiser-Wilhelm-Gesellschaft, KWG).



Fritz Haber (left) and Albert Einstein (right) at the "Fritz-Haber-Institut" (1915).

Fritz Haber was appointed director of the institute following the recommendation of the famous Swedish physical chemist Svante Arrhenius. Haber's personality and his previous scientific achievements were considered particularly appropriate for a leader of this new institute, focusing on basic research in the field of physical chemistry, which was expected to give new momentum to the development of the German chemical industry, at that time regarded as a world leader.

In 1951, at the age of 71, Max von Laue became chief director of the institute. This started a new period of consolidation in which Max von Laue applied all his influence and his great scientific reputation to the task of rebuilding the institute.



Max von Laue at a colloquium, 9 October, 1953

1955 **Max von Laue**, director of the institute
1953 Rename in Fritz-Haber-Institut of the Max-Planck-Gesellschaft
1954 **Ernst Ruska**, Scientific Fellow of the institute
1957 "Institute for Electron Microscopy of the Fritz-Haber-Institut".
1959 **Rudolf Brill**, director of the institute, *catalytic properties for heterogeneous reactions, XRD, kinetic measurements*
1969 **Heinz Gerischer**, Dept. of Physical Chemistry, *studies of solid surfaces under ultra-high vacuum conditions and their interaction with gases*
1969 **Jochen H. Block**, *kinetic processes on metal surfaces were studied using field electron and field ion microscopies*
1974 The institute was restructured to consist of three sections which were to combine their collaborative efforts: Physical Chemistry (directors: J. H. Block, H. Gerischer, K. Molière), Structure Research (directors: R. Hosemann, Kurt Ueberreiter), and Electron Microscopy (director: E. Ruska until 1974).
1976 **Elmar Zeitler**, Electron Microscopy
1980 Second reorganization introduced a collaborative structure for the institute with stronger emphasis on surface and interface science.
1980 **Alexander Bradshaw**, Dep. of Surface Physics, *spectroscopy of solid surfaces and the study of chemisorbed molecules*
1981 A. Bradshaw, Scientific Director of BESSY I, 1999 BESSY II, 1997 IPP
1985 **Gerhard Ertl**, Dept. of Physical Chemistry, *structure and chemical reactions on solid surfaces*
1986 Ernst Ruska was awarded the Nobel Prize in Physics
1988 **Matthias Scheffler**, Theory Dept., *surface theory, solid state research, quantum chemistry, computational physics*
1994 **Robert Schlögl**, Dept. of Inorganic Chemistry, *heterogeneous reactions on inorganic surfaces*
1995 **Hans-Joachim Freund**, Dept. of Chemical Physics, *adsorption and reaction on solids, in particular, on oxide surfaces*
2002 **Gerard Meijer**, Dept. of Molecular Physics, *molecular physics using the free-electron-laser*
2007 Gerhard Ertl was awarded the Nobel Prize in Chemistry
2008 **Martin Wolf**, appointed director of Dept. of Physical Chemistry

How to reach the Institute

By Train from Bahnhof Zoologischer Garten:

Take U-Bahn U9 direction Rathaus Steglitz. Change at Spichernstrasse. Take U3 direction Krumme Lanke. Go off at Thielplatz. Travel takes about 30 min. Costs are about Euro 2,00. Taxi takes about 20 minutes outside rush hours. Costs are about 15 Euro.

By Air from Flughafen Tegel:

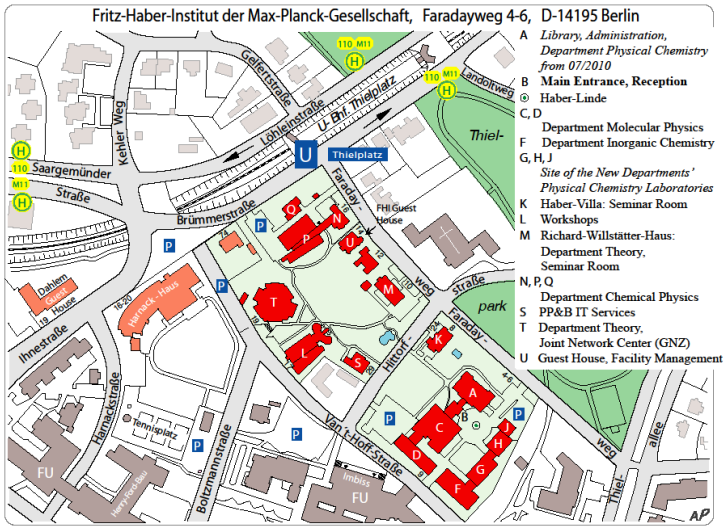
Take bus 109 to Jakob-Kaiser-Platz (about 3km away). From there take subway U7, direction Rudow. Change at Fehrbelliner Platz to U3 direction Krumme Lanke. Go off at Thielplatz. Travel takes about 50 min. Costs are about Euro 2,00. A Taxi is somewhat faster, about 25 minutes outside rush hours. Costs are about 20 Euro.

By Air from Flughafen Tempelhof:

Take subway U6 direction Alt-Tegel, change at Mehringdamm, take U7 direction Rathaus Spandau. Change at Fehrbelliner Platz to U3 direction Krumme Lanke. Go off at Thielplatz. Travel takes about 30 min. Costs are about Euro 2,00. Taxi takes about 20 minutes outside rush hours. Costs are about 15 Euro.

By Car:

On the freeway (Bundesautobahn) Potsdam-Berlin take exit Hüttenweg. Follow Hüttenweg to the end (about 3km), two crossings with traffic lights. (Königsallee/ Onkel-Tom-Str. and Clayallee). At the end of Hüttenweg turn right into Gelfert Straße, and take the second street to the right, Kehler Weg. At the next crossing, turn left (over the U-Bahn bridge) into Brümmer Straße. Take the next street to the right Faradayweg.



Fritz-Haber-Institut der Max-Planck-Gesellschaft

Faradayweg 4 – 6

14195 Berlin

Germany

Preface

Director:
Prof. Dr. Robert Schlögl
Tel: **49 30 8413 4400**
Fax: **49 30 8413 4401**
E-mail: **acsek@fhi-berlin.mpg.de**

The department AC in the Fritz-Haber-Institute aims to gain a generalized understanding of heterogeneous catalysis as a multi-scale phenomenon. To achieve this goal the department develops and applies in situ methodology and combines the obtained information with kinetic data. The rationale behind this approach is the realization that catalysts are dynamic materials whose active centres are formed or transformed under reaction conditions.

The FHI contributes within all departments towards the understanding of heterogeneous catalysts defined as the prediction of the macroscopically observable performance of a kinetically demanding reaction over a given catalyst system and under given reaction conditions.

This level of understanding being pre-requisite for a rational design of technologically important processes has only be achieved so far for kinetically non-demanding reactions, which exhibit no branching of reaction pathways and/or occur with an adsorption step as rate-determining process. Examples for this are isotope exchange reactions, ammonia synthesis, CO oxidation, decomposition of methanol, total oxidation of hydrocarbons.

Kinetically demanding reactions of interest to the department AC are currently: selective oxidations of un-functionalized or weakly functionalized hydrocarbons, selective hydrogenations of various functionalities, dehydrogenations, skeletal rearrangements of small organic molecules and C1 chemistry. All these reactions exhibit complex selectivity patterns and multiple reaction steps with intermediates. The diversity is seen as important to achieve a generalized understanding. However, links between these reactions exist through common elementary steps.

For example, a typical oxidation requires C-H activation, oxygen activation, oxygen insertion and oxygen addition reactions. Large bodies of phenomenological experience both from applied and fundamental studies exist, but neither the real mode of operation nor the nature of the working catalysts is known in sufficient detail. This lack in knowledge has led to the formulation of empirical concepts (such as: remote control of oxygen activity, synergy of catalyst phases, Mars-van Krevelen formal kinetics, radical-initiated reactions) none of which were as rigorously examined as the ammonia synthesis reaction. The necessary tools and methods to handle the enormous complexity of kinetically demanding chemical transformations are being developed world-wide under substantial participation of the FHI to which the department AC contributes its share in synthesis and development of analytical methodology.

The department AC studies a selection of reactions using materials and conditions typical of technical applications. These efforts and the model and theoretical studies carried out in the other departments are complementary.

The strategy of AC involves monitoring the synthesis of catalytically active materials by in situ techniques. Through understanding and ultimately controlling the processes of inorganic synthesis occurring during all unit operations of catalyst preparation an optimization is achieved resulting in reproducible and homogeneous active materials. The active centres are envisaged as unique configurations of one or more atoms at or near the surface whose existence is enabled by a surrounding matrix, which is ideally homogeneous.

For chemically and structurally complex systems simplified models are generated that exhibit the essential catalytic characteristics. Suitable specimens (e.g. polycrystalline thin films) are tailor-made for in-situ functional studies aiming at verifying the nature of the active ensemble and adsorbates.

Physical chemistry is the key discipline in the interdisciplinary effort of the department. The choice for experimental structure-function relationships requires quantitative kinetic and spectroscopic investigations. The in-situ analytical capability where the department holds a widely recognized position of competence forms the methodical core of the department. Instrumentation development (example: pressure-dependent surface analysis) and creation of novel coupled experiments are features enabling the investigation of working catalysts with an increasingly more complete suite of complementary methods describing geometric and electronic structural details. Physical chemistry is also the target of kinetic competence currently being expanded. Process development and technical implementations are outside the scope of the department.

Kinetic data and intermediate concentrations present input for theory and kinetic modelling. The model systems allow the comparison of fundamental material properties and of structural dynamics of the always metastable catalyst with those from rigorously defined models from surface science and cluster chemistry approaches typically studied in the other departments of the FHI.
A project is completed within the scope of the AC department when the scaling of chemical and structural complexity is defined and when a series of observable surface properties are described amenable to experimental and theoretical modelling.

An example for such a completed project is the dehydrogenation of ethylbenzene to styrene over iron oxide catalysts. Although the development of novel systems is not a primary goal, the department seeks to verify and implement its knowledge by the rational synthesis of improved catalysts (example Pd-Ga intermetallic compounds).

Co-operations are essential for the department. Theory and modelling as well as all the rigorously defined model systems and alternative synthetic concepts are incorporated into the projects through our partners inside and outside of FHI. With industrial partners the verifications of insight und functional understanding are performed. A number of long-standing academic collaborations augment the research portfolio. The department actively contributes to the Berlin research networks within the SFB 546 (transition metal aggregates) and the COE UniCat. Within the MPG the department critically contributes to the research network enerchem and has close cooperations with MPI Mülheim (Schüth), Golm (Antonietti), Dresden (Grin), Mainz (Müllen), Stuttgart (Maier). Larger external projects are the "Pd project" encompassing groups in Austria (Klötzer, Rupprechter) and the US (Zemlianov), the "intermetallics" project conducted with the MPI CPFS (Dresden) (Grin), the contribution of carboscale (Muhler/Wirth) to the national competence network INNOCNT and a PIRE project on renewable energies conducted with a consortium from the US led by J. Dumesic and A. Datye. Within the framework of the EU-NOE IDECAT and our franco-italian (Centi, Garin) collaboration (ELCASS) the department pioneered together with the TU Berlin the awarding of 2 European Doctoral Diplomas emphasizing the multinational character of the degree. This year we started work in the 7. Framework EU Programm Technotubes.

Internal Structure

The core competence of the Department is focused into the in situ metrology of synthesis and function of heterogeneous catalytic systems. The Scheme represents the current structure indicating its GL and PL and main methodical activities.

REACTIVITY

GL: Dr. A. Trunschke
Tel: 49 30 8413 4457
E-mail: trunschke@fhi-berlin.mpg.de

Mo-V compounds in alkane activation
18 members
Synthesis, vibrational and UV-vis spectroscopy, reactor technology and catalytic testing

NANOSTRUCTURES

GL: Dr. M. Behrens
Tel: 49 30 8413 4408
E-mail: behrens@fhi-berlin.mpg.de

Cu, Pd in C1 chemistry
15 members
Synthesis, Elemental analysis, X-Ray and neutron diffraction, TG, DSC, EXAFS

ELECTRONIC STRUCTURE and ADSORPTION

GL: Dr. A. Knop-Gericke
Tel: 49 30 8413 4422
E-mail: knop@fhi-berlin.mpg.de

Metals in sel oxidation
Emmy Noether / PL: Dr. R. Horn
22 members
Photoelectron spectroscopy, TP desorption, TP reaction, Raman, Calorimetry, BET, MBMS, Laser spectroscopy, BESSY II

MICRO- AND NANOSTRUCTURE

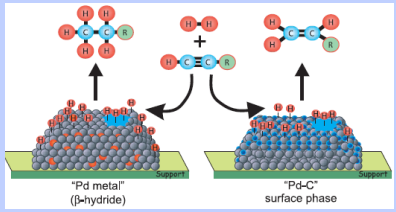
GL: Dr. D. S. Su
Tel: 49 30 8413 5406
E-mail: dangsheng@fhi-berlin.mpg.de

Nanocarbon in energy chemistry
C-OH chemistry / PL: J. P. Tessonnier
TEM service group: Dr. D. S. Su
21 members
TEM, SEM, ELNES, RFA, Nanoreaction

Group leader: GL Project leader: PL

Highlights

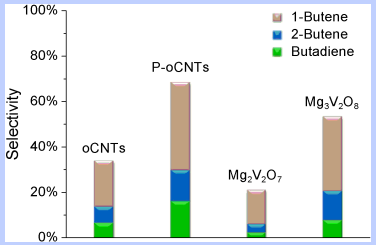
The Roles of Subsurface Carbon and Hydrogen in Palladium-Catalyzed Alkyne Hydrogenation (*Science 320 (2008) 86-98*)



Alkynes can be selectively hydrogenated into alkenes on solid palladium catalysts. This process requires a strong modification of the near-surface region of palladium, in which carbon occupies interstitial lattice sites. In situ X-ray photoelectron spectroscopic measurements under reaction conditions indicated that much less carbon was dissolved in palladium during unselective, total hydrogenation. Additional studies of hydrogen content using in situ prompt gamma activation analysis, which allowed us to follow the hydrogen content of palladium during catalysis, indicated that unselective hydrogenation procceds on hydrogen-saturated β-hydride, whereas selective hydrogenation was only possible after decoupling bulk properties from the surface events. Thus, the population of subsurface sites of palladium, by either hydrogen or carbon, governs the hydrogenation events on the surface.

Surface-modified Carbnon Nanotubes Catalyze Oxidative Dehydrogenation of n-Butane *(Science 322 (2008) 73)*

Butenes and butadiene, which are useful intermediates for the synthesis of polymers and other compounds, are synthesized traditionally by oxidative dehydrogenation (ODH) of *n*-butane over complex metal oxides. Such catalysts require high O_2 to butane ratios to maintain the catalyst, which heads to unwanted product oxidation. We show that carbon nanotubes CNTs) with modified surface functionality efficiently catalyze the ODH of *n*-butane to butenes, especially butadiene. (For low O_2 to butane ratios, a high selectivity to alkenes was achieved for periods as long as 100 hours. This process is mildly catalyzed by ketonic C=O groups and occurs via a combination of parallel and sequential oxidation steps. A small amount of phosphorus greatly improved the selectivity by suppressing the combustion of hydrocarbon.



D/E

Instrumentation

REACTIVITY

Dr. A. Trunschke

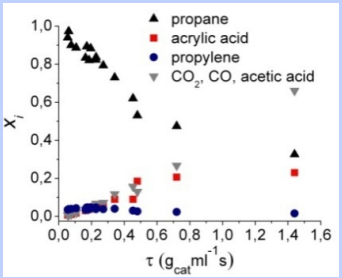
Contact:
Dr. A. Trunschke
trunschke@fhi-berlin.mpg.de

The sophisticated formulation and complexity of current heterogeneous catalysts requires the application of controlled synthesis conditions and well-defined chemicals for their reproducible preparation. The work of the group is targeted on a deeper understanding of **catalyst synthesis** ranging from the assembly of molecular building blocks in solution to phase transformations during thermal pretreatment procedures. New synthetic concepts are developed using **automated laboratory reactor systems for precipitation and hydrothermal synthesis** equipped with probes for measuring pH, conductivity, turbidity, viscosity, pressure, temperature, and UV-vis spectra. The thermal treatments are performed in rotating furnaces under controlled atmosphere.

Molecular spectroscopy is used to understand catalyst synthesis. The nature and number of the active sites on the catalyst surface and the reaction mechanism are addressed by adsorption of reactants and probe molecules in static or flow operation at 77-873K, in-situ spectroscopic experiments, and **microreactor** studies.

Examples of the technical equipment:

Analytic autoclave HPM-PT-040 (Premex Reactor GmbH)



Oxidation of propane to acrylic acid over crystalline MoVTeNb oxide at T=400°C and different residence times (3% C_3H_8, 6% O_2, 40% H_2O, 51% N_2

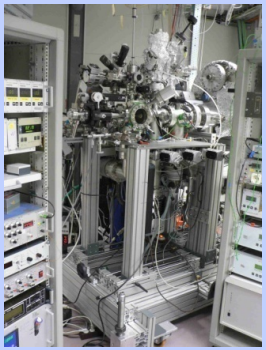
- Automated laboratory reactor system (Mettler-Toledo Labmax®), analytic autoclave HPM-PT-040 (Premex), parallel microwave reactors Speed*wave* MWS-3 (Berghof)
- Lambda 650 UV-vis spectrometer (Perkin Elmer) with Harrick DR accessory
- IFS 66 FTIR (Bruker) and Spectrum 100 FTIR (Perkin Elmer) for in-situ measurements in transmission, diffuse reflectance and ATR
- Single-tube and parallel (ILS) fixed-bed reactors for gas phase oxidation equipped with GC-MS, GC (Agilent), and MS OmniStar™ (Pfeiffer)

ELECTRONIC STRUCTURE AND ADSORPTION

Dr. A. Knop-Gericke

Contact:
Dr. A. Knop-Gericke,
knop@fhi-berlin.mpg.de

ISISS: Soft X-ray station at BESSY :

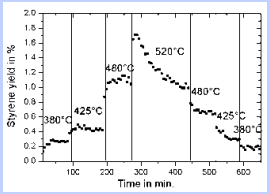


In situ XPS endstation of the ISISS beamline

BESSY and the FHI installed the facility ISISS (Innovative Station for In Situ Spectroscopy). ISISS consists of 3 main parts: a) the in situ XPS endstation, b) a state of the art soft X-ray beamline, and c) a permanent infrastructure on site for experiments with a chemical background. This facility allows measurements of XP and XA spectra in the soft energy range under reaction conditions (mbar pressure range, T <600°C.) One aim of these investigation is the identification of correlation between the electronic surface structure of a working catalyst and its catalytic performance. Subsurface species were observed under reaction conditions by the help of photon energy variation (depth profile).

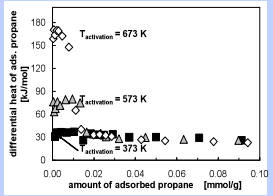
Combined TDS, XPS and reactivity studies of low surface area (model) catalysts

Combining thermal desorption (TDS) with the surface and element sensitive method XPS and a micro flow reactor yield a powerful investigation toolset of low surface area (model) catalysts. The figure shows the yield of styrene in the oxidative dehydrogenation (ODH) of ethylbenzene over ~0.03mg carbon nanotube on highly oriented pyrolytic graphite, HOPG.



Measurement of isotherms & differential heats of adsorption by microcalorimetry

This is a direct method to determine number, strength and energy distribution of the adsorption sites on a catalyst. It allows for measuring the differential heats evolved when known amounts of adsorbed gas probe molecules. The evolved heat is related to the energy of the bonds formed between the adsorbed species and the adsorbent. The data obtained of substantial value for comparing theoretical and experimental hypotheses about reaction pathways.



Differential heats of propane adsorption on differently dehydr. 10wt%V_xO_y/SBA15 at 313 K

Instrumentation

NANOSTRUCTURES

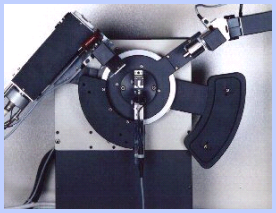
Dr. M. Behrens

Contact:
Dr. M. Behrens
behrens@fhi-berlin.mpg.de

Scaleable and reproducible preparation under controlled conditions is a prerequisite for knowledge-based catalyst design. Precursor phases, intermediates during the preparation process and the final catalyst have to be submitted to comprehensive characterization using various analytical tools. The facilities in the group include:

- **Automated laboratory reactor system** (Mettler-Toledo Labmax, photo) for controlled precipitation and ageing. Chemistry in solution and suspension can be monitored in-situ using probes for pH, conductivity, turbidity and UV-vis spectroscopy
- Lab scale (Mini Büchi B-191) and technical scale (Niro Minor Mobile, photo) **spray dryer** for rapid and continuous drying and solidification.
- Determination of **particle size distributions** and **zeta potentials** of suspensions (Malvern Zetasizer Nano).

- **Gloveboxes** for handling of reactive samples in inert atmosphere
- **Thermal analysis** in a thermobalance (Netzsch STA 449C Jupiter) with coupled mass spectrometry (Pfeiffer Omnistar) or with high pressure differential scanning calorimetry (HP DSC 827e, Mettler-Toledo)
- **Temperature programmed desorption or reaction** in various gas atmospheres (TPDRO 1100, CE instruments) with thermal conductivity detector or coupled mass spectrometry (Pfeiffer Omnistar)



- **X-ray diffraction** (XRD) in transmission (STOE Stadi-P with autosampler) or reflection geometry (Bruker D8 Advance, photo)
- **In-situ X-ray diffraction** on a STOE theta-theta diffractometer equipped with a high temperature reactor chamber (Anton Paar XRK 900) with coupled mass spectrometry (Pfeiffer Omnistar)

MICROSTRUCTURE

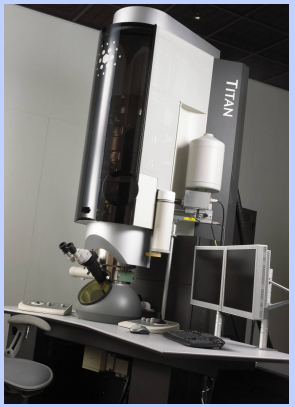
Dr. D. S. Su

Contact:
Dr. D. S. Su,
dangsheng@fhi-berlin.mpg.de

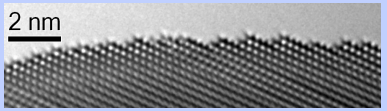
For microstructural investigations, 5 electron microscopes are available.

Morphological studies in vacuum or at low pressures are carried out in a FEI Quanta 200 FEG scanning electron microscope (SEM). This machine is capable of operating at pressures up to 4000Pa and has a resolution of ca. 1.2nm at 30kV acceleration voltage. The Quanta FEG SEM features a heating stage for conducting experiments at elevated temperatures. For morphological studies, a Hitachi S-4800 scanning electron microscope is used. This machine has a resolution of approx. 1.4nm/0.8nm at 1kV/30kV and features various types of detectors. For structural studies, transmission electron microscopy (TEM) is applied. For general studies a Philips CM200 LaB6 with an information limit of ca. 2Å is used. For higher resolution work, a Philips CM200 with a field emission gun is available. This microscope has an information limit of about 1.4Å.

For Sub-Ångstrøm resolution work, an aberration-corrected FEI Titan 80-300 is available. This microscope has an information limit of ca. 0.8Å. The CM200 FEG and the Titan are both equipped with a Gatan Tridiem energy filter (GIF) for acquiring energy-loss spectra (EELS) and energy-filtered images, with an energy resolution <1eV and <0.8eV respectively. All electron microscopes are equipped with EDAX Genesis energy-dispersive X-ray spectrometers (EDS). A well-equipped laboratory is available for preparation of TEM and SEM samples. For the quantitative chemical analysis of macroscopic bulk materials, powders and fluids, wavelength dispersive X-ray fluorescence spectrometry (WDXRF) is used.



FEI Titan 80-300 aberration corrected TEM.



Surface of a silver particle imaged using an aberration corrected TEM.

Understanding catalysis

Why in-situ analysis ?

The department AC has continued its activities centred on heterogeneous catalysis at the interface between fundamental studies of model systems and applied catalysis involving technical systems, practical catalyst synthesis and „real“ reaction conditions. In this large field of scientific activity the department concentrates on in-situ functional analysis and defined material synthesis.

A **concept** of heterogeneous catalysts is developed linking the surface chemistry of the substrate (the desired process) with the material chemistry of the catalyst (an „invisible“ process).

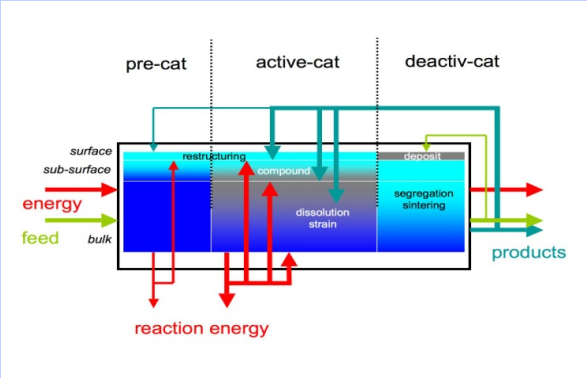
The **key** feature in the concept is the acknowledgement of the essential role of structural dynamics of an active catalyst (has been evidenced by numerous phenomena) under high performance operation conditions.

The essential role of structural dynamics is scientific justification for the use of **in-situ methods** and for the enormous experimental resources required for this kind of catalysis research.

The **aims** of this research are a generic definition of structural dynamics as well as the evolution of synthesis concepts for suitable materials (inorganic target synthesis). A core point is the confirmation of the observation that the optimal function of a catalyst is linked to one well-defined material as opposed to intended or unintentional mixtures of systems.

Working catalyst

alter the structure of the operating catalyst



Schematic representation of a catalyst operating at low performance (model) conditions (pre-cat), at high performance conditions and in deactivated forms. The arrows indicate feedback processes to different compartments of the catalyst. The scheme applies to bulk systems. Similar feedback structures can be constructed for supported systems.

The working catalyst is characterized by the conversion of a low-active precursor phase into a highly active metastable active state through processes of restructuring. These processes are driven by sub-surface chemistry of reactant fragments being incorporated into the catalyst material, a process fuelled by the excess energy liberated during substantial transformation of the educts. The metastability induced by operation in the active mode is expression of the fact that highly reactive systems are far apart from their thermodynamic equilibrium. The price for this evolution is the propensity of the active phase to deactivate through phase transformations (redox processes, segregation or sintering). It is the “art” of catalyst synthesis to select composition and real structure such, that the transformation of the pre-catalyst into the active phase is as facile as possible during the process of “activation“ and that the subsequent equilibration into the thermodynamically stable situation through „deactivation“ occurs as slowly as possible.
The extent to which surface science at low conversion and high structural definition can describe a catalytic reaction depends on the strength of coupling of the feedback loops into structure and stability of the material. A strong coupling will be the more needed, the more demanding the catalytic reaction is, i.e. the more other elementary steps than sorption of molecules control the reaction. Highly specific catalysts of complex chemical composition or delicate geometric structure (such as mixed oxides or nanoparticles) will react strongly on the changes in energy throughput and modification of the reactants chemical potential and thus exhibit strong coupling constants in the feedback loops shown above.

Scientific Progress

The Department AC is uniquely positioned at the crossroads of synthetic inorganic chemistry and metrology augmented by method development capabilities. Using these elements it seems possible to arrive at the development of truly rational synthesis procedures of nanostructured (defined in several dimensions of size) catalytic materials that can be used as intermediate systems to build the experimental bridge between complex technical and the present model systems. It will be necessary to develop in addition to the bare materials also suitable handling forms for in-situ experimentation such as thin films or nanocrystals. Such catalyst forms require the adaptation of testing environments to allow the novel systems to be used for static model experiments with validated functional performance.

The target of the Department that will be pursued in four of the research areas and one of the associated group:

Reactivity / Oxides: *"Mo-V compounds for C3,C4 oxidation"*

Nanostructures / Bulk structure : *"Cu, Pd in C1"*

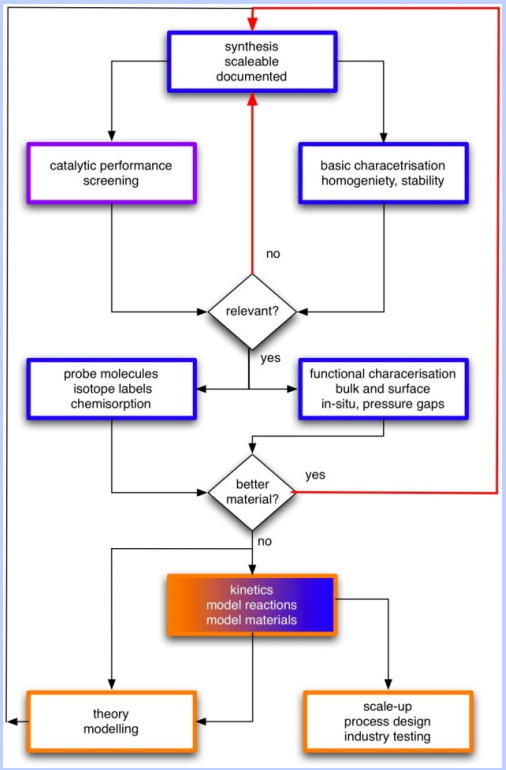
Electronic Structure and Adsorption / Metals: *"Metals in sel oxidation"*

Micro-and Nanostructure / Carbon: *"Nanocarbon in energy chemistry"*

Emmy-Noether-Group: *"High Temperature Catalysis"*

The target of the Department is the rational development of complex model systems. The current profile of the Department allows defining the choices of systems to be synthesized on the basis of in-situ observations of technical systems rather than on pragmatic arguments of nominal catalyst composition or availability of equilibrium phases of a compound catalyst.

Research concept



→ We study non-equilibrium systems: kinetics is all-important:
- optimize synthesis
- document quantitatively the synthesis (in-situ observations)
- thorough multi-method characterization including reactivity (probe molecule adsorption, thermal methods).

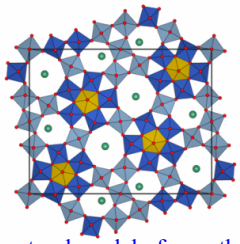
→ We are interested in generic effects: always reproduction of every single experiment.

→ We need quantitative results:
- multiple steady state kinetics
- pressure gaps, wide variations of process conditions
- quantification of structural data.

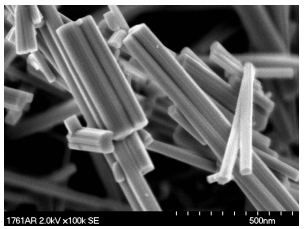
→ We want high-quality representation of results in graphics and images.

Scientific Progress

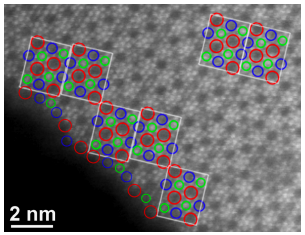
Nanostructured MoV catalysts in activation of light alkanes



1 Structural model of an orthorhombic MoVTeNbO$_x$ phase



2 SEM image of phase-pure M1

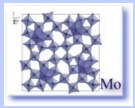


3 HRTEM image of M1 viewed along the <001> zone axis

Background and objective

The project is aimed at understanding the factors that primarily determine the reactivity of MoV oxide based catalysts in oxidative dehydrogenation and selective oxidation of C2-C4 alkanes to valuable olefins, unsaturated aldehydes or acids. The research analyzes similarities and specifics of these reactions addressing the effects of (i) molecular structure of active ensembles on the catalyst surface, (ii) structural motives in the catalyst framework, (iii) chemical and structural complexity, (iv) oxidation state of the elements under reaction conditions, (v) the collective electronic properties of the solid, and (vi) the dynamics of the catalyst surface under varying operation conditions.

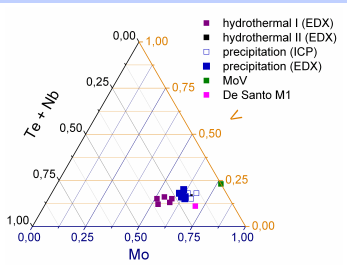
The oxidative dehydrogenation of propane is studied on supported vanadium and molybdenum oxides. Vanadium in turn is an essential constituent of crystalline phases such as vanadium phosphates or molybdenum oxide based bronze structures, which are active in selective oxidation of propane to acrylic acid. Furthermore, the redox system of molybdenum and vanadium is approached from the side of low oxidation states by synthesis of model carbide catalysts and the study of their reactivity in alkane conversions.



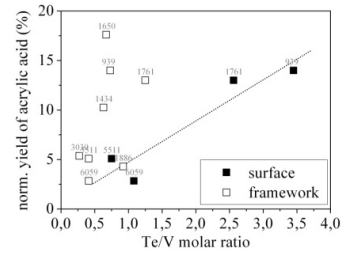
Results

Correlations between structural characteristics, surface termination and catalytic properties in selective oxidation of propane to acrylic acid have been studied over phase-pure MoVTeNbO$_x$ model catalysts consisting of an orthorhombic bronze-like phase denominated as M1 (ICSD 55097, **1-3**). The catalysts were prepared by hydrothermal synthesis. The chemical composition of M1 was varied resulting in homogeneous, isostructural materials within the phase width of the M1 structure (**4**). The yield of acrylic acid increases with decreasing percentage of Mo and increasing molar ratio of Te/V at the surface (**5**). In-situ XPS experiments revealed an enhanced mobility of Te especially in presence of water vapor. It is proposed that surface restructuring may provoke spatial isolation of vanadium containing active sites.

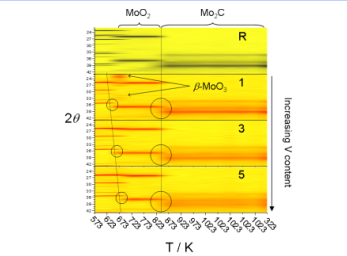
Starting from single phase mixed-metal oxide precursors such as *h*-(Mo,V)O$_3$ structures, M$_5$O$_{14}$-type oxides, (M=Mo,V,Nb), other oxidic bronzes and polyoxometallate species, a range of binary and ternary transition metal carbides with tunable compositions and nanostructures were synthesized by temperature-programmed reaction (**6**). The catalytic properties of the novel materials are explored in alkane conversions.



4 Phase width of M1



5 Yield of acrylic acid as function of the Te/V ratio in M1



6 Phase transformations during carburization monitored by in-situ XPS

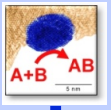
Contact:
Dr. Annette Trunschke
trunschke@fhi-berlin.mpg.de

External collaborations:
University Bonn (Prof. Dr. Glaum), MPI CPfS (Prof. Dr. Kniep), TU Berlin (Prof. Dr. R. Schomäcker)
University Malaya, Kuala Lumpur, Malaysia (Ass. Prof. Dr. Sharifah Bee Abd Hamid)

Financial support:
Südchemie AG
BMBF 033R028B

Scientific Progress

Copper and palladium catalysts in C1 chemistry



1 Methanol chemistry

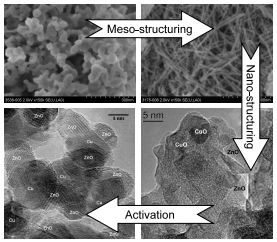
Methanol steam reforming

$CH_3OH + H_2O \rightarrow CO_2 + 3H_2$

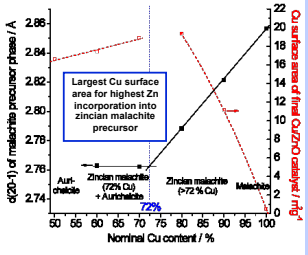
Methanol synthesis

$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$

2 Preparation of Cu/ZnO



3 Precursor effects



Cu/ZnO/(Al_2O_3) in methanol chemistry

Methanol is already one of the most important basic chemicals in chemical industry. Furthermore, it has the potential to act as a sink for the greenhouse gas CO_2 by chemical fixation. In the future, it might also serve as a chemical hydrogen carrier for mobile applications of fuel cells via the methanol synthesis and steam reforming reaction network (1). Nanostructured Cu/ZnO/Al_2O_3 is active in both reactions, but increasing demand and variations in feed gas composition require further optimization.

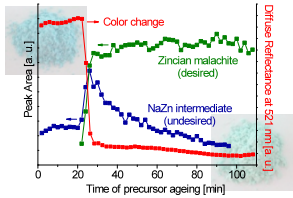
Goal of our work is to understand the industrially applied complex multi-step catalyst synthesis to establish a basis for further more rational optimization. We also develop new methods of preparation using novel precursor systems. Moreover, we aim at finding (micro) structure-performance relations to better understand the nature of catalytically active "methanol copper". Our approach is to comprehensively characterize the nano-structured ensemble present in highly active "real" catalysts using a variety of complementary (in-situ) methods in order to identify relevant features for catalytic performance.

Examples of results from our recent work are development of a hierarchical microstructure-directing model for catalyst preparation (2) based on a structure-property relationship found for the precursor phase of the catalyst (3), identification of a crystalline intermediate during precursor ageing by in-situ methods (4) and preparation of a novel catalyst material with very small Cu nano-particles and unique microstructure by application of the microemulsion technique for co-precipitation of CuZnAl hydrotalcite-like precursors (5).

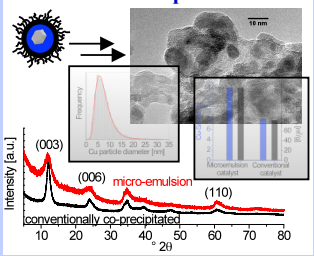
Intermetallic Pd/X catalysts (X=Ga, Zn, …)

Pd/X model systems have been successfully investigated in our department for several years. In order to transfer the fundamental results obtained on model samples to high performance catalysts, the focus of the work in the Nanostructure group is on exploring co-precipitation methods as routes to Pd-based intermetallic catalysts by application of similar preparative concepts as for Cu/ZnO. As first results, a nanoparticulate Pd_2Ga catalyst supported on MgO/Ga_2O_3 has been developed (6). The average size of the intermetallic particles is below 20 nm, which is impossible to achieve by conventional melt synthesis.

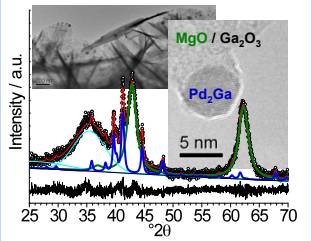
4 Chemistry of ageing



5 Microemulsion precursors



6 Pd_2Ga intermetallic catalyst



External collaborations (Cu):
Technical University Berlin (T. Ressler, R. Schomäcker)
Ruhr-University Bochum (M. Muhler)
University Malaya, Kuala Lumpur (Sharifah Bee Abd Hamid)
Süd-Chemie AG, Bruckmühl

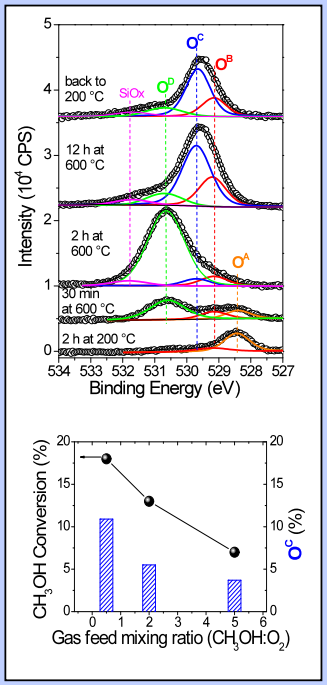
External collaborations (Pd):
MPI for Chemical Physics of Solids (Y. Grin, M. Armbrüster)
University of Innsbruck (B. Klötzer, S. Penner)
Technical University Vienna (G. Rupprechter)
Federal University of Rio de Janeiro, COPPE (M. Schmal)

Contact:
Dr. Malte Behrens
behrens@fhi-berlin.mpg.de

Scientific Progress

Silver in partial oxidation reactions

The remarkable catalytic activity of silver in partial oxidation reactions is known for decades. Particularly, the ethylene epoxidation and formaldehyde synthesis reactions are two industrially important processcess which received most attention. However, apart from the great effort done in the past years, there are still open questions about the mechanistic details of these reactions. It is well known that silver can accommodate many oxygen species depending on the temperature, partial pressure of gas feed, the structure and morphology of the silver catalyst , nevertheless, the role of these different species as active sites, or spectators in the catalytic reactions is not clear and sometimes even controversial in the literature.



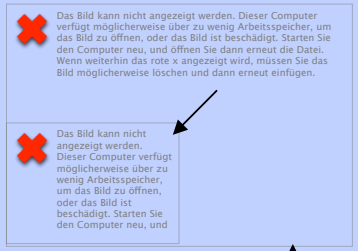
In order to shed some light on these questions, we have investigated Ag catalysts in equilibrium with gas phase under reaction conditions with pressures in the mbar range by *in situ* XPS.
The upper panel in the figure shows the oxygen 1s spectra of a Ag foil at different temperatures relevant for ethylene (200 °C) and methanol oxidation (600 °C) reactions. Briefly, four different oxygen species were identified with distinct binding energies, thermal stability and associated formation of ionic Ag.
The different thermal behavior and spectroscopic characteristics of these species arises from their dissimilar bonding with the Ag, which leads to different roles in oxidation reactions
For instance, under methanol oxidation reaction at 600 °C, the species named $\mathbf{O^A}$ is not present, $\mathbf{O^b}$ nearly vanishes, and $\mathbf{O^D}$ does not change. On the other hand, the species $\mathbf{O^C}$, which appears only at high temperatures under pure O_2, present a good correlation with the methanol conversion, as can be seen in the lower panel, which suggests its role as a relevant site for this reaction.

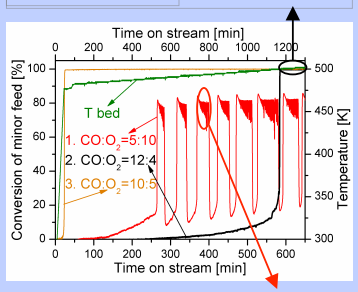
Contact:
Dr. Axel Knop-Gericke
knop@fhi-berlin.mpg.de

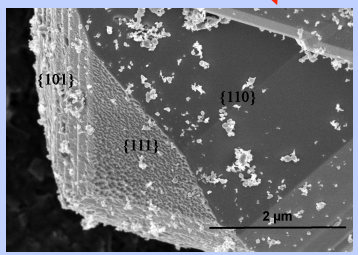
Scientific Progress

Oxygenated Ruthenium in oxidation reactions

CO-oxidation on oxygenated Ruthenium was believed to be an outstanding example for the pressure gap; very high activity under ambient pressure faced low activity in UHV. Two different phenomena were identified as reasons for this pressure gap by different research groups in the literature: the kinetically inhibited growth of RuO_2, namely the (110) surface and the also inhibited growth of a complete (1x1) oxygen monolayer. To shed some light on this highly controversial discussion we started our experiments with calcined RuO_2 which exhibits an “octagonal” habit and is completely inactive in the CO-oxidation. Consecutive experiments with varying feed composition (100 Nml/min total flow) show long induction periods in net-oxidizing and net-reducing feed. After activation in net-oxidizing feed still a long induction period is necessary in net-reducing feed. Oscillations occur only in the net-oxidizing feed (figure 2). While roughening of apical facets occur in net-reducing feed the net-oxidizing feed leads to faceting of apical surfaces (SEM, figs. 1 and 3, respectively).
Chlorine is one of the essential basic chemicals of the chemical industry, because a large portion of processes require at certain steps chlorine. On the large scale, it is produced using electrolysis of NaCl (or HCl) solutions and very recently by the heterogeneous gas phase oxidation of HCl (Deacon Process). Interestingly both processes rely on RuO_2-based materials! Currently, we are involved in characterizing materials used in the above processes and find that the surface-near region of the samples undergoes strong modification (phase changes, segregation) during reaction. We will apply in situ methods to identify the active state of "RuO_2" and to suggest possible routes to enhance reactivity or substitute Ru with cheaper alternatives.







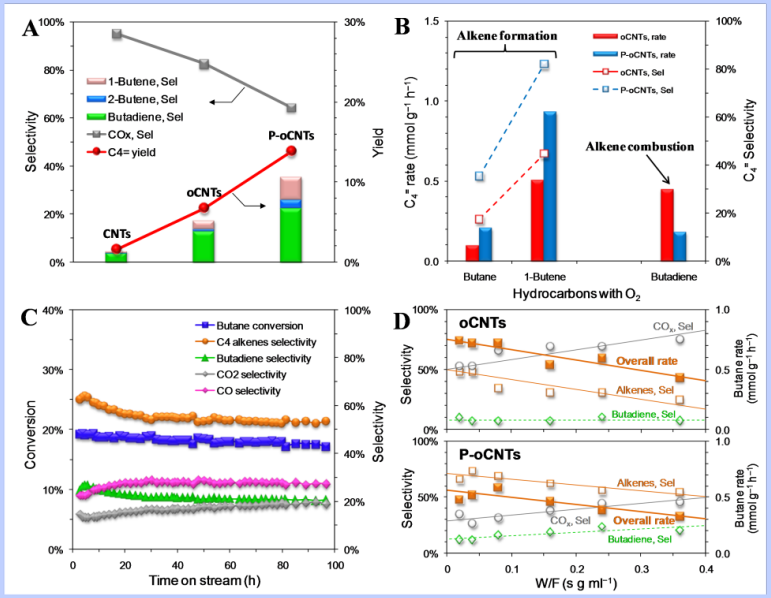
Contact:
Dr. D. Rosenthal, Dr. D. Teschner
dirkrose@fhi-berlin.mpg.de, teschner@fhi-berlin.mpg.de

Scientific Progress

Carbon in catalysis

Surface-Modified Carbon Nanotubes for Oxidative Dehydrogenation of *n*-Butane:

We show that carbon nanotubes with modified surface functionality efficiently catalyze the oxidative dehydrogenation of *n*-butane to butenes, especially butadiene. This process is mildly catalyzed by ketonic C=O groups and occurs via a combination of parallel and sequential oxidation steps. A small amount of phosphorus greatly improved the selectivity by suppressing the combustion of hydrocarbons. (Science Vol. 322, 73-77 (2008))



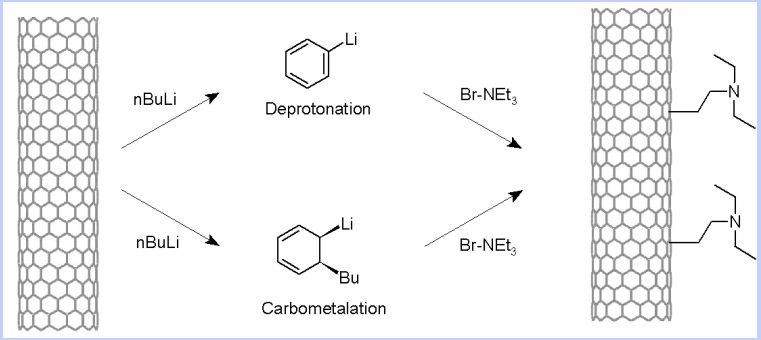
(A) ODH activities of various CNTs.
(B) Performance of modified CNTs in ODH of butane and 1-butene and in combustion of butadiene.
(C) Stability of P-oCNTs in ODH.
(D) Dependence of product selectivity and reaction rate on residence time.

Fe-Co Alloy Nanoparticles on Carbon Nanotubes for Ammonia Decomposition:

Fe-Co alloy nanoparticles were synthesized inside the tubular channel of CNTs. The prepared system shows an unusual synergism in alloy catalysis. The alloy nanoparticles with widely varying Co/Fe ratio are kept as active as Co for the H_2 production from NH_3 decomposition. The stability of Co was significantly improved by alloying with Fe. (Nano Letters, Vol. 8, 2738-2743 (2008))

Covalent Functionalization of Carbon Nanotubes with Amines and the Application as Basic Heterogeneous Catalyst for Biomass Conversions:

Amino groups have been grafted on CNTs by a simple, one-pot, deprotonation/ carbometalation reaction followed by an electrophilic substitution. This produces very homogeneous samples with a high number of easily accessible basic groups. The concentration of the basic groups is closed to the concentration of Brønsted acid sites in zeolites, without any optimization of the grafting procedure. The obtained samples are active for a typical biomass conversion to biodiesel.



Functionalization of CNTs by deprotonation/carbometaltion followed by the eletrophilic attack of the bromo-triethylamine.

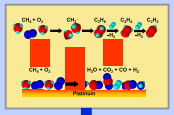
Contact:
Dr. Dangsheng Su
dangsheng@fhi-berlin.mpg.de

External collaborations:
European Laboratory for Catalysis and Surface Science (ELCASS)
further collaborations under L „External Funds“

Financial support:
European Union
Deutsche Forschungsgemeinschaft

Scientific Progress

High temperature catalysis research



The one step transformation of natural gas components like methane and ethane into valuable chemicals like methanol, formaldehyde, ethylene or synthesis gas (Fig. 1), is a formidable challenge for catalysis research and chemical engineering in the 21st century. Heterogeneous catalytic alkane oxidations at high temperatures and pressures might be a way to accomplish these transformations provided that it is possible to optimize the interaction between reactions at the catalyst surface and in the surrounding gas phase and to maximize the kinetically controlled formation of partial oxidation products.

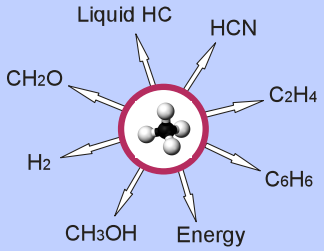


Fig. 1

Fig. 2

The research in our high temperature catalysis project aims at a mechanistic understanding of chemical and physical surface gas interactions in catalytic alkane oxidations on various catalysts (metals, oxides) under high temperature (up to 1300 °C) and high pressure (up to 5 MPa) conditions. Novel in-situ diagnostic techniques like Spatial Profile Measurements, Raman Spectroscopy, Cavity Ringdown Spectroscopy and Molecular Beam Mass Spectrometry (MBMS, Fig.2) are developed and applied in the project to provide insight into surface and gas phase chemistry under high temperature, high pressure reaction conditions. In the future, experimental results will be compared to microkinetic numerical simulations coupling detailed surface and gas phase reaction models with physical transport mechanisms of mass, heat and momentum.

Results: The methane oxidation on Pt has been investigated both, on α-Al_2O_3 foam catalysts coated with Pt nanoparticles (reticulated pore structure, $d_{pore} \approx$ 300-500µm, Fig. 3) and polycrystalline Pt tubes with 4.4mm inner diamater (Fig. 4).

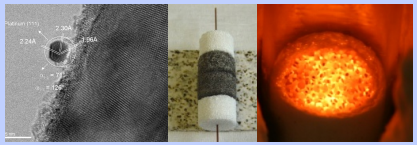


Fig. 3

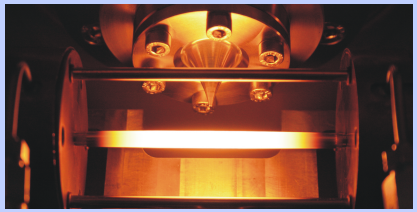


Fig. 4

Reactor measurements on the foam catalysts with a geometric surface to volume ratio of about 160cm^{-1} show H_2, CO, H_2O and CO_2 as reaction products. Spatially resolved species and temperature profiles (Fig. 5) reveal that these products are formed at the Pt surface by partial and total oxidation of methane followed by steam reforming. CO_2 reforming is not observed.

Methane oxidation in a Pt tube with only ~7cm^{-1} surface to volume ratio leads at temperatures below 1100°C also to H_2, CO, H_2O and CO_2. However, above 1100°C surface temperature, a sudden formation of C2 products (C_2H_6, C_2H_4, C_2H_2) is observed (Fig. 6). Quantitative measurements of gas phase CH_3· radicals reveal the onset of gas phase chemistry at this point. C2 products are obviously formed by reaction of CH_3· radicals with CH_4 molecules in the gas phase and subsequent dehydrogenation. H_2, CO, H_2O and CO_2 are formed by surface oxidations supplying heat to drive the gas phase chemistry.

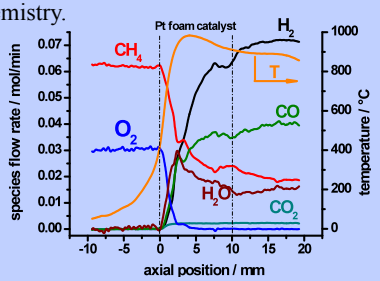


Fig. 5

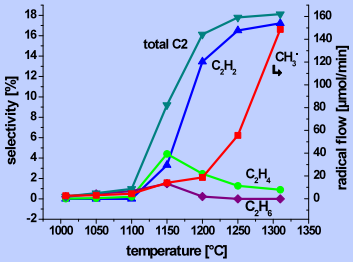


Fig. 6

Contact:
Dr. Raimund Horn
horn_r@fhi-berlin.mpg.de

External collaborations:
Cluster of Excellence „Unifying Concepts in Catalysis – UniCat “
Prof. Lanny D. Schmidt, Deptartment of Chemical Engineering and Materials Science, University of Minnesota, USA

Financial support:
BMBF
German Research Foundation

FHI Library

FHI Library

collects special literature covering the research fields of the institute. The library has about 15.500 monographs and 32.000 journal volumes. In addition, the library offers about 30.000 currently subscribed electronic journals, most of them based on central MPG agreements. The range of electronic services of the FHI Library includes various databases, access terms and conditions for e-journals as well as catalogues. Therefore, the qualified library personnel will remain indispensable also in the new age of electronic „libraries without walls“. The acceptance of electronic media is very high within the FHI due to constant efforts and the regular training of the users.
The traditional services as interlibrary loan service, acquisition of books and other information material, literature searches and reader service are also available. Furthermore, the library participates in the development and maintenance of the Max Planck Virtual Library (VLib).

Max Planck Virtual Library (VLib)

Max Planck Virtual Library VLib

This system is a portal to various information resources available to members and guests of the Max Planck Society. To support that system the library is giving feedback to VLib by intensely testing the user interface and integrating library catalogs that run with the library system Allegro. In addition, the library prepares manuals and offers seminars for colleagues (train the trainer) and for FHI scientists.

External Collaborations

The library cooperates with various institutions, for example with:

- libraries of other Max Planck Institutes
- libraries of Fraunhofer Institutes and Institutes of the Helmholtz Society
- university libraries in Berlin and Brandenburg
- local bookshops and international publishers

Open Access

Open Access @ Max Planck Society

The library is constantly monitoring the publication market, especially in respect of to new trends, e.g. Open Access. The FHI is practicing open access to scientific results as stated in the „Berlin Declaration on Open Access to the Knowledge in the Sciences and Humanities“ in two ways: Publication in Open Access Journals and institutional self-archiving on the eDoc Server. Currently about 1400 open access documents from FHI scientists are available on the eDoc Server.
In July 2009 the library arranged a seminar on ‘Open Access and Author Rights’ (http://www.fhi-berlin.mpg.de/bib/news/oa_authorrights.epl).
The library attended with some activities on the International Open Access Week in October 2009 (http://www.openaccessweek.org/).

eDoc Server

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Contact:
Uta Siebeky
siebeky@fhi-berlin.mpg.de

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Inventors: R. Schloegl, H. Werner, M. Wohlers

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"Process for the disposal of halogenated hydrocarbons"
Inventors: C. Scholz, W. Holzinger, R. Schloegl

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„Preparation of methacrylic acid"
Inventors: F. Rosowski, H. Hibst, R. Schloegl, D. Herein, S. Berndt

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Inventors: R. Schlögl, Th. Ressler, F. Giergsdies, H. Purnama, R. Schomaecker, M. Antonietti, J.H. Schattka, Y. Wang, R. Caruso

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Inventors: Z. Zhu, D. Su, R. Schlögl

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Inventors: R.Schlögl, S.B. Abd Hamid

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"Catalyst comprising nanocarbon structures for the production of unsaturated hydrocarbons"
Inventors: R. Schlögl, G. Mestl

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Inventors: R. Schlögl, T. Ressler, R. Jentoft

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Inventors: J. Osswald, R. Giedigkeit, M. Armbrüster, K. Kovnir, R.E. Jentoft, T. Ressler, Yu. Grin, R. Schlögl

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Inventors: R. Schlögl, S.B. Abd Hamid

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Inventors: M. Armbrüster, M. Schmidt, K. Kovnir, M. Friedrich, K. Weinhold, Yu. Grin, R. Schlögl

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Inventors: DS. Su, J. Zhang, R. Schlögl, J. Maier

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"Novel synthetic route to mesostrcutured MoVTe mixed oxide"
Inventors: R. Schlögl, A. Trunschke

Application USA 2008
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Inventors: O. Timpe, S. Ayyamperiumal. A. Trunschke, R. Schlögl

EP submission 08167109.1, 10/ 2008
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Inventors: R.Schlögl, A. Trunschke, O. Timpe, A.C. Sanfiz

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"Bi-modified Mo-V-Nb mixed oxide catalyst"
Inventors: R.Schlögl, A. Trunschke, O. Timpe, A.C. Sanfiz

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Inventors: M. Armbrüster, M. Schmidt, K. Kovnir, M. Friedrich, K. Weinhold, Yu. Grin, R. Schlögl

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Inventors: M. Armbrüster, K. Kovnir, Yu. Grin, R. Schlögl, P. Gille, M. Heggen, M. Feuerbacher

Guest - lectures
2004 - 2009

Date	Guest - Lecturer	Titel
12. 02.2004	**Dr. Frank Ogletree** Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, USA	Oxygen on Pd(111) investigated with variable temperature STM and in-situ photoemission
31. 03.2004	**Dr. Cécile Hébert** Institut für Festkörperphysik , TU Wien, Austria	New aspects of the reduction of V_2O_5 in the TEM
18.05.2004	**Prof. Dr. Lanny Schmidt** Dept. of Chemical Engineering and Material Sciences, Univ. Minneapolis, USA	Hydrogen from Fossil and Renewable Fuels by Autothermal Reforming
09.06.2004	**Dr. Martin Steinhart** Max Planck Institute of Microstructure Physics, Halle	Template wetting - a modular assembly for 1D nanostructures
03.11.2004	**Prof. Dr. Joachim Mayer** Gemeinschaftslabor für Elektronenmikroskopie, RWTH Aachen und Ernst Ruska-Centrum für Mikroskopie und Spektroskopie mit Elektronen am Forschungszentrum Jülich	Hochauflösende analytische TEM und ihre Anwendungen in der Nanowissenschaft
15.11.2004	**Prof. Dr. Freek Kapteijn** Reactor and Catalysis Engineering, DCT-TU Delft, The Netherlands	Catalysis Engineering - putting Science into Practice
01.12.2004	**Prof Dr. H. Kuzmany** Institut für Materialphysik, Universität Wien	Physics and Chemistry Inside Carbon Nanocages

Date	Guest - Lecturer	Titel
05.01.2005	**Dr. Harry Bitter** Department of Inorganic Chemistry, Debye Istitute, Universiteit Utrecht	Tunable carbon nanofibers based catalysts - synthesis, characterization and catalysis

Date	Speaking Guest	Titel
24.01.2005	**Dr. A. Barinov** Sincrotrone Trieste	Electron Confinement Effect on the Reactivity of Thin Mg Films
23.03.2005	**Prof. Dr. M. Rühle** MPI für Metallforschung, Stuttgart	Nanoanalysis of materials by TEM techniques
06.04.2005	**Prof. Dr. J. W. Niemantsverdriet** Schuit Institute of Catalysis, Eindhoven University of Technology	Planar Models of Supported Catalysts for Polymerization
15.06.2005	**Prof. Dr. Pérez Omil, José A.** Solid chemistry and Catalysis group; Inorganic Department; University of Cadiz	Contributions of Electron Microscopy to Understanding the Redox Behaviour of Ce-based catalysts
13.07.2005	**Prof. Francesca Porta** Dip. Chimica Inorganica Metallorganica ed Analitica Via Venezian 21, 20133 Milano, Italia	Preparation of metallic sols dedicated to catalysis and biology: Properties and applications
27.07.2005	**Prof. Michael Giersig** Forschungszentrum Cesaer, Bonn	Fabrication of Nanoscale Rings, Dots, and Rods by Combining Shadow Nanosphere Lithography and Annealed Polystyrene Nanosphere Masks
07.09.2005	**Prof. Dr. Bo-Qing Xu** Department of Chemistry, Tsinghua University, Beijing, China	New approach for the preparation of advanced heterogeneous metal catalysts
21.09.2005	**Prof. Norbert Kruse** Université Libre de Bruxelles Chimie-Physique des Matériaux,	Catalytic and Non-catalytic Surface Reaction at the Atomic Scale
12.10.2005	**Dr. Gang Hu** Inorganic Chemistry Laboratory, South Parks Road, Oxford OX1 3QR, U.K.	Some Progresses in LDHs Chemistry: From a Synthetic Point of View

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Guest - lectures

2004 – 2009

Date	Speaking Guest	Titel
02.11.2005	**Prof. Archie Howie** Cavendish Laboratory, University of Cambridge, U.K.	Magnifying the Contribution of Electron Microscopy to Catalyst Characterization
09.11.2005	**Dr. Karoly Lázár** Institute of Isotope and Surface Chemistry, Chemical Research Centre of the Hungarian Academy of Sciences	In situ Mossbauer spectroscopy in catalysts studies
23.11.2005	**Prof. Dr. K.-P. Dinse** Phys. Chem. III, Darmstadt University of Technology	Multifrequenz EPR in Chemie und Materialwissenschaften
07.12.2005	**Dr. Frederic Goettmann** Max Planck Institute for Colloids and Interfaces	Zirconium rich mesoporous powders in catalysis, more than just a support
21.12.2005	**Prof. Julie L. d'Itri** Department of Chemical Engineering, University of Pittsburgh	Controlling the Rate of more than One Elementary Reaction Step with One Surface

Date	Speaking Guest	Titel
04.01.2006	**Dr. Maja Mrak** National Institute of Chemistry and University of Ljubljana	New mesoporous catalysts
11.01.2006	**Dr. Thierry Visart de Bocarmé** Université Libre de Bruselles	Catalytic Surface Reactions on the Atomic Scale
18.01.2006	**Prof. Dr. Guido Busca** Department of Chemical and Process Engineering, University of Genova,	On the use of CO and nitriles as probe molecules in the IR characterization of different catalysts (oxides, supported metals, zeolites)
25.01.2006	**Dr. Polona Umek** Institute "Jožef Stefan",Ljubljana, Slovenia	Impact of Structure and Morphology of Titanate-Based Nanotubes and Nanoribbons Effect on Gas Adsorption of NO_2
29.03.2006	**Prof. Dr. Silvana Fiorito** LCVN-CNRS, Universite Montpellier	Toxicity of Carbon nanoparticles towards human cells
30.03.2006	**Dr. Cécile Hébert** Inst. f. Festkörperphysik, TU Wien	Low Loss EELS and the measurment of optical properties

Date	Speaking Guest	Titel
06.04.2006	**Dr. Jean-Pierre Candy** CPE-Lyon, CNRS, France	Surface Organo-Metallic Chemistry on Metals: Genesis, Characterization and Application
12.04.2006	**Prof. Dr. Arne Andersson** Department of Chemical Engineering, University, Lund, Sweden	The V-Sb-W-Al- and Mo-V-Nb-Te-oxide systems for propane ammoxidation
09.05.2006	**Prof. Hengyong Xu,** Dalian Institute for Chemical Physics, Chinese Academy of Science	Novel Technologies for Palladium Membrane Preparation and Hydrogen Production
14.06.2006	**Prof. Dr. Daniel Resasco** University of Oklahoma School of Chemical, Biological and Materials Engineering	Controlled Growth of SWNT on Solid Catalysts with Narrow (n,m) Distribution
21.06.2006	**Prof. Panagiotis Smirniotis** Chemical & Materials Engineering Department, University of Cincinnati	Molecular Sieve-based Photocatalysts for Photodegradation Reactions of Organics
23.08.2006	**Prof. Dr. Serafin Bernal** University of Cadiz, Spain	Nano-structural properties and redox behaviour of ceria-zirconia mixed oxides"
13.09.2006	**Prof. Dr. Helmut Knözinger** Ludwig-Maximilians-Universität München , Department of Chemie, Physikalische Chemie	n-Pentan-Isomerisierung an promotierten WZr-Katalysatoren
15.09.2006	**Dr. Michel Daage** ExxonMobil Research and Engineering, USA	Modeling Catalysts: An Experimentalist Point of View
29.09.2006	**Dr. Konstantinos Fostiropoulos** Hahn-Meitner-Institut Berlin GmbH	Organic nano-structures for photovoltaic applications
02.10.2006	**Prof. Dr. Hui Gu** Chinese Academy of Sciences , Shanghai Institute of Ceramics	Quantitative EELS analysis of grain boundary and Interface
18.10.2006	**Prof. Dr. Florian Banhart** Institut für Physikalische Chemie, Johannes Gutenberg-Universität Mainz, Germany	Carbon Onions and Nanotubes as Nanolaboratories in the Electron Microscope

Guest - lectures

2004 - 2009

Date	Speaking Guest	Titel
22.11.2006	**Prof. Feng-shou Xiao** Jilin University, Changchun, China	Hydrothermally Stable Mesoporous Materials and Functionality of Catalytically Active Species in Mesoporous Materials
29.11.2006	**Prof. Krijn P. de Jong** Inorganic Chemistry and Catalysis, Department of Chemistry, Utrecht University, The Netherlands	Fundamental Studies on the Preparation of Supported Catalysts

Date	Speaking Guest	Titel
10.01.2007	**Dr. Xiaoming Ren** Acta S.p.A., Crespina (PI) - Italy	Non-Pt catalysts for advanced direct alcohol fuel cells
17.01.2007	**Prof. Claus Hviid Christensen** Technical University of Denmark, Center for Sustainable and Green Chemistry, Department of Chemistry	Rational Approaches to Catalyst Design and Discovery
23.01.2007	**Prof. Zhenping Zhu** Institute for Coal Research, Chinese Academy of Science, Taiyuan, China	Construction, mechanism and properties of nanostructures
24.01.2007	**Dr. Vincent Huc** Université Paris – ORSAY	Beyond the C60: from Calixarenes to metallic nanoparticules
07.02.2007	**Prof. Jürgen Behm** Abt. Oberflächenchemie und Katalyse, Universität Ulm	Electrocatalysis in Polymerelectrolyte Fuel Cell: Problems, Challenges and New Developments
15.02.2007	**Dr. Frank de Groot** Department of Chemistry, Utrecht University , Netherlands	New X-ray spectro-microscopic techniques for the in-situ study of heterogeneous catalysts
28.02.2007	**Dr. Susana Valencia** Instituto de Tecnología Química (UPV-CSIC), Valencia	New trends in the synthesis of zeolites
25.04.2007	**Dr. Xinyu Xia** Industrial Chemistry, Ruhr-University Bochum, Germany	Temperature-Programmed Desorption from Porous Materials in a Flow Set-up: Experiments and Simulation
08.05.2007	**Prof. Tao Zhang** Dalian Institute of Chemical Physics, Dalian, China	Catalysis for aerospace applications

Date	Speaking Guest	Titel
09.05.2007	**Prof. Dmitry Yu. Murzin** Laboratory of Industrial Chemistry, Abo Akademi University, Turku, Finland	Challenges in developing catalysts for cleaning exhaust gases from diesel engines: HC-SCR of NOX
13.06.2007	**Dr. Bruno Chaudret** Toulouse, CNRS, France	Organometallic Nanoparticles: Synthesis and Surface Chemistry
11.07.2007	**Dr. Christophe Coperet** CNRS, France	Design and understanding of heterogeneous olefin metathesis catalysts
18.07.2007	**Prof. Michael Köhler** TU Ilmenau, Germany	Micro fluid segment technique for miniaturized synthesis and screening
12.09.2007	**Prof. Valerii I. Bukhtiyarov,** Boreskov Institute of Catalysis, Novosibirsk, Russia	Size effects of supported nanoparticles in catalysis
12.12.2007	**Dr. Juan P. Holgado Vázquez** Instituto de Ciencia de Materiales de Sevilla (Univ. Sevilla - CSIC)	Strategies for design nanostructured catalysts: from real materials to model systems

Date	Speaking Guest	Titel
21.02.2008	**Prof. Lanny D. Schmidt** Dept. of Chemical Engineering and Materials Science, University of Minnesota, Minneapolis	Catalytic Autothermal Reforming of Renewable Fuels at Millisecond Times
13.03.2008	**Dr. Nicola Pinna** Laboratorio Associado CICECO Universidade de Aveiro Campus Universitario de Santiago	Non-aqueous sol-gel routes to nanostructured metal oxides
02.04.2008	**Dr. Stephan Hofmann** Centre for Advanced Photonics and Electronics, Uni. of Cambridge, UK	Catalyst Dynamics during Carbon Nanotube and Si Nanowire CVD
16.04.2008	**Prof. E. Joseph Nordgren** Uppsala University, Physics Dept., Sweden	Soft X-ray fluorescence and resonant inelastic scattering for materials and chemical physics
28.04.2008	**Dr. Jan Haubrich** Dept. of Chemistry and Chemical Biology, Harvard University	Adsorption, Wechselwirkung und Reaktivität von Aldehyden und Alkenen mit Legierungsoberflächen und Oxiden

K

Guest - lectures

2004 - 2009

Date	Speaking Guest	Titel
30.04.2008	**Prof. Theodor Doll** Johannes Gutenberg-Universität Mainz und dem Institut für Mikrotechnik Mainz GmbH	The Electroadsorptive Effect in Fully Depleted Metal Oxide Film Gas Sensors
11.06.2008	**Dr. Fachri Atamny** OC Oerlikon Balzers Ltd, Solar	Photovoltaic Solar: Market and Technology Trends
02.07.2008	**Dr. Wolfgang Kleist** Institut für Chemie- / Bioingenieur-wiss., ETH Zürich, Schweiz	Modified Metal-Organic Frameworks - Synthesis, Properties and Potential in Catalysis
09.07.2008	**Prof. Michael Smith** Villanova Univ., Villanova, PA, USA	Order on what scale? Studies in the structure of porous carbons and mesoporous silicates
10.07.2008	**Prof. Shriram Ramanathan** School of Engineering and Applied Sciences, Harvard Uni., Cambridge	Structure-Property relations in ultra-thin fluorite metal-oxides
29.07.2008	**Prof. Laurent Duda** Uppsala University, Sweden	Resonant inelastic soft x-ray scattering as a tool for studying chem. processes in situ
30.07.2008	**Prof. Josef Breu** Lehrstuhl fuer Anorganische Chemie I, Uni. Bayreuth, Germany	Colloids and Hybrids
13.08.2008	**Dr. Karen Wilson** Uni. of York, Dept. of Chemistry	Recent developments in environmental catalysis
27.08.2008	**Prof. Konstantin I. Hadjiivanov** Institute of General and Inorganic Chemistry, Bulgarian Academy of Sciences	IR Spectroscopy of Isotopically Labelled Surface Species
03.09.2008	**Prof. Jean Marie Basset** Laboratoire de Chimie Organométallique de Surface, Villeurbanne, France	Surface organometallic chemistry: a predictive approach of heterogeneous catalysis?
17.09.2008	**Prof. Leon Lefferts** University of Twente, Catalytic Processes and Materials Group	Heterogeneous catalysis in liquid phase; Fundamental and engineering challenges
01.10.2008	**Prof. Robert Glaum** Institut für Anorganische Chemie, Universität Bonn, Germany	Ein Festkörperchemiker auf Abwegen

Date	Speaking Guest	Titel
22.10.2008	**Prof. Rüdiger Kniep** MPI für chemische Physik fester Stoffe, Dresden/Germany	Apatit-Gelatine-Nanocomposites (aus dem Reich der Borophosphate)
05.11.2008	**Prof. Juri Grin** Chemische Metallkunde, MPI für chemische Physik fester Stoffe, Dresden/Germany	Intermetallic compounds and redox reactions
09.12.2008 10.12.2008	**Prof. Gabor A. Somorjai** Department of Chemistry and Lawrence Berkeley National Laboratory, University of California, Berkeley, USA	**Winner of the Gerhard Ertl Lecture Award 2008** Molecular Foundations of Heterogeneous Metal Catalysis

Date	Speaking Guest	Titel
21.01.2009	**Prof. Douglas J. Buttrey** Center for Catalytic Science and Technology, Department of Chemical Engineering, Univ. of Delaware/USA	Using Aberration-Corrected STEM Imaging to Explore Chemical and Structural Variations in the MoVNbTeO and Related Systems
13.05.2009	**Prof. Claude F. Goldsmith** Massachusetts Institute of Technology, Department of Chemical Engineering, Cambridge MA, USA	Predicting Combustion Properties of Hydrocarbon Fuel Mixtures
03.07.2009	**Dr. E. Emilio Bunel** Director Chemical Sciences and Engineering Division Argonne, National Laboratory Argonne/USA	Applications of Homogenous Catalysis to the Pharmaceutical Industry
14.07.2009	**Prof. Alberto Morgante** Laboratorio Nazionale TASC-CNR-INFM, Trieste Italy and Physics Dapartment Trieste University, Italy	Resonant photoemission spectroscopy in organic thin films
21.08.2009	**Prof. Dan V. Goia** Clarkson University/Center for Advanced Materials Processing, Potsdam, NY/USA	Highly dispersed uniform metallic particles: Preparation and Applications
21.08.2009	**Prof. Brent H. Shanks** NSF Engineering Research Center for Biorenewable Chemicals, Iowa State University/USA	Biorenewable Chemicals: Creating a Generalized Production Paradigm

External Funds

Project Name	Akronym	Referenz No.	Funds´ Provider	Funding Period	Project Leader at FHI	Cooperation Partner	Coordinator
"Upgrading of natural gas and palm oil to higher added value speciality chemicals using combinatorial technologies and catalysis"	COMBICAT	PS 681	University of Malaya	2002 - 2009	Prof. Dr. R. Schlögl Dr. A. Trunschke	Prof. Dr. S. B. Abd Hamid	Prof. Dr. S. B. Abd Hamid
Integrated Design of Nanostructured Catalytic Materials for a Sustainable Development ERIC provides services to improve effectiveness of research	IDECAT / ERIC European Research Institute on Catalysis (ERIC)	PSFHI 805	European Union	2005 – 2010 ERIC -Nov. 2008	Prof. Dr. R. Schlögl	Prof. H.J. Freund Prof. M. Scheffler Prof. M. Reetz Prof. F. Schüth and other (17 European partners) http://.idecat.org	Prof. Dr. G. Centi
In situ Characterization of Propene Oxidation Catalysts and Catalysis	Sumitomo	PS 251	Sumitomo Chemical Co., Ltd	1.10..2004 - 2009 continuing	Prof. Dr. R. Schlögl Dr. A. Knop-Gericke	Prof. Dr. Hiroshi Yamachika (Japan)	Prof. Dr. R. Schlögl Prof. Dr. Hiroshi Yamachika
ENERCHEM Nanochemical Concepts for a Sustainable Energy Supply Projects of Max Planck Institutes	ENERCHEM	M.IF.A.FHI 08025	MPG	2005 - 2010	Prof. R. Schlögl Dr. D. S. Su	Prof. F. Schüth (MPI für Kohleforschung), Prof. J. Maier (MPI für Festkörper-forschung), Prof. K. Müllen (MPI für Polymerforschung)	Verbundprojekt
Oxidnitride des Zirconiums als Materialien und Modellverbindungen für die katalytische Aktivierung von Ammoniak	DFG	SCHL 332/9-2	Deutsche Forschungs-gemeinschaft	23.10.2006 continuing	Prof. R. Schlögl	Prof. M. Lerch Prof. R. Schomäcker	Prof. T. Ressler
Mischoxide		PSFHI 253	Südchemie	2007 - 2010	Prof. Dr. R. Schlögl Dr. A. Trunschke	Südchemie AG	Prof. Dr. S. B. Abd Hamid
Joint project with Bayer AG Teilprojekt AP1: “Aufklärung, Reaktionsmechanismus und Optimierung des bestehenden Katalysatore”	CarboScale	PSFHI 105	BMBF Fkz: 03X0040H	2007 - 2012	Prof. Dr. R. Schlögl Dr. D.S. Su Dr. J. P. Tessonnier	TU Berlin Ruhr-Uni. Bochum Univ. Erlangen Univ. Clausthal Future Carbon GmbH Bayer Ehrfeld Mikrotechnik - BTS GmbH Leibnitz-Inst, Dresden TU Ilmenau Frauenhofer-Gesellschaft München H. C. Starck GmbH	Bayer

External Funds

Project Name	Akronym	Referenz No.	Funds´ Provider	Funding Period	Project Leader at FHI	Cooperation Partner	Coordinator
"Unifying Concepts in Catalysis", application to become Cluster of Excellence 	CoE Unicat	PSFHI 770	German Federal and State Governments to Promote Science and Research at German Univ.	starting 2007	Prof. R. Schlögl Prof. H.J. Freund Prof. G. Meijer Prof. M. Scheffler	http:// www.unicat.tu-berlin.de **http://www.unicat.tu-berlin.de**	Prof. M. Driess (TU Berlin)
International Partnership for Research and Education: "Molecular Engineering for Conversion of Biomass derived Reactants to Fuels, Chemicals and Materials"	PIRE	MPG		2012	Prof. R. Schlögl Dr. M. Behrens (host German site)	Prof. M. Antonietti Prof. M. Scheffler Prof. R. J. Davis Prof. J. A. Dumesic Prof. M. Neurock Prof. B. Shanks Prof. C. Christensen Prof. I. Chorkendorff Prof. J. K. Nørskov Prof. S. Hellweg	Prof. A.K.Datye (Univ.of New Mexico)
Elektroden-Charakterisierung	FuEV	PSFHI 254	Bayer AG 	1.7.2007 – 20.6.2009 continuing	Prof. R. Schlögl	Prof. R. Schlögl (FHI der MPG) Prof. R. Schomäcker (TU Berlin)	
Struktur, Dynamik und Reaktivität von Übergangsmetalloxid- Aggregaten	Sfb	Sfb 546	Sonder-forschungs-bereich	2000 - 2010	Prof. Dr. R. Schlögl	Prof. H.J. Freund Prof. R. Schomäcker Prof. Schubert	Prof. Dr. J. Sauer
Nanocarbon – Nanocarbon related materials in heterogeneous catalysis	ELCASS II 	M.AP.AFHI 00001	MPG and CNRS (Centre nationale de la recherche scientifique)	2004 - 2010	Dr. D. S. Su	Prof. G. Centi Dr. Cuong Pham-Huu Prof. M. Ledoux Prof. F. Garin	Dr. D. S. Su
1)Electron microscopy study of one-dimensional II-VI semiconductor nanostructures grown by molecualr-beam epitaxy 2)Design and characterisation of supported metal particles as selective oxidation catalysts 3) Synthesis, characterization and catalytic properties of mesoporous materials 4) Synthesis, characterization, and catalytic properties of ordered mesoporous silica and carbon materials 5) Characterization of the geometric and electronic structure of CNT supported vanadium oxides at the nanometer scale 6) Study of atomic structures at defects and interfaces in one-dimensional nanostructures by ultra high resolution transmission electron microscopy	DAAD	PS 963	Deutscher Akademischer Austauschdienst DAAD DAAD Deutscher Akademischer Austausch Dienst German Academic Exchange Service	1) 2004 - 2005 2) 2007-2008 3) 2007 – 2009 4) 2008 5) 2008 – 2009 6) 2008-2009 continuing	Dr. D. S. Su	1) Prof. N. Wang 2) Prof. L. Prati 3) Prof. Feng-Shou Xiao (Changchun, China) 4) Prof. F. Xiao 5) Dr. M. Willinger 6) Prof. N. Wang	DAAD

External Funds

Project Name	Akronym	Referenz No.	Funds´ Provider	Funding Period	Project Leader at FHI	Cooperation Partner	Coordinator
Partner group Dalian, Chinese Academy of Sciences. "Carbon-based challenging nanostructured materials for catalytic application"	Bao	MCHAFHI 00001	MPG	1.10.2000 – 2009 (2011)	Dr. D. S. Su		Prof. Dr. Xinhe Bao
Nonstructural catalysts for environment protection and green chemistry	Krakow		MPG	2002 – 2009 continuing	Dr. D. S. Su	Prof. Dr. M. Najbar	Dr. D. S. Su
Cooperation Zagreb "TEM and Raman spectroscopy of nanostructured transition metal oxides"	Zagreb	K-500Z	MPG	2004 – 2005 continuing	Dr. D. S. Su	Dr. K. Furic (Zagreb, Kroatien)	Dr. D. S. Su
In situ studies of oxygen species in the ethylene epoxidation over silver			MPG	1999 – 2010	Dr. A. Knop-Gericke	Prof. V. L. Bukhtiyarov (Novosibirsk, Russian)	Dr. A. Knop-Gericke
Development of a high pressure photoelectron spectrometer			MPG and Lawrence Berkeley National Laboratories, USA	2001 – 2010	Dr. A. Knop-Gericke	Prof. Dr. M. Salmeron	Prof. Dr. M. Salmeron
Pd model catalysts in oxidation reactions			MPG	2004 - 2010	Dr. A. Knop-Gericke	Dr. B. Klötzer (Innsbruck, Austria) Dr. D. Zemlyanov (Limerick, Irland)	Dr. A. Knop-Gericke
Functional analysis of noble metal catalysts in selective hydrogenation	Partner Group	M.PG.A.FHI00 002	MPG and Inst. of Isotopes (Budapest, Hungary)	2006 – 2009 (2011)	Prof. R. Schlögl Dr. A. Knop-Gericke	Prof. Dr. Z. Paál	Prof, Dr. R. Schlögl Prof. Dr. Zoltán Paál
In situ XPS collaboration			UOP LLC, a Honeywell company	2006 continuing	Dr. A. Knop-Gericke	Ally S. Chan Simon Bare	
Technology for Wafer-Scale Carbon Nanotube Applications	Technotubes		EU NMP-2008 4.0.3. CP-IP 228579-1	2009-2012	Dr. Axel Knop-Gericke	Univ. of Cambridge, AIXTRON, AG, Philips GmbH, IMEC, Thales Research and Technology, Thales Electron Devices, Cambridge CMOS sensors, Technical Uni. Berlin, Technical Uni. Denmark, ETH Zürich, CNR-Trieste	Prof. Dr. J. Robertson

External Funds

Project Name	Akronym	Referenz No.	Funds´ Provider	Funding Period	Project Leader at FHI	Cooperation Partner	Coordinator
Ambient-XAS	EFRE		EU	2009	Dr. A. Knop-Gericke	Techical University Berlin	Prof. Dr. R. Schomäcker
Interaction of Surface and Gas Reactions in High Temperature (max ca.1300°C) High Pressure (max. ca. 5 M Pa) Catalytic Alkane Oxidations	Emmy-Noether-Nachwuchs-gruppe	EM.FHI 707	Deutsche Forschungs-gemeinschaft	2007 - 2012	Dr. R. Horn		
Identification of local environment of transition metal promoter cations in heterogeneous catalysts.	DFG	436 MOL	Deutsche Forschungs-gemeinschaft-	2004 – 2006 continuing	Dr. A. Trunschke	Prof. Dr. S. Klokishner (Kishinev, Acad. Sci. Moldova)	
Ressourceneffiziente AlkanSelektiveOxidation an neuen kristallinen Festkörperphasen. TP2: High-end In-situ-Analytik unter realistischen Bedingungen- Ermittlung verbesserungswürdiger Strukturmotive	ReAlSelOx	FHI 107	BMBF Fkz : 033R028B	1.7.2009-30.6.2012	Prof. R. Schlögl Dr. A. Trunschke	Prof. Dr. Glaum (Uni. Bonn), Prof. Dr. Kniep (MPI CPfS) BASF hte	BASF
Development of a long-term stable methanol synthesis catalyst	Cu IX	PSFHI 255	Bayerisches Staatsministerium für. Wirtschaft, Infrastruktur, Verkehr u. Technologie	Starting 2010	Prof. Dr. R. Schlögl Dr. M. Behrens	Südchemie, Prof. M. Muhler (Ruhr-Uni. Bochum), Prof. Hinrichsen (TU München)	Südchemie
Novel Pd-based catalysts for non-oxidative methane activation	DFG	444 BRA-113/56/0-1	Deutsche Forschungs-gemeinschaft-	2009-2010	Dr. M. Behrens	Prof. Dr. M. Schmal (Centro de Tecnologia, COPPE, Rio de Janeiro, Brazil)	

Cluster of Excellence CoE

Excellence Initiative by the German Federal and State Governments to Promote Science and Research at German Universities

unicat
Unifying Concepts in Catalysis

What is UniCat ?

UniCat is the acronym for a new initiative on the area of catalysis research in the Berlin-Brandenburg area (Germany). This initiative is being developed within the bounds of the Excellence Initiative started by the German Federal and State Governments, under the supervision of the German Research Foundation (Deutsche Forschungsgemeinschaft: DFG).

Overview

Current challenges in catalysis range from the efficient exploitation of energy resources to the creative use of natural and artificial enzymes.
Our strategic goal is to unify concepts in catalysis by bridging the gaps between homogeneous and heterogeneous catalysis, between elementary gas-phase reactions and complex processes in highly organised biological systems, as well as between fundamental and applied catalysis research.
Our initiative focuses on analysing catalytic mechanisms, designing novel catalytic materials and strategies, and developing new catalytic processes on laboratory and miniplant scales. We want to integrate the expertise in chemistry, biology, physics, and engineering in the Berlin area into an innovative research program. We aim at creating a centre of catalytic research and generating new synergisms in this central field of science and technology.

UniCat is currently being developed by the

Host University: Technische Universität Berlin
Humboldt Universität Berlin
Freie Universität Berlin
Fritz-Haber Institut der Max-Planck Gesellschaft, Berlin
Max-Planck Institut für Kolloidforschung Potsdam
Universität Potsdam
Uhde PolyAn SCHERING BASF Bayer

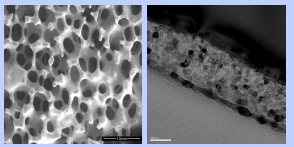
Coordinator of the FHI der MPG, Dept. of AC:
Dr. Raimund Horn
horn_r@fhi-berlin.mpg.de

http://www.unicat.tu-berlin.de

The projects of FHI / Dept. of AC within UniCat
Research area A: Bridging the materials gap in complex catalysis

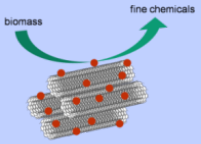
1. Direct oxidative coupling of methane to ethylene on Li-MgO catalysts
(Dr. U. Zavyalova, S. Mavlyankariev, Dr. I. Oprea, Dr. R. Horn)

Goal: Understanding of mechanistic details of the methane activation towards design of tailored basic oxide catalysts. Comprehensive study of the heterogeneous-homogeneous reaction mechanism on Li/MgO catalysts with various surface-to-volume ratios.



2. Conversion of biomass on the MWCNT-supported metallic nanoparticles
(Sylvia Reiche)

Goal: Design and application of MWCNT-supported metallic catalysts for conversion of biomass into building blocks for the production of biodegradable polymers.



What is BIG-NSE? BIG NSE

The Berlin International Graduate School for Natural Sciences and Engineering (BIG-NSE) is the graduate program of the UniCat Cluster of Excellence. With the founding of BIG-NSE, UniCat aims to recruit gifted students and young researchers from all over the world and offer them a broad, high level structured educational program in order to prepare them for the high-ranking research performed at the cluster. Within a so-called “Initial Phase” of three months, basic lectures are given on topics of all three areas of the cluster. In addition soft skill courses, such as language courses, training in personal skills (presentation, communication), counseling on setting up a business, project management, funding acquisition etc., as well multiple excursions to scientific institutes and industrial enterprises complete the educational program.


http://www.big-nse.tu-berlin.de

L

European Union - Network of Excellence / NoE

What is the SIXTH FRAMEWORK PROGRAMME (FP6) - PRIORITY 3 ?

Nanotechnology and nanosciences, knowledge based multifunctional materials, new production processes and devices –NMP

At the Lisbon summit in March 2000, EU governments called for a better use of European research efforts through the creation of an internal market for science and technology - a 'European Research Area' (ERA). FP6 is the financial instrument to help make ERA a reality.

http://cordis.europa.eu

http://idecat.org

NoE IDECAT: "Integrated Design of Catalytic Nanomaterials for a Sustainable Production" NMP3-CT-2005-011730

What is a Network of Excellence

- An instrument to mobilize transnational research collaborations between partners sharing a commitment to long-term integration
- A series of common initiatives on integration, research, spreading of excellence and transfer to companies with the final goal to create a self-sustaining **Durable Integration Structure (DIS)**

- The DIS of IDECAT is the **European Research Institute on Catalysis** (ERIC) which started operations in Nov. 2008
- ERIC , with headquarter in Belgium, operates in close partnership with industry to create a long-term scientific, institutional, industrial and societal awareness on catalysis
- ERIC provides services to improve effectiveness of research

ERIC a.i.s.b.l. European Research Institute of Catalysis

Scientific vision of IDECAT

- Synthesis and mastering of nano-objects, to develop next-generation knowledge-based catalysts
- Bridging the gaps in catalysis and integrate homogeneous, heterogeneous and bio-catalysis
- A multi-disciplinar approach which synergetic integrates competences from surface science and modeling to catalyst and reactor engineering

IDECAT: numbers

•37 labs from 17 institutions, over 500 researchers
•5 years project ending on Sep. 2010; 9.5 M€ budget
•33 companies associated in the Industrial Council

IDECAT: activities

- 5 books resulting from the specific activity; many common publications and high-level reviews
- over 60 running research collaborative projects
- annual high-profile IDECAT Conference on Catalysis
- organization of many events (school, scientific meetings, promotion of science and catalysis, courses, etc.)
- 22 joint PhD, mobility and young researchers training
- start of various projects externally financed

Courtesy: Prof. G. Centi; Coordinator
Contact: Dr. Sabine Wrabetz or Dorothea Damm
wrabetz@fhi-berlin.mpg.de, damm@fhi-berlin.mpg.de

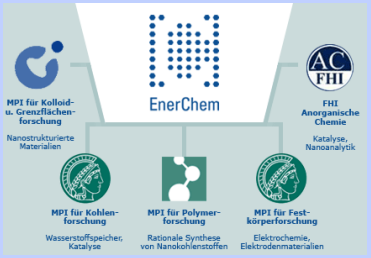
EnerChem

Projects of Max Planck Institutes
Nanochemical Concepts for a Sustainable Energy Supply

http://www.enerchem.de

What is EnerChem ?

EnerChem is a research association, initiated by five Max Planck institutes. The aim is to combine the chemical expertise and capacities of these institutes to generate solutions to the emerging problems of energy supply, storage and saving with the focus on nanostructured carbon materials. The Department of Inorganic Chemistry is member of the Project House EnerChem of the Max-Planck Society.



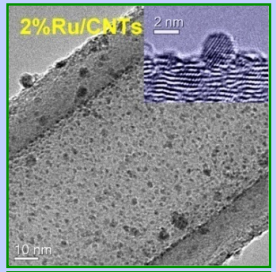
The world energy consumption is at present based nearly to 90% on fossil sources of energy (coal, oil, natural gas). Low efficiency of energy utilization has speeded up the depletion of fossil fuels and global warming. With the establishment of "nano-chemical concepts of lasting power supplies – EnerChem", a scientific basis for new mobile energy storage and more effective methods of energy production was founded.

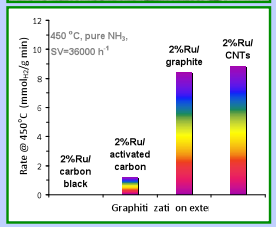
The projects of AC in the EnerChem are:

1. Ammonia as energy carrier

Ammonia decomposition ($2NH_3 \rightarrow N_2+3H_2$) is free of CO_x and environmentally benign. Conversion of nearly 100% can be achieved at 400°C on the supported metals. Carbon nanotube is the best support due to its high electric conductivity and thermal/chemical stabilities. The graphitic structure as the electron reservoir greatly enhances the reaction rate via optimizing electron exchange on the local domain of active sites.

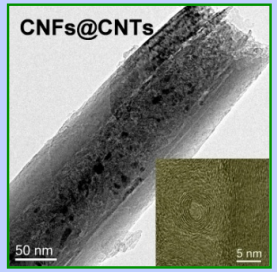
Structure of carbon was found to determine the activity of supported metals, *i.e.* the higher the graphitization, the higher the activity. As revealed by *in-situ* XPS at a near-ambient pressure, the decomposition activity shows a positive dependency on the efficiency of electron transfer inside the "Ru-C-promoter" ternary interfaces. Advantage of CNTs is only found on its confinement on the stability.





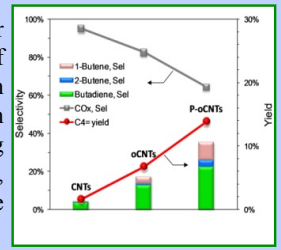
2. Novel nanocarbons for electrochemical energy storage

Li-ion rechargeable batteries are not only consumer electronics but, most importantly, green carrier of electricity in hybrid electric vehicles. Carbon as a richly available and low-cost resource is a promising electrode material. Carbon nanotube-encapsulated nanofibers (CNFs@CNTs) as a superior electrode material provides a long-term stability at a high storage capacity. Facile fabrication benefits it a great potential to be commercialized.



3. Carbon-based metal-free catalysis

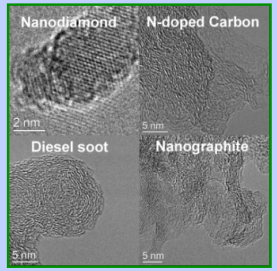
Traditional metal catalysts are deeply involved in their chemical complexity, such as lattice oxygen, various forms of polyvalent metals, parallel coke formation, etc. We use carbon with nanostructure to catalyze oxidative dehydrogenation reactions of propane, butane and ethylbenzene, producing important industrial monomers including propene, butenes, butadiene, and styrene. A superior selectivity to alkenes can be observed for a long period of time, *e.g.* 500 h.



This catalytic process is mediated by surface ketonic carbonyl groups embedding in graphitic substrate. The turnover over local active sites is simplified as:
>C=O + alkane → ≥C–OH + alkene. The selectivity can be further improved by the addition of B or P to passivate the sites for total combustion. We note that the reaction is generally coke-free.

4. Structural characterization of novel nanocarbons

There is a great amount of carbons with novel structures, for example nanodiamond, nanographite, nano-onion, graphene, diesel engine soot, N-doped carbon, *etc.* We focus on characterizing the effect of their structural parameters on practical uses in electrochemistry, catalysis and environmental science.



Contact:
Dr. Dangsheng Su
dangsheng@fhi-berlin.mpg.de

External collaborations:
MPG-Colloid and Interfaces (Golm), MPI-Coal Research (Muelheim),
MPI-Polymer Research (Mainz), MPI-Solid State Science (Stuttgart),

Financial support:
MPG

L

Collaborative Research Centre

Collaborative Research Centers are long-term university research centers in which scientists and researchers work together within a cross-disciplinary research program.

SFB 546: **Structure, Dynamics and Reactivity of Aggregates of Transition Metal Oxides**

Sub-project B2: **Partial oxidation of small hydrocarbon molecules with microscopic amounts of vanadia catalysts**

What is a Collaborative Research Centre ?

Under the Collaborative Research Centre Program, funding may be provided for Collaborative Research Centers **(SFBs),** which are generally based at up to three universities.
In addition to the scientific projects funded in the SFB programs, specific project modules may also be incorporated. Examples include transfer projects, PR projects, integrated Research Training Groups, projects on information infrastructure and research service projects. Independent junior research groups that are funded in the Emmy Noether Program may be integrated in an SFB. International cooperation is also promoted in a variety of forms.

What aims the SFB 546 ?

Transition metal oxides find applications in many areas. The aim of the collaborative research centre 546 is focused on the relation between structures of transition metal oxides in different aggregation states and their functions. For this purpose gas-phase and solid state studies are combined: in the gas-phase diatomic molecules and small clusters are generated, characterized, and their reactivity is studied. Comparison is made with clusters deposited on surfaces as well as with epitaxical films and single crystal surfaces. Finally, "real" transition metal catalysts on supports will be studied.

Part of the SFB 546 are currently:

Technische Universität Berlin · WARWICK · Humboldt-Universität zu Berlin · Freie Universität Berlin

Spokesperson:
Prof. Dr. Joachim Sauer
Institut für Chemie
Humboldt-Universität
Unter den Linden 6
10099 Berlin
js@chemie.hu-berlin.de

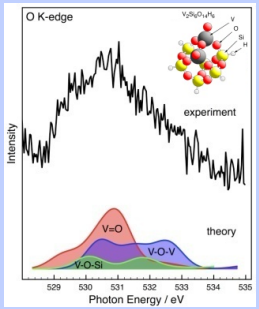
Contact:
Dr. Annette Trunschke
trunschke@fhi-berlin.mpg.de

Program Summary

Project B2 aims at establishing structure-activity relations for partial oxidation reactions of small alkane molecules using small VxOy particles and supported VxOy aggregates. An understanding of structure-activity relations requires on one hand the development of well-defined, realistic model systems, on the other hand the thorough characterization before and during reaction. The findings from the last funding period regarding the structural properties of VxOy/SBA-15 catalysts provide an excellent basis for future in situ investigations as well as the targeted development of novel synthetic strategies.

The objectives of AC in the SFB are:

All B projects dealing with polycrystalline materials (Poly B), i.e. sub-projects B2, B3, B6 and B7, will strongly focus on the **common goal to understand and maximize the selectivity in propane selective oxidation.** This approach is expected to yield synergistic effects as each sub-project will strongly focus on its area of expertise. The common sample pool begins with up scaling SBA-15 samples in order to provide SBA-15/V series, then SBA-15 modified samples and in parallel V on carbon nanotubes.



Theorie compared to experiment
In collaboration with Prof. Dr. Klaus Hermann (FHI), an experimental in-situ oxygen K-NEXAFS spectrum of 10.8 wt% V/SBA-15 has been compared to theoretical spectra of different oxygen coordinations. The theoretical spectra have been obtained by DFT calculations for a $V_2Si_6O_{14}H_6$ cluster as shown in the Figure. This comparison suggests the presence of V-O-V bridging bonds in the VO_x species on SBA-15.

http://www.chemie.hu-berlin.de/sfb546/index.html

PIRE: PARTNERSHIPS *for* INTERNATIONAL RESEARCH & EDUCATION

Molecular Engineering for the Conversion of Biomass Derived Reactants into Fuels, Chemicals and Materials

Prof. Abhaya K. Datye
(Principal Investigator)
University of New Mexico
Albuquerque, NM, USA

Prof. Robert J. Davis
(co-Principal Investigator)
University of Virginia
Charlottesville, VA, USA

Prof. James A. Dumesic
(co-Principal Investigator)
University of Wisconsin-Madison
Madison, WI, USA

Prof. Matthew Neurock
(co-Principal Investigator)
University of Virginia,
Charlottesville, VA, USA

Assoc. Prof. Brent Shanks
(co-Principal Investigator)
Iowa State University
Ames, IA, USA

Prof. Dr. Robert Schlögl
(Host: Germany site)
Fritz Haber Institute
Berlin, Germany

Prof. Claus Hviid Christensen
(Host: Denmark site)
Technical University of Denmark
Lyngby, Denmark

Environmental problems created by our dependence on fossil fuels, such as global climate change, are driving the search for renewable sources of energy, chemicals, and materials. While petroleum resources are highly concentrated in a few countries, biomass constitutes a more globally distributed resource. The PIRE research program serves to investigate critical steps in the chemical transformations of biomass-derived reactants into clean burnings fuels and other useful products.

The PIRE: Molecular Engineering for the Conversion of Biomass Derived Reactants to Fuels, Chemicals, and Materials program provides international research internship opportunities for graduate and undergraduate students.

The NSF PIRE program based out of the University of New Mexico is a collaborative partnership between educators and researchers at 8 institutions, spanning both the United States and Europe, and is also the international component of the NSF Engineering Research Center (ERC) for Biorenewable Chemicals based out of Iowa State University.

The UNM PIRE Program is funded by NSF grant OISE 0730277.

(Text and graphic: http://www.unm.edu/~pire/)

In the framework of the PIRE program, the Department of Inorganic Chemistry at FHI acts as a German host for student from the US sites. It offers its infrastructure and expertise to resolve scientific questions in a collaborative manner ideally within short-term projects of several months.

Moreover, the department contributes to the program by sending staff to research stays abroad, which are integrated into PhD or post-doctoral studies.

Issues related to the conversion of biomass currently studied at FHI include the application of functionalized carbon nanotubes as catalysts and the conversion of glucose using noble metal/carbon systems (see ??).

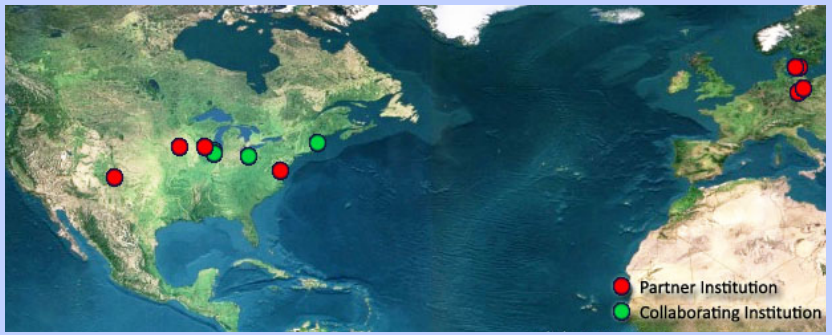
Prof. Dr. Matthias Scheffler
Fritz Haber Institute
Berlin, Germany

Prof. Dr. Markus Antonietti
Max Planck Institute of Colloids and Interfaces
Potsdam, Germany

Prof. Ib Chorkendorff
Technical University of Denmark
Lyngby, Denmark

Prof. Jens K. Nørskov
Technical University of Denmark
Lyngby, Denmark

Dr. Stig Helveg
Haldor Topsøe A/S
Lyngby, Denmark



Contacts:
Dr. Malte Behrens
behrens@fhi-berlin.mpg.de

http://www.unm.edu/~pire/

Teaching Activities

Staff scientists are regularly involved in the course programme of the Freie Universität, Humboldt Universität and Technische Universität in Berlin.

The AC Department covers teaching aspects within the IMPRS (International Max Planck Research School; http://www.imprs-cs.mpg.de) of the FHI on the chemistry of heterogeneous catalysts and on the aspects of preparation of inorganic solids.

Modern Methods in Heterogeneous Catalysis Research
Robert Schlögl, Annette Trunschke et al.
http://www.fhi-berlin.mpg.de/acnew/department/pages/lectures.html
"Modern Methods in Heterogeneous Catalysis Research" is a class aimed at giving advanced students, who are interested or involved in catalysis research, insight into the methods of catalyst preparation, catalyst testing, and catalyst characterization. The class consists of a series of individual and largely independent lectures given by different instructors.

International Max Planck Research School
Complex Surfaces in Materials Science

Coordinator (coordinator@imprs-cs.mpg.de):
Dr. Thomas Risse; FHI; Dept. of Chemical Physics
http://www.imprs-cs.mpg.de
The International Max Planck Research School on "Complex Surfaces in Material Science" aims at combining the expertise of several strong research groups in the Humboldt Universität zu Berlin, the Freie Universität Berlin, and the Fritz-Haber-Institut der Max-Planck-Gesellschaft, creating a unique opportunity for foreign and German students in terms of cutting-edge research and a thorough training in the methods, concepts, and theoretical basis of the physics and chemistry of surfaces. The Research School provides an interdisciplinary environment, and a wealth of methods using state-of-the-art equipment.

Annual forum for technology, science and economy organized by the HUMBOLDT secondary school to Berlin
Instructor: O. Timpe
"Concentration Ranges in Solution - Trace Analysis"

unicat
Unifying Concepts in Catalysis

Chair: Prof. Dr. Matthias Driess (matthias.driess@tu-berlin.de) http://www.unicat.tu-berlin.de
UniCat is the acronym for a new initiative on the area of catalysis research in the Berlin-Brandenburg area (Germany). UniCat is a Cluster of Excellence and BIG-NSE is its graduate school (http://www.big-nse.tu-berlin.de). UniCat has been developed within the Excellence Initiative started by the German Federal and State Governments, under the supervision of the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG).

Physical Chemistry Laboratory Class (WS only)
Instructor: S. Wrabetz
http://w3.rz-berlin.mpg.de/ac/teaching/teaching.html
"Adsorption Calorimetry" is an experiment in the Physical Chemistry laboratory class for 7th semester students at the Humboldt Universität in Berlin.

Dalian Institute for Chemical Physics, Chinese Academy of Science, Dalian, China
Instructor: D. S. Su
"Electron Microscopy and Its Application in Heterogeneous Catalysis: A basic lecture to understanding electron microscopy"

Fritz-Haber-Institut der Max-Planck-Gesellschaft, Dept. of AC
Instructor: D. S. Su
"Basics Course on Electron Microscopy and Its Applications"

Freie Universität Berlin (SoSe 2009)
Instructors: M. Behrens
Vorlesung AC III "Festkörperchemie", Bachelor-Studiengang Chemie

Humboldt Universität in Berlin, Institute of chemistry, Department of Anorganic Chemistry
Instructors: A. Trunschke
"Reaction Mechnisms in Heterogeneous Catalysis"

Lange Nacht der Wissenschaften

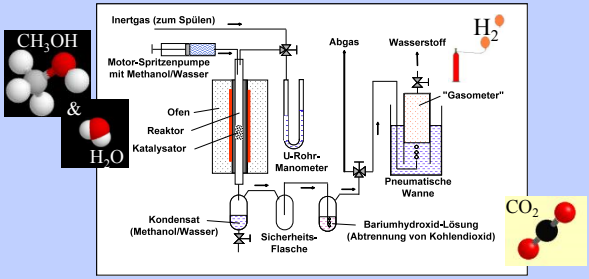
Wasserstofftechnologie

Anhaltende Diskussionen um die Gestaltung der zukünftigen Energieversorgung haben auch das allgemeine öffentliche Interesse erreicht. Innovative Ansätze umfassen dabei mit dem Begriff *Wasserstofftechnologie* bezeichnete Prozesse, dabei kommt der Brennstoffzellentechnologie eine zentrale Bedeutung zu.

Fundamentale Prozesse der heterogen katalysierten Stoffumwandlung sind Gegenstand der Forschung in der Abteilung AC am Frith-Haber-Institut. Vielfältige Eigenschaften von katalytisch relevanten Materialien werden untersucht. Dabei kommen Methoden zur Anwendung, die Einblicke in Mechanismen des katalytischen Prozesses selbst auf atomarer Ebene gewähren. Mitarbeiter der Abteilung arbeiten seit längerem an der Aufklärung der Wirkungsweise von Katalysatoren für die Methanol-Reformierung wie auch der Wassergas-Shift-Reaktion. Beides Reaktionen, die im Rahmen der Wasserstofftechnologie eine Rolle spielen.

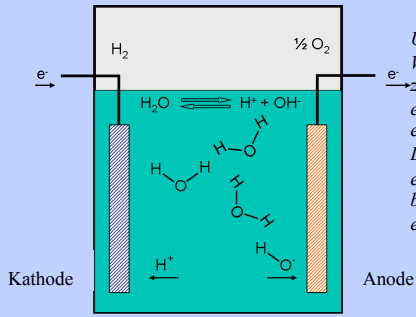
Woher kommt der Wasserstoff / Where does hydrogen come from?

z.B. aus Methanol CH_3OH



Anlässlich der Langen Nacht der Wissenschaften hat die Abteilung Anorg. Chemie einen generellen Überblick der physikalischen und chemischen Grundlagen zur Nutzung von Wasserstoff als Energieträger dargeboten. Mit einigen Exponaten und Versuchen wurden dem Besucher Entwicklungen und Techniken der Wasserstoffwirtschaft veranschaulicht. Mit einem Stirlingmotor wurden prinzipielle Gesetzmäßigkeiten der Energieumwandlung demonstriert. Mit einer Brennstoffzelle wurde der aktuelle Stand der Technik vorgestellt.

(http://w3.rz-berlin.mpg.de/ac/news)



Unter Energiezufuhr kann Wasser in seine Bestandteile Wasserstoff und Sauerstoff gespalten werden. Die zugeführte Energie ist dann quasi in der Form des erzeugten Wasserstoffes gespeichert und kann bei erneuter Bildung von Wasser wieder freigesetzt werden. Die Spaltung des Wassers lässt sich am einfachsten in einer Elektrolysezelle (Hofmannscher Apparat) bewerkstelligen. Die Energie wird hier in Form elektrischer Energie zugeführt.

$2\,H^+ + 2\,e^- \longrightarrow H_2$ $\qquad$ $2\,OH^- \longrightarrow H_2O + \frac{1}{2}\,O_2 + 2\,e^-$

DMFC – Direct Methanol Fuel Cell

The DMFC converts methanol and oxygen electrochemically into electrical power, heat, carbon dioxide and water. At the anode (negative electrode), the methanol is first split into hydrogen and carbon dioxide before the same catalyst splits the hydrogen into protons and electrons. These reactions require a special platinum/ruthenium catalyst. The protons then diffuse across the polymer membrane to the cathode (positive electrode), while the electrons pass as current through the external circuit. At the cathode, the electrons then recombine with the protons that have passed across the membrane and with oxygen to form water. The cathode reaction is catalyzed by e.g. platinum particle. The voltage generated by a single DMFC cell is 0.3-0.9 V.

Reformer/ Katalysator: $CH_3OH + H_2O \rightarrow CO_2 + 3H_2$

Anodenreaktion: $H_2 \rightarrow 2H^+ + 2e^-$

Kathodenreaktion: $\frac{1}{2}\,O_2$ (Luft) $+ 2H^+ + 2e^- \rightarrow H_2O$

Long Night of Science

LANGE NACHT DER WISSENSCHAFTEN 2009

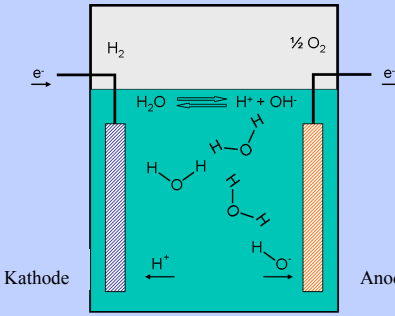
Hydrogen Technology

ngoing discussions about power supply in ed in a general Public interest. Innovative approaches comprise the processes well-known as hydrogen technology. Among these fuel cells are of special importance.

The Department of Inorganic Chemistry (IC) at the Fritz-Haber-Institut of the MPG is doing research related to basic processes of heterogeneously catalysed transformation of materials. We are studying for example properties of catalyst materials applying methods to allow insights into the mechanism of the catalytic process itself even on atomic level. Members of the department have been working for some time to explain the mode of action of catalysts for methanol reforming as well as the watergas-shift-reaction. Both are processes important for hydrogen technology.

On occasion of the Long Night of Sciences, the IC department gave a general overview of the physical and chemical basis for the use of hydrogen as a source of energy. Various experiments and exhibits were illustrating to the visitors the development and techniques of hydrogen economy. By means of a sterling motor basic principles of energy transformation were shown. A fuel cell demonstrated the state-of-the-art.

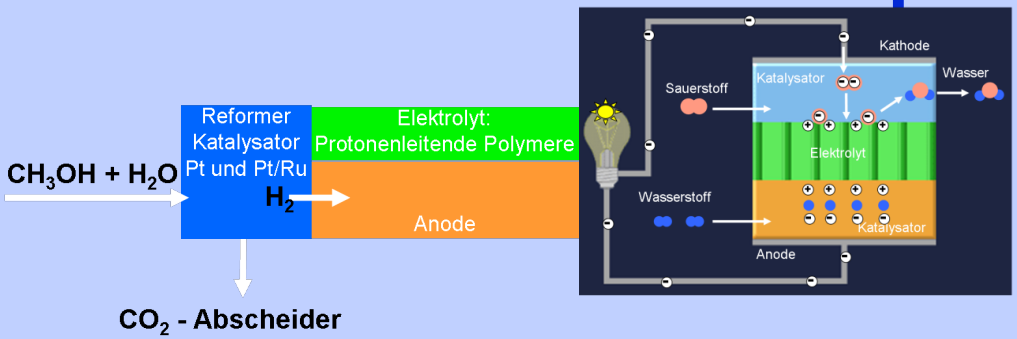
(http://w3.rz-berlin.mpg.de/ac/news)



Additional energy makes water decompose into hydrogen and oxygen. Energy is saved in form of the generated hydrogen molecule and may be released again when water reforms.. Water decomposition is done best within an electrolysis cell (Hofmannscher Apparat). Here energy is supplied in form of electric energy.

$2\,H^+ + 2\,e^- \longrightarrow H_2$ $\qquad$ $2\,OH^- \longrightarrow H_2O + \frac{1}{2}\,O_2 + 2\,e^-$

Funktionsweise einer BZ / Function principle of a fuel cell



Anwendung / Application

Practical Courses

jugend forscht the competition in natural sciences, mathematics and technique for young people up to the age of 21. They can do research on their on own or in groups of two or three. „Jugend forscht“ fields of research are: working world, biology, chemistry, geo and space sciences, mathematics/computer science, physics, engineering. It goes without saying that the **participants can win awards or incentives, such as a 2-weeks research training at the Fritz-Haber-Institut of the MPG**. This research training is especially looked for and popular. The young participants appreciate to be included into the daily working routine of highly-qualified scientists. Under professional guidance they may tackle their own research tasks.

Johannes Kohlmann und Yosri Hassanein *(Oktober 2008, 3. Semester, Chemiestudenten)*
Noch in unserer Schulzeit nahmen wir an „Jugend forscht“ teil und gewannen ein zweiwöchiges Praktikum im Fritz-Haber-Institut der MPG. Während der 2 Wochen durchliefen wir verschiedene Forschungsgruppen der Abt. AC, welche sich mit heterogener Katalyse befassen. Zu den besuchten AG`s gehören unter anderem TEM, SEM, IR- & UV-vis-Spektroskopie und Mikrokalorimetrie. Dort bekamen wir eine ausführliche und interessante theoretische Einweisung in die Arbeitsweise der Geräte und deren praktische Anwendung. Auch fehlte es niemals am entsprechenden chemisch-theoretischen Background. Durch das Praktikum haben wir viele neue fachliche Kenntnisse gewonnen und es gewährte uns einen Blick auf eine mögliche Zukunft als Forscher. Auch führten wir erste wissenschaftliche Gespräche in Englisch.

LetteVerein

Occupation practical course

Today the Lette Foundation incorporates five more or less independent educational institutions. Courses are currently offered for the following diplomas in the following departments: Technical Assistant in Metallography and Physical Material Analysis Chemistry and Biology Electronics and Data Processing Pharmacy Laboratory Medicine and Radiology.

Nadine Schechner *(3.-18.1.2005)*
Das 4-wöchige Berufspraktikum am FHI verging viel zu schnell. Es waren eindrucksvolle 4 Wochen. Ich lernte viele neue Labor-Geräte und Labor-Apparaturen kennen sowie neue Messtechniken, konnte aber auch gelerntes anwenden. Alles war sehr spannend für mich. Die Mitarbeiter waren alle hilfsbereit und freundlich. Das Labor war unglaublich gut organisiert.

Förderverein Chemie-Olympiade e.V.

Olympic games in Chemistry are an international competition for pupils of comprehensive schools. About 60 groups of pupils from different countries annually meet to compete and to put their knowledge in Chemistry to the test. Each nation is self-responsible for the selection of participants. In Germany candidates have to pass a 4-round test procedure. Some pupils from the 3rd round are given the chance to take part in a **2-weeks taster course at Fritz-Haber-Institut der Max-Planck-Gesellschaft.**

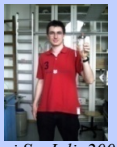
M. Martineau, A. Altman, F. Kühne
June 2003

Pupil practical course

Torsten Scholl *(April 2009):*
Mein Name ist Torsten Scholl und ich bin Auszubildender zum Chemielaboranten am MPI für Kohlenforschung in Mülheim. In meinem 3. Ausbildungsjahr konnte ich ein dreiwöchiges Praktikum in der Abt. für Anorganische Chemie des FHI absolvieren. Mein Praktikum wurde in drei Schwerpunkte gegliedert: Der erste war die Mikrokalorimetrie und deren Anwendung an Nb_2O_5 mit Hilfe von Gasen wie Propan. Der zweite Schwerpunkt war die Uv-vis Spektroskopie. Anfangs wurde ich in diesem Abteilungsbereich in die Probenvorbereitung durch Verdünnen mit UV inaktiven Substanzen eingewiesen. Neben eigenen Probenvorbereitungen erlernte ich die Durchführung von Backgroundkorrekturen, die Kalibrierung von Gasströmen und das Messen von Proben (z.B. VOx/SBA-15) bei tiefen (flüssiger Stickstoff) und höheren Temperaturen. Die FTIR – Spektroskopie war meine dritte und letzte Station. Neben Probenvorbereitungen in KBr – Pressling und selbsttragender Presslingsform, untersuchte ich zunächst Karbonatgruppen auf LiMgO und anschließend Brönstedt/Lewis - Säuren von Zirkonoxidkatalysatoren unter Zuhilfenahme von CO Adsorption. In allen Bereichen erhielt ich - neben der praktischen Arbeit - Einblicke in die Auswertungsarbeit über Excel und Origin. Durch die teils auch selbstständige Auswertungsdarstellung bekam ich insgesamt ein besseres Verständnis von Untersuchungen mit spektroskopischen Methoden. Während meines Aufenthalts fühlte ich mich, durch die herzliche Aufnahme in den Arbeitskreis, sehr wohl. Ich hoffe, dass ich das erlernte Wissen bei meiner Abschlussprüfung zum Chemielaboranten anwenden kann. Für die schönen und interessanten drei Wochen möchte ich mich noch mal recht herzlich bedanken.

Nina K.; Januar 2005

Anne T.; July 2006



Toni S.; Juli 2008

Paula W.; Juli 2009

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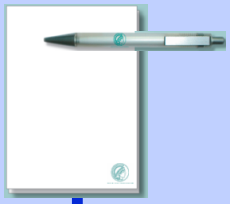

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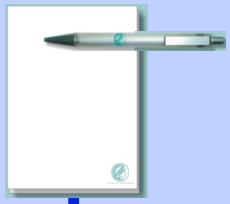
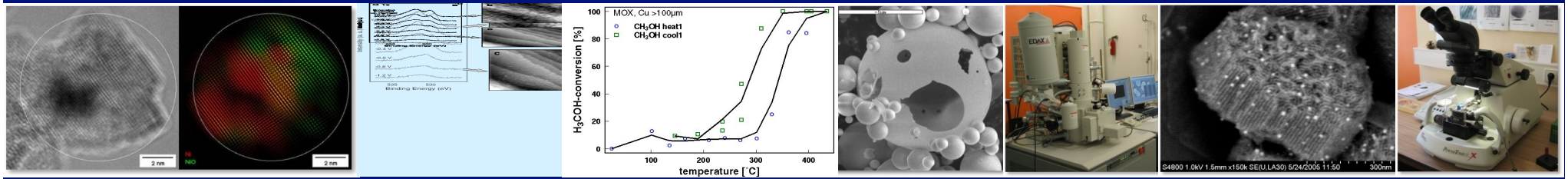
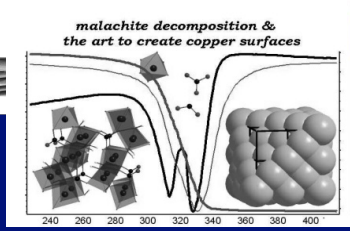
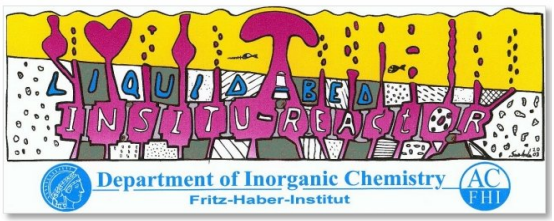
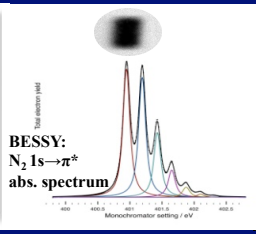


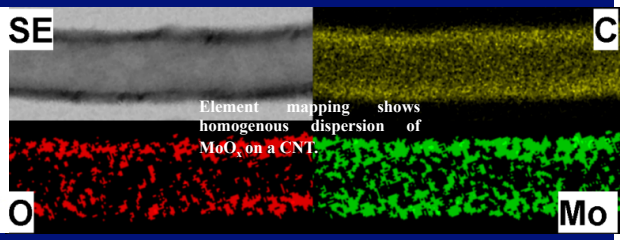


http://www.fhi-berlin.mpg.de









Address	Fritz-Haber-Institut der Max-Planck-Gesellschaft Department of Inorganic Chemistry Faradayweg 4 – 6 D-14195 Berlin Germany
Phone	+49 (0) 30 8413 4404 (Prof. Dr. R. Schlögl) +49 (0) 30 8413 4468 (Dr. S. Wrabetz)
Fax	+49 (0) 30 8413 4401
	http://www.fhi-berlin.mpg.de
Editor	Prof. Dr. Robert Schlögl acsek@fhi-berlin.mpg.de Dr. Sabine Wrabetz wrabetz@fhi-berlin.mpg.de
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