Mid-Term Review
Virtual Institute in 5. Funding Period
I. Status Quo Report

Initiative Fund funding code:	VH-VI-403
Project title:	In-Situ Nano-Imaging of Biological and Chemical Processes
Leading scientist:	Prof. Dr. Christian Schroer
Coordinating Helmholtz centre:	DESY
Other participating Helmholtz centres:	KIT
Participating universities or other partners:	TU Dresden, Uni. Göttingen, Uni. Bochum
Approved funding:	500,000 Euro/year
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1. Summary

In the emerging fields of nano science, chemical technology, and the life sciences there is an increasing demand for imaging of micro- to nanometer sized objects with highest possible spatial resolution. The physical, chemical, and biological properties of nano-sized objects strongly depend on their structure. Therefore, nanoscopic structure determination is at the heart of understanding biological and chemical processes and is crucial to address the grand challenges in health, environmental, and energy research.

X-ray imaging techniques are well suited to these ends, as they provide element specific, chemical, and structural contrast at high spatial resolution also from the interior of bulk samples or from samples in special environments. The new sources at DESY, PETRA III and FLASH, are ideal to reach these goals. In particular X-ray imaging techniques on the nanoscale directly benefit from the high brilliance of theses sources.

In the frame of this Virtual Institute we bring together expertise in x-ray imaging, biology, chemistry, and chemical engineering to enable in-situ imaging of biological and chemical processes with the x-ray microscopes at PETRA III and FLASH, and at the European XFEL in the future. In example applications, we will address important questions in biology (membranes, cell ultrastructure, self-assembly mechanisms) and chemistry (catalysis, redox and precipitation reactions), adapting and developing further the x-ray microscopes and special sample environments, such as chemical reactors, microfluidic cells, and cryogenic sample environments.

Our Virtual Institute comprises groups from four universities (U. Göttingen, U. Bochum, KIT Campus South, and TU Dresden) and DESY. The strong interaction with KIT Campus North also integrates this Helmholtz Center into our Virtual Institute.

In the following, we summarize the most important results obtain so far within the VI and discuss the future aims.

In **Topic I, Bioimaging**, new microfluidic devices were used to study cells. In freeze-dried samples, we were able to visualize network structures inside cells in real and reciprocal space, including local structure, orientation, and characteristic length scales. In hydrated samples, we showed that chemical fixation alters intracellular nanostructures. X-ray imaging offers, for the first time, a method that can directly compare living, unfixed, unstained samples with samples that had undergone considerable sample preparation. New full-field imaging techniques yield quantitative phase contrast images of cells at comparably low dose and with about 50 nm spatial resolution. The ultrastructure of melanosomes with different genetic background was analyzed with in-situ small-angle x-ray scattering, and the element distribution of marine adhesives was characterized with high spatial resolution.

In the second part of the funding period of the VI, we plan to apply and extend the established techniques from the first half. In particular a combination (e.g. full-field methods and local, scanning techniques) of different x-ray imaging techniques shall be pursued. The melanosome project will be extended to analyze the chemical composition of organelles of different genetic background. The marine-adhesives project will be continued trying to differentiate bulk and surface contributions. Finally, we aim at establishing a platform for conducting experiments with cells and other biological specimens that will also be available to the user community.

In **Topic II, Chemical Processes**, catalysts were analyzed with two- and three-dimensional hard x-ray imaging on the micrometer scale. Realistic exhaust gas catalysts could be investigated and aging effects could be followed for individual samples. Various catalysts were investigated under working conditions, monitoring the temperature field by IR thermography in combination, the chemical state by x-ray absorption spectroscopy (XAS), and the catalytic reaction by mass spectrometry. In view of following catalytic reactions in operando on the nanometer scale, we improved the sensitivity and resolution of ptychographic imaging of catalytic particles and designed and fabricated a catalytic micro reactor. After the shutdown of PETRA III, we aim at performing the first in-operando imaging of the chemical state of individual catalyst particles under reaction conditions.

The formation of solids and colloidal metal particles by precipitation reactions is another important aspect of materials design and was investigated by time-resolved small-angle x-ray scattering (SAXS). For this purpose, special microreactors with cyclone mixers on a chip and a microfluidic channel were realized that allow one to investigate the chemical state or the mesoscopic structure in the mixed solution as a function of position along the channel and thus of the reaction time. First micro-SAXS and micro-XAS experiments on the formation of gold colloids and the $BaSO_4$ precipitation reaction were carried out. In the next two years, our goal is to study mechanisms of the formation of nanoparticles using different x-ray analytical techniques, to image catalytic reactions inside a reactor in three dimensions and hope to follow aging effects during sintering processes in real time.

In **Topic III, Methods & Instrumentation**, two major activities were pursued, the development of x-ray microscopy techniques, in particular with coherent radiation, and the development of special sample environments and sample delivery systems. In x-ray microscopy, the four x-ray microscopes that are part of the VI were developed further, both instrumentally and methodologically. At the nanoprobe station at P06, a special flight-tube and beamstop system was installed to improve the sensitivity and resolution in scanning coherent x-ray diffraction microscopy (ptychography), reaching unprecedented sensitivity and spatial resolution for the imaging of catalytic nanoparticles. At the GINIX ensstation at P10, the modular optical design was extended and characterized by ptychography, allowing for compound optical systems that can overcome the limitations concerning resolution and efficiency of the single components. In this way, it was possible to generate a world-record 5 nm focus. In addition, a variety of near-field imaging techniques were developed that enable dose efficient and fast imaging. At P11 a scanning transmission microscope and a Zernike phase contrast full-field microscope was commissioned and first experiments with biological samples were carried out. Both instruments are specially designed for stability, allowing two- and three-dimensional imaging of biological samples. Spatial resolutions of 50 nm have been demonstrated and 30 nm isotropic resolution is targeted.

A major instrumental focus was lain on the development of various sample environments. Microfluidic cells for various applications were designed: microfluidic devices for x-ray experiments, which are compatible with biological systems such as proteins, DNA or cells, have been developed and tested at different beamlines. In addition, first prototypes of microfluidic cells for gas and liquid phase chemical reactions were developed, fabricated, and testet. A cryogenic sample preparation chain was implemented at DESY and at Ruhr-Univ. of Bochum, keeping biological samples at all times at low temperatures. A liquid-jet sample delivery system for the soft x-ray microscope HORST was implemented and used for experiments at FLASH.

In the second part of the VI funding period, the scanning microscope at P06 will be upgraded to improve spatial resolution and sensitivity to nanometer-sized objects, the soft x-ray microscope HORST and the tender x-ray microscope at P11 will be fully commissioned. In microfluidics, the main goal is to establish a platform, which can be applied to a variety of chemical and biological experiments also by external users. In particular, chemical reactors for in-situ tomography of catalytic reactions are to be developed and in-situ cells for combining x-ray and electron microscopy are to be improved.

2. Progress report and results

2.1. **Starting position:** Dynamics in both biological and chemical systems can only be fully understood if the relevant length scales (nanometers) and time scales (nanoseconds and below in chemistry and usually milliseconds to hours in biology) are resolved. Biology, chemistry, and chemical technology have often developed separately in the past. However, at the microscopic level, these disciplines converge methodologically. This VI was implemented to foster the synergies in development and application of imaging techniques that are applicable to both these fields. For this joint effort, we have chosen specific (model-)systems, which we will investigate by combining high-resolution x-ray microscopy methods and tailor-built sample environments.

In the three topics, bioimaging (Topic I), chemical processes (Topic II), and methods & instrumentation (Topic III), the following aims were identified:

Topic I, Bioimaging:

Membranes: Membranes are often denoted as the most important interface in biology. To follow functions associated with membranes, we aim at in-situ imaging of processes and structures in biological membranes as well as in model lipid membranes as their much simpler counterpart. Specific examples, include intermediate structures in membrane fusion processes and the structure of myelinated axons in nerve cells. In model systems, we study the non-equilibrium structural dynamics of membranes and membrane structures under large external forces, for example undulations after controlled excitation of membranes by optical or electro-acoustic pathways. To this end, time-resolved diffraction and pump-probe methods, also in combination with nano-focusing and coherent diffraction imaging, were proposed and developed.

Cells: A central challenge in life sciences is the imaging of cells at high temporal and spatial resolution. The most widely used techniques are fluorescence microscopy and electron microscopy (EM). Fluorescence microscopy makes use of specific labeling of cellular components, can be used on living cells (if appropriate labeling methods are available) and reaches ever-higher resolution in recent years, thanks to the advent of superresolution microscopy. EM offers even higher resolution, but at the expense of very extensive sample preparation. We proposed to advance x-ray imaging as a third, complementary group of methods to study (living) cells. X-rays provide high penetration power and high spatial resolution. In order to be able to eventually visualize dynamic processes in the system, appropriate sample environments are needed, which are compatible with x-rays but also with in-situ cell culture. We thus proposed to develop appropriate microfluidic flow devices.

Melanosomes: Melanosomes are hypothesized to be involved in the outbreak of the disease glaucoma, which can lead to blindness. The objective was to apply X-ray imaging techniques to hydrated melanosomes — 1 μm sized organelles extracted from the iris of mice — in order to shed light on their ultrastructure. The working hypothesis was if small-angle x-ray scattering (SAXS) is capable to reveal structural differences of vitrified and suspended organelles with different genetic background to indicate a different probability of “leakage” of toxic components.

Curing mechanism of marine adhesives: Adhesion is a crucial step in the progression of biofouling, an expensive and worldwide challenge. Here, the objective was to characterize the occurrence of chemical elements in the adhesives of marine organisms. The starting project were diatoms, secreting extracellular polymeric substances (EPS). Modern synchrotron nanobeams should be applied to reveal the presence and distribution of metals in the EPS. During the project we extended the scope to barnacle adhesives.

Topic II, Chemical Processes:

Studies on chemical reactions, the formation of solids and derivation of structure-performance relationships are of utmost importance for chemical product design, energy storage/conversion and catalytic applications. In all cases, the study from the nanoscale to the real system is important. For example, if considering that 95% of all chemical products have seen a catalyst in one reaction step, improvement has a strong impact. Particularly, in-situ imaging of the chemical processes has a strong potential, which is studied in several parts of the project. The aim is to study in a spatially and time-resolved manner in microfluidic reactors the formation of solids and of colloidal particles. Moreover, microreactors can be used to understand the catalysts on a nano- and microscale. Finally, the gap between these in operando studies and electron microscopy studies needs to be bridged, particularly with improved in-situ x-ray microscopic techniques including ptychography.

Topic III, Methods and Instrumentation:

Over the last two decades, significant advances were made in x-ray microscopy, both in the soft and hard x-ray range. In soft x-ray microscopy, both full-field and scanning techniques are available, achieving spatial resolutions down to about 10 nm. For biological imaging, the energy range in the so-called water window is very relevant, and spatial resolutions down to below 40 nm are reached in tomographic imaging. Hard x-ray microscopy is a much younger field and has evolved quickly with the advent of highly brilliant hard x-ray synchrotron radiation sources. Today, the spatial resolution of hard x-ray techniques is approaching that in the soft x-ray range, reaching real space resolutions of several 10 nm. In hard x-ray microscopy, a broad range of contrasts can be exploited, such as x-ray fluorescence analysis, x-ray absorption spectroscopy, and scattering techniques, making these microscopes sensitive to the chemical composition with trace element sensitivity, the chemical state and local chemical environment of a given atomic species, and to the local atomic or nano-structure. The most prominent property of hard x-rays, the large penetration depth in matter, can be exploited both for 3D imaging and for in-situ or in-operando investigation of biological and chemical systems inside a special sample environment.

Within the virtual institute, we have a strong background in x-ray microscopy, operating four x-ray microscopes. The aim of the VI was to further develop x-ray microscopy techniques, based on the expertise and instrumentation available within the team. In order to take full advantage of the in-situ capabilities of x-ray microscopy, a strong focus was put on the development of special sample environments, such as microfluidic chambers both for biological and chemical studies. In addition, cryo-preparation and liquid jet techniques are being developed. The goal is to create a platform to make these instruments available to biology and chemistry.

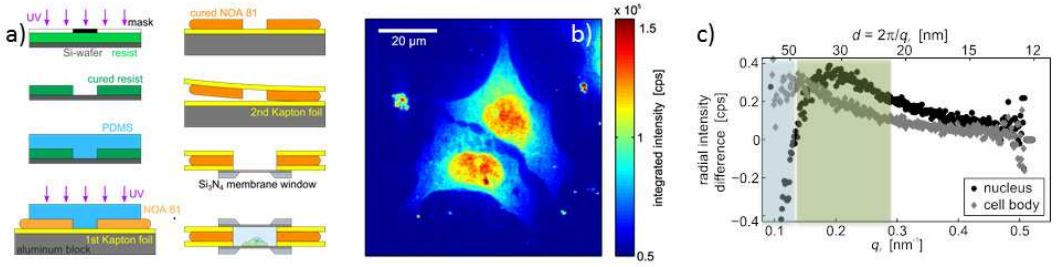

FIGURE 1. a) Procedure for fabricating x-ray compatible microfluidic devices for cell studies; b) x-ray dark field image of a chemically fixed cell recorded at PETRA III/P10; c) intensity difference profiles (living minus fixed cells) for the cell nucleus and cell body; the blue region corresponds to structures, which emerge due to fixation, the green region shows structures, which are destroyed upon fixation.

2.2. **Presentation of the interim results.**

The interim results are subdivided according to three topics, Topic I, Bioimaging, Topic II, Chemical Processes, and Topic III, Methods & Instrumentation. We briefly review the main results in these areas of research.

2.2.1. *Topic I, Bioimaging:*

Cell imaging: we chose a 3-step approach to eventually image living cells using x-rays. Starting with freeze-dried cells, we were able to image the cells by x-ray nanodiffraction, distinguish clearly cell nuclei and cell periphery and could even visualize the intracellular keratin networks of bundles. We thus obtained high-resolution images in real space given by the step size for scanning ($50 - 100$ nm) and in reciprocal space, defined by the accessible q-range ($2\pi/q_{\min}$ on the order of 10 nm). Analyzing the individual diffraction patterns, we were able to obtain information about the local structure orientation, degree of orientation and characteristic spacings/distances.

As a next step, we performed measurements on chemically fixed, hydrated samples. We designed microfluidic flow-through devices connected to a syringe pump system and constantly flushed with media or buffer during the experiments. Although the signal-to-noise drops considerably and a much longer exposure time is necessary, we could still image the cells well in dark field, distinguish different cell regions and obtain information in reciprocal space from the power spectrum of the different regions.

We then conducted parallel experiments on living cells. When comparing the data from living versus chemically fixed cells we observed clear differences in the nanostructure (on the order of few tens of nm). This is a particularly interesting result, since chemical fixation is a routine method in life sciences, often performed before staining with fluorescent dyes or antibodies. X-ray nanodiffraction now offers the possibility to directly compare fixed and non-fixed cells as the fixation is no necessary prerequisite for the imaging methods (as is it, e. g., in electron microscopy). We are now in the position to apply these new techniques to more specific scientific questions.

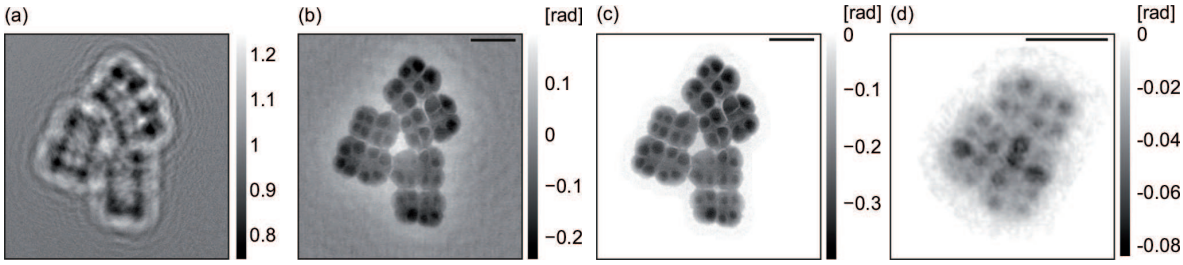

FIGURE 2. (a) Hologram of *Deinococcus radiodurans* cells (freeze dried), obtained in a single recording with 8 s dwell time. (b) Phase reconstruction based on the contrast transfer functions (CTF) using the data shown in (a). (c) Enhanced phase reconstruction by the mHIO algorithm. The support information was obtained from the reconstruction shown in (b). (d) Live cells in buffer, mHIO phase reconstruction, accumulation time 200 s. Scale bars, 4 μm. (Bartels, et al, unpublished).

Apart from nano-beam diffraction and scanning transmission x-ray microscopy, live cell imaging has also been realized in form of the full-field holographic propagation imaging. With adaptable field of view, the entire cell or even several cells can be recorded within a few seconds, and changes can be monitored quickly. Optimized phase retrieval yields quantitative contrast values corresponding to the projected electron density. Fig. 2 shows an example of bacterial cells (*Deinococcus radiodurans*). The field of view is 20 μm $\times$ 20 μm. Analysis of the power spectral density (PSD) yields a cross-over to the noise plateau at about 0.19 cycles per pixel corresponding to a resolution of about 53 nm. Flux density in the sample plane ($\simeq$ 16 mm behind KB focal plane) was $5 \cdot 10^5$ ph/μm^2/s, and the total dose for a single 8 second exposure was $D = 5.2 \cdot 10^3$ Gy, corresponding to a fluence of $4 \cdot 10^6$ ph/μm^2. This is almost three orders of magnitude less than a recent ptychographic reconstruction of the same bacteria at similar photon energy and resolution (46 nm), recorded at a dose of $4.9 \cdot 10^6$ Gy [1].

For overall comparison, single cells have been imaged in different states (freeze dried, chemically fixed, cryogenically fixed, initially alive) and in different x-ray contrast modes and modalities (darkfield diffraction, differential phase contrast, x-ray fluorescence, ptychographic imaging and full field propagation imaging/tomography. Full-field phase contrast imaging and tomography has further been carried out on biological tissues and multi-cellular organisms. In myelinated nerves, individual axons were identified in hydrated states without staining, and tissue (typically $\simeq$ 0.5 mm thickness) from central nervous tissue as well as from a lung were reconstructed at cellular and sub-cellular resolution.

Melanosomes: Melanosomes [2] are membrane bound organelles that contain melanin [3] and fulfill important biochemical functions in their host cells, such as protection against the damaging effects of UV radiation and scavenging of free radicals [4]. Variations in melanosome structure and function are also associated with multiple diseases, including albinism [5], cancer [6], and eye disease [7]. Melanosomes have been the subject of numerous microscopy studies aiming at correlating morphology and to provide insights into their roles in health [8, 9]. The exceptional electron density of melanin, however, has been an obstacle in probing the ultrastructure of melanosomes by approaches such as transmission electron microscopy

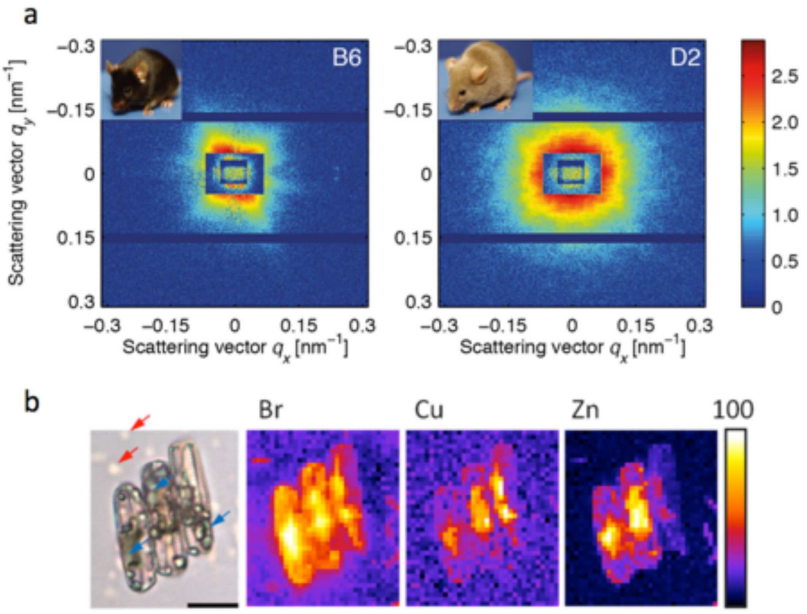

FIGURE 3. (a) X-ray scattering applied to physiologically intact melanosomes from C57BL/6J (B6) and DBA/2J (D2) mice. (b) X-ray fluorescence microprobe analysis of adherent diatoms.

(TEM). We applied scanning transmission X-ray microscopy (STXM) and small-angle X-ray scattering (SAXS) to vitrified and suspended melanosomes from C57BL/6J (B6) and DBA/2J (D2) mice to study their ultrastructural differences [10].

SAXS experiments at the BioSAXS beamline P12 at PETRA III (in coll. with Helmholtz-Center Geesthacht) yield scattering curves, which were fitted by a theoretical model to distinguish the scattering from surface and volume [11]. The interpretation of the resulting fit parameters leads to the conclusions that B6 organelles feature a smooth surface and are made up of densely packed 22 nm small subunits. D2 melanosomes, however, are agglomerates composed of 31 nm fuzzy objects. In order to access information on the surfaces of D2, a combined STXM and SAXS study was carried out at the GINIX nanofocus endstation of the P10 beamline at PETRA III using vitrified organelles. Fig. 3a shows the sums of 13 scattering patterns from B6 and D2 melanosomes. The B6 sample features a 'streaky' fingerprint, whereas the D2 counterpart exhibits more uniform scattering. This indicates that in contrast to the smooth B6 surface, D2 has a rough interface [10]. This melanosome study is the first combined suspension SAXS and single particle SAXS study on vitrified organelles. The precise characterization of electron dense organelles with a size of only few μm in an in-situ environment showed genetically induced morphology changes and thus gives a clear example for the great potential of modern X-ray sources in developmental biology.

Curing mechanism of marine adhesives: Diatoms are an important class of biofilm forming micro-foulers and known to use extracellular polymeric substances (EPS) for adhesion. They are prevalent species on modern silicone based fouling release coatings [12]. Microprobe X-ray fluorescence at PETRA III was applied to reveal the distribution of metals in *Navicula*

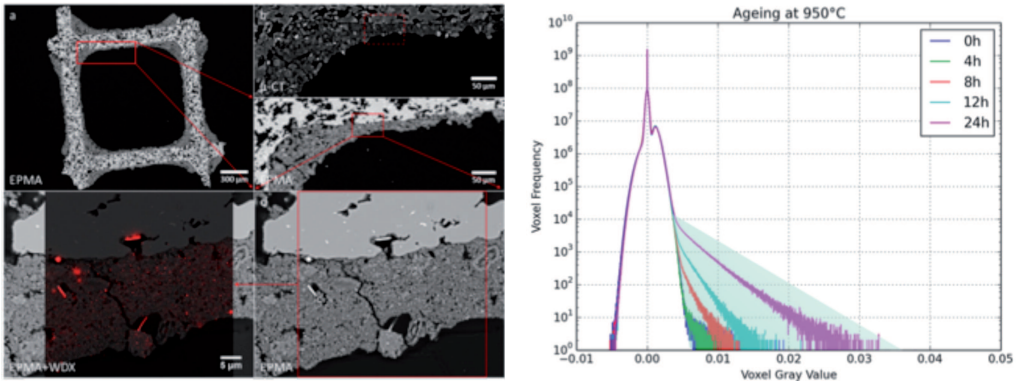

FIGURE 4. (left panel) Electron probe micro analyzer images at different zoom levels (a, c, d,) and μ-CT (b) of a Pt/Al_2O_3-catalyst aged 24 h at 950 °C in static air. (right planel) Histograms of reconstructed volumes of a Pt/Al_2O_3-catalyst aged at 950 °C in static air. With increasing ageing duration, particles with higher intensity (higher voxel gray value) occur.

perminuta and their adhesive. Experiments at the micro-focus endstation of P06 [13] revealed the distribution of elements the algae (Figure 3b). Besides Ca and Sr, Cu, Fe and Zn were detected. Especially the high bromine content supported the initial hypothesis that haloperoxidases might be present. Due to the restricted amount of beam time at P06 we were not yet able to separate adhesive layer and diatoms, but this is anticipated for the next phase of the project. Instead, barnacles were chosen as second marine biofouling model system, which due to their larger size could be investigated at ANKA's Fluo beamline. Also for barnacles, adhesion is a crucial step in their life-cycle [14, 15]. After selecting a suitable location, the cyprid larvae secrete an adhesive called cyprid cement. In-situ underwater measurements at the FLUO beamline [16] of juvenile barnacles and settled cyprids showed that besides Ca and Sr, a localized occurrence of high amounts of Br, Fe, Cu, and Zn was observed at the position, where the cyprid cement was secreted. This suggests their previously unknown involvement in the curing of barnacle adhesives.

2.2.2. *Topic II, Chemical Processes:*

The studies in the field of catalysis are manifold. With respect to exhaust gas catalysis, both 2D and 3D x-ray microscopy were successfully applied [17, 18]. For realistic catalysts usually thin catalytic layers in honeycombs are used. Both x-ray and electron microscopy were compared and give at first sight similar information. Fig. 4(left) compares for example state-of the art EPMA analysis (Electron Probe Micro Analyzer) and x-ray microtomography (μ-CT) on a specific three way catalyst based on Pt/Al_2O_3 [19].

However, more important is the study of sintering on a micro and nanoscale. Since electron microscopy is based on embedded and cut samples, this can only be performed on different samples. X-ray microscopy, however, allows studying quasi in situ the changes of the particles and can also unravel the migration of Pt. The results from several ageing times are given in Fig. 4(right).

Equally important is to study the catalysts under reaction conditions. Strong changes in the local structure of a catalyst can occur along a catalytic microreactor not only in the case of

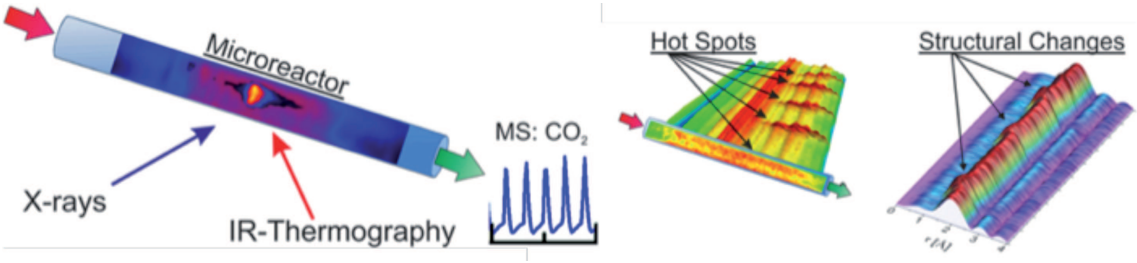

FIGURE 5. Combination of IR thermography, time and spatially resolved x-ray absorption spectroscopy and on-line catalytic measurements by mass spectrometry for the study of oscillating CO-oxidation in a microreactor.

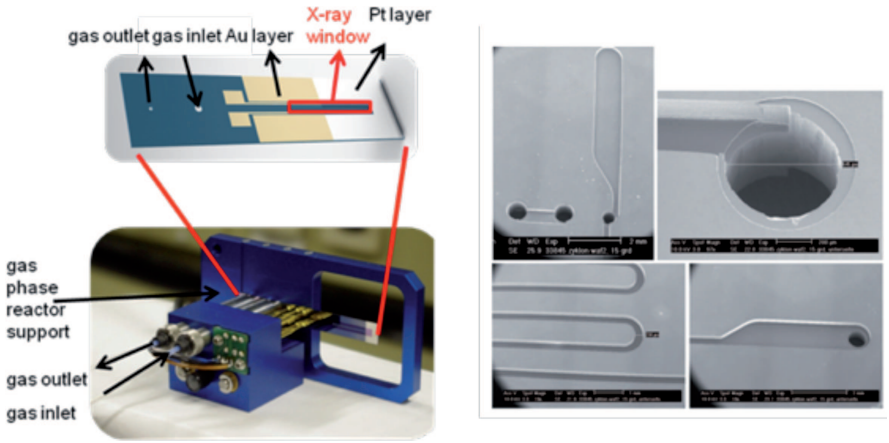

FIGURE 6. (left panel) Gas phase microreactor system built by lithography. (right panel) SEM images of a cyclon mixer of a lithographic liquid phase microreactor.

a strongly exothermic/endothermic reaction like the partial oxidation of methane but also other catalyst systems. We recently observed strong changes of the catalyst structure along a catalytic reactor during the selective catalytic reduction of NO_x by ammonia over Fe/zeolite and Cu/zeolite catalysts [20]. More recently, we have even monitored both the structure and catalytic activity in the case of CO oxidation over Pt-based catalysts [21]. This was achieved by a combination of IR thermography, time and spatially resolved x-ray absorption spectroscopy and on-line catalytic measurements by mass spectrometry (Fig. 5).

The next step for further improvements of the spatial resolution is the use of lithographically fabricated microreactors. A first gas phase microreactor [Fig. 6(left)] was developed in collaboration between AG Grunwaldt and AG Schroer. It has been used with a combination of techniques: XAS, Raman spectroscopy and thermography for studying the catalytic partial oxidation (CPO) of methane (CH_4).

Another important aspect in chemistry and materials design is studying the formation of solids by precipitation and the production of metal particles via colloidal approaches (redox reactions). Together with the group of Prof. Roland Dittmeyer (IMVT, KIT) special mixers were developed that allow liquid phase reactions under turbulent conditions [Fig. 6(right)].

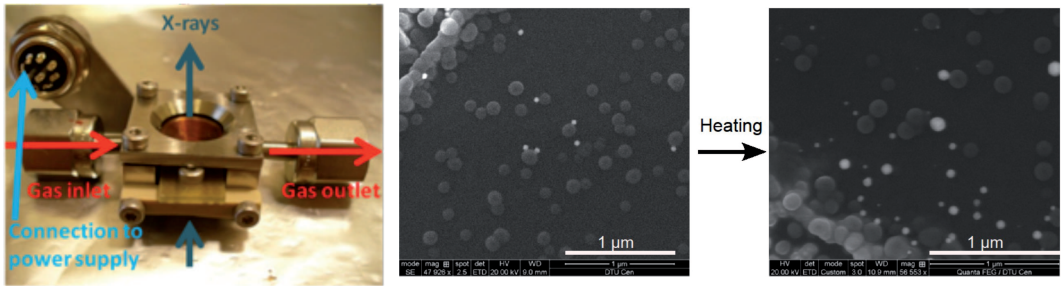

FIGURE 7. In-situ cell developed for ptychography (left) with gas and electrical connections (MEMS chip not visible). Sintering of gold nanoparticles deposited on the silicon nitride membrane of the MEMS chip before and after heating at 500 °C [synthetic air, SEM image (right)].

Despite these microreactors allow to monitor the catalysts with a hard x-ray beam of 100 nm [22], the present project also aims at studying sintering and shape changes in the sub-10 nm regime. For this purpose x-ray ptychography is excellently suited. In the course of the project, we were able to monitor Au-particles with a resolution of better than 20 nm [23]. Moreover, Pt-Pd-Au particles were resolved with a resolution better than 10 nm (publication in preparation, cf. section 2.2.3). Further improvements are expected with better analysis techniques and higher beam stability and beam focus.

The next step is the combination of x-ray and electron microscopy [24]. For this purpose a first in-situ cell based on MEMS chips was designed with DTU (Technical University of Denmark) (Fig. 7). The MEMS chip can be both analyzed by electron and x-ray microscopy.

2.2.3. *Topic III, Methods & Instrumentation:*

Microfluidic flow chambers: in our effort to develop suitable microfluidic devices to perform x-ray experiments on biological systems, we tested different materials for channel fabrication and measurement windows. UV-curable adhesives (NOA81) have been used as channel defining materials as they can easily be molded into the microstructure. However, the material is not very radiation resistant and is, therefore, not suitable for the intense beams at PETRA III. A combination with thin (8 μm) Kapton foil, however, proved to be a good choice: for cell experiments, we additionally incorporated a small silicon nitride (Si_3N_4) window. This material is virtually transparent for x-rays and at the same time a good substrate for many adherent cells.

Microfluidics has the important advantage that (owing to the usually small Reynolds numbers) only laminar flows have to be considered and can be predicted precisely using simulations (e. g., finite element method simulations). We used these methods extensively to optimize the device geometries and flow velocities. After the first three years of funding within this VI we now have systems available to study proteins (e. g., assembly, aggregation) and cells (including hydrated samples and living cells).

Nanoprobe at P06: In view of imaging catalytic nanoparticles in situ (Topic II: Chemical Processes), we continued our development of ptychographic imaging with highest sensitivity and spatial resolution. In the first year, we reached sub-10 nm resolution in ptychographic

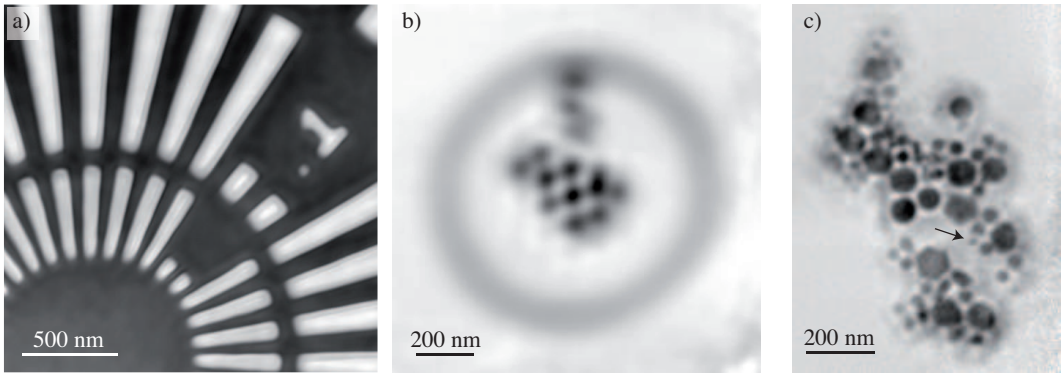

FIGURE 8. a) Ptychographic reconstruction of test pattern with 10 nm resolution, b) weakly scattering gold nanoparticles imaged by conventional ptychography, and c) various nanoparticles (Pd, Au, Pt, down to 15 nm in size, cf. arrow) imaged with ptychographic multiple exposure schemes.

imaging of a test object [Siemens star, Fig. 8a)] and were thus able to clearly exceed the resolution limits of conventional x-ray microscopy [25].

For weakly scattering objects, conventional ptychography reaches its sensitivity limits, due to background signals created by the direct beam on the detector. Therefore, small nanoparticles can not be resolved without appropriate background corrections. Fig. 8b) shows the ptychogram of 80 nm gold particles with numerical background correction. In this way, ptychography could be combined with absorption spectroscopy and resonant scattering to determine the chemical state of the nanoparticles [23]. In this experiment, a spatial resolution between 20 and 30 nm was reached for these weak scatterers, and spectroscopic information could be obtained on the ten atto-mol level.

In order to improve the signal-to-noise ratio, we upgraded our x-ray microscope with a flight-tube system and various beamstops. Based on this new instrumentation, we developed multi-exposure schemes in ptychography, making it is possible to record ptychograms of much smaller and more weakly scattering objects. Fig. 8c) shows a ptychogram of various nanoparticles made of gold, platinum, and palladium. The particle pointed to by the arrow in Fig. 8c) is about 15 nm in size, the spatial resolution is about 5nm. Compared to the previous example [23], the chemical sensitivity was increased by two orders of magnitude. The next step is a complete upgrade of the scanning microscope at P06 to improve stability and further suppress the background to push the spatial resolution to the level of 1 nm.

GINIX endstation at P10: The flexible and modular optical design, which can combine KB focusing with additional optical components (waveguide optics, Multilayer zone plate optics) has been significantly extended. Compound optics such as lens systems can overcome the limitations concerning resolution, efficiency, or aberrations, which fabrication constraints would impose on any single optical element.

New waveguides have been fabricated and are made available for holographic imaging. The beam of GINIX/P10 has been extensively characterized by ptychography. Phase retrieval algorithms have been developed, which are capable to simultaneously reconstruct the object and the probe also for extended wavefronts (generalized ptychography). Time-resolved

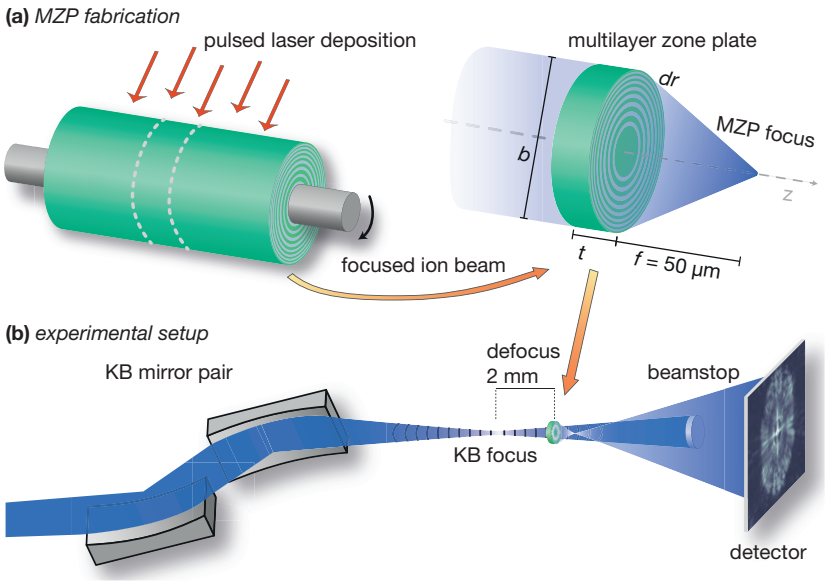

FIGURE 9. The setup for the 5nm focus at P10: (a) Schematic fabrication process: pulsed laser deposition of W and Si multilayer onto a rotating wire according to the Fresnel zone plate law. Focused ion beam fabrication of the MZP by cutting a slice out of the coated wire, placing it onto a sample holder and polishing it down to the optimal optical thickness of 0.7 μm. (b) Experimental implementation at P10: The MZP is positioned 2 mm downstream of the KB focus.

(bunch-clock synchronized) coherent imaging has been demonstrated in a proof-of-concept experiment.

As a particular milestone, we could demonstrate unprecedented sub-5 nm point focusing of hard x-rays, based on the combination of a high-gain Kirkpatrick-Baez (KB) mirror system and a high-resolution multilayer zone plate (MZP) for ultra-short focal length f, see Fig. 9 [26]. The pre-focusing allows limiting the MZP radius to below 2 μm, compatible with the required 5 nm structure width and essentially unlimited aspect ratios, provided by enabling fabrication technology based on pulsed laser deposition (PLD) and focused ion beam (FIB). A record focus with 5 nm cross section has been achieved by an optimized KB/MZP combination and further efforts are under way to use this for imaging.

Scanning Microscope at P11: A scanning transmission x-ray microscope (STXM) has been installed at beamline P11. Due to closed loop operation the STXM allows for experiments at very high spatial resolution. First successful experiments with biological samples have been carried out. This includes x-ray fluorescence measurements of bone samples and ptychographic measurements of different biological specimens. As an example, the high resolution ptychographic reconstruction of two adjacent HUH7 liver cells is shown in Fig. 10(A).

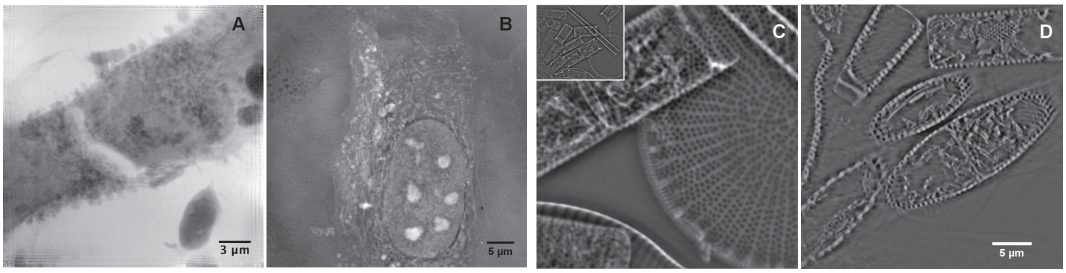

FIGURE 10. Ptyhographic reconstruction of two adjacent HUH7 liver cells (A) and x-ray Zernike phase contrast image of a HUH7 liver cell with a resolution of 50 nm, resolving small features such as the nuclear membrane (B). Microscopy image (C) and virtual slice from the reconstructed tomographic volume (D) of a fossile diatom obtained by x-ray Zernike phase contrast microscopy. All data were recorded at beamline P11 at the PETRA III storage ring.

In addition, a Zernike x-ray phase contrast full-field microscope was setup and user experiments were successfully performed with this setup. A sample image is shown in Fig. 10(B). With this setup a spatial resolution of 50 nm can be achieved in both 2D and 3D.

First nanotomography experiments were also successfully performed. Due to the high mechanical precision of the setup, image processing is straight forward and requires only very little realignment of the individual projections. A projection and a virtual slice from the tomographic reconstruction of a fossile diatom are shown in Fig. 10(C and D) showing features at great detail. Such a resolution has not been achieved with x-ray Zernike phase contrast microscopy of biological samples and has great potential for 3D imaging of cells and tissue at very high resolution. The microscope is currently further developed aiming at an isotropic resolution of 30 nm. Due to its short exposure times on the order of one second for the acquisition of 2D image and the large field of view of 50 μm, the P11 full-field microscope is also ideally suited to follow catalytic processes at 50 nm resolution.

In parallel, cryogenic techniques for sample preparation were established at DESY. In this course a Baltec HP-100 high-pressure freezing device was installed. Several biological samples were successfully high-pressure frozen using this device and later investigated with x-ray techniques. A full cryogenic chain was established, which allows the frozen samples to be transferred to the beamlines, while maintaining cryogenic temperatures. As a proof of the successful application of high pressure freezing of biological samples, several macromolecular and virus crystals have been high-pressure-frozen and subsequently investigated with x-ray diffraction. With this technique the crystal structure from the bovine enterovirus 2 could for the first time be determined at cryogenic temperatures. The fact that the high-pressure-frozen crystals still diffracted to 2.2 Å and beyond further proves that the distortions induced in the sample by applying this technique are very small and structural details are fully preserved.

In-situ sample environments for soft x-ray imaging: In the reporting period, in-situ sample environments for handling and investigating frozen-hydrated and suspended samples were implemented for x-ray imaging. Especially for the investigation of cryogenic samples,

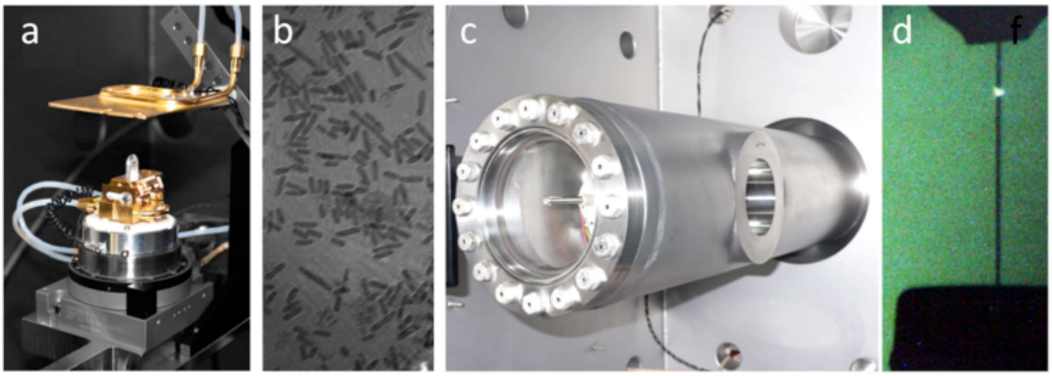

FIGURE 11. a) cryo stage implemented in HORST b) vitrified bacteria imaged with soft x-rays c) chamber-in-chamber liquid jet for single pulse experiments e) FLASH fs pulses hitting the water beam.

a cryo-preparation laboratory has been established in the Rosenhahn group. Samples can be plunge-frozen and investigated by in-situ optical microscopy for pre-characterization. The samples can then be transported to the synchrotron facilities and be investigated. For the melanosome project (cf. Topic I in section 2.2.1) cryogenic samples were prepared at KIT and transported to the P10 beamline at PETRA III to analyse their ultrastructure. A cryo transfer system in the x-ray scattering chamber HORST allows to handle and investigate the same samples with soft x-rays (Figure 11a). Panel b shows frozen-hydrated bacterial cells in a vitrified ice matrix as proof for the applicability to biological systems. The second major implementation is a liquid water jet. During the reporting period, this BMBF funded development has been implemented into the HORST chamber (c) and used for the first time at the free electron laser FLASH. Figure 11 (d) shows the plasma created by the femtosecond x-ray beam of FLASH at the surface of the water jet. In the future, the device can be used for sequential imaging and pump-probe experiments. The combined integration of cryogenic and liquid jet injection for coherent soft x-ray research into one instrument is unique in Germany, if not world wide.

2.3. **Progress of work to date.** (max. 3 DIN A4 pages)

Most of the milestones of the evaluation period have been reached, with a few exceptions. One important factor that led to some delays is the shutdown of PETRA III from early 2014 to spring 2015. Where possible, experiments were transferred to other synchrotron radiation sources. The shutdown, however, has also some advantages: Instrumental improvements can be carried out more easily this year, leading to improved experimental conditions in 2015.

In the following, we discuss the progress in each Topic and comment on the individual milestones.

2.3.1. *Topic I, Bioimaging:*

Mem1a (year 1): tomography of myelinated axons in nerve fibers (fixated tissue) was reached in the first year.

Mem1b (year 1): pump-probe experiment of dry membrane stack: milestone was reached in the first year.

Mem2a (year 2): propagation imaging of two adhering membranes was not yet reached, but isolated black lipid membranes in an electrophysiology setup have been successfully imaged at P10, and the analysis of data on fusion of monolayers in a microfluidic chamber has been completed.

Mem2b (year 2): hydrated membrane stack: this milestone was already reached in the first year.

Mem3a (year 3): synaptic vesicles in microfluidic channels interacting with lipid bilayers of liposomes, probed by nanoscale diffraction. This topic was postponed. The milestone is not reached.

Mem3b (year 3): nanoscale diffraction on membranes in microfluidic chambers has been carried out. Significant work on testing different microfluidic chambers has been performed, including adaptations of commercial one. We have decided to concentrate all efforts on cellular imaging and diffraction, and optimize the setting of P10 for these experiments, including beam preparation, fast scanning, ptychographic and holographic imaging. Since this topic is particularly timely, live-cell imaging has been a major emphasis, which has now been realized for several systems and contrast modes, including holographic imaging of bacterial cells and macrophages during phagocytatosis.

Cell1 (year 1): small-angle x-ray scattering (SAXS) on purified intermediate filaments and actin were performed using PETRA III beamlines: milestone was reached in the first year.

Cell2 (year 2): fixed cells: milestone reached in second year (cf. section 2.2.1)

Cell3 (year 3): model organisms and, first test of live cell imaging: milestone reached last year (cf. section 2.2.1)

Mel3 (year 3): imaging of frozen hydrated melanosomes: Frozen hydrated melanosomes were successfully imaged at P10 in a frozen hydrated state. (milestone reached)

Alg3 (year 3): investigation of frozen-hydrated marine biofouling organisms and cells: frozen-hydrated diatoms and bacterial cells were successfully imaged with ptychographic and zone plate imaging at BESSY. (milestone reached)

Due the the move of the Rosenhahn group from KIT to RU Bochum with the associated transfer of the project, less FTE were spent than initially anticipated. This underspending will be compensated in the coming years.

In cell imaging many technical and experimental problems could be solved in the first part of the funding period. Therefore, it is now possible to focus even more on science questions in this field.

2.3.2. *Topic II, Chemical Processes:*

Cat1 (year 1): Tomographic imaging of exhaust-gas catalyst was performed successfully in 2011. This milestone was reached very early in the project. Detailed studies of exhaust gas catalysts were performed on the micrometer scale (cf. section 2.2.2).

Cat3 (year 3): In-situ study of the ignition of the catalytic partial oxidation of methane around a single catalyst particle. This milestone is not yet fully reached. The in-situ microreactors were successfully fabricated (cf. CatRe3) and the ptychographic imaging techniques were improved to have sufficient sensitivity and resolution (cf. section 2.2.2). Due to the shutdown of PETRA III, the in-situ experiment could not be performed, so-far. We are, however, ready to perform this experiment when beamtime is available again at PETRA III.

Sin2 (year 2): Imaging of metal particles by XANES ptychography. XANES ptychography was successfully performed for 80 nm gold nanoparticles [23]. Signal-to-noise ratio in XANES ptychograms was significantly improved by multiple exposure schemes (cf. section 2.2.2). In addition a XANES ptychogram of an alloy sample was successfully recorded. Milestone reached in 2013.

React2 (year 2): microreactor device for studying flow pattern and reaction mechanisms in the homogeneous redox reaction from Cu(II) and Au(III) precursors to colloids. The microreactor was realized and several experiments for redox reactions from Au(III) and for $BaSO_4$ precipitation reactions have been performed. Time-resolved SAXS data on $BaSO_4$ precipitation were recorded and are currently evaluated. The formation of gold colloids was also investigated by time-resolved SAXS and XAS experiments. Milestone reached in 2013.

2.3.3. *Topic III, Methods & Instrumentation:*

Mfluid1 (year 1): test experiments to tailor microfluidic devices to experimental parameters (flow rates, pressure, time resolution): Successful design and construction of microfluidic cells for precipitation reactions and gas-phase heterogeneous catalysis. We have developed and successfully used different microfluidic flow chambers (a semi-commercial version developed together with IBIDI, Munich and a self-developed version as a further development from our own, home-built microfluidic devices. The millstone was reached in the first year (cf. section 2.2.1).

Mfluid2 (year 2): test experiments to choose optimal window materials for given experiment/beamline and development of such devices: milestone successfully reached (cf. section 2.2.1)

Mfluid3 (year 3): microfluidic devices for use in beamlines P06, P10 and P11: we tested our microfluidic devices at P10; we were, unfortunately not successful yet at P11 and still have to work on this point. We did not get beamtime for measurements at P06 and will try again in the next beamtime proposal round.

CatRe3 (year 3): in-situ reactor for 2D study of catalytic reactions. Two types of chemical microreactors were realized for catalysis (gas flow) and in-situ liquid cell for chemical reactions. For these first prototypes, the optimal temperature homogeneity and stability at elevated temperatures is not sufficient for CPO. These microreactors are well suited for selective catalytic reduction of NO_x or for CO oxidation.

Mdiff2 (year 2): integration of the high-q detectors into the STXM: due to the expected PETRA III shutdown from February 2014 to late spring 2015 and a limitation of financial resources, it was decided to postpone the integration of a second detector for WAXS measurements into 2015 (Mdiff2 was foreseen for 2013). This has the further advantage that newest detector technology with much better performance will be integrated into the setup.

Mdiff3 (year 3): cryogenic micro-diffraction experiments on melanosomes and cytoskeleton of cells. Due to the one-year shutdown of PETRA III, this milestone can not be reached this year. It is now foreseen for 2015 when PETRA III resumes operation.

Ins1 (year 1): microfluidic cell designed and built, ready for implementation at P06.

Soft1 (year 1): implement real-time ptychographic reconstruction on DESY computers. This milestone was reached in 2011: A dedicated computer with GPU was installed at DESY, running the ptychographic software.

Theo1 (year 1): evaluation of coherent properties of FELs from experimental data. Milestone reached in the first year [27, 28, 29, 30].

Theo2 (year 2): model of partially coherent nanobeams. Milestone reached in 2013 [5].

Theo3 (year 3): improved ptychographic reconstruction, taking mechanical instabilities into account. Several algorithms were developed that cope with different types of instability [33, 24]. Milestone reached in 2013.

2.4. **Potential for exploitation (only for application-oriented topics).**

- In the course of the project, a collaboration with the French synchrotron Soleil was implemented in order to make the microscope and techniques, which are developed at DESY also available to Soleil. In addition, people involved at DESY on the technical developments are currently in the process of funding a company to commercialize several technical developments made in framework of VI-403.
- The tomographic studies especially under in-situ or quasi in-situ conditions are interesting for chemical and car industry. Furthermore, catalyst manufacturers, especially a well-known company, had shown interest in these new imaging techniques.

3. Qualification of young scientists

During the reporting period PD Dr. Axel Rosenhahn was appointed as W2 professor for analytical chemistry at the Ruhr-University Bochum.

The following measures to support young scientists were taken:

- Dr. Amélie Rochet was granted a Humboldt research fellowship at KIT for studies in x-ray microscopy (starting Sept. 2013) and was promoted group leader at ITCP/KIT.
- Research stay of Britta Weinhausen at the APS, Argonne, USA (09-10/2011, financed through the SFB 755 of the DFG as a measure for gender equality and support of young researchers).
- PhD students were encouraged to present their work at international conferences to discuss their results with experts in the field.

Postdoctoral researchers funded by the VI:

- Dr. Amélie Rochet has been employed as a PostDoc (Sep. 2012 — Aug. 2013) before she was granted the Humboldt research fellowship.
- Dr. Janine Fischer has been employed within the VI as a PostDoc at DESY between Jan. 2013 and Nov. 2013. She has been on parental leave since December 2013.
- Dr. Hudson Carvalho (partly assigned to this project, KIT)
- Dr. Ruslan Kurta (DESY)

Postdoctoral researchers not funded by VI:

- Dr. Dmitry Doronkin, KIT
- Dr. Maria Casapu, KIT
- Dr. Sergei Lazarev, DESY

Academic achievements of young scientists:

- Dissertation Britta Weinhausen (Scanning X-Ray Diffraction on Eukayotic Cells: From Freeze-Dried to Living Cells, Göttingen 12/2013)
- Dissertation Matthias Bartels (Cone beam x-ray phase contrast tomography of biological samples, Göttingen 11/2013)
- Dissertation Tobias Reusch (Non-equilibrium dynamics of lipid membranes, Göttingen 2013)
- Dissertation Sandra Stephan (High-Resolution 3D Ptychography, TU Dresden 04/2013)
- Dissertation Thomas Gorniak (Melanosomen im Real- und Fourierraum, Heidelberg 2013)
- Dissertation Martha Bennrich (Cation induced self-assembly of intermediate filaments, 07/2012)

- Dissertation Sebastian Aeffner (Stalk structures in lipid bilayer fusion studied by x-ray diffraction, Göttingen 2012)
- Dissertation Markus Osterhoff (Wave optical simulation of x-ray nano-focusing optics, Göttingen 2012)
- Dissertation Sebastian Kalbfleisch (A dedicated endstation for waveguide-based x-ray imaging, Göttingen 2012)
- Dissertation Andre Beerlink (Black lipid membranes studied by x-ray phase contrast imaging, Göttingen 2011)
- Physics Diploma Frank Seiboth (Strahlcharakterisierung einer rotationsparabolischen Röntgenlinse aus Beryllium mit Hilfe ptychographischer Bildgebung," TU Dresden, 11/2011)
- Physics Diploma Alexander Schavkan (Design and characterization of fast X-ray cameras for XPCS experiments, TU Dresden 02/2012)
- Physics Diploma Adam Kubec (Untersuchungen zur Fokussierbarkeit von harter Röntgenstrahlung mittels Multischicht-Laue-Linsen, TU Dresden 06/2012)
- Physics Diploma Juliane Reinhardt (Hochauflösende Bildgebung mit chemischem Kontrast durch Ptychographie, TU Dresden 11/2012)
- Physics Diploma Vivienne Meier (Röntgenstrahl-Charakterisierung am Freie-Elektronen-Laser mit Hilfe der Ptychographie, TU Dresden, 11/2012)
- Chemistry Diploma Martin Reichardt (Prepaparation und Anwendung von Goldkolloiden in der Katalyse und Sensorik, ITCP/KIT, 2012)
- Chemistry Diploma Andreas Gänzler (In-situ studies on Pt/Al_2O_3 catalysts during CO and NO oxidation, ITCP/KIT 2013)
- Physics Diploma Maria Scholz (Refraktive Lamellarlinsen (RLL) für die Mikroskopie mit harter Röntgenstrahlung, TU Dresden, 02/2014)
- Master thesis Jan-David Nicolas (Zeitaufgelöste kohärente Röntgenbeugung an akustischen Oberflächenwellen, Göttingen 2014)
- Master thesis Aike Ruhlandt (Dreidimensionale Phasenrekonstruktion in propagationsbasierter Phasenkontrast-Radiographie, Göttingen 2013)
- Master thesis Johannes Hagemann (Zur Rekonstruktion des Leerstrahls in der Vollfeld Röntgenbildgebung, Göttingen, 2013)
- Master thesis Martin Krenkel (Quantitative Phasenkontrast-Mikrotomographie, Göttingen, 2012)
- Master thesis Anna-Lena Robisch (Phasenrekonstruktion von Objekttransmissions- und Beleuchtungsfunktion auf Basis nichtlinearer Optimierung, Göttingen, 2012)
- Bachelor thesis Tobias Duddeck (An X-ray compatible microfluidic dialysis chamber, Göttingen 07/2014)

- Bachelor thesis Malte Vassholz (Röntgendiffraktion mit Nanofokus: Erhöhung des dynamischen Bereichs durch semitransparente Strahlfänger, Göttingen 2012)
- Bachelor thesis Mareike Töpperwien (Röntgenstrukturanalyse von Aktinsuspensionen, Göttingen 2012)
- Bachelor thesis Christina Böhme (Zeitaufgelöste Röntgendiffraktion an akustisch angeregten Lipidmembranen, Göttingen 2012)
- Bachelor thesis Felix Witwer (Aufbau und Erprobung eines Aufbaus für optische Ptychographie“, TU Dresden 05/2012)
- Bachelor thesis Jakob Seifert (Strahlanalyse durch Ptychographie, TU Dresden 05/2012)
- Bachelor thesis Clemens Wagner (Röntgenmikroskopie mittels Röntgenfluoreszenzanalyse, TU Dresden 05/2012)
- Bachelor thesis Karla Roszeitis (Zusammenhang zwischen resonanter Streuung und Absorption von Röntgenstrahlung, TU Dresden 01/2013)
- Bachelor thesis Martin Seyrich (Optische Ptychographie, TU Dresden 05/2013)
- Bachelor thesis Melanie Rödel (Optische Ptychographie an photorefraktiven Materialien, TU Dresden 05/2013)
- Bachelor thesis Johannes Richter (Hochauflösende Röntgenmikroskopie: Signal-Rausch-Verhältnis in der Ptychographie unter Nutzung von Beamstops, TU Dresden 05/2013)
- Bachelor thesis Florian Brack (Charakterisierung eines Röntgennanofokus mittels des Ronchi-Tests, TU Dresden 06/2013)
- Bachelor thesis Florian Heinsch (Untersuchungen zum Signal-Rausch-Verhältnis in der Ptychographie mit harter Röntgenstrahlung, TU Dresden 09/2013)
- Bachelor thesis Constantin Bernert (Detektion photorefraktiver und elektrooptischer Eigenschaften mittels optischer Ptychographie, TU Dresden 01/2014)
- Karolina Stachnik, a student from AGH Krakow, Poland, performed STXM measurements at P11 at DESY for her bachelor thesis (finished in 2013) and ptychographic experiments for her Master thesis (expected to be finished in September 2014) in the framework of VI-403.

Additional qualifications for PhD students:

- Sina Baier has been at DTU-CEN for PhD-exchange for a few weeks for in-situ cell design and testing. A longer stay of her's at DTU is planned.
- Georg Hofmann stayed several weeks at DTU-CEN for preparing and characterizing the nanoparticle samples for ptychography.
- Oliva Saldanha (U. Göttingen) and Robert Hoppe (TU Dresden) attended the HERCULES 21 course on x-ray science in Grenoble, France in 2011.
- Robert Hoppe attended the DESY Research Course (19.03.2013 – 22.03.2013), Hamburg

- The RACIRI Summer School in St. Petersburg, Russia, was attended by Robert Hoppe, Juliane Reinhardt, Stephan Ritter, and Maria Scholz.
- Sina Baier, Amélie Rochet, and Georg Hofmann visited the TU Dresden group for training courses in ptychography and tomography.

4. Public relations activities

We have launched the following press releases concerning highlight publications:

- press release about publication [31], Univ. Göttingen, DESY. This release received broad attention (e. g., highlight in Nature Materials).
- press release (DESY, Uni Göttingen) about publication [26]

  `http://www.desy.de/infos__services/presse/pressemeldungen/@@news-view?id=6381\&lang=ger`

  highlighted also in many newspapers and physics information services, e. g.:

  `http://www.pro-physik.de/details/news/5307151/Drahtscheibe_fokussiert_Roentgenstrahl.html`
- press release (DESY) about publication [25]

  `http://www.desy.de/infos__services/presse/pressemeldungen/@@news-view?id=3421&lang=ger`
- Press release at KIT about start of the project

  `http://www.kit.edu/kit/8049.php`

Publications and information on the projects are disseminated via the websites of the different partners.

5. Publications in scientific journals, conference contributions, scientific papers and diploma theses or bachelor/master theses, dissertations, habilitations, reports and other publications (list, see questionnaire).

Peer-Reviewed Articles

[1] C. Eberl, F. Döring, T. Liese, F. Schlenkrich, B. Roos, M. Hahn, T. Hoinkes, A. Rauschenbeutel, M. Osterhoff, T. Salditt, and H.-U. Krebs, Appl. Surf. Sci. , dOI:10.1016/j.apsusc.2014.04.089.

[2] J. Hagemann, A.-L. Robisch, D. R. Luke, C. Homann, T. Hohage, P. Cloetens, H. Suhonen, and T. Salditt, Opt. Express **22**, 11552 (2014).

[3] G. Hofmann, A. Rochet, S. Baier, M. Casapu, S. Ritter, F. Wilde, M. Ogurreck, F. Beckmann, and J.-D. Grunwaldt, J. Phys.: Conf. Ser. **499**, 012017 (2014).

[4] A. Ruhlandt, M. Krenkel, M. Bartels, and T. Salditt, Phys. Rev. A **89**, 033847 (2014).

[5] A. Singer and I. A. Vartanyants, J. Synchrotron Rad. **21**, 5 (2014).

[6] A. V. Zozulya, A. Shabalin, H. Schulte-Schrepping, J. Heuer, M. Spiwek, I. Sergeev, I. Besedin, I. A. Vartanyants, and M. Sprung, J. Phys. Conf. Ser. **499**, 012003 (2014).

[7] D. Dzhigaev, U. Lorenz, R. P. Kurta, F. Seiboth, T. Stankevic, S. Mickevicius, A. Singer, A. Shabelin, O. M. Yefanov, M. N. Strikhanov, G. Falkenberg, C. G. Schroer, R. Feidenhans'l, and I. A. Vartanyants, J. Phys. Conf. Ser. **499**, 012020 (2014).

[8] R. P. Kurta, L. Grodd, E. Mikayelyan, O. Y. Gorobtsov, I. Fratoddi, I. Venditti, M. Sprung, S. Grigorian, and I. A. Vartanyants, J. Phys. Conf. Ser. **499**, 012021 (2014).

[9] F. Seiboth, A. Schropp, R. Hoppe, V. Meier, J. Patommel, H. J. Lee, B. Nagler, E. C. Galtier, B. Arnold, U. Zastrau, J. B. Hastings, D. Nilsson, F. Uhlén, U. Vogt, H. M. Hertz, and C. G. Schroer, J. Phys. Conf. Ser. **499**, 012004 (2014).

[10] T. Gorniak, T. Haraszti, A. H. Suhonnen, Y. Yang, A. Hedberg-Buenz, D. Koehn, R. Heine, M. Grunze, A. Rosenhahn, and M. Anderson, Pigment Cell & Melanoma Research (2014), accepted for publication.

[11] I. Vartiainen, M. Warmer, D. Goeries, E. Herker, R. Reimer, C. David, and M. A., J. Synchrotron Rad. (2014), accepted for publication.

[12] D. Doronkin, M. Casapu, T. Günter, O. Müller, R. Frahm, and J.-D. Grunwaldt, J. Phys. Chem. C **118**, 10204 (2014).

[13] T. Gorniak, T. Haraszti, V. M. Garamus, A. R. Buck, T. Senkbeil, M. Priebe, A. Hedberg-Buenz, D. Koehn, T. Salditt, M. Grunze, M. G. Anderson, and A. Rosenhahn, PLoS ONE **9**, 90884 (2014).

[14] B. Weinhausen, O. Saldanha, R. N. Wilke, C. Dammann, M. Priebe, M. Burghammer, M. Sprung, and S. Köster, Phys. Rev. Lett. **112**, 088102 (2014), research Highlight in Nature Materials 13, 323 (2014).

[15] M. E. Brennich, S. Bauch, U. Vainio, T. Wedig, H. Herrmann, and S. Köster, Soft Matter **10**, 2059 (2014).

[16] M. Brennich and S. Köster, Microfluidics and Nanofluidics **16**, 39 (2014).

[17] F. Uhlen, D. Nilsson, A. Holmberg, H. M. Hertz, C. G. Schroer, F. Seiboth, J. Patommel, V. Meier, R. Hoppe, A. Schropp, H. J. Lee, B. Nagler, E. Galtier, J. Krzywinski, H. Sinn, and U. Vogt, Opt. Express **21**, 8051 (2013).

[18] Y. Yang, R. Heine, F. Xu, H. Suhonen, L. Helfen, A. Rosenhahn, T. Gorniak, S. Kirchen, T. Schwartz, and T. Baumbach, J. Phys. Conf. Ser. **463**, 012053 (2013).

[19] S. K. Ghosh, B. Salgin, D. Pontoni, T. Reusch, P. Keil, D. Vogel, M. Rohwerder, H. Reichert, and T. Salditt, Langmuir **29**, 815 (2013).

[20] M. Krenkel, M. Bartels, and T. Salditt, Opt. Express **21**, 2220 (2013).

[21] O. Deutschmann and J.-D. Grunwaldt, Chemie Ingenieur Technik **85**, 595 (2013).

[22] S.-C. Gleber, B. Weinhausen, S. Köster, J. Ward, D. Vine, L. Finney, and S. Vogt, J. Phys. Conf. Ser. **463**, 012005 (2014).

[23] F. Döring, A. L. Robisch, C. Eberl, M. Osterhoff, A. Ruhlandt, T. Liese, F. Schlenkrich, S. Hoffmann, M. Bartels, T. Salditt, and H. U. Krebs, Opt. Express **21**, 19311 (2013).

[24] M. Beckers, T. Senkbeil, T. Gorniak, K. Giewekemeyer, T. Salditt, and A. Rosenhahn, Ultramicroscopy **126**, 44 (2013).

[25] R. N. Wilke, M. Vassholz, and T. Salditt, Acta Cryst. A **69**, 490 (2013).

[26] K. Giewekemeyer, R. N. Wilke, M. Osterhoff, M. Bartels, S. Kalbfleisch, and T. Salditt, J. Synchrotron Rad. **20**, 490 (2013).

[27] B. Weinhausen and S. Köster, Lab on a Chip **13**, 212 (2013).

[28] R. Hoppe, J. Reinhardt, G. Hofmann, J. Patommel, J.-D. Grunwaldt, C. D. Damsgaard, G. Wellenreuther, G. Falkenberg, and C. G. Schroer, Appl. Phys. Lett. **102**, 203104 (2013).

[29] M. Bartels, V. H. Hernandez, M. Krenkel, T. Moser, and T. Salditt, Appl. Phys. Lett. **103**, 083703 (2013).

[30] A.-L. Robisch and T. Salditt, Opt. Express **21**, 23345 (2013).

[31] T. Reusch, F. Schülein, C. Bömer, M. Osterhoff, A. Beerlink, H. J. Krenner, A. Wixforth, and T. Salditt, AIP Advances **3**, 072127 (2013).

[32] T. Reusch, D. D. Mai, M. Osterhoff, D. Khakhulin, M. Wulff, and T. Salditt, Phys. Rev. Lett. **111**, 268101 (2013).

[33] A. Schropp, R. Hoppe, V. Meier, J. Patommel, F. Seiboth, H. J. Lee, B. Nagler, E. C. Galtier, B. Arnold, U. Zastrau, J. B. Hastings, D. Nilsson, F. Uhlen, U. Vogt, H. M. Hertz, and C. G. Schroer, Scientific Reports **3**, 1633 (2013).

[34] R. P. Kurta, R. Dronyak, M. Altarelli, E. Weckert, and I. A. Vartanyants, New J. Phys. **15**, 013059 (2013).

[35] V. G. Kohn, O. Y. Gorobtsov, and I. A. Vartanyants, J. Synchrotron Rad. **20**, 258 (2013).

[36] R. P. Kurta, M. Altarelli, and I. A. Vartanyants, Adv. Cond. Mat. (2013).

[37] A. V. Zozulya, J.-M. Meijer, A. Shabalin, A. Ricci, F. Westermeier, R. P. Kurta, U. Lorenz, A. Singer, O. Yefanov, A. V. Petukhov, M. Sprung, and I. A. Vartanyants, J. Appl. Cryst. **46**, 903 (2013).

[38] A. Singer, U. Lorenz, F. Sorgenfrei, N. Gerasimova, J. Gulden, O. M. Yefanov, R. P. Kurta, A. Shabalin, R. Dronyak, R. Treusch, V. Kocharyan, E. Weckert, W. Wurth, and I. A. Vartanyants, Phys. Rev. Lett. **111**, 034802 (2013).

[39] O. M. Yefanov and I. A. Vartanyants, J. Phys. B **46**, 164013 (2013).

[40] R. P. Kurta, B. I. Ostrovskii, A. Singer, O. Y. Gorobtsov, A. Shabalin, D. Dzhigaev, O. M. Yefanov, A. V. Zozulya, M. Sprung, and I. A. Vartanyants, Phys. Rev. E, Brief Reports **88**, 044501 (2013).

[41] R. P. Kurta, Y. Chesnokov, E. Weckert, and I. A. Vartanyants, J. Phys. Conf. Ser. **463**, 012046 (2013).

[42] D. D. Mai, J. Hallmann, T. Reusch, M. Osterhoff, S. Düsterer, R. Treusch, A. Singer, M. Beckers, T. Gorniak, T. Senkbeil, R. Dronyak, J. Gulden, O. M. Yefanov, A. Al-Shemmary, A. Rosenhahn, A. P. Mancuso, I. A. Vartanyants, and T. Salditt, Opt. Express **21**, 13006 (2013).

[43] A. Burkhardt, A. Wagner, M. Warmer, R. Reimer, H. Hohenberg, J. S. Ren, E. E. Fry, D. I. Stuart, and A. Meents, Acta Cryst. D **69**, 308 (2013).

[44] D. Nilsson, F. Uhlen, A. Holmberg, H. M. Hertz, A. Schropp, J. Patommel, R. Hoppe, F. Seiboth, V. Meier, C. G. Schroer, E. Galtier, B. Nagler, H. J. Lee, and U. Vogt, Opt. Lett. **37**, 5046 (2012).

[45] S. Köster and T. Pfohl, Mod. Phys. Lett. **B 26**, 1230018 (2012).

[46] M. Dubslaff, M. Hanke, J. Patommel, R. Hoppe, C. G. Schroer, S. Schöder, and M. Burghammer, Nanoscale Research Letters **7**, 553 (2012).

[47] S. P. Krueger, H. Neubauer, M. Bartels, S. Kalbfleisch, K. Giewekemeyer, P. J. Wilbrandt, M. Sprung, and T. Salditt, J. Synchrotron Rad. **19**, 227 (2012).

[48] A. Ruhlandt, T. Liese, V. Radisch, S. P. Krüger, M. Osterhoff, K. Giewekemeyer, H. U. Krebs, and T. Salditt, AIP Advances **2**, 012175 (2012).

[49] S. K. Ghosh, S. Castorph, O. Konovalov, T. Salditt, R. Jahn, and M. Holt, Biophys. J. **102**, 1394 (2012).

[50] A. Beerlink, S. Thutupalli, M. Mell, M. Bartels, P. Cloetens, S. Herminghaus, and T. Salditt, Soft Matter **8**, 4595 (2012).

[51] S. Aeffner, T. Reusch, B. Weinhausen, and T. Salditt, P. Natl. Acad. Sci. USA **109**, E1609 (2012).

[52] R. N. Wilke, M. Priebe, M. Bartels, K. Giewekemeyer, A. Diaz, P. Karvinen, and T. Salditt, Opt. Express **20**, 19232 (2012).

[53] C. Olendrowitz, M. Bartels, M. Krenkel, A. Beerlink, R. Mokso, M. Sprung, and T. Salditt, Phys. Med. Biol. **57**, 5309 (2012).

[54] A. Singer, F. Sorgenfrei, A. P. Mancuso, N. Gerasimova, O. M. Yefanov, J. Gulden, T. Gorniak, T. Senkbeil, A. Sakdinawat, Y. Liu, D. Attwood, S. Dziarzhytski, D. D. Mai, R. Treusch, E. Weckert, T. Salditt, A. Rosenhahn, W. Wurth, and I. A. Vartanyants, Opt. Express **20**, 17480 (2012).

[55] R. Dronyak, J. Gulden, O. M. Yefanov, A. Singer, T. Gorniak, T. Senkbeil, J.-M. Meijer, A. Al-Shemmary, J. Hallmann, D. D. Mai, T. Reusch, D. Dzhigaev, R. P. Kurta, U. Lorenz, A. V. Petukhov, S. Düsterer, R. Treusch, M. N. Strikhanov, E. Weckert, A. P. Mancuso, T. Salditt, A. Rosenhahn, and I. A. Vartanyants, Phys. Rev. B **86**, 064303 (2012).

[56] M. Bartels, M. Priebe, R. N. Wilke, S. P. Krüger, K. Giewekemeyer, S. Kalbfleisch, C. Olendrowitz, M. Sprung, and T. Salditt, Optical Nanoscopy **1**, 10 (2012).
[57] J.-D. Grunwaldt, J. B. Wagner, and R. E. Dunin-Borkowski, Chem. Cat. Chem. **5**, 62 (2013).
[58] J. Stötzel, R. Frahm, B. Kimmerle, M. Nachtegaal, and J.-D. Grunwaldt, J. Phys. Chem. C **116**, 599 (2012).
[59] A. Schropp, R. Hoppe, J. Patommel, D. Samberg, F. Seiboth, S. Stephan, G. Wellenreuther, G. Falkenberg, and C. G. Schroer, Appl. Phys. Lett. **100**, 253112 (2012).
[60] B. Weinhausen, J.-F. Nolting, C. Olendrowitz, J. Langfahl-Klabes, M. Raynolds, T. Salditt, and S. Köster, New J. Phys. **14**, 085013 (2012).
[61] W. F. Schlotter, J. J. Turner, M. Rowen, P. Heimann, M. Holmes, O. Krupin, M. Messerschmidt, S. Moeller, J. Krzywinski, R. Soufli, M. Fernández-Perea, N. Kelez, S. Lee, R. Coffee, G. Hays, M. Beye, N. Gerken, F. Sorgenfrei, S. Hau-Riege, L. Juha, J. Chalupsky, V. Hajkova, A. P. Mancuso, A. Singer, O. Yefanov, I. A. Vartanyants, G. Cadenazzi, B. Abbey, K. A. Nugent, H. Sinn, J. Lüning, S. Schaffert, S. Eisebitt, W.-S. Lee, A. Scherz, A. R. Nilsson, and W. Wurth, Rev. Sci. Instrum. **83**, 043107 (2012).
[62] R. P. Kurta, M. Altarelli, E. Weckert, and I. A. Vartanyants, Phys. Rev. B **85**, 184204 (2012).
[63] A. P. Mancuso, M. R. Groves, O. E. Polozhentsev, G. J. Williams, I. McNulty, C. Antony, R. Santarella-Mellwig, A. V. Soldatov, V. Lamzin, A. G. Peele, K. A. Nugent, and I. A. Vartanyants, Opt. Express **20**, 26778 (2012).
[64] U. Lorenz, N. M. Kabachnik, E. Weckert, and I. A. Vartanyants, Phys. Rev. E **86**, 051911 (2012).
[65] J. Gulden, O. M. Yefanov, A. P. Mancuso, R. Dronyak, A. Singer, V. Bernátová, A. Burkhardt, O. Polozhentsev, A. Soldatov, M. Sprung, and I. A. Vartanyants, Opt. Express **20**, 4039 (2012).
[66] A. Burkhardt, M. Warmer, S. Panneerselvam, A. Wagner, A. Zouni, C. Glockner, R. Reimer, H. Hohenberg, and A. Meents, Acta Cryst. F **68**, 495 (2012).
[67] I. A. Vartanyants, A. Singer, A. P. Mancuso, O. M. Yefanov, A. Sakdinawat, Y. Liu, E. Bang, G. J. Williams, G. Cadenazzi, B. Abbey, H. Sinn, D. Attwood, K. A. Nugent, E. Weckert, T. Wang, D. Zhu, B. Wu, C. Graves, A. Scherz, J. J. Turner, W. F. Schlotter, M. Messerschmidt, J. Luning, Y. Acremann, P. Heimann, D. C. Mancini, V. Joshi, J. Krzywinski, R. Soufli, M. Fernandez-Perea, S. Hau-Riege, A. G. Peele, Y. Feng, O. Krupin, S. Moeller, and W. Wurth, Phys. Rev. Lett. **107**, 144801 (2011).
[68] J. Gulden, S. O.Mariager, A. P. Mancuso, O. M. Yefanov, J. Baltser, P. Krogstrup, J. Patommel, M. Burghammer, R. Feidenhans'l, and I. A. Vartanyants, Phys. Status Solidi A **208**, 2495 (2011).
[69] M. E. Brennich, J.-F. Nolting, C. Dammann, B. Nöding, S. Bauch, H. Herrmann, T. Pfohl, and S. Köster, Lab on a Chip **11**, 708 (2011).
[70] J. Gulden, O. M. Yefanov, E. Weckert, and I. A. Vartanyants, AIP Conference Proceedings **1365**, 42 (2011).
[71] S. Roling, B. Siemer, M. Wostmann, H. Zacharias, R. Mitzner, A. Singer, K. Tiedtke, and I. A. Vartanyants, Phys. Rev. STAB **14**, 080701 (2011).
[72] T. Gorniak, R. Heine, A. P. Mancuso, F. Staier, C. Christophis, M. E. Pettitt, A. Sakdinawat, R. Treusch, N. Guerassimova, J. Feldhaus, C. Gutt, G. Grubel, S. E. amd A. Beyer, A. Golzhauser, E. Weckert, M. Grunze, I. A. Vartanyants, and A. Rosenhahn, Opt. Express **19**, 11059 (2011).

Book Contributions

[1] T. Salditt and T. Ducic, in *Springer Protocols Neutromethods 86*, edited by E. F. Fornasiero and S. O. Rizzoli (Springer, Berlin, 2014), Chap. X-Ray Microscopy for Neuroscience: Novel Opportunities by Coherent Optics In Super-Resolution Microscopy in the Neurosciences.
[2] I. A. Vartanyants and J. Zegenhagen, in *The X-ray Standing Wave Technique. Principles and Applications*, Vol. 7 of *Series on Synchrotron Radiation Techniques and Application*, edited by J. Zegenhagen and A. Kazimirov (World Scientific, Singapore, 2013), Chap. 11. Theory of photoelectron emission from an x-ray interference field, pp. 181–215.
[3] C. G. Schroer and J.-D. Grunwaldt, in *In-situ Characterization of Heterogeneous Catalysts*, edited by J. A. Rodiguez, J. C. Hanson, and P. J. Chupas (Wiley, New York, 2013), Chap. 2. Spatially Resolved X-Ray Absorption Spectroscopy, pp. 49–73.
[4] J.-D. Grunwaldt, in *Chemical Energy Storage*, edited by R. Schlögl (Walter de Gruyter GmbH, Berlin, 2012), Chap. In situ Analysis of Heterogeneous Catalysts in Chemical Energy Conversion, p. 311.

Highlighted Articles

[1] T. Gorniak, T. Haraszti, V. M. Garamus, A. R. Buck, T. Senkbeil, M. Priebe, A. Hedberg-Buenz, D. Koehn, T. Salditt, M. Grunze, M. G. Anderson, and A. Rosenhahn, PLoS ONE **9**, 90884 (2014).

[2] B. Weinhausen, O. Saldanha, R. N. Wilke, C. Dammann, M. Priebe, M. Burghammer, M. Sprung, and S. Köster, Phys. Rev. Lett. **112**, 088102 (2014), research Highlight in Nature Materials 13, 323 (2014).

[3] D. Doronkin, M. Casapu, T. Günter, O. Müller, R. Frahm, and J.-D. Grunwaldt, J. Phys. Chem. C **118**, 10204 (2014).

[4] A. Singer, U. Lorenz, F. Sorgenfrei, N. Gerasimova, J. Gulden, O. M. Yefanov, R. P. Kurta, A. Shabalin, R. Dronyak, R. Treusch, V. Kocharyan, E. Weckert, W. Wurth, and I. A. Vartanyants, Phys. Rev. Lett. **111**, 034802 (2013).

[5] O. M. Yefanov and I. A. Vartanyants, J. Phys. B **46**, 164013 (2013).

[6] F. Döring, A. L. Robisch, C. Eberl, M. Osterhoff, A. Ruhlandt, T. Liese, F. Schlenkrich, S. Hoffmann, M. Bartels, T. Salditt, and H. U. Krebs, Opt. Express **21**, 19311 (2013).

[7] B. Weinhausen and S. Köster, Lab on a Chip **13**, 212 (2013).

[8] R. Hoppe, J. Reinhardt, G. Hofmann, J. Patommel, J.-D. Grunwaldt, C. D. Damsgaard, G. Wellenreuther, G. Falkenberg, and C. G. Schroer, Appl. Phys. Lett. **102**, 203104 (2013).

[9] A. Burkhardt, A. Wagner, M. Warmer, R. Reimer, H. Hohenberg, J. S. Ren, E. E. Fry, D. I. Stuart, and A. Meents, Acta Cryst. D **69**, 308 (2013).

[10] A. Schropp, R. Hoppe, J. Patommel, D. Samberg, F. Seiboth, S. Stephan, G. Wellenreuther, G. Falkenberg, and C. G. Schroer, Appl. Phys. Lett. **100**, 253112 (2012).

5.1. **Third-party funding:**

- AG Köster: SFB755 "Nanoscale photonic imaging", DFG, renewed in 2011, next reewal coming up now (2015). Funding period 2011-2015: 307,000 Euro plus overhead (20%).
- AG Schroer: DFG (SCHR 1137/1-1): "Focusing x-ray free-electron-laser beams for imaging and creating extreme conditions in matter," 04/2012 - 03/2014, 52,800 Euro (incl. overheads).
- AG Schroer: Verbundforschung DESY-PT (05K13OD2): "Erzeugung und Charakterisierung von nanofokussierten XFEL-Pulsen zur Abbildung ultraschneller Prozesse in Materie," 07/2013 - 06/2016, 571,939,20 Euro (incl. overheads).
- AG Schroer: Verbundforschung DESY-PT (05K13OD4): "In-situ-Röntgenmikroskop mit Ortsauflösung im Nanometerbereich," 07/2013 - 06/2016, 902,961,20 Euro (incl. overheads).
- AG Grunwaldt: Humboldt grant for Amélie Rochet, starting Sep. 2013
- AG Grunwaldt: SIBW grant for Sina Baier, starting 2013
- AG Grunwaldt: Verbundforschung DESY-PT, "In-situ Röntgenmikroskopie mit höchster Ortsauflösung," 07/2013 - 06/2016, 447,886 EURO (incl. overheads)
- AG Salditt: SFB 755 TP C1, C10
- AG Salditt: SFB 803 TP B1
- AG Salditt: SFB 937 TP A7, A11
- AG Salditt: BMBF Verbundforschung (PETRA III)

- AG Köster & AG Salditt: Verbundforschung DESY-PT (05K13MG5) "Ultrastrukturuntersuchungen biologischer Zellen in Mikrofluidikprobenumgebung durch kohärente Einzelpuls-Bildgebung an XFEL," 07/2013 - 06/2016, 389.374,80 Euro (imcl. overheads)
- AG Meents: "Development and integration of an X-ray Microscope for the Nanoscopium beamline at Soleil," engineer position for three years funded by Soleil (about 180 kEuro personnel cost and 50 KEuro investment cost for technical developments).
- AG Rosenhahn: Marie Curie International Training Network "SeaCoat"

5.2. **Embedding into the scientific community:**

5.2.1. *Collaboration partners.*

- DTU Kopenhagen with Christian Danvad Damsgaard, Jakob Wagner (DTU-CEN).
- IMVT at KIT, Prof. Dittmeyer, in particular with Angela Ewinger, Günter Rinke, Sabine Heideker (formation of gold cluster), with Peter Pfeifer on Cu/Zn catalysts, with Dr. Andreas Kölbl SAXS analysis of $BaSO_4$ precipitation reactions.
- INT at KIT with Christian Kübel, Di Wang on combination of electron microscopy with x-ray microscopy.
- Ernst Ruska Centre, FZ Jülich, with Prof. Rafal Dunin-Borkowski on combination of electron microscopy with x-ray microscopy.
- Harald Herrmann, DKFZ Heidelberg (Biochemistry): cooperation on in vitro experiments on intermediate filaments as a step towards cell experiments.
- Rudolf Leube, RWTH Aachen (Cell biology) cooperation on cell experiments using x-rays.
- Jienwei Miao, UCLA, photo induced processes and dynamics of colloidal particles.
- Christian Gutt, Uni Siegen, KB coherent imaging of colloids.
- Hans-Ulrich Krebs, Univ. Göttingen, Multilayer Zone Plate fabrication.
- Klaus Giewekemeyer/Adrian Mancuso, eXFEL, ptychography of nuclear pore complex, yeast cells, 7.9 keV, mmpad detector, cryo.
- Stefano Lagomarsino, Univ. Rome, cellular analysis, fluorescence (Fe), cryo, waveguide imaging.
- Florian Rehfeldt, Univ. Göttingen, stem cells, wet chambers for cells.
- Jesper Wallentin, University of Lund and University of Göttingen, nanowire diffraction, ptychography, test of lambda detector.
- Wiebke Moebius, MPI Experimentelle Medizin, Göttingen, ultrastructure of nerve tissue, myelin structure.
- Frauke Alves, MPI Experimentelle Medizin, Göttingen, lung tissue in astma models.

- Tobias Moser, Universitätsmedizin, Göttingen, cochlea implants, structure of auditory nerve.
- V. Haramus, HZG, BioSAXS beamline P12.
- S. Braun, Fraunhofer IWS Dresden, development of Multi-Layer-Laue lenses.
- S. Niese, E. Zschech, Fraunhofer IZFP Dresden, x-ray microscopy with Multi-Layer-Laue lenses.
- J. Hastings, LCLS Stanford, Menlo Park, CA, USA, nanofocusing XFELs for time-resolved imaging of matter in extreme conditions.
- Andrea Somogyi, Synchrotron Soleil, cooperation on x-ray microscope development.
- Heinrich-Pette-Institut, Leibniz-Institut für Experimentelle Virologie, groups of Eva Herker and Rudolph Reimer, Hamburg, Germany: Cooperation on sample preparation and investigation of lipidic droplet formation in hepatitis infected liver cells.
- Andrey Petukhov, University of Utrecht (Department of Applied Chemistry): cooperation on experiments on colloidal crystals.
- Lars Samuelson, University of Lund (Physics Department): cooperation on experiments on the structure of nanowires (in the frame of EU FP7).

5.2.2. *National and international initiatives/consortia and memberships in committees.*

- Christian Schroer: Member of Science Advisory Committee of the ESRF (until 2012).
- Christian Schroer: Member of the Committee for Synchrotron Radiation in Germany (KFS) (2011 - 2014 as co-chair).
- Christian Schroer: Chair of the beam transport advisory and review team (BT-ART) for XFEL (since 2011).
- Christian Schroer: Member of the Project Review Panel of the Linac Coherent Light Source at SLAC, Menlo Park, California. (until Oct. 2012).
- Tim Salditt: Spokesperson DFG / SFB 755 *Nanoscale Photonic Imaging*.
- Tim Salditt: Member of the Committee for Synchrotron Radiation in Germany (KFS).
- Tim Salditt: Member of the Scientific Advisory Board MID beamline eXFEL.
- Tim Salditt: Member of the Scientific Advisory Board SoftiMax /MAX II.
- Tim Salditt: Editorial Board Member: Optical Nanoscopy (Springer).
- Sarah Köster: Vice speaker SFB 755 (since 2011).
- Sarah Köster: Editorial Board Journal of Physics D: Applied Physics (since 2013).
- Jan-Dierk Grunwaldt: Member of the Committee for Synchrotron Radiation in Germany (since 2011, elected for next period in 2014).
- Jan-Dierk Grunwaldt: Member of the International X-ray Absorption Spectroscopy Society (since 2012, elected by European Members).

- Jan-Dierk Grunwaldt: Member of the commission of the German catalysis society (GeCatS).
- Jan-Dierk Grunwaldt: Chairman of the next International EXAFS Conferenence XAFS16 in Germany in 2015.
- Axel Rosenhahn: Executive Committee Member of the Biointerfaces Division of the American Vacuum Society (Annual AVS meeting 2011, 2012, 2013).
- Axel Rosenhahn: Member of the Permanent International Committee for Research on the Preservation of Materials in the Marine Environment (COIPM).
- Ivan Vartanyants: SAC Member of MAX IV.
- Ivan Vartanyants: Proposal Review Member of FERMI.

5.2.3. *Conference, Workshops, and Schools.* The members of the VI were involved in organizing seven conferences, workshops, and schools listed below:

- Satellite Workshop "4th Workshop on X-Ray Nano-Imaging of Biological and Chemical Systems at PETRA III" to the DESY Photon Science Users' Meeting 2014 (attendance $\approx$ 102). The workshop is organized by the VI in collaboration with beamline P06 at PETRA III (Chair: Christian Schroer and Gerald Falkenberg).
- International Congress on X-Ray Optics and Microanalysis (ICXOM22), held in Hamburg from Sept. 2. - 6., 2013 (attendance 210). C. Schroer was co-chair of the conference and A. Meents was part of the organizing committee.
- Satellite Workshop "3rd Workshop on X-Ray Nano-Imaging of Biological and Chemical Systems at PETRA III" to the DESY Photon Science Users' Meeting 2013 (attendance $\approx$ 74). The workshop is organized by the VI in collaboration with beamline P06 at PETRA III (Chair: Christian Schroer and Gerald Falkenberg).
- Symposium "Microscopy and in-situ spectroscopy for catalysis: Present and future," organized by J.-D. Grunwaldt and Di Wang, AKNA/KNMF-User Meeting 2013, Bruchsal, September 27, 2013.
- Satellite Workshop "2nd Workshop on X-Ray Nano-Imaging of Biological and Chemical Systems at PETRA III" to the DESY Photon Science Users' Meeting 2012 (attendance $\approx$ 65). The workshop is organized by the VI in collaboration with beamline P06 at PETRA III (Chair: Christian Schroer and Gerald Falkenberg). The first workshop was organized in 2011 before the beginning of the VI as the inauguration of beamline P06.
- International congress on marine fouling and corrosion 2012 (Seattle) and 2014 (Singapore) (Axel Rosenhahn, Member of the organization committee).
- American Vacuum Society: Annual meetings 2011, 2012, 2013, Program committee Biointerfaces Division (Axel Rosenhahn, Member of the organizing committee).

5.2.4. *List of PhD Students.* Financed by VI:

- Martha Brennich (graduated in 2012, Göttingen) — female, German

- Sarah Schwarz (graduated in 2012, Göttingen) — female, German, Portuguese, US American
- Clement Hemonnot (expected graduation in 2016, Göttingen) – male, French
- Oliva Saldanha (expected graduation in 2015 or 2016, Göttingen) — female, Indian
- Jens Nolting (expected graduation in 2014, Göttingen) — male, German
- Marten Bernhardt (expected graduation in 2016, Göttingen) — male, German
- Anna-Lena Robisch (expected graduation in 2015) — female, German
- Susanne Hönig (currently on maternity leave, expected graduation in 2015, TU Dresden) — female, German
- Stephan Ritter (expected graduation in 2015, TU Dresden) — male, German
- Frank Seiboth (expected graduation in 2015, TU Dresden) — male, German
- Georg Hofmann (expected graduation in 2014, KIT) — male, German
- Sina Baier (expected graduation in 2015, KIT) — female, German
- Thomas Gorniak (graduated in 2013, RU Bochum) — male, German
- Tobias Senkbeil (expected graduation in 2014, RU Bochum) — male, German
- Andreas Buck (expected graduation in 2015, RU Bochum) — male, German

Financed by other sources:

- Britta Weinhausen (graduated in 2013) – female, German
- Juliane Reinhardt (expected graduation in 2016, DESY and TU Dresden) — female, German
- Robert Hoppe (expected graduation in 2015, TU Dresden) — male, German
- Maria Scholz (starting now, DESY) — female, German
- Anatoly Shabalin (expected graduation in 2014, DESY) — male, Russian
- Dmitri Dzhigaev (expected graduation in 2015, DESY) — male, Russian
- Oleg Gorobtsov (expected graduation in 2015, DESY) — male, Russian
- Ivan Zaluzhnyy (expected graduation in 2016, DESY) — male, Russian
- Max Rose (expected graduation in 2016, DESY) — male, German
- Andreas Gänzler (expected graduation in 2016, KIT) — male, German
- Elan Ogel (expected graduation in 2016, KIT) — female, German

5.2.5. *Outreach.*

A number of talks have been given, also for educating pupils. Jan-Dierk Grunwaldt has promoted this research area among pupils participating in the chemistry Olympiad (high school students) and also interested students at two workshops of the International Chemistry Olympiad.

Public lectures:

- 27.06.2013, J. Patommel "Der Röntgen-Freie-Elektronen-Laser: Ein Mikroskop zur Untersuchung chemischer Prozesse in Echtzeit," lecture within the public lecture series "Naturwissenschaften Aktuell" at TU Dresden.
- 08.12.2012, C. G. Schroer "Wie Dinge im Kleinen aussehen: Mikroskopie und Beugung mit Licht und Elektronen'," lecture within the series "Physik am Samstag" that is held for high-school students at TU Dresden.
- 13.10.2011, C. G. Schroer "Der Röntgen-Freie-Elektronen-Laser: Ein Mikroskop zur Untersuchung chemischer Prozesse in Echtzeit," lecture within the public lecture series "Naturwissenschaften Aktuell" at TU Dresden.

5.2.6. *Conference participation.* The members of the VI made 101 contributions to conferences until Dec. 2013:

- Oct. 2013, A. Rochet, S. Baier, G. Hofmann, J.-D, Grunwaldt "Gradients in the catalyst bed during the partial oxidation of methane," Catalyse, réactivité de surface et rayonnement synchrotron, Lille, France (poster)
- 27.10.2013, A. Buck, T. Gorniak, T. Senkbeil, V. Haramus, K. Hilpert, A. Rosenhahn "X-ray analysis of ultrastructure of vitrified biological objects," Long Beach, USA, The AVS International Symposium & Exhibition
- 27.10.2013, A. Buck, T. Gorniak, T. Senkbeil, V. Haramus, K. Hilpert, A. Rosenhahn, "X-ray analysis of ultrastructure of vitrified biological objects," Long Beach, USA, The AVS International Symposium & Exhibition
- 9-11.10.2013, J.-D. Grunwaldt "Challenges for operando X-ray absorption spectroscopy in catalysis," Journées du GdR C(RS)2, Villeneuve d'Ascq (Campus Lille 1), France (invited)
- 26.09.2013, Y. Yang, R. Heine, F. Xu, H. Suhonen, L. Helfen, A. Rosenhahn, T. Gorniak, S. Kirchen, T. Schwartz, T. Baumbach, Eggenstein-Leopoldshafen, Germany, ANKA User Meeting
- 18.09.2013, C. G. Schroer "Coherent X-Ray Diffraction Imaging," DFG Schule XFEL, Bad Honnef (invited)
- 09.09.2013, R. Heine, Y. Yang, T. Gorniak, A. Rosenhahn, M. Grunze "Visualization of bacterial biofilms on interfaces with synchrotron hard X-ray microscopy," Paris, France, the 19th International Vacuum Congress, IVC-19

- 09.09.2013, T. Gorniak, T. Haraszti, M. Anderson, M. Grunze, A. Rosenhahn "Synchrotron radiation as a probe for structural, elemental and chemical properties of melanosomes," Paris, France, the 19th International Vacuum Congress, IVC-19
- 09.09.2013, T. Senkbeil, T. Mohamed, M. Grunze, A. Rosenhahn "In-situ X-ray fluorescence analysis of barnacle larvae and juvenile barnacles," Paris, France, the 19th International Vacuum Congress, IVC-19
- 05.09.2013, J. Reinhardt "High-Resolution Chemical Imaging of Gold Nanoparticles Using Hard X-Ray Ptychography," International Congress on X-Ray Optics and Microanalysis, Hamburg
- 04.09.2013, R. Hoppe "Hard X-ray NANOPROBE P06, PETRA III," International Congress on X-Ray Optics and Microanalysis, Hamburg (poster)
- 04.09.2013, G. Hofmann, A. Rochet, S. Baier, M. Casapu, S. Ritter, F. Wilde, M. Ogurreck, F. Beckmann, J.-D. Grunwaldt "Ageing Effects on Exhaust Gas Catalyst: Microscopic changes captured by X-Ray Tomography," International Congress on X-Ray Optics and Microanalysis, Hamburg
- 2-6.09.2013, F. Seiboth "Full wavefield characterization of a nanfocused x-ray free-electron laser beam," International Congress on X-Ray Optics and Microanalysis, Hamburg
- Sep. 2013, S. Baier, G. Hofmann, E. Ogel, A. Rochet, J.-D. Grunwaldt "Overview on activities in spatially resolved techniques for catalysis," VI-403 Meeting, Hamburg
- 29.08.2013, C. G. Schroer "Hard x-ray scanning microscopy with coherent radiation: beyond the resolution of conventional x-ray microscopes," X-ray Nanoimaging, SPIE, San Diego (invited)
- 26.08.2013, C. G. Schroer "Hard X-Ray Nanofocusing with Refractive X-Ray Optics: Full Beam Characterization by Ptychographic Imaging," Advances in X-Ray/EUV Optics, SPIE, San Diego
- 20.08.2013, S. Ritter, "Prefocussing at the PETRA III Beamline P06," RACIRI Summer School, St. Petersburg (poster)
- 20.08.2013, J. Reinhardt "High-Resolution Chemical Imaging of Gold Nanoparticles Using Hard X-Ray Ptychography," RACIRI Summer School, St. Petersburg (poster)
- 20.08.2013, R. Hoppe "Hard X-ray NANOPROBE P06, PETRA III," RACIRI Summer School, St. Petersburg (poster)
- 08.08.2013, C. G. Schroer "X-Ray Microscopy for Nanoscience at Large-Scale Facilities," Gordon Research Conference, Stonehill College, Easton, MA (invited)
- 18.07.2013, C. G. Schroer "X-Ray Microscopy with Coherent Radiation,"' Physikkolloquium, Universität Siegen
- 11.07.2013, S. Köster, Institute of Chemistry, Hebrew University Jerusalem, Israel
- 08.07.2013, S. Köster, Hadassah Medical Center, Hebrew University Jerusalem, Israel

- 02.07.2013, C. G. Schroer "X-Ray Microscopy and Tomography with Elemental, Chemical, and Structural Contrast," FKA17, Chemnitz (invited)
- 27.06.2013, C. G. Schroer "Datenverarbeitung im Bereich Photon Science," BMBF, Bonn
- 25.06.2013, S. Köster, ESRF Grenoble, France
- 14.06.2013, C. G. Schroer "X-Ray Microscopy with Coherent Radiation," SFB-Kolloquium, Universität Göttingen
- 04.06.2013, C. G. Schroer "Focusing Hard X-Ray FEL Pulses," HIBEF Kick-Off Meeting, DESY, Hamburg
- 28.05.2013, C. G. Schroer "X-Ray Microscopy with Coherent Radiation," Kolloquium, Universität Bayreuth
- 27.05.2013, R. Hoppe "Making ptychography a real-time microscopy technique," GPU Workshop, TU Dresden, Dresden
- 17.05.2013, C. G. Schroer "X-Ray Microscopy for Nanoscience at Large-Scale Facilities," DESY, Hamburg
- 14-15.05.2013, J.-D. Grunwaldt "Synchrotron radiation & industrial catalysis: A tradition and future challenges," DORIS Photon Science Symposium, DESY, Hamburg (invited)
- 13.05.2013, A. Rosenhahn "Holographic imaging of biofouling events to understand settlement strategies in marine biofouling," NTU Singapore, (invited)
- May 2013, A. Rochet, G. Hofmann, S. Baier, J.-D, Grunwaldt "Gradients in the catalyst structure along a catalytic microreactor during the partial oxidation of methane," European-Material Research Society - 2013 Spring meeting, Strasbourg, France (poster)
- May 2013, A. Rochet, G. Hofmann, S. Baier, J.-D, Grunwaldt "Importance of spatial resolution in catalytic reactors: Gradients in the catalyst structure during the partial oxidation of methane," 112th Bunsentagung (Annual German Conference on Physical Chemistry), Karlsruhe (poster)
- May 2013, G. Hofmann, R. Hoppe, J. Reinhardt, C. Schroer, J.-D, Grunwaldt "Imaging catalysts by hard X-rays: New Opportunities of X-ray Tomography and Ptychography in the Nanoscale," 112th Bunsentagung (Annual German Conference on Physical Chemistry), Karlsruhe (poster)
- 07.05.2013, C. G. Schroer "Characterizing Nanobeams and X-Ray Optics using Ptychographic Imaging," Ptycho2013, Hohenkammer, Germany (invited)
- 06.05.2013, J. Reinhardt, "High-Resolution Chemical Imaging of Gold Nanoparticles Using Hard X-Ray Ptychography," Ptycho2013, Hohenkammer, Germany (poster)
- 06.05.2013, R. Hoppe "Hard X-ray NANOPROBE P06, PETRA III," Ptycho2013, Hohenkammer, Germany (poster)
- 06.05.2013, F. Seiboth "Full wavefield characterization of a CRL nanobeam at PETRA III and LCLS," Ptycho2013, Hohenkammer, Germany (poster)

- 25.04.2013, J. Patommel, "The Hard X-Ray Nanoprobe at P06," 1st Nanoanalysis Symposium, TU Dresden, Dresden (poster)
- 23.04.2013, R. Hoppe "Characterization of a focused FEL wave field with sub-100 nm resolution and direct imaging of shock waves," Institutsseminar, ISP, TU Dresden, Dresden
- 17.04.2013, R. Hoppe "Full characterization of a focused wave field with sub 100 nm resolution," SPIE, Conf. 8778, Prague, Czech Republic
- 11.4.2013, A. Rosenhahn "Chemical cues guide exploration and settlement of marine fouling organisms," ACS meeting, New Orleans, USA, (invited)
- 04.04.2013, S. Köster, University of Hamburg, Germany
- 25.03.2013, S. Köster, DESY Hamburg, Germany
- 23.03.2013, R. Hoppe "Hard x-ray scanning microscopy with diverse contrast mechanisms at P06," DGK Meeting, Freiberg
- 20.03.2013, J. Reinhardt "High-Resolution Imaging with Chemical Contrast," DGK Meeting, Freiberg (poster)
- 07.03.2013, S. Köster, CIC biomaGUNE, San Sebastian, Spain
- 25.01.2013, R. Hoppe "High-resolution Chemical Imaging of Gold Nanoparticles Using Hard X-Ray Ptychography," DESY Photon Science and European XFEL Users' Meeting, Hamburg (poster)
- 25.01.2013, G. Hofmann, J. Reinhardt, A. Rochet, C. Schroer, J.-D. Grunwaldt, "X-Ray Microscopy and Imaging of Exhaust Gas Catalysts," DESY Photon Science and European XFEL Users' Meeting, Hamburg (poster)
- 25.01.2013, F. Seiboth "Wavefield characterization of beryllium CRLs by ptychographic imaging," DESY Photon Science and European XFEL Users' Meeting, Hamburg (poster)
- 25.01.2013, J. Patommel, "The Hard X-Ray Nanoprobe at P06," DESY Photon Science and European XFEL Users' Meeting, Hamburg (poster)
- 24.01.2013, C. G. Schroer "Introduction to the Workshop," 3rd Workshop on X-Ray Nano-Imaging of Biological and Chemical Systems at PETRA III, DESY, Hamburg
- 15.01.2013, S. Köster, BioTEC Dresden, Germany
- 14.12.2012, C. G. Schroer "X-Ray Microscopy at a Diffraction Limited Storage Ring," Workshop on Diffraction Limited Storage Rings, SPring-8, Japan (invited)
- 12.12.2012, T. H. Mohamed, T. Senkbeil, S. Heissler, A. Di Fino, A. S. Clare, A. Rosenhahn "In-situ studies of barnacle cyprid and juvenile barnacle cement using XRF and micro-Raman spectroscopy," 2nd International conference on corrosion, mitigation and surface protection technologies, Hurghada, Egypt

- 11.12.2012, C. G. Schroer "XFEL Nanofocusing for Coherent X-Ray Diffraction Imaging and Creating Matter in Extreme Conditions," MID Workshop, XFEL, Hamburg (invited)
- 30.10.2012, T. Senkbeil, T. Gorniak, A. Buck, K. Giewekemeyer, T. Salditt, A. Rosenhahn "Coherent X-ray Imaging," AVS 59th Symposium and Exhibition, Tampa, FL, USA
- 30.10.2012, A. Rosenhahn "Coherent X-ray microscopy of vitrified biological samples," Symposium and Exhibition, Tampa, FL, USA (invited)
- 19.10.2012, C. G. Schroer "High-resolution imaging of shock-wave propagation in matter," Science beyond 4 Mbar using dynamic compression, XFEL, Hamburg (invited)
- 10.09.2012, S. Köster, BASF, Ludwigshafen, Germany
- Sep. 2012, G. Hofmann, J. Reinhardt, C. Schroer, J.-D. Grunwaldt, "X-Ray Imaging in Catalysis with Chemical Contrast: Microscopic 3D Information on Structure, Morphology and Composition in non destructive manner," HSC14 - HERCULES Specialized Courses: Neutrons and Synchrotron Radiation in materials for energy, Grenoble, France (poster)
- 08.08.2012, S. Köster, German Cancer Research Center (DKFZ) Heidelberg, Germany
- 08.08.2012, C. G. Schroer "Hard X-Ray Scanning Microscopy with Coherent Radiation," XRM 2012, Shanghai
- 11.7.2012, T. Gorniak, T. Senkbeil, A. Buck, A. Rosenhahn "Microscopic imaging of biological samples using soft X-ray synchrotron radiation in the water window," 11th International conference on synchrotron radiation instrumentation, Lyon, France
- 11.7.2012, R. Dronyak, J. Gulden, O.M. Yefanov, A. Singer, T. Gorniak, T. Senkbeil, J.M. Meijer, A. Al-Shemmary, J. Hallmann, D.D. Mai, A.R. Kurta, U. Lorenz, D. Dzhigaev, A. Pethukov, S. Duesterer, R. Treusch, E. Weckert, A. Mancuso, T. Salditt, A. Rosenhahn, I. Vartaniants "Dynamics of colloidal crystals studied by pump-probe experiments at FLASH," 11th International conference on synchrotron radiation instrumentation, Lyon, France
- 11.7.2012, D.D. Mai, J. Hallmann, T. Reusch, T. Salditt, A. Mancuso, I. Vartanyants, T. Senkbeil, T. Gorniak, A. Rosenhahn, A. Al-Shemmary, S. Duesterer, R. Treusch, "Time-resolved single-shot diffraction of lipid membrane with fs FEL pulses," 11th International conference on synchrotron radiation instrumentation, Lyon, France
- 10.07.2012, C. G. Schroer "Hard X-Ray Imaging with Coherent Radiation: Towards Nanometer Resolution," SRI 2012, Lyon (plenary invited)
- 02.07.2012, G. Hofmann "X-Ray Computerized Tomography: A brief Introduction," Helmholtz Reseach School for Energy-Related Catalysis, Schwetzingen, Germany
- 27.06.2012, S. Köster, Institut Charles Sadron, Strasbourg, France
- 27.06.2012, C. G. Schroer "Röntgenmikroradiographie zur Beobachtung von Erstarrungsprozessen in Schmelzen," Kolloquium Magnetofluiddynamik, TU Dresden

- 26.06.2012, T. Mohamed, T. Senkbeil, S. Heissler, A. Di Fino, A. S. Clare, A. Rosenhahn "In-situ study of barnacle cyprid and juvenile barnacle cement using XRF microscopy and micro-Raman spectroscopy," 16th International congress on marine corrosion and fouling, Seattle, USA
- 29.05.2012, S. Köster, TU Braunschweig, IGSM Summer School 2012, Burg Warberg, Germany
- 19.5.2012, T. Gorniak, T. Senkbeil, M. Beckers, A. Buck, M. Alles, K. Giewekemeyer, T. Salditt, A. Rosenhahn "Microscopic imaging of biological samples using soft X-ray synchrotron radiation from within the 'water window'," Bunsentagung, Leipzig
- 16.05.2012, C. G. Schroer "Elemental, Chemical, and Structural Imaging by Hard X-ray Microscopy," Workshop on Instrumentation and Methods Development for Synchrotron-based Biomedical Research, DESY, Hamburg (invited)
- 28.03.2012, C. G. Schroer "Hard X-ray Scanning Microscopy with Elemental, Chemical, and Structural Contrast," DPG Tagung, Berlin
- 28.03.2012, R. Hoppe "Raster Mikroskopie mit kohärentem Röntgenstreuungskontrast," DPG Tagung, Berlin
- 23.03.2012, T. Gorniak, T. Senkbeil, A. Buck, M. Alles, K. Giewekemeyer, T. Salditt, A. Rosenhahn "Cryogenic ptychography on plunge frozen marine organisms," XI. Research Course on X-Ray Science, Hamburg
- 14.03.2012, C. G. Schroer "Scanning coherent x-ray diffraction microscopy with spatial resolutions down to below 10 nm, " Jahrestagung der DGK, LMU München
- 23.02.2012, C. G. Schroer "Hard X-ray Scanning Microscopy with Coherent Radiation," Seminar der AG Pfeiffer, TU München
- 27.01.2012, C. G. Schroer "New Developments in X-Ray Microscopy at PETRA III," HASYLAB Users' Meeting, Hamburg (plenary invited)
- 27.01.2012, S. Ritter, "Prefocussing at the PETRA III Beamline P06," HASYLAB User' Meeting, Hamburg (poster)
- 27.01.2012, R. Hoppe "Ptychographic Imaging," HASYLAB User' Meeting, Hamburg (poster)
- 27.01.2012, J. Reinhardt "XANES Imaging," HASYLAB Users' Meeting, Hamburg (poster)
- 27.01.2012, J. Patommel, "The Hard X-Ray Nanoprobe at P06," HASYLAB Users' Meeting, Hamburg (poster)
- 26.01.2012, G. Hofmann, J.-D. Grunwaldt "Imaging in Catalysis Research: Example Applications at P06," HASYLAB Users' Meeting 2012 - Workshop on Nano Imaging, Hamburg
- 27.01.2012, F. Seiboth "Full CRL focus characterization by ptychographic imaging", Hasylab Users' Meeting (poster)

- 27.01.2012 T. Gorniak, T. Senkbeil, A. Buck, M. Alles, K. Giewekemeyer, T. Salditt, A. Rosenhahn "Cryogenic ptychography on plunge frozen marine organisms," European XFEL and HASYLAB Users' Meeting, Hamburg
- 14.12.2011, S. Köster, Institut Curie, Paris, France
- 07.12.2011, R. Hoppe "GPU Nutzung bei der Ptychographischen Bildgebung," GPU Workshop, TU Dresden, Dresden
- 05.12.2011, T. Senkbeil, T. Mohamed A. Di Fino, R. Gabilondo Toscano, A. S. Clare, A. Rosenhahn "X-Ray fluorescence microprobe analysis of marine macrofoulers," International Workshop on marine biofouling organized by the US Office of Naval Research and SeaCoat, Las Vegas, USA
- 05.12.2011, T. Mohamed, T. Senkbeil, S. Heissler, A. Di Fino, A. S. Clare, A. Rosenhahn "In-situ studies of barnacle cyprid cement using XRF and micro-Raman spectroscopy", International Workshop on marine biofouling organized by the US Office of Naval Research and SeaCoat, Las Vegas, USA
- 22.11.2011, S. Köster, Biocenter Basel, Switzerland
- 04.11.2011, C. G. Schroer "Beryllium Lenses: Hard X-ray Nanobeam Characterization by Ptychographic Imaging," XFEL Seminar, Hamburg
- 03.11.2011, C. G. Schroer "Bildgebung mit Röntgenstrahlung: Lokale quantitative Messung physikalischer und chemischer Eigenschaften," HGF Think Tank, Berlin (invited)
- 08.11.2011, C. G. Schroer "X-Ray Microscopy with Coherent Radiation," ICXOM21, Indaiatuba, Brazil (plenary invited)
- Nov. 2011, G. Hofmann, J.-D. Grunwaldt "Imaging in Catalysis Research: Towards tomographic and dynamic studies using synchrotron radiation," MAX-lab Users' Meeting, Lund, Sweden (invited)
- 18.10.2011, J. Patommel, "Hard X-Ray Scanning Microscopy - experiences and latest results," Workshop on hard X-ray imaging at MAX IV, Stockholm , Sweden
- Oct. 2011, G. Hofmann, J.-D. Grunwaldt "Opportunities of in-situ imaging of chemical and catalytic processes," Kick-off Meeting VH-VI-403, Göttingen
- 22.09.2011, S. Köster, Argonne, USA

5.2.7. *Awards.*

- Sarah Köster was elected as one of the "100 Frauen von morgen" initiated by "Deutschland, Land der Ideen" in 2011.

5.2.8. *Development of Instrumentation for LK II User Facilities and User Support.*

- The nanoprobe station at beamline P06 was developed in a collaboration between TU Dresden and DESY. The instrument is open to users of PETRA III and is booked about one third of the beamtime. For all user experiments in 2012 and 2013 at that instrument, scientists from the VI helped with the user support.

- In the funding period of the VI about 30 beamtimes were allocated by the standard peer review process at the GINIX endstation of beamline P10 / PETRA III, an instrument built and operated in cooperation between DESY and the University of Göttingen (Salditt group). Beamtime of external user groups were supported by sending members of the Göttingen group (local contact), or in form of collaborations. All equipment (focusing, optics, microscopes, software, reconstruction) was made available to the users. Among the user groups, there was a large number of newcomers to the field of synchrotron radiation, mostly from the biomedical field. These activities were mostly carried out in collaboration. Also, there were a number of groups, which are very established in the field, e. g., Prof. J. Miao, UCLA or Prof. Y. Takahashi, Osaka University. Finally, a larger number of groups from the DFG Sonderforschungsbereiche SFB 755 , SFB 937, SFB 803 in Göttingen became actively engaged.

- The HORST chamber was mainly used at BESSY, FLASH and P04/PETRA III. User groups included the Vartanyants group (DESY Photon Science), the Salditt group (University of Göttingen), and the Mancuso group (XFEL).

References

[1] R. N. Wilke, M. Priebe, M. Bartels, K. Giewekemeyer, A. Diaz, P. Karvinen, and T. Salditt, Opt. Express **20**, 19232 (2012).
[2] E. C. Dell'Angelica, Trends Cell Biol. **13**, 503 (2003).
[3] P. A. Riley, Pigm. Cell Res. **16**, 548 (2003).
[4] P. Meredith and T. Sarna, Pigment Cell Res. **19**, 572 (2006).
[5] J. F. Okulicz, R. S. Shah, R. A. Schwartz, and C. K. Janniger, J. Eur. Acad. Dermatol. Venereol. **17**, 251 (2003).
[6] J. Borovanský, P. Mirejovský, and P. A. Riley, Neoplasma **38**, 393 (1991).
[7] C. Tello, N. Radcliffe, and R. Ritch, in *The Glaucoma Book*, edited by P. N. Schacknow and J. R. Samples (Springer, New York, 2010), pp. 499–505.
[8] J. D. Simon, L. Hong, and P. D. N., J. Phys. Chem. B **112**, 13201 (2008).
[9] J. Borovanský, in *Melanins and Melanosomes - Biosynthesis, Biogenesis, Physiological, and Pathological Functions*, edited by J. Borovanský and P. A. Riley (Wiley-VCH, Weinheim, 2011), pp. 1–19.
[10] T. Gorniak, T. Haraszti, V. M. Garamus, A. R. Buck, T. Senkbeil, M. Priebe, A. Hedberg-Buenz, D. Koehn, T. Salditt, M. Grunze, M. G. Anderson, and A. Rosenhahn, PLoS ONE **9**, 90884 (2014).
[11] G. Beaucage, J. Appl. Cryst. **29**, 134 (1996).
[12] R. Wetherbee, J. L. Lind, J. Burke, and R. S. Quatrano, Journal of Phycology **34**, 9 (1998).
[13] C. G. Schroer, P. Boye, J. M. Feldkamp, J. Patommel, D. Samberg, A. Schropp, A. Schwab, S. Stephan, G. Falkenberg, G. Wellenreuther, and N. Reimers, Nucl. Instrum. Meth. A **616**, 93 (2010).
[14] L. J. Walley and E. I. S. Rees, Phil. Trans. Royal Soc. London, B Biol. Sci. 237 (1969).
[15] D. Maruzzo, N. Aldred, A. S. Clare, and J. T. Høeg, PLoS ONE **7**, e37408 (2012).
[16] R. Simon, G. Buth, and M. Hagelstein, Nucl. Instrum. Meth. B **199**, 554 (2003).
[17] G. Hofmann, A. Rochet, S. Baier, M. Casapu, S. Ritter, F. Wilde, M. Ogurreck, F. Beckmann, and J.-D. Grunwaldt, J. Phys.: Conf. Ser. **499**, 012017 (2014).
[18] O. Deutschmann and J.-D. Grunwaldt, Chemie Ingenieur Technik **85**, 595 (2013).
[19] G. Hofmann, A. Rochet, E. Ogel, S. Baier, M. Casapu, S. Ritter, M. Ogurreck, and J.-D. Grunwaldt, Phys. Chem. Chem. Phys. (2014), in preparation.
[20] D. Doronkin, M. Casapu, T. Günter, O. Müller, R. Frahm, and J.-D. Grunwaldt, J. Phys. Chem. C **118**, 10204 (2014).
[21] A. M. Gänzler, M. Casapu, A. Boubnov, O. Müller, H. Lichtenberg, and J.-D. Grunwaldt, Angew. Chem. Int. Ed. (2014), in preparation.

[22] C. G. Schroer and J.-D. Grunwaldt, in *In-situ Characterization of Heterogeneous Catalysts*, edited by J. A. Rodiguez, J. C. Hanson, and P. J. Chupas (Wiley, New York, 2013), Chap. 2. Spatially Resolved X-Ray Absorption Spectroscopy, pp. 49–73.

[23] R. Hoppe, J. Reinhardt, G. Hofmann, J. Patommel, J.-D. Grunwaldt, C. D. Damsgaard, G. Wellenreuther, G. Falkenberg, and C. G. Schroer, Appl. Phys. Lett. **102**, 203104 (2013).

[24] J. Stötzel, R. Frahm, B. Kimmerle, M. Nachtegaal, and J.-D. Grunwaldt, J. Phys. Chem. C **116**, 599 (2012).

[25] A. Schropp, R. Hoppe, J. Patommel, D. Samberg, F. Seiboth, S. Stephan, G. Wellenreuther, G. Falkenberg, and C. G. Schroer, Appl. Phys. Lett. **100**, 253112 (2012).

[26] F. Döring, A. L. Robisch, C. Eberl, M. Osterhoff, A. Ruhlandt, T. Liese, F. Schlenkrich, S. Hoffmann, M. Bartels, T. Salditt, and H. U. Krebs, Opt. Express **21**, 19311 (2013).

[27] S. Roling, B. Siemer, M. Wostmann, H. Zacharias, R. Mitzner, A. Singer, K. Tiedtke, and I. A. Vartanyants, Phys. Rev. STAB **14**, 080701 (2011).

[28] I. A. Vartanyants, A. Singer, A. P. Mancuso, O. M. Yefanov, A. Sakdinawat, Y. Liu, E. Bang, G. J. Williams, G. Cadenazzi, B. Abbey, H. Sinn, D. Attwood, K. A. Nugent, E. Weckert, T. Wang, D. Zhu, B. Wu, C. Graves, A. Scherz, J. J. Turner, W. F. Schlotter, M. Messerschmidt, J. Luning, Y. Acremann, P. Heimann, D. C. Mancini, V. Joshi, J. Krzywinski, R. Soufli, M. Fernandez-Perea, S. Hau-Riege, A. G. Peele, Y. Feng, O. Krupin, S. Moeller, and W. Wurth, Phys. Rev. Lett. **107**, 144801 (2011).

[29] A. Singer, F. Sorgenfrei, A. P. Mancuso, N. Gerasimova, O. M. Yefanov, J. Gulden, T. Gorniak, T. Senkbeil, A. Sakdinawat, Y. Liu, D. Attwood, S. Dziarzhytski, D. D. Mai, R. Treusch, E. Weckert, T. Salditt, A. Rosenhahn, W. Wurth, and I. A. Vartanyants, Opt. Express **20**, 17480 (2012).

[30] D. D. Mai, J. Hallmann, T. Reusch, M. Osterhoff, S. Düsterer, R. Treusch, A. Singer, M. Beckers, T. Gorniak, T. Senkbeil, R. Dronyak, J. Gulden, O. M. Yefanov, A. Al-Shemmary, A. Rosenhahn, A. P. Mancuso, I. A. Vartanyants, and T. Salditt, Opt. Express **21**, 13006 (2013).

[31] B. Weinhausen, O. Saldanha, R. N. Wilke, C. Dammann, M. Priebe, M. Burghammer, M. Sprung, and S. Köster, Phys. Rev. Lett. **112**, 088102 (2014), research Highlight in Nature Materials 13, 323 (2014).

II. Perspektivpapier

VH-VI-403: In-Situ Nano-Imaging of Biological and Chemical Processes

1. Ziele und Beschreibung der künftigen Programmatik des Vorhabens

In the last two and a half years, the virtual institute has been set on a strong fundament. All projects have been successfully started and are well on track. After establishing new methods and instrumentation and applying them to first demonstrations in biology and chemistry, we are now in the position to apply them systematically to the scientific questions in biophysics and chemistry. The second term of the virtual institute will also be used to consolidate the techniques and to make them available on a routine basis, also for other users of PETRA III and FLASH. The aim is to establish a platform for in-situ experiments in biology and chemistry, providing the expertise and instrumentation for such experiments and educating interested new users in x-ray microscopy and in-situ techniques.

In the field of bioimaging (Topic I), we plan to apply our methods and techniques to relevant question in cell research. For example the DNA packing in the cell nucleus at different stages in cell proliferation will be one project we want to pursue. As new project, we intend to use coherent x-ray scattering on bacteria to identify the interaction with antibiotics. Inspired by the scattering experiments on the melanosomes we will apply the sensitive scattering technique to differentiate mechanisms of interaction of known antibiotics and novel antimicrobial peptides. The marine-adhesives project will be continued trying to differentiate bulk and surface contributions. Finally, we aim at establishing a platform for conducting experiments with cells and other biological specimens that will also be available to the user community.

In chemistry (Topic II), we aim at understanding catalysts over all length scales and under in-situ conditions. In the next two years, our goal is to study mechanisms of the formation of nanoparticles using different x-ray analytical techniques, to image catalytic reactions inside a reactor in three dimensions and hope to follow aging effects during sintering processes in real time. This is important for future design of catalysts and will allow hierarchical design and modeling. In addition, the new techniques can provide important insight into the preparation of catalysts, which, today, is often still some "black art", and improve their stability.

Concerning methods & instrumentation (Topic III), the aim is to further improve the x-ray microscopes. In particular, a full upgrade of the scanning microscope at beamline P06 at PETRA III is planned, targeting routine single-digit nanometer spatial resolution for applications in catalysis. At all the x-ray microscopes, the imaging techniques, in particular with coherent radiation, will be further developed. Concerning microfluidic devices, a major goal is to develop a versatile method for fabricating the devices (rather than different methods and materials for each application). Ideally, this could be similar to the "soft lithography" methods introduced by George Whitesides many years ago and now established in the microfluidics-microscopy field.

2. Beschreibung der wichtigsten Aktivitäten und neuer Initiativen, die zusätzlich zum Geplanten in Angriff genommen werden müssen/sollen

After two years of operation of the x-ray microscopes at PETRA III, we see the need for special training of users in x-ray microscopy. Many users from biology and chemistry are not fully aware of the steps needed to prepare, perform, and evaluate successfully an experiment in x-ray microscopy, in particular in the case of in-situ studies. We want to address this by providing short special courses for scientists interested in learning more about x-ray microscopy and in-situ experiments and for example help users to fabricate and use microfluidic devices. For less experienced scientists and PhD students, more extended schools on x-ray microscopy and microfluidics can be envisaged.

In addition, we want to assess the possibilities to apply the new techniques to industrial applications and bring industrial users to DESY. This is particularly promising in the field of catalysis.

3. Erwartete Ergebnisse und Meilensteine

As of today, we expect that all major goals of the virtual institute will be reached by the end of the five-year period.

In the second part of the funding period of the VI, we plan to apply and extend the established techniques developed so far. In particular, a combination of different x-ray imaging techniques (e. g., full-field methods and local, scanning techniques) shall be pursued (including milestones Mem3b and Mem4). The melanosome project will be extended to analyze the chemical composition of organelles of different genetic background. The marine-adhesives project will be continued trying to differentiate bulk and surface contributions. Finally, we aim at establishing a platform for conducting experiments with cells and other biological specimens that will also be available to the user community.

Concerning chemical processes, our goal is to study mechanisms of the formation of nanoparticles using different x-ray analytical techniques (milestone React4), to image catalytic reactions inside a reactor in three dimensions (milestones CatRe5, Cat5) and hope to follow aging effects during sintering processes in real time (Sin5). With the in-situ catalytic reactor fully commissioned and ptychography being improved to resolve nanoparticles with high sensitivity and resolution, we aim at studying the ignition of catalytic reactions around single catalyst particles (milestone Cat3).

In the remaining part of the VI funding period, the scanning microscope at P06 will be upgraded to improve spatial resolution and sensitivity to nanometer-sized objects, the soft x-ray microscope HORST (milestone Horst5) and the tender x-ray microscope at P11 (milestone Mdiff5) will be fully commissioned. The instrumental developments will be complemented by further methodological advances, in particular for the processing of imaging data from scanning microscopes, coherent imaging, and tomography (milestone Theo5). In microfluidics, the main goal is to establish a platform, which can be applied to a variety of chemical and biological experiments also by external users (milestone Mfluid5). In particular, chemical reactors for in-situ tomography of catalytic reactions are to be developed and in-situ cells for combining x-ray and electron microscopy are to be improved.

4. Beschreibung der erforderlichen Rahmenbedingungen: Personal, Infrastruktur, Partner des künftigen Konsortiums/ Netzwerks

The virtual institute has successfully started and all projects are well on track. The personnel and infrastructure is adequate for the current scope of the VI.

5. Abstimmung in Bezug auf strategische Pläne (nach Möglichkeit auf die 5 Punkte eingehen):

(1) Strategische Planung des federführenden Zentrums (Vorstand) und ggf. auch zusätzlicher Helmholtz-Zentren und nach Möglichkeit der beteiligten Partnereinrichtungen

With PETRA III, DESY is operating the synchrotron radiation storage ring in the hard x-ray regime with the world wide smallest emittance. The small emittance results in a relatively high fraction of coherent photons that is essential for imaging techniques exploiting the coherence properties of the beam or for achieving a diffraction limited focusing. The penetration capabilities of hard x-rays provided at PETRA III allow for imaging, diffraction, and spectroscopy experiments in complex sample environments that are essential for in-situ or in-operando studies under relevant conditions. For biological imaging, coherent radiation in the so called water window (between K-edges of carbon and oxygen) is providing the highest contrast. These are exactly the conditions available at the soft x-ray FEL FLASH at DESY. Therefore, the main scientific direction of the virtual institute is very well aligned with the strategic direction of the research at PETRA III as well as at other photon facilities within the program MML in the research field Matter.

(2) Portfolio des Forschungsbereichs, thematisch verwandte Programme, Querschnittsthemen

The virtual institute is very well aligned with research goals at the photon facilities of the research field Matter. All of them have programs on micro or nano imaging and in-situ studies exploiting information in the imaging, diffraction, scattering as well as the spectroscopic information channel. The methodological results will be relevant for all programs in the nano and bio-science field as well as for new materials and energy research. The bio-imaging part of the VI will also reach out into biological programs and the cross program topic 'Structural Biology'.

(3) Forschungspolitische Vorgaben zum Forschungsbereich, dem das VI zuzuordnen ist

The main aims of the VI fit perfectly to the program 'From Matter to Materials and Life' of the research field Matter. It is targeting for the development of new and unique methods ('Methodenkompetenz') in the field of in-situ nano imaging and will apply these methods to urgent scientific questions at large scale facilities ('Forschungsinfrastrukturen'). Since the VI is per definition a collaboration between Helmholtz centres and universities, it contributes significantly to the 'Vernetzung mit Hochschulen' and to the 'Nachwuchs gewinnen and fördern' - aims mentioned in the FPV. The experiments carried out and planned require new x-ray optical elements for focussing x-rays

to extremely small focal spot sizes as well as developments for the positioning of samples with nm precision. Both technical developments bear a huge innovation potential and in one case led to an initiative for a planned spin-off company.

(4) Nationale Forschungsagenden und -initiativen (u.a. BMBF-Programme)

The VI is strongly interlinked with several projects within the BMBF Verbundforschung. Three of the four x-ray microscopes that form the instrumental and methodological basis of the VI were financed within this BMBF program.

(5) Internationale Roadmaps und Netzwerke

Imaging at the nano- and atomic scale at ultra short time scales to follow chemical, catalytic or biological processes or reactions is at the core of the scientific case of the European XFEL, which is one of the facilities on the ESFRI roadmap. It is expected that the method developments carried out within the VI will have considerable impact on the science that will be done at European XFEL, albeit at much shorter time scales in the hard x-ray regime than presently possible at synchrotron radiation sources.

III. Resources

Specifications for the presentation of the resources overview

For the current VI programme:

- Tabular overview of the people involved in the VI, showing home institution and position as FTE (or heads), separately for each topic and also the total sum (please show doctoral students separately).
- Overview of the means used for personnel, material and equipment costs, and investment costs and broken down according to work focuses (research topics), and planned financial means and their source (broken down according to topic and as a total sum).

Figures in	**Bioimaging**		**Chemical Processes**		**Meth. & Instrum.**				**Sum**	
Involved staff (heads)	IVF	total	IVF	total	IVF	total	IVF	total	IVF	total
TU Dresden (all staff)			1	3	2	7			**3**	**10**
KIT (all staff)			3	9					**3**	**9**
U. Göttingen (all staff)	4	5			3	3			**7**	**8**
U. Bochum (all staff)	3	3							**3**	**3**
DESY (all staff)					3	10			**3**	**8**
PhD Students*	7	9	3	5	6	12			**16**	**26**
Post-Doks/ Senior Scientists*		1	1	6	2	7			**3**	**14**
Technicians*				1		1				**2**
Total staff	**7**	**10**	**4**	**12**	**8**	**20**			**19**	**42**
Costs (in % or T€)										
Personnel (total = 100%)*		%		%		%		%	**886.4T€**	**T€**
Material/ equipment (total = 100%)*		%		%		%		%	**43,8T€**	**T€**
Investments (total = 100%)*		%		%		%		%	**T€**	**T€**
Backbone activities		-/-		-/-		-/-		-/-	**12.5T€**	**T€**
Involvement of international partners		-/-		-/-		-/-		-/-	**T€**	**T€**
Total spend until 31 Dec 2013, indicate No of month									**942,7T€**	**T€**
Total left for funding Period (indicate No month)									**T€**	**T€**
Total (IFV/own)									**T€**	**T€**

Male* (in %):	**total phD**	65%	**Post-Doks and Senior Scientists**	**71%**
Female* (in %)	**total phD**	35%	**Post-Doks and Senior Scientists**	**29%**

* of all partners

IV. Proposal

An die Geschäftsstelle der
Helmholz-Gemeinschaft
Ahrstraße 45
53175 Bonn

über das Direktorium des DESY
Notkestrasse 85, 22603 Hamburg

Antrag auf Einrichtung eines Virtuellen Instituts im Rahmen des Impuls- und Vernetzungsfonds des Präsidenten der Helmholtz-Gemeinschaft

In-Situ Nano-Imaging of Biological and Chemical Processes

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Das Projekt ist auf eine Laufzeit von 5 Jahren angelegt.

Keywords: biological cells, cell ultrastructure, chemical reactions, catalysis, microfluidics, in-situ x-ray microscopy

Das Projekt ist dem Forschungsbereich **Struktur der Materie** zugeordnet.

Contents

1 Scope

In the emerging fields of nano science, chemical technology and the life sciences there is an increasing demand for imaging of micro- to nanometer sized objects with highest possible spatial resolution. The physical, chemical, and biological properties of nano-sized objects strongly depend on their structure. Therefore, nanoscopic structure determination is at the heart of understanding biological and chemical processes and is crucial to address the grand challenges in health, environmental, and energy research.

X-ray imaging techniques are well suited to these ends, as they provide element specific chemical and structural contrast at high spatial resolution also from the interior of bulk samples or from samples in special environments. The new sources at DESY, PETRA III and FLASH, are ideal to reach these goals. In particular X-ray imaging techniques on the nanoscale directly benefit from the high brilliance of theses sources.

In the frame of this Virtual Institute we would like to bring together expertise in x-ray imaging, biology and chemistry to enable in-situ imaging of biological and chemical processes with the x-ray microscopes at PETRA III and FLASH, and at the European XFEL in the future. In example applications, we will address important questions in biology (membranes, cell ultrastructure, self-assembly mechanisms) and chemistry (catalysis, redox and precipitation reactions), adapting and developing further the x-ray microscopes and special sample environments, such as chemical reactors, microfluidic cells and cryogenic sample environments.

Our Virtual Institute comprises groups from four universities (U. Göttingen, U. Heidelberg, KIT Campus South, and TU Dresden) and DESY. The dual affiliation of two scientists to KIT Campus North also brings this Helmholtz Center into our Virtual Institute.

Zusammenfassung

In den Nanowissenschaften, der Chemie und den Lebenswissenschaften gibt es einen wachsenden Bedarf an hochauflösenden bildgebenden Verfahren auf der Micro- und Nanometerskala. Die physikalischen, chemischen und biologischen Eigenschaften eines Objekts hängen stark von dessen Struktur ab. Daher ist die Strukturbestimmung grundlegend für das Verständnis biologischer und chemischer Prozesse, die einen wichtigen Beitrag zu Themen, wie Gesundheit, Umwelt und Energie leisten.

Bildgebende Verfahren mit Röntgenstrahlung sind dazu besonders geeignet, da sie chemischen und strukturellen Kontrast liefern können und dabei den zerstörungsfreien Blick ins Innere eines Objektes oder einer speziellen Probenumgebung ermöglichen. Die neuen Strahlungsquellen bei DESY, PETRA III und FLASH, sind für die Röntgenmikroskopie besonders geeignet, da letztere besonders von der hohen Brillanz dieser Quellen profitiert.

Im Rahmen dieses Virtuellen Instituts soll die Expertise aus der Röntgenmikroskopie, der Biologie und der Chemie zusammengeführt werden um in-situ bildgebende Verfahren zu entwickeln für biologische und chemische Prozesse für die Röntgenmikroskope bei PETRA III, FLASH und später am Europäischen XFEL. Als Anwendungebeispiele werden wichtige Fragen aus Biologie (Membrane, Zellstruktur, Selbstaggregation) und Chemie (Katalyse, Redox- und Fällungsreaktionen) behandelt, in dem die Röntgenmikroskope mit speziell entwickelten Probenumgebungen ausgerüstet werden, wie etwa Mikrofluidikzellen, chemische Mikroreaktoren oder Kryostaten.

Das Virtuelle Institut setzt sich zusammen aus vier Universitätsgruppen (U. Göttingen, U. Heidelberg, KIT Campus Süd und TU Dresden) und DESY. Durch die Zugehörigkeit zweier Wissenschaftler zum KIT Campus Nord wird auch dieses Helmholtzzentrum in das VI eingebunden.

2 State of the art

2.1 Understanding Biological Systems and Chemical Processes in Space and Time

Dynamics in both biological and chemical systems can only be fully understood if the relevant length scales (nanometers) and time scales (nanoseconds and below in chemistry and usually milliseconds to hours in biology) are resolved. Biology, chemistry, and chemical technology have often developed separately in the past. However, at the microscopic level, these disciplines converge methodologically. In the proposed VI, we would like to foster the synergies in development and application of imaging techniques that are applicable to both these fields. For this joint effort, we have chosen specific (model-)systems, which we will investigate by combining high-resolution x-ray microscopy methods and tailor-built sample environments.

2.1.1 Membranes

Membranes are considered as the most important interface in biology. Important functions of membranes are based on lipid-peptide interaction and self-assembly, ranging from transport properties to nerve conduction [1]. Understanding membrane functions based on the multi-component self-assembly of lipids, proteins and peptides requires studies of the organization of membranes from the molecular to the level of complex three-dimensional shapes and topologies by high-resolution structural analysis, compatible with hydrated (physiological) sample environments. Going beyond conventional capabilities, advanced x-ray diffraction and imaging methods and in particular the combination of diffraction and imaging are now at a point, where they can be applied to study membrane structure and dynamics in very localized configurations, which are not amenable to bulk ensemble studies by conventional x-ray small angle scattering [2].

Membrane fusion: An important essentially unsolved problem in membrane biophysics is a quantitative description of membrane fusion, as a basic mechanism in vesicular transport, viral infection, release of neurotransmitter at the chemical synapse, or fertilization [3]. One would like to understand how the energy barrier of the typical hydrophobic and hydrophilic interactions can be overcome, both in pure lipid model systems and in biological membranes such as synaptic vesicles. The merger of two biological membranes is believed to proceed by intermediate structures known in the literature as stalks. First experimental evidence of stalk structures was given by the discovery of an equilibrium phase of rhombohedral symmetry in pure phospholipid systems at low hydration [4, 5].

Synaptic vesicles (SV) are trafficking organelles in the presynaptic nerve terminal responsible for transport and release of neurotransmitters into the synaptic cleft [2, 6]. The synaptic membrane can be considered as an important functional interface in the central nervous system (CNS). The adhesion to this interface and the fusion with the membranes are essential steps of this Ca^{+2} dependent exocytosis process. Towards an understanding of the interaction of synaptic vesicles with the inner leaflet of the synaptic membrane, we propose advanced micro- and nanofocus x-ray diffraction and imaging experiments.

Non-equilibrium response of membranes to external field: We propose to study the non-equilibrium response of the lipid bilayer to a sudden change of the trans membrane electric field. An electric field strongly influences the elastic properties and interaction forces of the lipid bilayer, it affects the functional aspects, such as diffusion and/or parallel and perpendicular transport through the bilayer and it is a key parameter in the process of nerve pulse propagation. In addition, strong external fields can trigger non-equilibrium dynamics in the lipid bilayers, leading, e. g., to pore formation like in electro- and opto-poration. The process of pore formation

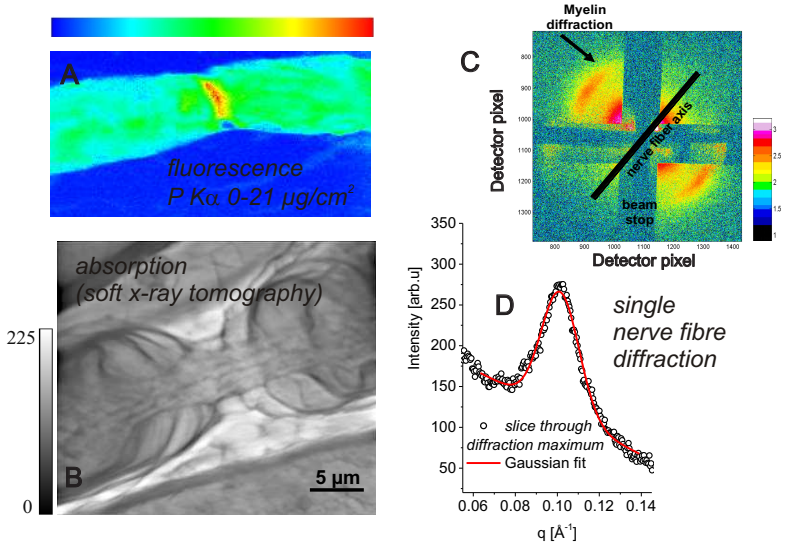

Figure 1: (A) P fluorescence map of a freeze dried isolated myelinated axon of a wild type mouse, close to a node of Ranvier, obtained at ID21/ESRF. (B) Tomographic reconstruction slice of a soft x-ray cryo microscopy experiment carried out at the new BESSY x-ray microscope. (C) Single nerve fibre diffraction data (ID22NI beamline) shows the multilamellar signal of the myelin, analyzed in (D). The signal reflects the myelin order in an illuminated spot size in the range between 100 and 200 nm [8].

requires the spatial rearrangement of lipid molecules and can be expected to take place on the 100 ps – 100 ns time scale, probably including the initial compression of the bilayers. Important open questions concern the basic structural dynamics of a lipid membrane responding to an optical (or electrical) excitation, which shall be followed by pump-probe experiments both in diffraction and imaging mode [7].

Myelin: Beyond simple model systems we will extend our studies to biological membranes in cells, in particular membranes important in the functioning of nerve cells. We propose to study the 3D structure the myelin sheath wrapped around the axon, in view of the significant physiological and pathological role associated with this structure. Myelin allows the fast saltatory conduction, the impulse propagation from node to node, rather than progressing slowly along the axon as in unmyelinated or demyelinated fibers. Myelin exhibits a (spiral) multi-lamellar structure with a repeat in the range of 12 – 15 nm. Each myelin sheath segment or internode appears to be 150 – 200 μm in length along the axon. Here we propose to study the structure of individual (isolated) myelinated nerve fibers, taking advantage of state-of the art nano-diffraction and nanoprobe techniques, as well as entire sciatic or optical nerves [8].

2.1.2 Ultrastructure of melanosomes and implication for the development of glaucoma

Melanosomes are specialized, intracellular membrane bound organelles, which produce and store melanin pigments, and determine the color of tissue (e. g., skin, hair, and iris). Melanin is capable of absorbing visible light, which is used by the iris to regulate the amount of light penetrating into the eye in order to avoid UV induced damages. A potential danger for the human body comes from the cytotoxic proteins and chemical substances involved in the production of melanin [9, 10]. If the structural integrity of melanosomes is disturbed, toxic substances can diffuse into

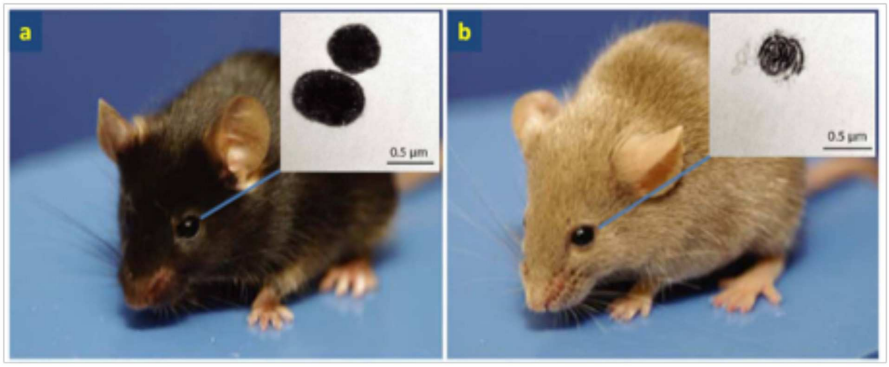

Figure 2: (a) C57BL/6J mouse as fully pigmented wild-type. The TEM images of thin sections of melanosomes in the inset show a electron dense structure with homogeneous appearance and low transmission for TEM (b) DBA/2J mouse with altered melanin synthesis and thus altered pigmentation. The inset shows a TEM micrograph of iris melanosomes purified from DBA/2J irides with flocculent pattern of melanin [11].

the surrounding tissue and damage vital cells. This mechanism is anticipated to be involved in the development of skin cancer or pigmentary glaucoma.

The mutation of two known genes, Tyrp1 and Gpnmb, leads in mice to a destruction of the iris pigmentation and thus to glaucoma. To study the disease of pigmentary glaucoma, the Jackson Laboratory, Maine, and the University of Iowa developed a mouse model, in which the DBA/2J branch develops spontaneously the hereditary disease, which is connected with the apoptosis of melanocytes. Electron microscopy revealed first indications for a morphology change between both phenotypes and a flocculent melanin pattern can be observed for the phenotype with altered melanin synthesis (fig. 2b). Light microscopic access to the 500 nm large and electron dense organelles is difficult as light and electron microscopy are unable to penetrate the tissue [12, 13]. Thus, cryotomes are used to prepare thin slices, and it is still under question if the structures observed in fig. 2 are preparation artifacts. X-rays in contrast are a unique probe, which allows to penetrate deep into tissue and thus to study the organization and the chemical properties of these organelles with high spatial resolution. With STXM at the NSLS the APC in Heidelberg in collaboration with the group of M. Anderson (University of Iowa) has been able to show that the different phenotypes show different NEXAFS fine structures at the carbon K-edge [11]. Within the virtual institute we will correlate genetical changes with the ultrastructure of melanosomes using x-ray nanoscopy.

2.1.3 The curing mechanism of the adhesives of marine algae

Marine algae are of relevance for maritime industries as they quickly foul manmade surfaces immersed into the ocean. Such biofouling, e. g., found on ship hulls, leads to extensive maintenance costs and additional fuel consumption [16, 17, 18]. All biofouling organisms have a thoroughly developed strategy to glue themselves to a surface by elaborate underwater adhesives [19]. Understanding the mechanism of curing of the adhesive and its surface interaction can inform the development of new anti-fouling coatings [19, 20, 21], and the development of biomimetic underwater adhesives [22]. Adhesives of bacteria, diatoms, algae or invertebrates contain majorly polymers, such as polysaccharides or glycoproteins [19]. While the composition of the organic compounds is determined by molecular biological or chemical analytical techniques, it is more challenging to study the inorganic components and their function. Interestingly many marine plants (e. g., brown algae such as *L. digitata*) are able to accumulate elements far above the

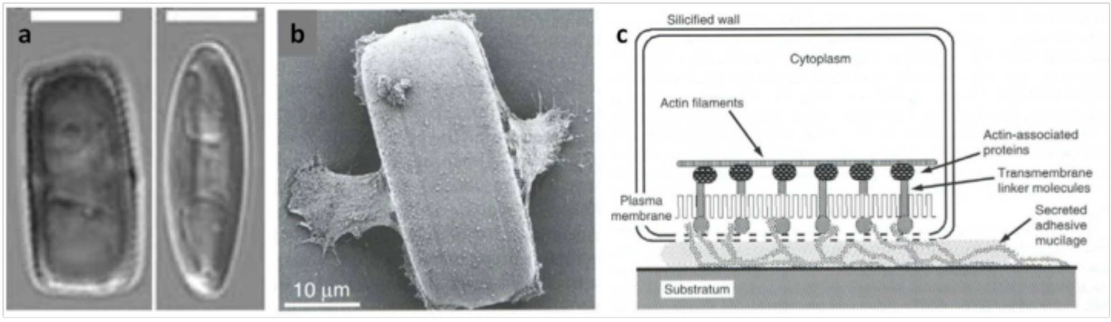

Figure 3: Diatoms (algae) on a surface (a) *Navicula perminuta* in girdle (left) and valve (right) view [14]. (b) *Pinnularia viridis* with sheets of adhesive extending from each raphe to anchor the cell to the substrate [15] (c) schematic mechanism of adhesion of diatoms [15].

concentrations present in seawater [23]. While the excess in carbon, nitrogen or phosphorous can be understood due to their use as building material for the cells, the purpose of excess in metals such as vanadium (30000×) or iron (6000×) is less obvious [23]. One occurrence is in the form of vanadoproteins, which are active in most marine algae, seaweed, and some lichens, and play a major role in the curing of their adhesives [24]. In the brown algae *A. nodosum*, *F. distichus*, and *L. digitata*, vanadium forms a complex with haloperoxidases, which mediates the oxidative crosslinking of the polymers in the adhesive via phenols [25, 26]. Marine diatoms are another important class of biofouling algae, which are highly relevant as they are prevalent on a range of foul release coatings [14, 27]. Among the most prominent species are *N. perminuta*, *A. coffeaeformis*, *C. australis*, and *A. longipes* [14, 15]. Johnson found that in *A. longipes* phenolics are present and different halide concentrations seriously affected the integrity of the adhesive and concluded that vanadium depending haloperoxidases must be active [28, 29]. As direct evidence for the activity of vanadoproteins in diatoms is lacking, microscopy techniques providing chemical information are desired. One common approach is SEM in conjunction with EDX detectors, which requires fixed and dried specimen. During this preparation metal ions can be eluted from the sample, and as a second drawback, not the full adhesive pad or stalk, but only its surface can be analyzed. Novel x-ray nanoprobes allow a much larger probing depth in cryogenically prepared samples, in particular in combination with tomography, and will allow to understand, which metals are involved, and thus contribute to understand the curing mechanism.

2.1.4 Protein aggregation and assembly – in vitro and in cells

While the membrane is the interface between the cellular interior and exterior, proteins are the fundamental building blocks of complex structures found in the cytosol and around the cell, in the so-called extra-cellular matrix (ECM). These protein structures can be studied in vitro or in vivo (i. e., in living cells) and both approaches have their own advantages. While simplified in vitro model systems often provide biophysical and biochemical insight into general mechanisms, experiments using living cells have to take into account the complex physico-chemical environment in cells (including gradients and geometric confinement). In the cell proteins form networks, bundles, contractile fibers, "tracks" for intracellular transport and display remarkable mechanical (viscoelastic) properties. It is still unknown, however, how the individual assembly steps (which are often organized in a hierarchical manner) are controlled. Many cellular structures have, for example, very defined length scales. How is the thickness of a fibrous protein or bundle thereof defined and how is it determined at which point the self-assembly process (which in many case is driven by electro-static processes) ends? Many of these open questions can only be

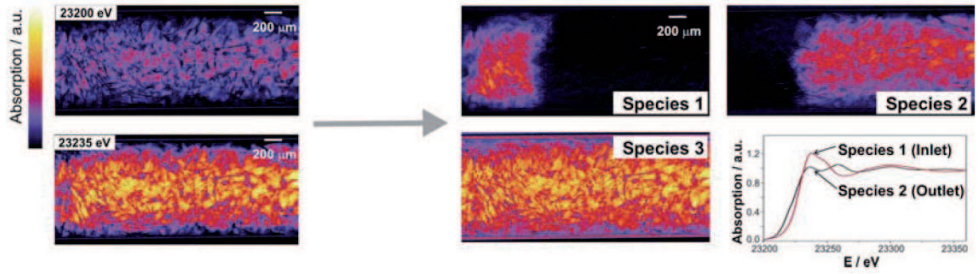

Figure 4: X-ray absorption inside a microreactor during partial oxidation of methane over a Rh/Al_2O_3 catalyst as a function of energy (left). On the right the distribution of reduced Rh (species 1), of oxidized Rh (species 2), and of other elements (species 3) are shown, together with the absorption spectra for the two Rh species [30].

approached by designing very controlled experiments, which on the one hand simplify the system and setup to a large enough extent so that we are able to understand the underlying principles and on the other hand capture specific parameters, which are crucial for the phenomenon under investigation.

While in vitro assembly processes provide important information from a fundamental point of view and generalized results can be derived, cellular processes often follow much different paths in order to develop complex structures from small subunits. Examples can be found in the cytoskeletal networks formed from thick bundles of fibrous proteins. The internal structure of these networks/bundles is often unknown and cannot be resolved by methods like electron microscopy. By contrast, x-ray imaging provides much greater penetration depth and structural information (through q-space) in addition to "direct" information from scanning the sample. One driving question of this VI is "how does nature assemble biomacromolecules into functional and dynamic structures as compared to in vitro processes with minimal externally fixed parameters?

2.1.5 Heterogeneous Catalysis

Understanding the kinetics of catalytic reactions is of utmost importance to improve reaction conditions and to design reactors. 95% of all chemical products have at least seen a catalyst in one reaction step, both in fine chemical production and in bulk chemistry; enzymes are very important for fine chemistry, in bulk chemistry heterogeneous catalysts play a major role. As there is an increasing demand of catalysis in energy related processes, further development is needed. One of the great challenges lies in the broad range of length and time scales involved, ranging from centimeters to the atomic scale and from seconds to femtoseconds.

X-ray absorption spectroscopy (XAS) and scattering techniques (SAXS, XRD) are powerful tools to investigate catalysts, giving access to the local chemical structure around an atomic species, e. g., a catalytic site (cf. [31, 32, 33] for an overview). Due to the large penetration depth, hard x-rays are particularly well suited for in-situ studies. As the concentrations and temperatures can vary throughout a reactor, the combination of XAS and imaging is a powerful tool to understand catalytic reactions. For example, we used x-ray microscopy to image the catalytic activity of a heterogenous catalyst during the partial oxidation of methane to carbon monoxide and hydrogen [31, 33, 30, 34, 35, 36, 37]. In this way, the reaction mechanism could be identified, i. e., combustion and reforming rather than direct partial oxidation. Besides investigations in a dynamic equilibrium [38, 30, 35, 33, 39, 39], reaction dynamics could be investigated during the ignition/extinction of the reaction [33, 36]. By combining XAS with

scanning microscopy and tomography it is possible to determine the local structure of a catalyst inside a chemical reactor [40].

The investigation of catalysts on the mesoscopic scale ($\approx$ 10 to 100 nm) [32] will provide insight into the detailed reaction mechanisms around catalytic particles and is thus one driving question of this VI.

2.1.6 Evolution of redox and precipitation reactions

Redox and precipitation reactions are generally important for rational materials design, understanding the mechanism of electron transfer, nucleation, and catalytic processes. This requires spatial information, e. g., on flow and diffusion properties, but also time-resolved studies, which can be furthered in stopped-flow cells and spatially resolved studies.

In-situ cells for microscopic investigations were already designed for technical applications [41] but also micro-Raman [42] and infrared-spectroscopic investigations [43, 44]. Only, recently the mixing in microreactors has been used to monitor changes on the millisecond timescale. One example is the CdSe-to-Ag_2Se nanocrystal cation exchange that was studied with a 17×7 μm^2 beam [45]. Similar experiments with smaller beams at our new x-ray microscopes should give access to the sub-microsecond time scale.

Microfluidics are ideal to investigate the reaction mechanisms. It is possible to study diffusion and reaction vs. time. In combination with nanofocused x-rays, time resolutions down to the nano-second scale will be accessible. The development of microfluidic cells will be fostered by the synergies with in-vitro biological imaging within this VI.

2.2 X-ray Microscopes for Space- and Time-Resolved Imaging

Over the last two decades, significant advances were made in x-ray microscopy, both in the soft and hard x-ray range. In soft x-ray microscopy, both full-field and scanning techniques are available, achieving spatial resolutions down to about 10 nm [46, 47]. For biological imaging, the energy range in the so-called water window is most relevant, and spatial resolutions down to below 40 nm are reached in tomographic imaging [48, 49, 50]. The HORST chamber is designed to work in this soft x-ray range. The limited penetration depth and depth-of-focus issues limit the thickness of biological samples in soft x-ray microscopy to about $10 - 20$ μm. Thus, soft x-ray microscopy is well suited to image single cells. It is limited, however, for imaging tissues, larger objects, or specimens inside special sample environments.

Hard x-ray microscopy is a much younger field and has evolved quickly with the advent of highly brilliant hard x-ray synchrotron radiation sources. Today, the spatial resolution of hard x-ray techniques is approaching that in the soft x-ray range, reaching real space resolutions of several 10 nm [51, 52, 53]. In hard x-ray microscopy, a broad range of contrasts can be exploited, such as x-ray fluorescence analysis, x-ray absorption spectroscopy, and scattering techniques, making these microscopes sensitive to the chemical composition with trace element sensitivity, the chemical state and local chemical environment of a given atomic species, and to the local atomic or nano-structure.

Due to the large penetration depth of hard x-rays in matter, microscopic information can be obtained from inside a sample without destructive sample preparation or from inside a special sample environment, such as a chemical reactor or a microfluidic cell. By combining scanning microscopy with tomography, local information from inside an object can be obtained.

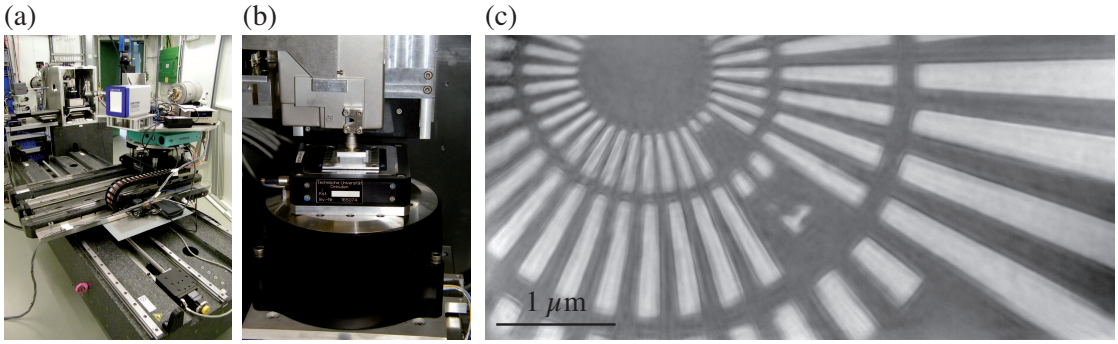

Figure 5: (a) hard x-ray scanning microscope (nanoprobe) at beamline P06 (PETRA III). (b) Sample on scanner table. The focusing optics are behind the metal shilding. (c) Hard x-ray ptychographic image of a test structure recorded at $E = 15.25$ keV (phase). The smallest features are 50 nm lines and spaces, and the spatial resolution lies between 10 and 20 nm.

As all x-ray optics are limited in numerical aperture, it is intrinsically difficult to reach nanometer resolution with an x-ray imaging optic. Coherent x-ray diffraction imaging can overcome this limitation [54, 55, 56, 57], also in combination with scanning microscopy (ptychography) [58, 59, 53, 60, 61]. Our team has considerable experience in this field, also in characterizing the coherence at synchrotron radiation sources and free-electron lasers [62, 63, 64].

Within the virtual institute, we have strong background in x-ray microscopy, operating four x-ray microscopes. These instruments are complementary in their energy range and the techniques they make available and are described in more detail below. The VI will create a platform to make these instruments available to biology and chemistry.

2.2.1 Beamline P11 at PETRA III

Beamline P11 at the PETRA III will provide two different experiments: A Scanning Transmission x-ray Microscope (STXM) and an x-ray crystallography endstation. The STXM will be operated at x-ray energies between 2.5 and 10 keV and is therefore ideally suited for structure determinations of weakly absorbing biological samples ranging from single cells to extended tissue sections. The instrument will be operated in vacuum and allows sample cooling down to 10 K in order to reduce radiation damage. Different detector systems will be available at the experiment: x-ray fluorescence detectors for element detection and a 2-dimensional detector for absorption, phase contrast and also coherent x-ray diffractive imaging (CXDI) experiments. It will be possible to perform all these experiments simultaneously in both mapping (2-dimensional) and tomography (3-dimensional) mode. This makes the instrument ideally suited to identify trace elements or nano-clusters used to label specific cells or part of cells in their larger biological context.

2.2.2 Hard x-ray nano-probe beamline P06 at PETRA III

Beamline P06 at PETRA III is dedicated to scanning microscopy and x-ray micro-/nanoprobe techniques in the hard x-ray range. The first instrument, the hard x-ray nanoprobe, is currently under commissioning and will start user operation in 2011. Designed by TU Dresden and built and installed in collaboration with DESY, the scanning microscope generates sub-100 nm hard x-ray beams for transmission, fluorescence, and diffraction imaging, giving elemental, chemical and nano-structural contrast [65]. Fig. 5 shows the instrument and a test micrograph.

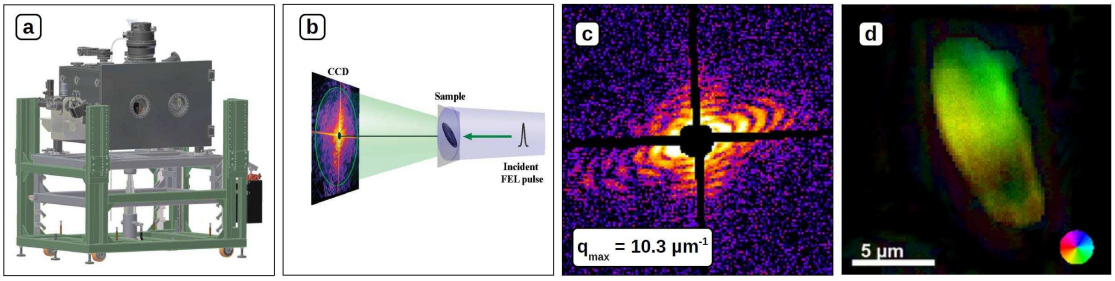

Figure 6: HORST system (a) schematic layout (b) schematic view on single pulse diffraction experiment at FLASH (c) diffraction pattern from single pulse and its reconstruction (d) [72].

Currently, the instrument is upgraded to optimize coherent x-ray diffraction microscopy (ptychography) for nanometer imaging (BMBF grant 05KS10OD1). In addition, special sample environments for imaging chemical reactions and catalysts are designed in collaboration with KIT (05K10VK1).

2.2.3 Göttingen endstation at beamline P10 at PETRA III

The recently commissioned coherent imaging endstation at beamline P10 at PETRA III is based on a highly coherent and divergent (cone) beam illumination, achieved by fixed curvature focusing mirrors with additional spatial and coherence filtering by x-ray waveguides. The instrument offers 200 nm focused beams by KB-mirrors and/or sub-50 nm beams by x-ray waveguides with cross-sections down to 30 nm [66, 67] and below [68, 69]. Quasi-spherical wave fronts emitted from x-ray waveguides and/or focusing mirrors can be used to yield magnified in-line holograms of the sample, formed by free space propagation [70, 71, 66].

The instrument can be used for lensless biological imaging and tomography, as well as for propagation imaging (e. g., of membranes) and for nanobeam diffraction. To precisely position heterogenous samples such as cells or tissues, or complex in-situ sample environments such as microfluidic platforms, the instrument is equipped with two in-situ optical microscopes. An option for cryogenic sample environment is under development.

2.2.4 Soft x-ray scattering chamber HORST for coherent imaging of biological samples

The soft x-ray scattering chamber HORST (holographic x-ray scattering chamber, cf. fig. 6(a)) has been constructed with BMBF funding (05KS4VH1, 08KS7VH1, 05K10VH4). Key property of the device is the easy adaption to different radiation sources including FLASH, FLASH II, PETRA III, XFEL, BESSY II, and ANKA. So far, HORST has been used at PG2 and BL2 at FLASH and UE49 and UE52 SGM at BESSY. The system is very flexible in terms of mechanical and optical elements (e. g., zone plates, apertures, sample alignment) and can be easily adapted to specific experimental demands. A recent upgrade allows the transfer of crogenic samples into the chamber and to image frozen hydrated biological material. Within the next year, a liquid jet will be developed as further module for HORST, by which biological liquids or suspended cells can be injected into x-ray beams, e. g., of free-electron laser sources. So far, our experiments with HORST were focused on digital soft x-ray holography [73, 74, 75, 76], soft x-ray ptychography [77], and coherent imaging experiments at FLASH [75, 78, 72] (fig. 6b-d). We demonstrated resonant imaging with chemical resolution [74] and were able to obtain spatial resolutions of down to 50 nm with both, amplitude and phase contrast [77].

2.3 Sample Environments

The key to bring biological and chemical science to the new x-ray microscopes lies in the development of special sample environments and the methods based thereon.

2.3.1 Microfluidics

Microfluidics has become a very popular approach in many branches of science and in particular in the life sciences and in chemistry. A reason for this success is the ability to manipulate the systems on the relevant length (nm $-$ μm) and time scales (μs $-$ hrs), and at the same time observe the response in situ. Recently much effort has been devoted to combining microfluidic devices also with high-resolution x-ray techniques [79, 80, 81]. Depending on the experimental method, the setup has to be tailor-build with regards to geometry, flow conditions and, very importantly, window material. Therefore, we have developed a variety of alternatives, using thin Kapton film [82, 83], UV-curable adhesive [84], or working without windows at all, as it is realized in the free liquid jet [85]. With this experience as a background we are now in the position to adapt a microfluidic setup for a given scientific question exactly to the experimental requirements, such as relevant q-space, technical parameters of the beamline, sample delivery method, and thermodynamic parameters, such as temperature and pressure.

2.3.2 Cryogenic Sample Preparation and Measurements

At newest generation synchrotron radiation sources it has become possible to generate extremely high flux densities in very small x-ray spots. Unfortunately, these high x-ray doses delivered to the sample in such experiments are causing severe radiation damage to samples, especially in case of hydrated biological samples [86]. Radiation damage manifests itself in the loss of high resolution information and contrast in diffraction and imaging experiments [87, 88]. From x-ray crystallography and electron microscopy it its well known that measurements at liquid nitrogen or even liquid helium temperatures slow down radiation damage by about two orders of magnitude compared to room temperature measurements. All static imaging experiments of hydrated biological samples in the frame of this proposal will, therefore, be performed at cryogenic temperatures. Another option is to permanently replace the samples, e. g., by using a liquid jet or a microfluidic flow cell.

To avoid the formation of hexagonal ice during cooling the temperature drop has to be applied extremely fast. Samples smaller then 10 µm can be flash cooled by plunge freezing. Larger samples can be flash frozen at high pressure [89]. Once the samples are successfully frozen they have to be kept at temperatures below 160 K. This involves special sample handling procedures for all steps involved.

2.3.3 Chemical reactors for x-ray analysis and imaging

Over the last years a series of reactor cells were designed by Grunwaldt et al. for in-situ investigation of gas and liquid phase reactions [90, 91, 92, 93, 94, 95, 96] and are currently extended to higher pressure [97, 98, 95] and temperature [99]. In addition, microstructured cells for in-situ parallel screening of catalysts were designed and successfully demonstrated [34, 37]. A current research project ("Mat-Akt") located at ANKA will provide additional input for the design and commissioning of in-situ cells.

3 Proposed activities

This VI serves to bring together key enabling technologies, namely x-ray microscopy techniques at the most brilliant synchrotron radiation source PETRA III and the free-electron-laser source FLASH at DESY, with biology and chemistry, addressing scientific questions relevant in health, energy and environmental science. The proposed activities will foster synergies between the two scientific fields in making x-ray imaging techniques available to them through the development of special sample environments and in-situ imaging techniques.

3.1 Scientific Goals

3.1.1 Membrane fusion intermediates

We propose to study membrane fusion intermediates in model lipids, to better understand the role of hydration and curvature elasticity in the formation of connections between two opposing membranes called stalks. We are currently studying equilibrium bulk lipid phases exhibiting stalks by x-ray diffraction (GISAXS). Coherent diffractive imaging (CDI) under cryogenic preservation will be used here to significantly extend these studies. Individual configurations of stalks and defects in the membrane can be visualized unaffected by the ensemble averaging process. The electron density data from the GISAXS experiments at hand will help us to guide the experiment.

Milestone: **Mem4** (year 4): The first transmission CDI of a pure lipid under cryogenic fixation in the stalk phase whowing the hexagonal arrangement of stalks with a resolution below 10 nm.

Instruments: PETRA III beamlines P03, P06, P08, and P10 and HORST

3.1.2 Adhesion and fusion in model membranes

We want to image monolayers and bilayers in close vicinity at the onset of fusion, and after fusion to derive information on the local distance as a function of solution properties and constituents (pH, Ca concentration, proteins, lipid type). By use of propagation imaging based on highly curved wavefronts, the contour as well as the local density profile across the membranes becomes accessible in solution. The previous work shall be significantly extended, based on the advanced microfluidics capabilities.

Milestone: **Mem2a** (year 2): Propagation imaging of two adhering membranes, and analysis of the local inter-membrane spacing as a function of solution parameters, before the onset of fusion.

Instruments: P06, P10

3.1.3 Synaptic vesicles (SV)

We want to investigate the interaction of SVs with model membranes. Observation of the docking state and interaction can reveal structural mechanisms of lipids interacting with fusiogenic proteins. By nanobeam diffraction we will avoid problems of sample heterogenity. We will also try to directly image a single SV at the membrane. (collaboration with Prof. Dr. R. Jahn, MPI for biophy. Chemistry, Göttingen).

Milestone: **Mem3a** (year 3): SVs in microfluidic channels interacting with lipid bilayers of liposomes, probed by nanoscale diffraction.

Instruments: P06, P10, HORST

3.1.4 Myelinated axons

We will use hard x-ray nanobeams to scan single myelinated axons of nerve cells, collecting scanning diffraction data, from which the local periodicity, lamellar ordering, number of bilayers can be inferred. Full 3D analysis by tomography is the long-term goal. We will start using freeze dried samples, and continue with frozen hydrated (plunge frozen) nerve cells of various mouse models (collaboration with Prof. Dr. K. A. Nave, MPI for exp. medicine, Göttingen).

Milestones: **Mem1a** (year one): diffraction mapping of a freeze dried and **Mem3b** (year three) frozen hydrated fibre around the node of Ranvier.

Instruments: P06, P10, P11

3.1.5 Ultra-fast dynamics in membranes

With the goal to study the non-equilibrium response to photoexcitation and strong external electric fields, we will study lipid bilayers in the pump-probe scheme, based on single FEL pulses, continuing an internal collaboration (with A. Rosenhahn and I. Vartanyants) at FLASH.

Milestones: **Mem1b** (year one): pump-probe experiment of dry membrane stack, **Mem2b** (year two) hydrated membrane stack.

Instruments: HORST at FLASH

3.1.6 Cells

With regard to structures in cells, the scientific question we would like to pose is how such structures evolve in space and time to reach their final, functional stage. To approach this question we plan to combine tailor-built sample environments (e. g., continuous flow microfluidic devices or the free liquid jet) with nanoscopic resolution at the beamlines of PETRA III and FLASH. Quite some developmental effort will be necessary to reach our goal in order to provide user friendly, reliable and reproducible setups (which will in the future also be offered to other users at the beamline thus opening up a wealth of experimental possibilities). If successful, we expect a thorough understanding of protein assembly processes in purified in vitro systems, which will, in turn, further our understanding of assembly processes in the cell that eventually lead to the structures that define cellular function.

Milestones: **Cell1** (year 1): in vitro experiments, **Cell2** (year 2): fixed cells, **Cell3** (year 3): model organisms and, first test of live cell imaging, **Cell4** (year 4): experiments on (initially) living cells (relevant cell lines), **Cell 5** (year 5): platform for conducting cell experiments including data analysis (also offered to beamline users).

Instruments: P06, P10, P11, HORST

3.1.7 Ultrastructure of melanosomes in view of the development of glaucoma

We challenge the hypothesis that the granular structure of melanosomes develops at a given genetic background. Such a correlation would be valuable as biomedical models currently assign such a change in ultrastructure with the ability of toxic components to leach into the surrounding tissue and thus to cause glaucoma. The new nanoscopy techniques applied to cryoprepared

samples at PETRA III will be used to tackle this question and to unravel its structure. Cryopreparation is of major importance for the project as it allows to fix the organelles in their natural structural state to ensure their structural integrity and to suppress radiation damage. In order to finally verify that the results are not induced by radiation damage we will use single pulse imaging at FLASH and XFEL with the soft x-ray scattering chamber HORST and in the later stage of the project using the permanent endstations at XFEL.

Milestone: **Mel3** (year 3): Imaging of frozen hydrated melanosomes.

Instruments: P11, HORST

3.1.8 Analyse curing mechanisms in adhesives of marine algae

We will study the elementary composition of the adhesives of marine algae (diatoms, brown algae, seaweed) with state of the art x-ray nanoprobe analysis in conjunction with cryogenic sample preparation. Cryopreparation offers the unique advantage of preserving all soluble components within the adhesive. The large penetration depth of x-rays allows to sample and image the entire volume of adhesive and to determine its elemental composition. Especially the possibility to determine the oxidation state of the metals by analysis of the NEXAFS shifts during the different curing phases will allow understanding the chemical reactions and the curing kinetics. For this project we rely on our previous experience in working with algae [100] and the preparation of diatoms for x-ray imaging (e. g., *N. perminuta*) [72], which was done in collaboration with the Callow group, School of Biosciences, University of Birmingham, UK. The focus of our previous work was to use the free-electron laser FLASH and soft x-rays provided by BESSY [75, 77, 72] to resolve the internal structures of diatoms. Within the virtual institute we will apply cryogenic sample preparation and use the unique potential of x-ray nanoprobe analysis to reveal the chemistry and thus the function of the adhesives of marine algae. The project will benefit to the recently started EU ITN SeaCoat (Surface Engineering for Antifouling – Coordinated Advanced Training) [101], in which the mechanism of biofouler-surface interaction is one key question.

Milestones: **Alg3** (year 3): Investigation of frozen hydrated marine biofouling organisms and cells. **Alg4** (year 4): Chemical contrast in adherent marine biofouling organisms.

Instruments: P11, HORST

3.1.9 Heterogeneous Catalysis & Sintering

The aim is to study solid catalysts in 2D and 3D with scanning and full-field x-ray microscopy. As a start, an ex-situ study of exhaust gas catalysts (3-way catalyst, NO_x-storage-reduction catalyst) is planned. In addition, the partial oxidation of methane will serve as model reaction for in-situ studies, in particular for time resolved imaging of the ignition around single catalyst particles. This will give insight into the presently hidden mesoscale. The engineering challenge is to design corresponding micronized reactors, the methodological challenge to combine scanning and full-field techniques.

Sintering and morphological changes of nanoparticles will be studied on the meso and nanoscale. For this purpose a small in-situ cell is required. We aim at imaging single catalyst particles by XANES ptychography to get the ultimate resolution. Aging in realistic atmospheres containing water and carbon dioxide will provide, e. g., information on the mechanism and the support. Complementary studies will be performed in an integral manner at ANKA and in a few mbar gas pressure by in-situ electron microscopy.

Milestones: **Cat1** (year 1): Tomography of exhaust gas catalysts ex situ, **Sin2** (year 2): Imaging of metal particles by XANES ptychography, **Cat3** (year 3): In-situ study of the ignition of the catalytic partial oxidation of methane around a single catalyst particle, **Sin4** (year 4): Time-resolved imaging of ageing during the sintering process, **Cat5** (year 5): Tomographic study of 3D-gradients in a reactor.

Instruments: P06, HORST

3.1.10 Redox and precipitation reactions

The use of a hard x-ray nanobeam for absorption spectroscopic and scattering experiments will be used to obtain high temporal resolution when imaging the steady flow along a microreactor. In this way, chemical redox reactions (e. g., the formation of copper and gold colloids from corresponding precursor solutions) and precipitation reactions that occur on a sub-millisecond time scale will be studied. For a well-designed microfluidic device, a better spatial resolution translates into a better time resolution. At flow speeds of up to several meters per second, temporal resolutions on the scale of 10 ns and below can be obtained.

Milestones: **React2** (year 2): microreactor device for studying flow pattern and reaction mechanism in the homogeneous redox reaction from Cu(II) and Au(III) precursors to colloids, **React4** (year 4): study mechanism of precipitation reaction using XAS, SAXS and XRD from the formation of clusters towards larger aggregates, e. g., copper-based catalysts for methanol synthesis.

Instruments: P06

3.2 Sample environments and methodological developments

3.2.1 Sample environments and in-situ imaging

Microfluidics: The power of microfluidic devices is that they provide highly controllable and well-defined sample environments for biological and chemical systems. For biological systems it is crucial to provide physiological or at least close-to-physiological conditions, concerning temperature, pH, ionic strength etc. For (bio-)chemical reactions, a thorough knowledge of reaction parameters such as concentrations and temperature is indispensable.

On the micron scale, diffusion length scales, and therefore time scales, are short. We will therefore be able to investigate chemical reactions (e. g., redox reactions, precipitation, and catalysis) on their "true" reaction time scales. By taking advantage of the laminar flow in such microreactors, high temporal resolution can be achieved by providing high spatial resolution (i. e., small beam sizes). The same advantages can be exploited for studying highly dynamic processes in biological systems, such as assembly or aggregation of biomacromolecules. Gradients (in certain reagents, ionic strength or pH) can be established and the response of the biological systems to such gradients can be followed. A very interesting and biologically relevant self-assembling system are cytoskeletal intermediate filaments [84, 102], since monomers assemble in a hierarchical manner into long filaments and networks and bundles. However, our approach can be generalized to numerous assembling systems, since this experimental approach combines extreme flexibility (channel geometries and dimensions, flow rates and window materials [84, 83] can be tailored to each particular scientific question) and a high degree of control due to the laminar (and therefore very predictable) flow conditions in the microchannels [103, 82]. In experiments where no window material can be used (FEL experiments), we plan to employ the free liquid jet [85], which in combination with HORST will be used for single pulse imaging of biological samples.

Milestones: **Mfluid1** (year 1): test experiments to tailor microfluidic devices to experimental parameters (flow rates, pressure, time resolution), **Mfluid2** (year 2): test experiments to choses optimal window materials for given experiment/beamline and development of such devices, **Mfluid3** (year 3): microfluidic devices for use in beamlines P06, P10 and P11, **Mfluid5** (year 5): microfluidic platforms, which can be applied (also by beamline users) to a variety of chemical and biological experiments.

Chemical reactors: appropriate in-situ cell designs both for catalysis and chemical reactions in general will be developed. These microdevices need to be mechanically stable, be compatible with the x-ray imaging techniques, allow liquid or gas flow, and must in certain cases be heatable over 500° C. For stationary conditions, these devices will be extended to tomographic imaging.

Milestones: **CatRe3** (year 3): in-situ reactor for 2D study of catalytic reactions. **CatRe5** (year 5): reactor of in-situ tomographic study.

Instruments: P06, P10, P11, HORST

3.2.2 Methods and instrumentation

During the project, all four instruments will be further developed. In particular, P06, P10, P11, and HORST will be equipped with enhanced sample environments, including both cryogenic and microfluidic platforms, as well as on-site image analysis and reconstruction.

The x-ray beam of the STXM at P11 will be used to perform x-ray fiber diffraction / wide angle x-ray scattering (WAXS) experiments at high spatial resolution. This yields the unique opportunity not only to image samples in the far field (with several tens of nanometer resolution) but also to collect additional information from local periodic arrangements such as protein self assemblies at atomic resolution. Scanning the sample through the x-ray beam allows one now identifying areas of local periodicity. Once identified, these areas can be centered in the beam and on the rotation axis and a complete diffraction pattern can be collected by rotating the sample. We propose to extend the x-ray microscope currently installed at beamline P11 by a microdiffraction capability for in-situ studying of protein self assembly in single cells and to investigate the local structure of melanosomes in cells and tissues sections. This will include the integration of a second detector covering high q-space, the development of sample cryo-preparation and measurement techniques and finally data analysis.

HORST will be upgraded with a cryogenic transfer system to image frozen hydrated material in the water window with coherent microscopy (Ptychography, CXDI, Propagation imaging). For experiments at FELs, the implementation of a liquid jet [84] into the HORST chamber (BMBF 05K10VH4) will allow to investigate chemical or biological processes under high shear rates and to prealign non-spherical biological objects [84]. It is of great technological importance that FLASH just reached the water window, which allows to verify that structures, which have been observed at synchrotron sources are real and to reveal potential influences of radiation damage. We will improve coherent x-ray imaging techniques, such as CXDI, holography, and ptychography, both for the synchrotron radiation source and the FELs, in view of resolution and acquisition time.

An important part for all experiments is the software development for routine data processing, i. e., the on-line reconstruction of holographic, ptychographic, nano-diffraction tomographic data.

Milestones: **Soft1** (year 1): implement real-time ptychographic reconstruction on DESY computers. **Ins1** (year 1): define and test interface for special sample environments at P06, P10, and P11. **Mdiff2** (year 2): integration of the high q-detectors into the STXM. **Mdiff3** (year 3): cryogenic micro-diffraction experiments on melanosomes and cytoskeleton of cells. **Horst5**

topic	2011	2012	2013	2014	2015	2016
membranes		Mem1a	Mem2a	**Mem3a**	Mem4	
		Mem1b	Mem2b	**Mem3b**		
cells		Cell1	Cell2	**Cell3**	Cell4	Cell5
melanosomes				**Mel3**		
algae				**Alg3**	Alg4	
catalysis		Cat1		**Cat3**		Cat5
sintering			**Sin2**		Sin4	
chem. reactions			**React2**		React4	
microfluidics		Mfluid1	Mfluid2	**Mfluid3**		Mfluid5
						Horst5
chem. reactors				**CatRe3**		CatRe5
M & I		Soft1	Mdiff2	**Mdiff3**		Mdiff5
		Ins1				
theory		Theo1	Theo2	**Theo3**		Theo5

Table 1: Time table with milestones for the different parts of the project. The milestones are described in the respective sections in part 3.

(year 5): complete implementation of the liquid jet. **Mdiff5** (year 5): Full availability of the new setup to the user community.

3.2.3 Theoretical modeling of coherent x-ray imaging

We will develop further the theoretical background of coherent x-ray imaging techniques, in view of partial coherence and focusing (by KB-mirrors, compound refractive lenses, Fresnel zone plates, and waveguides), both at synchrotron radiation sources (PETRA III) and the FELs. Improve the phase retrieval for propagation imaging techniques, such as CXDI, holography, and ptychography, e. g., extending the work in [66, 53]. Development of x-ray cross-correlation techniques for analysis of a small-angle scattering from biological samples in solution. Model SAXS imaging techniques in view of nano-diffraction from protein assemblies in cells and tissues [104].

Milestones: **Theo1** (year 1): evaluation of coherent properties of FELs (FLASH & LCLS) from experimental data. **Theo2** (year 2): model of partially coherent nanobeams. **Theo3** (year 3): improved ptychographic reconstruction, taking mechanical instability into account. **Theo5** (year 5): model SAXS imaging for scanning nano-SAXS and SAXS tomography.

4 Schedule and Milestones

The milestones are described in section 3 for each part of the project. The timeline and the due dates for the milestones are given in Table 1. The period for the VI is planned for five years. The three year review will be in 2014: the highlighted milestones in Tab. 1 are to be reached at the review.

5 Benefits

The aim of this virtual institute is to develop the x-ray imaging capabilities of PETRA III and FLASH in view of biological and chemical processes and apply them to selected questions in

biology, chemistry and chemical engineering. By the end of the five year period, we expect to have demonstrated the strength of in-situ x-ray imaging in both fields and have a portfolio of techniques available to address further questions. In addition, we will have first scientific results in both fields. This development will also be to the benefit of many users of these facilities that can take advantage of the new in-situ imaging capabilities. Of course, these techniques will be made available for user access on a routine basis.

A key strength of this VI is the joint development of both biological and chemical imaging techniques, as both fields require similar imaging capabilities and sample environments. In particular, we can build on the knowledge available in both fields for further development of sample environments and the use of complementary microscopy techniques. We plan to provide a joint sample platform and preparation protocols suited to tackle specific biological and chemical questions.

We expect that the outcome of this research will decisively strengthen the capabilities and the impact of imaging methods and instrumentation using PETRA III, FLASH as well as the European XFEL. It is thus of strategic importance to DESY, its user community and the university groups active in this field.

6 Involved Groups

The proposed virtual institute will be a collaboration between scientists from DESY and university groups in Dresden, Heidelberg, Karlsruhe, and Göttingen. Two Scientists are also affiliated with KIT.

Prof. Dr. Jan-Dierk Grunwaldt (Karlsruhe): Catalysis (exhaust gas, energy-related catalysis, fine chemistry in green solvents), rational materials design and chemistry, in-situ spectroscopy with focus on structure-performance relationships.

Prof. Dr. Sarah Köster (Göttingen): Biophysics, cytoskeletal mechanics, complex fluids, microfluidics.

Dr. Alke Meents (DESY, Hamburg): x-ray microscopy of biological systems, cryo-microscopy, nano-diffraction.

PD Dr. Axel Rosenhahn (Heidelberg University and Karlsruhe Institute of Technology): Biointerfaces, surface science, biofouling, coherent imaging with soft x-rays, holography.

Prof. Dr. Tim Salditt (Göttingen): Waveguide optics, holography, coherent imaging, biophysics, membranes, complex fluids.

Prof. Dr. Christian Schroer (Dresden): Refractive x-ray optics, nanofocusing, scanning and full-field X-ray microscopy and tomography, micro-/nano-spectroscopy, absorption spectroscopy in catalysis.

Dr. Ivan Vartaniants (DESY, Hamburg): Theory of coherence, coherent x-ray diffractive imaging, phase retrieval, bio-imaging at synchrotron and FEL sources, nano-imaging of quantum dots and nano-wires at synchrotron sources.

In addition, at DESY there is a collaboration and scientific exchange with the groups of Saša Bajt (x-ray optics) and Henry Chapman (lensless imaging).

External evaluation:

Georg-August-University Göttingen: SFB 755 “Nanoscale Photonic Imaging”, Project C1, C5: Tim Salditt, (also spokesperson of the SFB), Project B7: Sarah Köster. BMBF Ver-

bundforschung 05K10MGA, Tim Salditt. SFB 803 “Functionality controlled by organization in and between membranes”, Project B1: Tim Salditt. SFB 937 “Collective behavior of soft and biological matter”, Project A12: Sarah Köster, Projects A7 and A11: Tim Salditt. Courant Research Centre “Nano-Specroscopy and X-Ray Imaging” (Excellence Initiative of the DFG): Tim Salditt: Spokesperson, Sarah Köster: Junior Research Group Leader. Center for Molecular Physiology of the Brain (CMPB) and Excellence Cluster 171 of the DFG: Sarah Köster and Tim Salditt, members.

TU Dresden: ESTEC (European Space Agency): “X-ray Based Analytical and Imaging Devices”, TU Dresden. BMBF Verbundforschung 05K10OD1. NanoFOX: JRA ELISA (FP7 I3), Project 2.2 “Adiabatically focusing lenses”. GrK 1621: “Itineranter Magnetismus und Supraleitung in intermetallischen Verbindungen”, Project A3: C. Schroer.

KIT: BMBF Verbundforschung 05K10VKB. BMBF Verbundforschung 05K10VK1, Helmholtz-Kolleg “Energy related catalysis” at KIT with O. Deutschmann, “Catalysis for sustainable energy” with J. K. Nørskov at the Technical University of Denmark.

University of Heidelberg: BMBF Verbundforschung 05K10VH4. Surface Engineering for Anti-fouling - Coordinated Advanced Training (SEACOAT), A. Rosenhahn and M. Grunze, MC-ITN, EU 7^{th} FP, Coordinator Prof. J. Callow.

DESY: BMBF Verbundforschung 05K10CHG, DESY. GrK 1355” “Physik mit neuartigen kohärenten Strahlungsquellen”, Hamburger Landesexzellenzinitiative: Frontiers in Quantum Photon Science.

International collaboration:

- ID01, ID10, ID13 at ESRF, Grenoble: development of x-ray microscopy techniques and nano focusing, coherent diffraction imaging, ptychography, nanodiffraction.
- Paul-Scherrer-Institute, Switzerland; coherent diffraction imaging, ptychography
- RRC “Kurchatov Institute”, Shubnikov Institute of Crystallography RAS, Physics Department, Lomonosov Moscow State University, Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Southern Federal University, Russia: coherent diffraction imaging, scattering of ultrashort coherent pulses with matter.
- Center of Electronnanoscopy, Technical University of Denmark, in-situ electron microscopy.
- Van’t Hoff Laboratory for Physical and Colloid Chemistry, Debye Institute, University of Utrecht, The Nederlands: coherent diffractive imaging, colloidal crystals.
- ARC Centre of Excellence for Coherent X-ray Science, School of Physics, The University of Melbourne, Australia: coherent diffractive imaging of biological samples, measurements of coherence.
- University of California, Berkeley, SLAC National Accelerator Laboratory, Lawrence Livermore Natl. Lab., USA: measurements of coherence, focusing XFEL beams.
- APS, Argonne, USA: coherent diffractive imaging on biological samples.

7 Organization of the virtual institute

Budget control and financial management will be carried out by DESY. The virtual institute will be represented by its spokesperson, Prof. Dr. Christian Schroer (TU Dresden). Dr. Alke Meents at DESY will be appointed as the technical coordinator. The virtual institute will organize seminars and discussion meetings among the members on a regular basis. Project meetings

will be held on a monthly basis. Students and PostDocs will be exchanged for prolonged visits among the participating institutions for beamtimes, experimental preparation, data analysis, and sample preparation. Advanced Ph. D. courses for students from Göttingen, Karlsruhe, and Dresden will take place, e. g., at DESY with online training in x-ray imaging experiments and data analysis.

8 Support of young scientists

The virtual institute will allow young scientists on the PhD-student and postdoc level to gain experience at large-scale facilities well beyond the usual user access. The techniques developed in this project are taught in diploma-level lectures about x-ray physics, microscopy, applied spectroscopy in chemistry and chemical technology, nanoscience, and biophysics at the participating universities. The majority of the funds from this proposed project will be spent for postdoc and PhD student positions. They will also include travel expenses for enabling visits to workshops, conferences and beamtimes at large scale facilities if needed. The virtual institute will thus be a viable and highly synergistic joint venture between four universities and two Helmholtz Centers. In the past, this has worked very well, as illustrated by two alumnus from Uni. Göttingen, who both work at DESY now.

9 Declaration of continuation

The proposed investigations in the field of in-situ imaging of biological and chemical systems are at the center of the interest of the participating groups. The development of experimental techniques in this field is crucial for the biological and chemical user community. The participating groups see this VI as a nucleation point for in-situ imaging of biological and chemical processes at PETRA III and FLASH and will also enable new scientific opportunities at the future European XFEL.

10 Financial plan

10.1 Staff

We propose to employ 2 postdocs and 10 PhD students for this project. They will be distributed among the groups and work on the following tasks (in addition, there will be 5 PhD students and 2 postdocs funded by other sources):

DESY, A. Meents: One postdoc will work on the design and realization of a micro-diffraction setup integrated in beamline P11. DESY will contribute personnel (equiv. 40k€/a) to work for the VI, i. e., one postdoc for integration of a differential phase contrast (DPC) setup into beamline P11.

DESY, I. Vartaniants: One postdoc position will work in the field of coherent diffractive imaging of biological and nano samples. DESY will contribute personnel (equiv. 40k€/a) to work for the VI, i.!e., one postdoc for theoretical analysis of propagation of partially coherent x-rays through the focusing optics.

Uni. Göttingen, T. Salditt: 1 PhD student will focus on the imaging experiments involving model membranes. The second Ph.D. student will prepare and carry out experiments at

FLASH (membrane optical pump x-ray probe) together with the teams of the collaborating groups. A third Ph.D. student is employed and paid by University of Göttingen and concentrates on the biological cells, in particular myelinated nerve fibers.

Uni. Göttingen, S. Köster: 1 PhD student will work on developing microfluidic devices for the x-ray microscopes at PETRA III in view of biological assembly processes. One PhD student will work in close collaboration with the group of J.-D. Grunwaldt to develop microfluidic devices for chemical reactions. 1 PhD student will be funded by the university (equiv. 34k€/a), working on intracellular protein structures.

KIT, J.-D. Grunwaldt: 1 PhD student will be in charge of constructing the microreactor devices to investigate catalysis and to monitor diffusion and gradients in catalytic materials (contributed by KIT, equiv. 34k€/a). One PhD student will focus on fast chemical reactions (redox, precipitation) in microfluidic devices. Finally, 1 PhD student will focus on tomography and ptychography of small supported metal nanoparticles, including sintering processes.

IFG, KIT, A. K. Rosenhahn: 1 PhD student will be in charge of the melanosome project. The second student will work on the chemically resolved imaging of marine adhesives. IFG/APC will contribute 1 PhD student (equiv. 34k€/a), who will work on the implementation of the cryostage and the liquid jet into the HORST chamber.

TU Dresden, C. Schroer: 1 PhD student will work on the integration of chemical reactors for catalysis into the P06 nanoprobe, 1 PhD student will develop time resolved XAS and XDS techniques for studying redox and precipitation reactions. TUD will contribute 1 PhD student to develop ptychographic imaging techniques (equiv. 34k€/a).

10.2 Equipment

All equipment needed for the proposed investigations will be funded from other sources.

10.3 Travel expenses & consumables

The project is scheduled for 5 years (cf. Table 1). Each member group receives 3000€/a to cover travel expenses between the member sites and to relevant conferences and to cover consumables.

10.4 Distribution of annual costs

Institute	Staff	Invest.	Travel	Basic	Add.	Sum
DESY	2 postdocs	0	3.0	40.0	80.0	120.0
UGö (Salditt)	2 PhD	0	3.0	42.0	34.0	76.0
(Köster)	2 PhD	0	3.0	42.0	34.0	76.0
KIT (Grunwaldt)	2 PhD	0	3.0	42.0	34.0	76.0
UHei (Rosenhahn)	2 PhD	0	3.0	42.0	34.0	76.0
TUD (Schroer)	2 PhD	0	3.0	42.0	34.0	76.0
		0		250.0	250.0	500.0

Splitting of annual costs in k€ between DESY, University Göttingen (UGö), KIT, University of Heidelberg (UHei), and TU Dresden (TUD).

The additional funding is matched with additional funding from other sources (cf. section 10.1 for details).

References

[1] E. Sackmann, *Handbook of Biological Physics, Volume 1* (Elsevier Science B.V., 1995).

[2] S. Castorph, D. Riedel, L. Arleth, M. Sztucki, R. Jahn, M. Holt, and T. Salditt, Biophysical Journal **98**, 1200 (2010).

[3] R. Jahn and H. Grubm¸ller, Curr. Opin. Cell Biol. **14**, 488 (2002).

[4] L. Yang and H. W. Huang, Science **297**, 1877 (2002).

[5] S. Aeffner, T. Reusch, B. Weinhausen, , and T. Salditt, European Physical Journal E **30**, 205 (2009).

[6] S. K. Ghosh, S. Castorph, O. Konovalov, R. Jahn, M. Holt, and T. Salditt, New Journal of Physics **12**, 105004 (2010).

[7] A. Beerlink, M. Mell, M. Tolkiehn, and T. Salditt, Applied Physics Letters **95**, 203703 (2009).

[8] T. Ducic, S. Quintes, K.-A. Nave, J. Susini, M. Rak, R. Tucoulou, M. Alevra, P. Guttmann, and T. Salditt, Journal of Structural Biology **173**, 202 (2011).

[9] J. M. Pawelek and A. B. Lerner, Nature **276**, 627 (1978).

[10] N. P. M. Smit, S. Pavel, and P. A. Riley, in *Role of Cetechol Quinone Species in Cellular Toxicity*, edited by C. R. Creveling (F. B. Graham Publishing, Johnson City, TN, 2000), pp. 191–245.

[11] M. G. Anderson, T. Haraszti, G. E. Petersen, S. Wirick, C. Jacobsen, S. W. M. John, and M. Grunze, Micron **37**, 689 (2006).

[12] E. C. Dell'Angelica, Trends Cell Biol. **13**, 503 (2003).

[13] T. Kushimoto, J. C. Valencia, G. E. Costin, K. Toyofuku, H. Watabe, K. I. Yasumoto, F. Rouzaud, W. D. Vieira, and V. J. Hearing, Pigm. Cell Res. **16**, 237 (2003).

[14] R. Holland, T. M. Dugdale, R. Wetherbee, A. B. Brennan, J. A. Finlay, J. A. Callow, and M. E. Callow, Biofouling **20**, 323 (2004).

[15] A. Chiovitti, T. M. Dugdale, and R. Wetherbee, in *Biological Adhesives* (Springer, Berlin, 2006).

[16] M. P. Schultz, Biofouling **23**, 331 (2007).

[17] R. L. Townsin, Biofouling **19**, Suppl. 9 (2003).

[18] D. A. Lack, J. J. Corbett, T. Onasch, B. Lerner, P. Massoli, P. K. Quinn, T. S. Bates, D. S. Covert, D. Coffman, B. Sierau, S. Herndon, J. Allan, T. Baynard, E. Lovejoy, A. R. Ravishankara, and E. Williams, Journal of Geophysical Research-Atmospheres **114**, D00F04 (2009).

[19] A. M. Smith and J. A. Callow, *Biological Adhesives* (Springer, Berlin, 2006).

[20] A. Rosenhahn, T. Ederth, and M. E. Pettitt, Biointerphases **3**, IR1 (2008).

[21] B. A. Wustman, M. R. Gretz, and K. D. Hoagland, Plant Physiol. **113**, 1059 (1997).

[22] H. Lee, S. M. Dallatore, W. M. Miller, and P. B. Messersmith, Science **318**, 426 (2007).

[23] A. P. Vinogradov, *The elementary chemical composition of marine organisms* (Sears Foundation for Marine Research, Yale University, New Haven, 1953).

[24] G. J. Colpas, B. J. Hamstra, J. W. Kampf, and V. L. Pecoraro, J. Am. Chem. Soc. **118**, 3469 (1996).

[25] P. Potin and C. Leblanc, in *Biological Adhesives*, edited by A. Smith and J. A. Callow (Springer, Berlin, Heidelberg, 2006), Chap. 6, pp. 105–124.

[26] H. Bilter, Phytochemistry **23**, 1387 (1984).

[27] D. Howell, in *Advances in marine antifouling coatings and technologies*, edited by C. Hellio and D. Yebra (Woodhead Publishing Limited, Cambridge, 2009), Chap. 17, pp. 422–442.

[28] L. M. Johnson, K. D. Hoagland, and M. R. Gretz, Journal of Phycology **31**, 401 (1995).

[29] R. J. Lewis, L. M. Johnson, and K. D. Hoagland, Journal of Phycology **38**, 1125 (2002).

[30] J.-D. Grunwaldt, S. Hannemann, C. G. Schroer, and A. Baiker, J. Phys. Chem. B **110**, 8674 (2006).

[31] C. G. Schroer and J.-D. Grunwaldt, Synchrotron Radiation News **22**, 23 (2009).

[32] J.-D. Grunwaldt and C. G. Schroer, Chem. Soc. Rev. **39**, 4741 (2010).

[33] J.-D. Grunwaldt, B. Kimmerle, A. Baiker, P. Boye, C. G. Schroer, P. Glatzel, C. N. Borca, and F. Beckmann, Catalysis Today **145**, 267 (2009).

[34] J.-D. Grunwaldt, B. Kimmerle, S. Hannemann, A. Baiker, P. Boye, and C. G. Schroer, J. Mat. Chem. **17**, 2603 (2007).

[35] S. Hannemann, J.-D. Grunwaldt, N. van Vegten, A. Baiker, P. Boye, and C. G. Schroer, Catalysis Today **126**, 54 (2006).

[36] B. Kimmerle, J.-D. Grunwaldt, A. Baiker, P. Glatzel, P. Boye, S. Stephan, and C. G. Schroer, J. Phys. Chem. C **113**, 3037 (2009).

[37] B. Kimmerle, P. Haider, J.-D. Grunwaldt, A. Baiker, P. Boye, and C. G. Schroer, Appl. Catal. A: Gen. **353**, 36 (2009).

[38] J.-D. Grunwaldt, S. Hannemann, P. Boye, C. G. Schroer, and A. Baiker, Chimia **60**, 709 (2006).

[39] S. Hannemann, J.-D. Grunwaldt, B. Kimmerle, A. Baiker, P. Boye, and C. Schroer, Topics Catal. **52**, 1360 (2009).

[40] C. G. Schroer, M. Kuhlmann, T. F. Günzler, B. Lengeler, M. Richwin, B. Griesebock, D. Lützenkirchen-Hecht, R. Frahm, E. Ziegler, A. Mashayekhi, D. Haeffner, J.-D. Grunwaldt, and A. Baiker, Appl. Phys. Lett. **82**, 3360 (2003).

[41] R. L. Hartman and K. F. Jensen, Lab on a Chip (2009).

[42] A. Urakawa, F. Trachsel, P. R. von Rohr, and A. Baiker, Analyst **133**, 1352 (2008).

[43] R. Herzig-Marx, K. T. Queeney, R. J. Jackman, M. J. Schmidt, and K. F. Jensen, Anal. Chem. **76**, 6476 (2004).

[44] T. M. Floyd, M. A. Schmidt, and K. F. Jensen, Ind. Eng. Chem. Res. **44**, 2351 (2005).

[45] E. M. Chan, M. A. Marcus, S. Fakra, M. ElNaggar, R. A. Mathies, and A. P. Alivisatos, J. Phys. Chem. A **111**, 12210 (2007).

[46] W. Chao, B. D. Harteneck, J. A. Liddle, E. H. Anderson, and D. T. Attwood, Nature **435**, 1210 (2005).

[47] J. Vila-Comamala, K. Jefimovs, J. Raabe, T. Pilvi, R. H. Fink, M. Senoner, A. Maassdorf, M. Ritala, and C. David, Ultramicroscopy **109**, 1360 (2009).

[48] G. McDermott, M. A. Le Gros, C. G. Knoechel, M. Uchida, and C. A. Larabell, Trends Cell Biol. **19**, 587 (2009).

[49] C. A. Larabell and K. A. Nugent, Curr. Opin. Struc. Biol. **20**, 623 (2010).

[50] G. Schneider, P. Guttmann, S. Heim, S. Rehbein, F. Mueller, K. Nagashima, J. B. Heymann, W. G. Müller, and J. G. Mcnally, Nature Methods (2010), doi:10.1038/nmeth.1533.

[51] Y. S. Chu, J. M. Yi, F. De Carlo, Q. Shen, W.-K. Lee, H. J. Wu, C. L. Wang, J. Y. Wang, C. J. Liu, C. H. Wang, S. R. Wu, C. C. Chien, Y. Hwu, A. Tkachuk, W. Yun, M. Feser, K. S. Liang, C. S. Yang, J. H. Je, and G. Margaritondo, Appl. Phys. Lett. **92**, 103119 (2008).

[52] A. Carmona, P. Cloetens, G. Deves, S. Bohic, and R. Ortega, Journal of Analytical Atomic Spectrometry **23**, 1083 (2008).

[53] A. Schropp, P. Boye, J. M. Feldkamp, R. Hoppe, J. Patommel, D. Samberg, S. Stephan, K. Giewekemeyer, R. N. Wilke, T. Salditt, J. Gulden, A. P. Mancuso, I. A. Vartanyants, E. Weckert, S. Schöder, M. Burghammer, and C. G. Schroer, Appl. Phys. Lett. **96**, 091102 (2010).

[54] J. Miao, P. Charalambous, J. Kirz, and D. Sayre, Nature **400**, 342 (1999).

[55] D. Shapiro, P. Thibault, T. Beetz, V. Elser, M. Howells, C. Jacobsen, J. Kirz, E. Lima, H. Miao, A. M. Neiman, and D. Sayre, P. Natl. Acad. Sci. USA **102**, 15343 (2005).

[56] H. N. Chapman, A. Barty, S. Marchesini, A. Noy, S. P. Hau-Riege, C. Cui, M. R. Howells, R. Rosen, H. He, J. C. H. Spence, U. Weierstall, T. Beetz, C. Jacobsen, and D. Shapiro, J. Opt. Soc. Am. A **23**, 1179 (2006).

[57] C. G. Schroer, P. Boye, J. Feldkamp, J. Patommel, A. Schropp, A. Schwab, S. Stephan, M. Burghammer, S. Schöder, and C. Riekel, Phys. Rev. Lett. **101**, 090801 (2008).

[58] J. M. Rodenburg and H. M. L. Faulkner, Appl. Phys. Lett. **85**, 4795 (2004).

[59] P. Thibault, M. Dierolf, A. Menzel, O. Bunk, C. David, and F. Pfeiffer, Science **321**, 379 (2008).

[60] A. Schropp, P. Boye, A. Goldschmidt, S. Hönig, R. Hoppe, J. Patommel, C. Rakete, D. Samberg, S. Stephan, S. Schöder, M. Burghammer, and C. G. Schroer, J. Microscopy **241**, 9 (2010).

[61] M. Dierolf, A. Menzel, P. Thibault, P. Schneider, C. M. Kewish, R. Wepf, O. Bunk, and F. Pfeiffer, Nature **467**, 436 (2010).

[62] A. Singer, I. A. Vartanyants, M. Kuhlmann, S. Duesterer, R. Treusch, and J. Feldhaus, Phys. Rev. Lett. **101**, 254801 (2008).

[63] I. A. Vartanyants and A. Singer, New Journal of Physics **12**, 035004 (2010).

[64] I. A. Vartanyants, A. P. Mancuso, A. Singer, O. M. Yefanov, and J. Gulden, J. Phys. B **43**, 194016 (2010).

[65] C. G. Schroer, P. Boye, J. M. Feldkamp, J. Patommel, D. Samberg, A. Schropp, A. Schwab, S. Stephan, G. Falkenberg, G. Wellenreuther, and N. Reimers, Nucl. Instrum. Meth. A **616**, 93 (2010).

[66] K. Giewekemeyer, H. Neubauer, S. Kalbfleisch, S. P. Kr¸ger, and T. Salditt, New Journal of Physics **12**, 035008 (2010).

[67] S. Kalbfleisch, M. Osterhoff, K. Giewekemeyer, H. Neubauer, S. P. Krüger, B. Hartmann, M. Bartels, M. Sprung, O. Leupold, F. Siewert, and T. Salditt, in *American Institute of Physics Conference Series*, Vol. 1234 of *American Institute of Physics Conference Series*, edited by R. Garrett, I. Gentle, K. Nugent, and S. Wilkins (2010), pp. 433–436.

[68] T. Salditt, S. P. Kruger, C. Fuhse, and C. Bahtz, Phys. Rev. Lett. **100**, 184801 (2008).

[69] S. P. Krüger, K. Giewekemeyer, S. Kalbfleisch, M. Bartels, H. Neubauer, and T. Salditt, Opt. Express **18**, 13492 (2010).

[70] P. Cloetens, W. Ludwig, J. Baruchel, D. Van Dyck, J. Van Landuyt, J. P. Guigay, and M. Schlenker, Appl. Phys. Lett. **75**, 2912 (1999).

[71] P. Bleuet, P. Cloetens, P. Gergaud, D. Mariolle, N. Chevalier, R. Tucoulou, J. Susini, and A. Chabli, Rev. Sci. Instrum. **80**, 056101 (2009).

[72] A. P. Mancuso, T. Gorniak, F. Staler, O. M. Yefanov, R. Barth, C. Christophis, B. Reime, J. Gulden, A. Singera, M. E. Pettit, T. Nisius, T. Wilhein, C. Gutt, G. Gruebel, N. Guerassimova, R. Treusch, J. Feldhaus, S. Eisebitt, E. Weckert, M. Grunze, A. Rosenhahn, and I. Vartanyants, New Journal of Physics **12**, 035003 (2010).

[73] A. Rosenhahn, R. Barth, X. Cao, M. Schuermann, M. Grunze, and S. Eisebitt, Ultramicroscopy **107**, 1171 (2007).

[74] A. Rosenhahn, R. Barth, F. Staier, T. Simpson, S. Mittler, S. Eisebitt, and M. Grunze, J. Opt. Soc. Am. A **25**, 416 (2008).

[75] A. Rosenhahn, F. Staier, T. Nisius, D. Schaefer, R. Barth, C. Christophis, L.-M. Stadler, S. Streit-Nierobisch, C. Gutt, A. Mancuso, A. Schropp, J. Gulden, B. Reime, J. Feldhaus, E. Weckert, B. Pfau, C. M. Guenther, R. Koennecke, S. Eisebitt, M. Martins, B. Faatz, N. Guerassimova, K. Honkavaara, R. Treusch, E. Saldin, S. Schreiber, E. A. Schneidmiller, M. V. Yurkov, I. Vartanyants, G. Gruebel, M. Grunze, and T. Wilhein, Opt. Express **17**, 8220 (2009).

[76] R. Barth, F. Staier, T. Simpson, S. Mittler, S. Eisebitt, M. Grunze, and A. Rosenhahn, J. Biotechnol. **149**, 238 (2010).

[77] K. Giewekemeyer, M. Beckers, T. Gorniak, M. Grunze, T. Salditt, and A. Rosenhahn, Opt. Express **19**, 1037 (2011).

[78] A. P. Mancuso, A. Schropp, B. Reime, L.-M. Stadler, A. Singer, J. Gulden, S. Streit-Nierobisch, C. Gutt, G. Gruebel, J. Feldhaus, F. Staier, R. Barth, A. Rosenhahn, M. Grunze, T. Nisius, T. Wilhein, D. Stickler, H. Stillrich, R. Froemter, H.-P. Oepen, M. Martins, B. Pfau, C. M. Guenther, R. Koennecke, S. Eisebitt, B. Faatz, N. Guerassimova, K. Honkavaara, V. Kocharyan, R. Treusch, E. Saldin, S. Schreiber, E. A. Schneidmiller, M. V. Yurkov, E. Weckert, and I. A. Vartanyants, Phys. Rev. Lett. **102**, 035502 (2009).

[79] L. Pollack, M. W. Tate, N. C. Darnton, J. B. Knight, S. M. Gruner, W. A. Eaton, and R. H. Austin, Proc. Natl. Acad. Sci. U. S. A. **96**, 10115 (1999).

[80] L. Pollack, M. W. Tate, A. C. Finnefrock, C. Kalidas, S. Trotter, N. C. Darnton, L. Lurio, R. H. Austin, C. A. Batt, S. M. Gruner, and S. G. J. Mochrie, Phys. Rev. Lett. **86**, 4962 (2001).

[81] R. Russell, I. S. Millett, M. W. Tate, L. W. Kwok, B. Nakatani, S. M. Gruner, S. G. J. Mochrie, V. Pande, S. Doniach, D. Herschlag, and L. Pollack, Proc. Natl. Acad. Sci. U. S. A. **99**, 4266 (2002).

[82] S. Köster, H. M. Evans, J. Y. Wong, and T. Pfohl, Biomacromolecules **9**, 199 (2008).

[83] R. Dootz, H. Evans, S. Köster, and T. Pfohl, Small **3**, 96 (2007).

[84] M. E. Brennich, J.-F. Nolting, C. Dammann, B. Nöding, S. Bauch, H. Herrmann, T. Pfohl, and S. Köster, Lab on a Chip (2010), dOI:10.1039/C0LC00319K.

[85] M. Priebe, S. Kalbfleisch, M. Tolkiehn, S. Köster, B. Abel, R. Davis, and T. Salditt, New Journal of Physics **12**, 043056 (2010).

[86] A. Meents, S. Gutmann, A. Wagner, and C. Schulze-Briese, P. Natl. Acad. Sci. USA **107**, 1094 (2010).

[87] H. Hope, Acta Cryst. B **44**, 22 (1988).

[88] N. S. Blanc, D. Studer, K. Ruhl, and J. Dubochet, J. Microscopy **192**, 194 (1998).

[89] H. Hohenberg, M. Tobler, and M. Müller, J. Microscopy **183**, 133 (1996).

[90] J.-D. Grunwaldt, J. Phys. Conf. Ser. **190**, 012151 (2009).

[91] J.-D. Grunwaldt, M. Caravati, S. Hannemann, and A. Baiker, Phys. Chem. Chem. Phys. **6**, 3037 (2004).

[92] S. Hannemann, M. Casapu, J.-D. Grunwaldt, P. Haider, P. Trussel, A. Baiker, and E. Welter, J. Synchrotron Rad. **14**, 345 (2007).

[93] C. Keresszegi, J.-D. Grunwaldt, T. Mallat, and A. Baiker, Chem. Commun. **18**, 2304 (2003).

[94] C. Keresszegi, J.-D. Grunwaldt, T. Mallat, and A. Baiker, J. Catal. **222**, 268 (2004).

[95] J.-D. Grunwaldt, M. Caravati, and A. Baiker, J. Phys. Chem. B **110**, 9916 (2006).

[96] C. Mondelli, D. Ferri, J.-D. Grunwaldt, F. Krumeich, S. Mangold, R. Psaro, and A. Baiker, J. Catal. **252**, 77 (2007).

[97] J.-D. Grunwaldt, M. Caravati, M. Ramin, and A. Baiker, Catal. Lett. **90**, 221 (2003).

[98] M. Caravati, J.-D. Grunwaldt, and A. Baiker, Phys. Chem. Chem. Phys. **7**, 278 (2005).

[99] J.-D. Grunwaldt, N. van Vegten, and A. Baiker, Chem. Commun. **44**, 4635 (2007).

[100] A. Rosenhahn, S. Schilp, H. J. Kreuzer, and M. Grunze, Phys. Chem. Chem. Phys. **12**, 4275 (2010).

[101] http://www.seacoat.bham.ac.uk/.

[102] S. Köster, Y.-C. Lin, H. Herrmann, and D. A. Weitz, Soft Matter **6**, 1910 (2010).

[103] J. F. Edd, D. Di Carlo, K. J. Humphry, S. Köster, D. Irimia, D. A. Weitz, and M. Toner, Lab on a Chip **8**, 1262 (2008).

[104] C. G. Schroer, M. Kuhlmann, S. V. Roth, R. Gehrke, N. Stribeck, A. Almendarez-Camarillo, and B. Lengeler, Appl. Phys. Lett. **88**, 164102 (2006).

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Curriculum Vitae:

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1989-1993	Studies in Chemistry (Diploma), University of Hamburg and University of Newcastle upon Tyne / Great Britain
1993-1998	Ph.D. thesis, Dept. of Chemistry, ETH Zürich, CH, supervised by A. Baiker
1998-2001	Project manager at the catalyst and engineering company Haldor Topsøe A/S, Kgs. Lyngby, Denmark
2001-2006	Habilitation, Venia legendi in Technical Chemistry, ETH Zürich, CH
2006-2008	Privatdozent, ETH Zürich, Inst. of Chemical and Biochemical Engineering, CH
2008-2010	Full Professor, Chair in Catalysis and Chemical Engineering, Department of Chemical Engineeering, Technical University of Denmark (DTU), DK
Since 2010	Professor (W3/Full), Chair in Chemical Technology, Institute for Chemical Technology and Polymer Chemistry, KIT – Campus South
Since 2010	Head of Group "Heterogeneous Catalysis" at Institute for Catalysis Research and Technology (IKFT), KIT – Campus North, since 2011 member of the extended board of directors
Since 2010	Adj. Professor at the Technical University of Denmark (DTU), Kgs. Lyngby

Membership: Project Review Panel (PRP) at HASYLAB (2002-2005), Scientific Board at ANKA (2003-2007, chairman 2006-2007), SNX-Council at the Swiss-Norwegian Beamlines at ESRF (2005-2007), PRP Swiss Light Source (since 2005), BTAP at ESRF (2007-2011), Election Committee of the ANKA International User Committee (2007-2011), President of the Nordic Catalysis Society (2009-2010).

Main Fields of Research: Synchrotron Research, microscopy, in situ characterization and new spectroscopic approaches, catalysis in biomass conversion, energy-related catalysis, exhaust gas catalysis & fine chemistry, rapid chemical reactions, nanomaterial preparation, chemical engineering

Selected Publications:

[1] J.-D. Grunwaldt, A. M. Molenbroek, N.-Y. Topsøe, H. Topsøe, B. S. Clausen, "In Situ Investigations of Structural Changes in Cu/ZnO Catalysts", J. Catal. **194**, 452 (2000).

[2] J.-D. Grunwaldt, M. Caravati, S. Hannemann, A. Baiker, "In situ X-ray Absorption Spectroscopy under Reaction Conditions", Phys. Chem. Chem. Phys. **6**, 3037 (2004).

[3] J.-D. Grunwaldt, S. Hannemann, C. G. Schroer, A. Baiker, "2D-Mapping of the Catalyst Structure inside a Catalytic Microreactor at Work: Partial Oxidation of Methane over Rh/Al2O3", J. Phys. Chem. B **110**, 8674 (2006).

[4] B. Kimmerle, J.-D. Grunwaldt, A. Baiker, P. Glatzel, P. Boye, S. Stephan, C. G. Schroer, "Visualizing a Catalyst at Work during the Ignition of the Catalytic Partial Oxidation of Methane", J. Phys. Chem. C **113**, 3037 (2009).

[5] J.-D. Grunwaldt, C. G. Schroer, "Hard and soft X-ray microscopy and tomography in catalysis: Bridging the different time and length scales", Chem. Soc. Rev. **39**, 4741 (2010).

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Curriculum vitae

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1998-2003	Studies of Physics (Diploma), University of Ulm
2003-2006	PhD thesis under the supervision of Prof. Dr. T. Pfohl, Institute for Applied Physics, University of Ulm and Max Planck Institute for Dynamics and Self-Organization, Göttingen
2006-2008	Postdoc with Prof. Dr. D. A. Weitz, Harvard University, Cambridge, USA
since 2008	Junior Professor (W1) at Georg-August-University Göttingen

Main Fields of Research:

Biophysics, cell mechanics, cytoskeletal dynamics, actin, intermediate filaments, microfluidics, microscopy, x-ray imaging/scattering

Selected Publications:

[1] M. E. Brennich, J.-F. Nolting, C. Dammann, B. N^ding, S. Bauch, H. Herrmann, T. Pfohl and S. Köster, Dynamics of intermediate filament assembly followed in micro-flow by small angle x-ray scattering, Lab on a Chip 2011, DOI:10.1039/C0LC00319K

[2] M. Priebe, S. Kalbfleisch, M. Tolkiehn, S. Köster, B. Abel, R. Davis and T. Salditt, Orientation of Biomolecular Assemblies in a Microfluidic Jet, New Journal of Physics 2010, **12**, 043056.

[3] S. Köster, Y.-C. Lin, H. Herrmann, and D. A. Weitz, Nanomechanics of Vimentin Intermediate Filament Networks, Soft Matter 2010, **6**, 1910-1914

[4] S. Köster and T. Pfohl, An in vitro Model for Cytoskeletal Confinement, Cell Motility and the Cytoskeleton 2009, **66**, 771-776

[5] S. Köster, H. M. Evans, J. Y. Wong, and T. Pfohl, An in-situ study of collagen self-assembly processes, Biomacromolecules 2008, **9**, 199-207.

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Curriculum vitae:

Born: 11 February 1974

since 2009	Beamline scientist in charge of beamline P11
since 2007	Staff scientist at HASYLAB-DESY
2005-2007	Postdoctoral position at Paul-Scherrer-Institut, Switzerland
2001-2005	PhD thesis in physics, Hamburg University
1995-2001	Studies in Chemistry (diploma), University of Bonn
1996-2001	Studies in Mineralogy (diploma), University of Bonn

Main Fields of Research:

Time resolved X-ray diffraction, Experimental charge density determinations of organic molecules, Radiation damage studies in biological materials, Instrument design of nano-positioning devices for X-ray experiments, X-ray microscopy of biological samples

Selected publications:

[1] D. Lübbert, A. Meents, E. Weckert: Accurate rocking-curve measurements on protein crystals grown in a homogeneous magnetic field of 2.4 T. Acta Crystallogr D Biol Crystallogr. (2004) **60**,987-998.

[2] A. Meents, A. Wagner, R. Schneider, C. Pradervand, E. Pohl, S. Schulze-Briese: Reduction of X-ray-induced radiation damage of macromolecular crystals by data collection at 15 K: a systematic study. Acta Crystallogr D Biol Crystallogr. (2007) **63**, 302-309.

[3] A. Meents, B. Dittrich, S. Gutmann: A new aspect of specific radiation damage: hydrogen abstraction from organic molecules. J. Synchrotron Rad. **16** (2009) 183-190.

[4] A. Meents, B. Reime, M. Kaiser, X-.Y. Wu, R. Abela, E. Weckert, C. Schulze-Briese: A fast X-ray chopper for single-bunch extraction at synchrotron sources. J. Appl. Cryst. (2009), **42**, 901-905.

[5] A. Meents, S. Gutmann, A. Wagner, C. Schulze-Briese: Origin and temperature dependence of radiation damage in biological samples at cryogenic temperatures. PNAS (2010), **107**,1094-1099.

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Curriculum vitae

Born 15.6.1972	
1992-1997	Studies of Chemistry (Diploma), University of Bonn
1997-2000	PhD thesis under the supervision of Prof. Dr. K. Wandelt Institut for Physical Chemistry, University of Bonn
2001-2002	Postdoc in the group of Prof. Dr. C. S. Fadley Lawrence Berkeley National Laboratory and ALS, Berkeley, USA
2002-2010	Habilitation in the group of Prof. Dr. M. Grunze Applied Physical Chemistry, University of Heidelberg
since 2009	Group leader Biointerfaces & Holography Institut of Functional Interfaces, KIT Campus Nord

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Main Fields of Research:

Physical Chemistry of interfaces, self assembled mono- and multilayers, micro- and nanopatterning, surface analysis (XPS, AES, STM, AFM, SEM, contact angle, ellipsometry, IRRAS), biofouling, cell adhesion, chemotaxis, microfluidics, optical microscopy, 3D tracking of microorganisms by hologrpahic microscopy, coherent X-ray microscopy, correlative microscopy.

Selected Publications:

[1] A. Rosenhahn, R. Barth, F. Staier, T. Simpson, S. Mittler, S. Eisebitt, M. Grunze, Digital In-line Soft X-ray Holography with chemical resolution, Journal of the Optical Society of America A, 2008, **25(2)**, 416.

[2] A. Rosenhahn, ..., E. Weckert, ..., I. A. Vartaniants, ..., Holographic microscopy of biological specimen with femtosecond VUV radiation provided by the Free-electron laser FLASH, Optics Express 2009, **17(10)**, 8220.

[3] A.P. Mancuso, T. Gorniak, F. Staier, O.M. Yefanov, R. Barth, C. Christophis, B. Reime, J. Gulden, A. Singer, M.E. Pettit, T. Nisius, T. Wilhein, C. Gutt, G. Grübel, N. Guerassimova, R. Treusch, J. Feldhaus, S. Eisebitt, E. Weckert, M. Grunze, A. Rosenhahn and I.A. Vartanyants, Coherent imaging of biological samples with femtosecond pulses at the free electron laser FLASH, New Journal of Physics 2010, **12**, 035003.

[4] A. Rosenhahn, S. Schilp, H. J. Kreuzer, M. Grunze, The role of "inert" surface chemistry in marine biofouling prevention, Phys. Chem. Chem. Phys. 2010, **12**, 4275.

[5] K. Giewekemeyer, M. Beckers, T. Gorniak, M. Grunze, T. Salditt, A. Rosenhahn, Ptychographic coherent x-ray diffractive imaging in the water window, Optics Express 2011, **19**, 1037.

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1993-1995	Ph.D. in Physics, University of Munich, 1995, Prof. Dr. J. Peisl
1995	Ernst-Eckard-Koch prize for an outstanding research work using synchrotron radiation
1996-03/1997	Postdoctoral research, University of California at Santa Barbara (UCSB), Prof. C. Safinya (NATO/DAAD Postdoctoral fellowship)
2000	Habilitation in Experimental Physics, Sektion Physik, University of Munich
2000	Associate Professor (C3) at University of Saarland, Saarbrücken
2002	Full Professor for Experimental physics (C4), Georg-August-University Göttingen

Membership/professional activities: Spokesperson SFB 755 *Nanoscale Photonic Imaging* (Univ. Göttingen, since 2007), Spokesperson Courant Research Center "Nano-Spectroscopy and X-Ray Imaging" (Univ. Göttingen, since 10/2007), co-organizer of several international symposia and conferences in x-ray science, Komittee Forschung mit Synchrotronstrahlung (2002-2005), Scientific Advisory Board ESRF, Grenoble (term 2006-2008), Kuratorium Laserlabor Göttingen.

Main Fields of Research:

structure and dynamics of biomolecular assemblies, membrane biophysics, x-ray optics, x-ray imaging, synchrotron radiation

Selected Publications:

[1] K. Giewekemeyer, P. Thibault, S. Kalbfleisch, A. Beerlink, C. M. Kewish, F. P. Martin Dierolf, T. Salditt: *Quantitative biological imaging by ptychographic x-ray diffraction microscopy*. Proceedings of the National Academy of Sciences **107**, 2010: 529–534.

[2] A. Beerlink, M. Mell, M. Tolkiehn, T. Salditt: *Hard x-ray phase contrast imaging of black lipid membranes*. Applied Physics Letters **95**, 2009: 203703.

[3] T. Salditt, S. P. Krüger, C. Fuhse, C. Bähtz: *High-transmission planar X-ray waveguides*. Physical Review Letters **100**, 2008: 184801.

[4] M. Rheinstädter, W. Häußler, T. Salditt: *Dispersion relation of lipid membrane shape fluctuations by neutron spin-echo spectrometry*. Physical Review Letters **97**, 2006: 048103.

[5] A. Jarre, C. Fuhse, C. Ollinger, J. Seeger, R. Tucoulou, T. Salditt: *Two-dimensional hard x-ray beam compression by combined focussing and waveguide optics*. Physical Review Letters **94**, 2005: 074801.

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Curriculum Vitae:

Born 22.12.1967 in Trier	
1986-1992	Studies of Physics, Aachen University
1992	Diploma in physics, Aachen University
1995	Doctoral thesis in mathematical physics under supervision of G. Eilenberger, University of Cologne
1995-1996	Postdoc at research center Jülich in the group of G. Eilenberger
1996-1998	Postdoc at the University of Maryland in the group of Prof. E. Ott
1998-2004	Habilitation in X-ray physics at Aachen University in the group of Prof. B. Lengeler
2004-2006	Staff scientist at HASYLAB at DESY.
2006	Full Professor (W3), Chair of Structural Physics, Dresden University of Technology

Membership: ESRF SAC (since 2006), Beamtime Allocation Panel "MI" of the ESRF (chair, since 2008), Komittee für Synchrotronstrahlung (since 2008, responsible for user affairs), Proposal Review Panel "MI" of LCLS in Stanford (since 2010), board of trustees of the MPI Physics of Complex Systems in Dresden (since 2010).

Main Fields of Research:

His research areas are (refractive) X-ray optics, nanofocusing, scanning and full-field X-ray microscopy and tomography, micro-/nanospectrosocpy, and coherent diffraction imaging.

Selected Publications:

[1] J.-D. Grunwaldt, C. G. Schroer, Hard and soft x-ray microscopy and tomography in catalysis: Bridging the different time and length scales, Chem. Soc. Rev. **39**, 4741 (2010).

[2] A. Schropp, P. Boye, A. Goldschmidt, S. Hönig, R. Hoppe, J. Patommel, C. Rakete, D. Samberg, S. Stephan, S. Schöder, M. Burghammer, and C. G. Schroer. Non-destructive and quantitative imaging of a nano-structured microchip by ptychographic hard x-ray scanning microscopy. J. Microscopy, **241(1)**, 9 (2010).

[3] A. Schropp, P. Boye, J. M. Feldkamp, R. Hoppe, J. Patommel, D. Samberg, S. Stephan, K. Giewekemeyer, R. N. Wilke, T. Salditt, J. Gulden, A. P. Mancuso, I. A. Vartanyants, E. Weckert, S. Schöder, M. Burghammer, and C. G. Schroer. Hard x-ray nanobeam characterization by coherent diffraction microscopy. Appl. Phys. Lett., **96**, 091102 (2010).

[4] C. G. Schroer, P. Boye, J. Feldkamp, J. Patommel, A. Schropp, A. Schwab, S. Stephan, M. Burghammer, S. Schöder, and C. Riekel. Coherent x-ray diffraction imaging with nanofocused illumination. Phys. Rev. Lett., **101**, 090801 (2008).

[5] C. G. Schroer, O. Kurapova, J. Patommel, P. Boye, J. Feldkamp, B. Lengeler, M. Burghammer, C. Riekel, L. Vincze, A. van der Hart, and M. Küchler. Hard x-ray nanoprobe based on refractive x-ray lenses. Appl. Phys. Lett., **87(12)**,124103 (2005).

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1984-2009	Leading Research Scientist, Shubnikov Institute of Crystallography, Russian Academy of Sciences
2000-2004	Research Associate Professor, Department of Physics, University of Illinois at Urbana-Champaign
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Main scientific interests: Theory of Coherent X-ray Scattering and Diffraction, Inverse Problems in X-ray Optics (phase problem), Theory of X-ray Dynamical Diffraction and X-ray Standing Wave method in real crystals, Theory of X-ray Photoelectron process in X-ray Interference field

Membership: Member of American Physical Society (2002), Member of the ESRF Proposal Review Panel: Surface and Interface (from 2009).

Professional Service: Co-organizer of the International Conference "Coherence 2010" June 8-11, 2010, Rostock-Warnemünde, and many other International Conferences and Workshops.

Selected Publications:

[1] J.M. Zuo, I. A. Vartanyants, M. Gao, R. Zhang , and L.A. Nagahara Atomic Resolution Imaging of a Single Double-Wall Carbon Nanotube from Diffraction Intensities, Science, , **300**, 1419-1421 (2003).

[2] M. A. Pfeifer, G. J. Williams, I. A. Vartanyants, R. Harder, and I. K. Robinson,Three-dimensional mapping of a deformation field inside a nanocrystal, Nature, **442**, 63-66 (2006).

[3] A. Singer, I.A. Vartanyants, M. Kuhlmann, S. Duesterer, R. Treusch, and J. Feldhaus, Transverse-Coherence Properties of the Free-Electron-Laser FLASH at DESY, Phys. Rev. Lett. **101**, 254801 (2008).

[4] A.P. Mancuso, A. Schropp, B. Reime, ..., A. Rosenhahn, ..., E. Weckert, and I.A. Vartanyants, Coherent-pulse 2D Crystallography at Free Electron Lasers, Phys. Rev. Lett. **102**, 035502 (2009).

[4] A.P. Mancuso, Th. Gorniak, F. Staier, O.M. Yefanov, R. Barth, ..., B. Reime, J. Gulden, A. Singer, ..., E. Weckert, M. Grunze, A. Rosenhahn, and I. A. Vartanyants Coherent imaging of biological samples with femtosecond pulses at the free-electron laser FLASH, New J. Phys. **12**, 035003 (2010).

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1979-1984	Studies in Materials Science at Universität Erlangen-Nürnberg
1988	Ph.D. in crystallography at Universität Erlangen-Nürnberg
1997	Habilitation at the physics faculty of Universität Karlsruhe (TH)
1997-2000	Lecturer at Universität Karlsruhe (TH)
since 2000	Leading senior scientist at DESY
2001-2005	Lecturer at University of Hamburg
since 2005	Professor (according to §17 of Hamburgisches Hochschulgesetzes) at Universität Hamburg
2008	Acting Director for Photon Science at DESY
since 1.1.2009	Director for Photon Science at DESY
since July 2009	Member of the board of directors of the Helmholtz Institute Jena

Membership: Project Review Panel of the Linear Coherence Light Source (LCLS) at the Stanford Linear Accelerator Center, Science Advisory Committee of ANKA, Science Advisory Committee of European XFEL, Science Advisory Committee of SSRL (SLAC, Stanford), National Committee of Gesellschaft für Kristallographie, International Scientific Advisory Committee of the Courant Research Center 'Nano-Spectroscopy and X-ray Imaging' at University of Göttingen, HERCULES program International Advisory Committee.

Main Fields of Research:

X-ray physics, multi-beam diffraction, phase problem in crystallography; precise determination of crystal structures; radiation damage in proteins; application of free electron laser radiation for the determination of non periodic structures.

Selected Publications:

[1] Ecker, A., Weckert, E., Schnöckel, H. Synthesis and Structural Characterization of an Al77 Cluster. Nature **387** (1997) 379-381.

[2] Weckert, E., Hümmer, K. Multiple-Beam X-ray Diffraction for Physical Determination of Reflection Phases and its Applications. Invited leading article for Acta Cryst. A**53** (1997) 108-143.

[3] Neutze, R., Wouts, R., v.d. Spoel, D., Weckert, E., Hajdu, J. Potential for biomolecular imaging with femtosencond X-ray pulses. Nature **408** (2000) 752-757.

[4] Mancuso A.P., Rosenhahn A., Weckert E., Vartanyants I, Coherent-Pulse 2D Crystallography Using a Free-Electron Laser X-Ray Source, Phys. Rev. Lett. **102**, 035502 (2009)

[5] Ziaja B., Wabnitz H., Wang F., Weckert E., Möller T., Energetics, Ionization, and Expansion Dynamics of Atomic Clusters Irradiated with Short Intense Vacuum-Ultraviolet Pulses, Phys. Rev. Lett. **102**, 205002 (2009)