MM 35: SYBM Bioinspired Materials

Time: Thursday 14:45–20:45 Location: H16

MM 35.1 Thu 14:45 H16

Reflection of water jets on biological and bio-inspired artificial surfaces — •Michael Scharnberg[1], Vladimir Zaporojtchenko[1], Rainer Adelung[1], Srdjan Milenkovic[2], and Achim Walter Hassel[2] — [1]Chair for Multicomponent Materials, Technical Faculty, University of Kiel, Germany — [2]Electrochemistry and Corrosion, Max-Planck-Institut für Eisenforschung, Düsseldorf, Germany

Water jets impinging on a nasturtium leaf, a biological ultrahydrophobic surface (lotus effect), were observed to flow across the surface for a distance in the order of several jet diameters before it is reflected off the surface as a coherent jet under an angle that is close to or smaller than the angle of incidence. Design and technical applications of ultrahydrophobic surface require understanding of the physical processes involved, however biological surfaces often have defects and irregularities like leaf veins that impede experiments. A ds-NiAl-W alloy, microstructured by etching and coated with a sputtered polytetrafluoroethylene (PTFE) thin film is also ultrahydrophobic (contact angle $> 160°$). Due to the regular microstructure of its surface that can also be easily varied by controlling the needle length, this ultrahydrophobic material system is well suited for investigation of the water jet reflection phenomenon. In this presentation the influence of the microstructure, the water pressure and the angle of incidence will be discussed.

MM 35.2 Thu 15:00 H16

Enhancement of capillary forces by multiple liquid bridges — •Emerson Jose De Souza[1], Camilla Mohrdieck[2], Martin Brinkmann[3], and Eduard Arzt[4] — [1]Max Planck Institute for Metals Research, Heisenbergstr, 3, Stuttgart, Germany — [2]Institute of Physical Metallurgy, Universität Stuttgart, Stuttgart, Germany — [3]Max Planck Institute for Dynamics and Self-Organisation, Göttingen, Germany — [4]Max Planck Institute for Metals Research, Heisenbergstr, 3, Stuttgart, Germany

Capillary forces can significantly increase the adhesion of micro-scale objects in biology and technology. We calculate numerically the force exerted by a liquid meniscus between two homogeneous flat plates for different contact angles. The resulting force distance curves show good quantitative agreement with previous investigations. On this basis, we set an initial separation and split the volume of one bridge into n smaller ones. The results for the total force as a function of n show a novel and unexpected maximum force for moderately hydrophilic surfaces (i.e. contact angles around 70 degrees). Further, we calculate the minimum area for multiple bridges, the stress (i.e. force per area) and the work required to separate the plates. The results are presented in two dimensional maps, which may be very useful in the understanding and design of biological and artificial contact systems.

MM 35.3 Thu 15:15 H16

Bacterial S-layers used as bio-templates for the regular arrangement of nanoparticles — •Ute Queitsch[1], Elias Mohn[1], Franziska Schäffel[1], Ludwig Schultz[1], Bernd Rellinghaus[1], Anja Blüher[2], and Michael Mertig[2] — [1]IFW Dresden, P.O. Box 270116, D-01171 Dresden, Germany — [2]Max Bergmann Center for Materials Research, TU Dresden, D-01069 Dresden, Germany

Owing to the statistical nature of the deposition process nanoparticles from the gas phase are usually randomly distributed on the substrate. For many applications however, a regular arrangement of the particles is mandatory. We have therefore investigated to which degree the use of so-called S-layers – regular protein crystals with different 2-dimensional lattice symmetries – allows to compensate for this disadvantage. S-layers of *bacillus sphaericus NCTC 9602* with p4 symmetry and a square lattice of pores with a lattice constant of 12.5 nm are used as bio-templates for the deposition of gas-phase prepared FePt nanoparticles. Sheets of these S-layers were deposited onto amorphous carbon films, which were then exposed to a beam of FePt nanoparticles under high vacuum conditions. Structural characterization of likewise prepared particle films is carried out by transmission electron microscopy (TEM). We find that the structure of the S-layers remains unaltered upon particle deposition. Furthermore, a symmetry transfer from the bio-template to the arrangement of the deposited particles is clearly observed. Statistical analysis of the TEM micrographs reveals that the majority of the particles are located within or in the close vicinity of the pores of the bio-template.

MM 35.4 Thu 15:30 H16

Inversion of micro-patterned polymer surfaces based on bicomponent polyelectrolyte layers — •Alla Synytska[1], Manfred Stamm[1], Stefan Diez[2], and Leonid Ionov[2] — [1]Leibniz Institute of Polymer Research Dresden, 01069 Dresden, Hohe Strasse 6, Germany — [2]Max-Planck-Institute of Molecular Cell Biology and Genetics, Pfotenhauerstrasse 108, 01307 Dresden, Germany

Micropatterned surfaces are of considerable importance for microelectronics,printing technology, microfluidic and microanalitical devices,information storage, biosensors, etc. However, once a pattern is generated it cannot be easily changed on the fly. Therefore, it is desirable to develop methods for fabrication of structured surfaces with switchable and rewritable patterns.

In the present study, we report on the fabrication of micropatterned surfaces which allow the switching of topography, wettability, and charge in an inverse manner. The concept of these stimuli-responsive surfaces, which are made by a combination of photolithography, liftoff and grafting to techniques, is based on the site-selective grafting of two oppositely charged polyelectrolytes. Depending on the pH of the surrounding one kind of the polymer chains is swollen (charged and hydrophilic) while the other is collapsed (uncharged and hydrophobic). The main advantage of such surfaces is their capability of inverse switching, for example hydrophilic patterns can be reversibly converted into hydrophobic ones and vice versa, via external stimuli.

15 min break

MM 35.5 Thu 16:00 H16

Structure and dynamics of biological materials — •Martin Müller — Institut für Experimentelle und Angewandte Physik, Christian–Albrechts–Universität zu Kiel

Almost all biological materials are hierarchically structured on many different length scales. On a mesoscopic level, usually a composite morphology with nanocrystalline regions embedded in a softer, disordered matrix is found. The matrix is accessible to water, and the water content is of major influence on the mechanical properties of biomaterials.

We investigate structural changes of biomaterials (cellulose fibres, wood and particularly silkworm silk) under mechanical load in *in situ* X–ray scattering experiments with microbeam synchrotron radiation. A novel sample environment allows us to systematically vary the water content of the samples. The soft, water–accessible matrix plays an important role in the microscopic model we obtain for deformation mechanisms in dry and wet biomaterials [1].

The combination of the X–ray results with those from the complementary technique of inelastic neutron scattering allowed us to develop a deeper understanding of the interplay of crystalline and disordered regions in silkworm silk [2].

[1] I. Grotkopp, PhD thesis, Kiel, 2006.
[2] T. Seydel, K. Kölln, I. Krasnov, I. Diddens, N. Hauptmann, G. Helms, M. Ogurreck, S.–G. Kang, M. M. Koza, M. Müller, Macromolecules, in press.

MM 35.6 Thu 16:15 H16

The actuation of organ movement by the generation of tensile and compressive stresses in wood cell walls — •Ingo Burgert, Michaela Eder, Notburga Gierlinger, and Peter Fratzl — Max Planck Institute of Colloids and Interfaces, Department of Biomaterials, 14424 Potsdam, Germany

Active movement is usually associated with animals rather than plants. Plants do not have muscles, but they are able to pre-stress their tissues in order to actuate their organs. Here, we demonstrate for softwoods that either tensile or compressive stresses can be obtained during swelling of the cell wall. This can be well understood by simple mechanical considerations, taking into account the cell shapes and the observed cellulose fibril orientations. The almost inextensible cellulose fibrils redirect the forces generated by the swelling of the matrix by purely geometrical constraints to produce tension or compression forces according to needs. This principle could be simple enough to be reproduced in artificial systems and one may consider developing fiber-reinforced hydrogels as effective microactuators. The main technical challenge would be to reproduce the well controlled fiber orientation found in wood cells.

MM 35.7 Thu 16:30 H16

Bamboo: Mechanical Optimisation and Efficiency — •Ulrike G.K. Wegst[1] and Michael F. Ashby[2] — [1]Max-Planck-Institut für Metallforschung, Heisenbergstr. 3, D-70569 Stuttgart, Germany — [2]Cambridge University Engineering Department, Trumpington Street, Cambridge CB2 1PZ, UK

An optimised structure is one which uses the smallest quantity of the best material to perform its function, with adequate safety factor. Structural optimisation occurs not only in mechanical engineering, but also in nature: plants whose stems or stalks approach the optimum shape gain efficiency and a height advantage. Bamboo does this exceptionally. It provides the most efficient material for mechanical performance at minimum mass, supporting large loads due to self-weight and external forces. Bamboo achieves its efficiency in three ways: (i) by using efficient materials such as composites, (ii) by grading the structure, (iii) by shaping the component to form a tube. Investigated here is the material aspect of the structural optimisation of the orthotropic bamboo tube and the role which the microstructure plays in its mechanical performance. Concentrating on the elastic bending behaviour, the stiffness, strength and failure modes of bamboo are reviewed and algorithms and diagrams are proposed which allow the optimum property gradient and section shape to be selected. Man-made materials which exploit all three of bamboo's strategies for mechanical efficiency seem to be very rare. Given the ultimate structural efficiency that this combination allows, developing them in wood-based and other composites, for example, would appear to be worth serious consideration.

MM 35.8 Thu 16:45 H16

Hierarchical ceramics from biomimetic processing of wood — •Oskar Paris, Atul Deshpande, and Ingo Burgert — Max Planck Institute of Colloids and Interfaces, Department of Biomaterials, Potsdam, Germany

The processing of plant tissues has been used since hundreds of years to obtain useful materials such as paper and activated carbons. The rich structural hierarchy of plant tissues makes them ideal as scaffolds or casting moulds for the synthesis of hierarchically structured inorganic materials based on carbon or ceramics. Besides potential applications as lightweight nanocomposites for structural applications, such materials are typically porous at several length scales, making them interesting candidates for catalysts and filters. A major challenge in the synthesis process of such materials is to preserve the hierarchical plant structure at all levels while retaining the mechanical integrity. We have used wood tissue as a casting mould for the synthesis of hierarchical mesoporous oxide ceramics with directional porosity on the micrometer and the nanometre scale. In particular, we could demonstrate that the entire structure of the wood tissue including the spiralling microfibrillar orientation of the cellulose fibrils can be transformed into a mesoporous Ce0.5Zr0.5O2 ceramic [1].

[1] A. Deshpande, I. Burgert, O. Paris, Small 2 (2006) 994.

15 min break

MM 35.9 Thu 17:15 H16

TiO2 nanotubes: a bio-inspired and bio-inspiring Material — •Sebastian Bauer[1], Jung Park[2], Klaus von der Mark[2], Eugeniu Balaur[1], and Patrik Schmuki[1] — [1]Department of Materials Science, Friedrich-Alexander-University, Martensstr. 7, 91058 Erlangen. — [2]Department of Experimental Medicine I, Friedrich-Alexander-University, Glückstr. 6, 91054 Erlangen.

Self-organized porous structures have had a high impact in surface science due to the simplicity of fabricating nanostructured surfaces. Particularly highly ordered porous Al and Si have attracted significant scientific interest due to the potential applications in different fields. These structures can be achieved essentially by simple anodization under optimized electrochemical conditions. For Titanium we recently reported the preparation of self-organized nanotubular TiO2 layers on titanium surfaces by anodization in various electrolytes containing fluorides. We showed that tailoring the diameter of the formed nanotubes in a wide range (15 - 100 nm) can be achieved by varying the applied potential of the electrochemical setup. The resulting different nanoscale surfaces can be used to evaluate size effects on biorelevant reactions. We will discuss the wetting behavior of these nanoporous surfaces and show that it can be tailored from super-hydrophilic to super-hydrophobic by variation of tube diameter and by light interactions. Furthermore as titanium and its alloys are mainly used as implant materials it is also of interest to see how tissue reacts to the different nanoscales. To evaluate the influence of tube size, tests with rat mesenchymal stem cells were carried out and will be reported.

MM 35.10 Thu 17:30 H16

Material and structural dynamics in trabecular bone — •R. Weinkamer[1], D. Ruffoni[1], J. Dunlop[1], M. Hartmann[2], Y. Brechet[3], P. Roschger[4], K. Klaushofer[4], and P. Fratzl[1] — [1]Max Planck Institute of Colloids and Interfaces, Potsdam, Germany — [2]C.E.A./Saclay, Gif-sur-Yvette, France — [3]LTPCM, ENSEEG, Grenoble, France — [4]Ludwig Boltzmann Institute of Osteology, Vienna, Austria

In trabecular bone different hierarchical levels contribute to its mechanical performance. In our simulation work we focus on the level of the foam-like architecture and on the inhomogeneity of the material bone itself. Two different processes are responsible for the ongoing changes on the structural and material level: the remodeling where small bone packets are continuously resorbed and deposited and the mineralization process where the mineral content increases in a newly deposited bone packet. The renewal of bone material is mechanically controlled, that is bone is deposited preferentially at mechanically highly loaded sites. Since the details of this control are unknown, a computer model with different realizations of the mechanical feedback loop has been employed, to study their influence on architecture and time evolution. With a separate model, the heterogeneous mineral content of bone at the material level was investigated. An increase in the mineral content results in a stiffer, but also more brittle material. Predictions are presented of the evolution of the frequency distribution of mineral content in situations of increased remodeling like in osteoporosis or in therapies which aim at reducing the remodeling.

MM 35.11 Thu 17:45 H16

Influence of structural principles on the mechanics and efficiency of different biological materials using lobster cuticle as a model material — •Christoph Sachs, Helge Fabritius, Svetoslav Nikolov, and Dierk Raabe — Max-Planck-Institut für Eisenforschung, 40237 Düsseldorf, Germany

The cuticle of the lobster Homarus americanus is a nano-composite material consisting of a matrix of chitin-protein fibers associated with various amounts of crystalline and amorphous calcium carbonate and is organized hierarchically on all length scales. The chitin protein fibers are arranged in horizontal planes where the long axes of the fibers are all oriented in the same direction. These planes are stacked with the orientation of the fibers in superimposed layers rotating gradually around the normal axis of the cuticle, thus creating a typical twisted plywood structure. Additionally, the fibers are arranged around the cavities originating from the extremely well developed pore canal system of the lobster which gives the structure a honeycomb-like appearance. Tensile, compression and shear tests performed on both cuticle in its natural hydrated and in the dry state show that both structural principles, twisted plywood and honeycomb, are reflected in the obtained mechanical data of the material. The comparison of hard mineralized cuticle and unmineralized joint membranes shows the influence of the incorporation of minerals on the performance of the material, which is optimized for the role the material has to play in the living organism. The obtained mechanical properties are used to deduce general analytical models describing the mechanics of different biological materials.

MM 35.12 Thu 18:00 H16

Recombinantly produced Spider Silk in a Microfluidic Device — •Sebastian Rammensee[1], Ute Slotta[2], David Keerl[2], Thomas Scheibel[2], and Andreas Bausch[1] — [1]Technische Universität München, Physik-Department E22-Biophysik, James-Franck-Strasse 1, 85747 Garching — [2]Technische Universität München, Department Chemie, Lichtenbergstrasse 4, 85747 Garching

Spider Silks are protein materials which show mechanical properties being superior to all man-made materials in regard to toughness and elasticity. However, commercial applications of natural spider silk are complicated by the highly cannibalistic and territorial behavior of spiders. This problem can be circumvented by recombinant production of spider silk analogous proteins in bacteria. In vivo, the highly complex spinning process is performed in a specialized organ, being a topic of current research. We study the process of silk fiber formation in microfluidic devices under laminar flow conditions, where mixing occurs only by diffusion. As we have a whole set of recombinantly produced spider silk analogous proteins available for experiments, the influence of different structural features of the proteins on fiber formation can be studied. We present secondary structure information obtained by infrared spectroscopy and Scanning Electron Microscopy images of the produced silk assemblies. We model the elongational flow in the microfluidic channel by Finite Element Simulations, and thus correlate the structure and mechanical properties of the resulting silk structures with the conditions in the spinning channel.

MM 35.13 Thu 18:15 H16

Tension and geometry determine cell and tissue shape — Ilka Bischofs[1], Dirk Lehnert[2], Franziska Klein[2], Martin Bastmeyer[2], and •Ulrich Schwarz[3] — [1]University of California at Berkeley, Department of Bioengineering, 717 Potter Street, Berkeley CA 94720, USA — [2]University of Karlsruhe, Institute of Zoology I, Haid-und-Neu-Strasse 9, D-76131 Karlsruhe, Germany — [3]University of Heidelberg, Im Neuenheimer Feld 293, D-69120 Heidelberg, Germany

Cells adapt their shape in response to the biochemical and physical properties of their environment. Cell shape in turn can determine cell growth and fate. In order to study cell shape as a function of spatially separated ligand patches, we have cultured cells on a square arrangement of fibronectin dots with a large variety of different dots sizes and lattice constants. We found that in any case, cell shape resembles a sequence of circular arcs composed of actin fibers connecting neighboring sites of adhesion. The same morphology has been observed before on the tissue level, namely for fibroblast-populated collagen gels pinned to a flat substrate. Quantitative image analysis revealed that in both cases, a characteristic relation exists between spanning distance and arc radius which can be explained by a mechanical model which includes the effect of both tension and elasticity. Our results suggest that the same universal principles determine the shape of cells and tissues.

MM 35.14 Thu 18:30 H16

The cytoskeleton as an example of a highly adaptive structure — Florent Dalmas[1,2] and •Camilla Mohrdieck[1,3] — [1]Max Planck Institute for Metals Research, Stuttgart, Germany — [2]Present Address: Laboratoire de Recherche sur les Polymères, CNRS - UMR 7581, 94320 Thiais, France — [3]Inst. for Physical Metallurgy, University of Stuttgart, Germany

The internal polymer network of eukaryotic cells, the cytoskeleton, is a very interesting example of a smart structure that integrates sensors, actuators and control systems to perform many vital cellular functions. It is able to adapt and respond to a large variety of intra and extracellular stimuli efficiently and often also interactively. This agility is largely due to a variety of molecules that bind to cytoskeletal fibers to execute certain functions, e.g. crosslinking the fibers. To mimic the adaptiveness of the cytoskeleton in engineered structures, it is necessary to identify the components that act as sensors or actuators and how they interplay.

To address this complex issue, we have focused on the effect of crosslinking on the mechanical stability and the adaptiveness of the cytoskeleton. In a new modeling approach, we describe the cytoskeletal fibers and the molecules that crosslink them into a three dimensional network as homogeneous straight beams in a constant volume. The response to a mechanical stimulus is simulated by subjecting the network to a homogeneous shear stress and calculating its shear modulus. New scaling behaviors of the shear modulus are found and analysed. They indicate general design principles of adaptive networks.

MM 35.15 Thu 18:45 H16

Biomimetic mineralization: the effect of polystyrenesulfonate on the growth of calcite crystals — •Barbara Aichmayer, Helmut Cölfen, Oskar Paris, and Peter Fratzl — Max Planck Institute of Colloids and Interfaces, 14424 Potsdam, Germany

Macromolecules are of crucial importance for the control of size, shape and arrangement of mineral crystals in biological tissues. Pokroy et al. [1] recently showed that organic molecules in biogenic calcite even induce remarkable lattice distortions. Inspired by the concept of biomineralization, we use a soluble polymeric additive to modify the growth of calcite, which is crystallized from calcium chloride solutions using the CO2 vapor diffusion technique. Polystyrenesulfonate (PSS) was previously shown to have a pronounced effect on the morphology of calcite particles, which were found to be composed of ordered nanocrystalline substructures. According to thermogravimetric analysis, the particles contained a significant amount of polymer (3wt%). [2] By complementing these results and electron microscopy studies with X-ray scattering we aim to get a more detailed picture of the structure of the calcite-PSS particles. Using a microfocus beam (micro-focus beamline at BESSY, Berlin and ID13 at ESRF, Grenoble) enables us to study the wide- and small-angle X-ray scattering behavior of single particles. Our findings on lattice spacings, texture and internal structure of the calcite mesocrystals contribute to a better understanding of biological and biomimetic mineralization.

1 B. Pokroy, A.N. Fitch, E. Zolotoyabko, Adv. Mater. 2006, 18, 2363.

2 T. Wang, M. Antonietti, H. Cölfen, Chem. Eur. J. 2006, 12, 5722.

MM 35.16 Thu 18:45 H16

Diatoms - the source of biotribological inspiration for novel 3D MEMS — Ille C. Gebeshuber[1] and •Richard M. Crawford[2] — [1]Institut für Allgemeine Physik, Technische Universität Wien, Wiedner Hauptstrasse 8-10/134, 1040 Wien, Austria & Austrian Center of Competence for Tribology, Viktor Kaplan-Strasse 2, 2700 Wiener Neustadt, Austria — [2]Alfred-Wegener Institute for Polar and Marine Research, Bremerhaven, Germany

Diatoms are single-celled organisms with rigid parts in relative motion at the micrometre scale and below. They produce interlocked hydrated silica structures with high precision. These micromechanical parts have been evolutionarily optimized during the last 150 million years or more. It is suggested that MEMS/NEMS researchers meet with diatomists to discuss future common research attempts regarding biomimetic ideas and approaches for novel and/or improved MEMS and NEMS with optimized tribological properties [1,2].

[1] Gebeshuber I.C. and Crawford R.M. (2006) Micromechanics in biogenic hydrated silica - hinges and interlocking devices in diatoms, Proc. IMechE Part J: J. Eng. Tribol. 220(8), 787-796

[2] Gebeshuber I.C., Stachelberger H. and Drack M. (2005) Diatom bionanotribology - Biological surfaces in relative motion: their design, friction, adhesion, lubrication and wear, J. Nanosci. Nanotechnol. 5(1), 79-87

MM 35.17 Thu 18:45 H16

Investigation of the Orientation Relationship Between α-Chitin and Calcite in Crustacean Cuticle Using Synchrotron x-ray Diffraction — •Ali Al-Sawalmih[1], Helge Fabritius[1], Sangbong Yi[2], and Dierk Raabe[1] — [1]Max-Planck-Institut f. Eisenforschung, Max-Planck-Str. 1, 40237 Düsseldorf. — [2]Institut für Werkstoffkunde und Werkstofftechnik, Technische Universität Clausthal, 38678 Clausthal-Zellerfeld.

Crustacean cuticle contains α-chitin-protein organic fibers associated with crystallites of calcite and considerable amounts of amorphous calcium carbonate (ACC). In this study, x-ray pole figure analysis was performed to investigate the crystallographic texture (preferred orientation) of the crystalline calcite and α-chitin, with respect to their orientation relationship, in edible crab *Cancer pagurus* and american lobster *Homarus americanus* cuticles using synchrotron wide-angle x-ray diffraction (XRD). It was observed that the c-axis of the calcite and the b-axis of the α-chitin are firstly preferentially aligned parallel to each other and secondly oriented along the surface normal. The other axes of the α-chitin and calcite are co-aligned with respect to each other throughout the cuticle plane. The synchrotron x-ray crystallographic texture results gave for the first time a statistical description of the orientation relationship between the organic and inorganic components in arthropod cuticle. This result strongly suggests that the fibrous structure of α-chitin assists the growth of calcite crystals in crustacean cuticle, by functioning directly or indirectly as a template for nucleation and subsequent growth of calcite.

MM 35.18 Thu 18:45 H16

Evaluation of different constitutive models for the mechanical behavior of bone at submicron scale — •Svetoslav Nikolov, Helge Fabritius, Christoph Sachs, and Dierk Raabe — Max-Planck-Institut für Eisenforchung, 40237 Düsseldorf, Germany

Hard biological tissues, such as vertebrate bone, show a complex hierarchical structure at all length scales. The basic structural unit of bone is a fibrous collagen matrix containing small hydroxyapatite crystals in the form of platelets. Here we focus on the constitutive modeling of a bundle of these mineralized collagen fibrils in order to predict their mechanical response. The material is modeled via a two-step homogenization procedure * a first homogenization step at the level of one single mineralized fibril, and a second one at the level of a fibril bundle embedded in an extrafibrillar matrix. We compare different combinations of homogenization models, such as shear-lag models, self-consistent estimates, Mori-Tanaka and double-inclusion homogenization schemes, in order to elucidate which two-step homogenization scheme better reproduce the mechanical data available from experiments. We additionally perform a parametric study on the microstructure parameters, such as the aspect ratio and the volume fraction of collagen fibrils and apatite platelets, the Young*s modulus of the constituents and their density in order to extract some structural optimization principles involved in the natural formation of hard tissues.

MM 35.19 Thu 18:45 H16

Grazing-incidence X-ray scattering investigation on the structure of thin films of recombinant spider silk proteins — •E. Metwalli[1], U. Slotta[2], C. Darko[1], S. Roth[3], T. Scheibel[2], and C. Papadakis[1] — [1]Physikdepartment E13, TU München, 85747 Garching — [2]Chemiedepartment, TU München — [3]HASYLAB at DESY, Hamburg

Protein immobilization on solid supports is important for many potential applications such as protein microarrays. Recombinant spider silk proteins offer the possibility to control the molecular sequence and thus the material properties [1]. Spin-coating was used to prepare films of synthetic spider silk protein derived from the garden spider's (Araneus diadematus) dragline silk protein ADF-4. A transition from alfa-helix to beta-sheet rich structures upon methanol treatment of the films has been detected by IR and circular dichroism spectroscopies [2]. We present here direct evidence for this structural transformation. We have observed crystalline domains within the films after treatment and could determine their size and shape using grazing-incidence X-ray diffraction (GIXD) and small-angle scattering (GISAXS). GIXD showed Bragg peaks from beta-sheet poly-alanine crystallites having a size of 8 nm. GISAXS confirmed the presence of crystallites of this size. We conclude that the protein film structure after the methanol treatment consists mainly of crystalline beta-sheet rich regions embedded in an amorphous matrix. [1] Scheibel T., Current Opinion in Biotechnology 16, 427 (2005). [2] Hummerich D., Slotta U., and Scheibel T., Applied Phys. A-Materials Sci. & Processing 82, 219 (2006).

MM 35.20 Thu 18:45 H16

Structural adaptation in trabecular bone — •John Dunlop[1], Markus Hartmann[2], Yves Bréchet[3], Peter Fratzl[1], and Weinkamer Richard[1] — [1]Department of Biomaterials, Max Planck Institute of Colloids and Interfaces, Research Campus Golm, 14424, Potsdam, Germany — [2]Service de Chimie Moléculaire, C.E.A./Saclay, Bat. 125, 91191 Gif-sur-Yvette cedex, France — [3]Groupe Physique du Métal, LTPCM/ENSEEG INPG, Domaine Universitaire de Grenoble, 38402 Saint Martin d'Hères, France

The structure of trabecular bone results from the complex interaction between bone producing cells (osteoblast), bone absorbing cells (osteoclasts) and signalling cells (osteocytes), and the performance of the bone matrix itself. One of the important factors that regulates the trabecular architecture is mechanical loading. This can be generalised by the Wolff-Roux law: that is, bone in general is deposited where it is mechanically needed and removed where it is not. Changes in mechanical loading are clearly seen to affect cellular activity and also to modify the resultant bone architecture. The precise details of how cells "feel" a stimulus and exactly how they respond are not known, although there are many suggestions that have been proposed. Computer simulation techniques are ideally suited to testing these theories. In this contribution a 3D lattice model of trabecular bone is presented and used to investigate the link between individual cell response and trabecular architecture through both the "remodelling" and "stimulus" rules.

MM 35.21 Thu 18:45 H16

Creation and Surface-Functionalization of Microcapsules of Recombinant Spider-Silk Protein — •Markus Harasim[1], Teresa Bauer[1], Kevin Hermanson[1], Sebastian Rammensee[1], Thomas Scheibel[2], and Andreas Bausch[1] — [1]Physik Department, E22-Biophysik, Technische Universität München, James-Franck-Str.1, 85747 Garching — [2]Department Chemie, Lehrstuhl für Biotechnologie, Technische Universität München, Lichtenbergstr. 4, 85747 Garching

Micron-size sculpted structures are important for encapsulation and functionalization technologies and as building blocks for larger devices. Here, spherical capsules are created through the self-assembly of recombinant spider-silk at liquid interfaces and in solution. Due to the natural properties of the spider silk the capsules are mechanically strong and biocompatible. These capsules can be formed either in bulk or through microfabrication using microfluidic devices, which allow for the direct control of capsule size and shell thickness. Functionalization of the capsules can also be achieved using common biochemical techniques. Because of the silk's unique properties, this technique potentially offers a convenient approach to the formation of biologically-compatible, easily-functionalizable structures.

MM 35.22 Thu 18:45 H16

Effect of calcium concentration on the structure of casein micelles in thin films — •Ronald Gebhardt[1], Ali Ezzeldin Metwalli[2], Stephan Volkher Roth[3], Wolfgang Doster[2], and Peter Müller-Buschbaum[2] — [1]European Synchrotron Radiation Facility, B.P. 220, F-38043 Grenoble Cedex, France — [2]TU München, Physik Department LS E13, James-Franck-Str.1, 85748 Garching (Germany) — [3]HASYLAB at DESY, Notkestr. 85, 22603 Hamburg (Germany)

Caseins are organized in poly-disperse, roughly spherical aggregates with diameters ranging between 150 and 300 nm. They represent with about 80% the largest protein component in milk. The casein micelle of bovine milk consists of four different phosphor-proteins which can be divided into two groups: the calcium insensitive κ-casein and the calcium sensitive αS1-, αS2- and β-caseins. Casein micelles are the raw material for the production of gelled and flocculated milk products, such as cheese, yogurt and ice-cream. Additionally, casein micelles find a broad application in casein films as adhesives or paint, prepared with solution casting or spray coating techniques.

We have investigated the effect of calcium on the structure of casein micelles in thin films using grazing incidence small angle x-ray scattering (GISAXS) at the BW4 USAXS beamline at HASYLAB/DESY in Hamburg. The GISAXS measurements are complemented with optical microscopy and atomic force microscopy to picture the surface structure [1].

[1] Müller-Buschbaum P., Gebhardt R., Maurer E., Bauer E., Gehrke R., Doster W. (2006) Biomacromolecules 7, 1773-1780

MM 35.23 Thu 18:45 H16

Hardness anisotropy of crystalline α-chitin: An ab-initio based conformational analysis — •Michal Petrov, Martin Friák, Liverios Lymperakis, Jörg Neugebauer, and Dierk Raabe — Max-Planck-Institut für Eisenforschung, Max-Planck-Strasse 1, 402 37, Düsseldorf, Germany

The α-chitin is one of the most abundant biological materials. The complex structure of α-chitin results in a low-weight and high-strength material, which make it a favorable system for potential bio-inspired functional materials applications. In order to gather a deeper understanding of the mechanical properties of α-chitin, study of the elastic properties of pure single-crystalline α-chitin is crucial. We have therefore explored the atomic structure and the hardness anisotropy of crystalline α-chitin. A challenge in identifying the equilibrium structure of α-chitin is the large size of the unit cell consisting of 108 atoms. In order to resolve this complex structure a series of hierarchical approaches/methods is used: A conformational analysis of chitin is performed using computationally fast empirical potentials and tight binding calculations. Based on the conformational analysis a small number of possible atomic configurations could be identified. These structures have then been used as input for accurate ab-initio calculations in order to derive the ground state atomic geometry and the elastic properties of chitin. Finally based on these results we discuss and explain the strong elastic anisotropy of α-chitin in terms of the interplay between covalent and hydrogen bonds.

MM 35.24 Thu 18:45 H16

Micropatterning of ceramics by ion beam sputtering for dental implants — •Sebastian Wille[1], Bin Yang[2], and Rainer Adelung[1] — [1]Lehrstuhl für Materialverbunde, Technische Fakultät der CAU Kiel, Kaiserstr. 2, 24143 Kiel — [2]Universitätsklinikum Schleswig-Holstein Campus Kiel, Klinik für Zahnärztliche Prothetik, Propädeutik und Werkstoffkunde, Arnold-Heller-Strasse 16, 24105 Kiel

Due to their attractive esthetics, biocompatibility and mechanical properties, zirconia ceramics are increasingly used for dental implants. But they do not form an osseo-integration due to chemical inertness. In order to improve the osseo-integration of zirconia ceramic implants, a microstructure on the ceramic surface is developed with an ion beam sputter process through a thin film mask which exhibits low sputtering rates. The thin film masks covering ceramic surface are fractured to obtain a microcrack network . After sputtering, the network of cracks is transferred as a network of micro- and submicro channels. With this, relatively high aspect ratios for the microstructures can be obtained. Moreover, by filling the cracks with another material with a high sputter resistance, it is also possible to obtain the inverted network microstructure on zirconia ceramic surface.

MM 35.25 Thu 18:45 H16

Optical and Structural Characterisation of Metallised Oligonucleotides — •Nadine Holzapfel[1], Glenn Burley[2], Johannes Gierlich[2], David Hammond[2], Thomas Carell[2], Gerhard Abstreiter[1], and Ulrich Rant[1] — [1]Walter Schottky Institut, Technische Universität München, Am Coulombwall 3, 85748 Garching — [2]Ludwig-Maximilians-Universität München, Butenandtstr. 5-13, 81377 München

Metallised DNA structures have received considerable attention recently; mainly for their potential applications in nanoelectronic devices. Aside from this, metallised oligonucleotides of nanometer dimensions are expected to exhibit intriguing optical properties due to the excitation of collective oscillations of the conducting electrons by visible light (plasmons). In this study, we used two different methods to deposit silver on oligonucleotides of different lengths (23-96 base pairs). The first method involved the specific labelling of nucleotides with aldehyde groups, followed by exposure to Tollens reagens and a developer, whereas the second method relied on the photoinduced deposition of Ag onto unmodified DNA samples. Several preparation parameters (DNA sequence, buffer salt type, Ag concentration, UV illumination time) were varied systematically. The optical properties of the resulting metallised DNA samples were characterised by recording the extinction spectra using a UV/VIS absorption spectrometer. An extinction maximum was found at ca. 410 nm which is indicative of a plasmonic mode. In addition, the metallised DNA structures were deposited on single crystalline Si wafers and imaged by SEM and AFM.

MM 35.26 Thu 18:45 H16

The rate of bone renewal controls its mechanical behavior — •Davide Ruffoni[1], Peter Fratzl[1], Paul Roschger[2], Klaus Klaushofer[2], and Richard Weinkamer[1] — [1]Max Planck Institute of Colloids and Interfaces, Potsdam, Germany — [2]Ludwig Boltzmann Institute of Osteology, Vienna, Austria

At the material level bone is a nano-composite consisting of collagen and mineral particles. A crucial factor for the mechanical behavior is the amount and distribution of mineral. Bone material evolves in time as the result of a remodeling and a mineralization process. In trabecular bone the presence of bone packets with different degrees of mineralization is characterized by a bell-shaped frequency distribution of the mineral content, called the bone mineralization density distribution (BMDD). A tailor-made continuity equation is developed to answer how the rate of bone deposition and bone resorption influence the time evolution of the BMDD. First, the steady state solution of the model equation enables the extraction of information on the mineralization kinetics taking the measured BMDD as starting point. Secondly, the knowledge of the mineralization kinetics can be used to predict the full time evolution of the BMDD. Increasing the remodeling rate causes a less mineralized and more heterogeneous mineral distribution. Conversely, when reducing the turnover the BMDD displays transiently a sharp peak corresponding to bone with an unusual uniformity in its mineral content. Later in time higher and less uniform mineralization distributions are attained. From a mechanical view point this suggests an evolution towards stiffer but more brittle bone.

MM 35.27 Thu 18:45 H16

Mechanical properties of silk: Interplay of deformation on macroscopic and molecular length scales — •Imke Diddens[1], Nadine Hauptmann[1], Gesa Helms[1], Igor Krasnov[1], Malte Ogurreck[1], Tilo Seydel[2], Sergio S. Funari[3], and Martin Müller[1] — [1]Institut für Experimentelle und Angewandte Physik, Christian–Albrechts–Universität zu Kiel — [2]Institut Laue–Langevin, Grenoble, France — [3]HASYLAB at DESY, Hamburg

Using an *in situ* combination of tensile tests and X–ray fibre diffraction, we have directly determined the mechanical properties of both the crystalline and the disordered phase of the biological nanocomposite silk. We have adapted a model from linear viscoelastic theory, which fully accounts for the semicrystalline morphology of silk. The elastic moduli of the two phases were determined as well as the relaxing modulus and the viscosity of the disordered matrix. The high extensibility of silk results principally from the disordered phase, however, important elastic deformation was also found in the β–sheet protein crystals. The observed interplay between morphology and mechanical properties will have strong impact on the design of novel protein–based high performance fibres.

MM 35.28 Thu 18:45 H16

Fibrillar level deformation mechanisms in antler — •Stefanie Krauss[1], Himadri Shikhar Gupta[1], Jong Seto[1], John Currey[2], Tomas Landete-Castillejos[3], Sergio Souza Funari[4], Stephan Volkher Roth[4], and Peter Fratzl[1] — [1]Department of Biomaterials, Max Planck Institute of Colloids and Interfaces, Potsdam, Germany — [2]Department of Biology, University of York, York, United Kingdom — [3]IREC (Sec. Albacete) y ETSI Agronomos, IDR, Univ. Castilla-La Mancha, Albacete, Spain — [4]HASYLAB-DESY, Hamburg, Germany

In bone and related biomineralized tissues, the combination of a ductile organic matrix (mostly Type I collagen) with stiff mineral crystallites leads to a material with high stiffness and excellent resistance to fracture. As recently shown by us, the mechanisms leading to this in bone involve shearing in the interfibrillar matrix as well as cooperative deformation between mineral and collagen within the fibril. Deer antler is a less mineralized bone type that shows an extremely high toughness, which has obvious advantages for its physiological function as a weapon during dominance fights between male deer in the rutting period. Using in-situ mechanical testing with time-resolved synchrotron X-ray measurements of the meridional collagen small-angle diffraction pattern, we measured the changes in fibril strain while simultaneously stretching the tissue to failure. We compare the fibril and tissue strain and the variation of the 3rd order meridional collagen peak shape with increasing stress. We discuss how these structural changes at the nanoscale may influence the macroscopic toughness of antler.