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GENERAL INFORMATION

INTRODUCTION

The scope of this conference is to provide an interdisciplinary platform for discussions of novel developments and trends in the field of biological and bio-inspired surfaces. Topics will encompass functional mechanisms as well as the characterization of biological surfaces with different functionalities: adhesion, friction, wear-resistance, wettability, photonics, etc. Based on this knowledge, a further key topic will be the consideration of structural principles in biological systems as potential models for the generation of novel technical surfaces and their implementations into engineering systems.

The following aspects will be covered at the symposium:

/biological surfaces and physical principles of their functioning

/technical bio-inspired micro- and nanosctructured surfaces

/tribological surfaces: adhesion, friction, wear-resistance

/wettability and self-cleaning

/photonical surface

SCIENTIFIC ORGANIZER

Stanislav N. Gorb / University of Kiel

WEBSITE

nanosurfaces.beilstein-symposia.org

DATES

- **Scientific program** May 9 to 11
- **Traveling days** May 8 and 12
- **Welcome reception** May 8 at 7 pm

CONFERENCE HOTEL

The conference, lunches and dinners will take place at:

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SCIENTIFIC PROGRAM

Tuesday, May 9

9:00	**Welcome and introduction**
	Session chair: Stanislav N. Gorb
9:20	Insect structural coloration: from nanostructures to animal behavior Rhainer Guillermo Ferreira / Federal University of Triangulo Mineiro, Brazil
10:00	Iridescence from biological gratings in snakes and transparent fish Qibin Zhao / Shanghai Jiao Tong University, China
10:40	Poster introduction Short introduction of posters #1–6
11:10	***Coffee break and Poster session***
11:40	Butterfly wings with structural colors: from DNA to photocatalysis Gábor Piszter / Center for Energy Research, Hungary
12:20	Biological hairs across scales Guillermo Amador / Wageningen University and Research, Netherlands
13:00	***Lunch***
	Session chair: Rhainer Guillermo Ferreira
14:30	Performance of living biological adhesive systems in hot and humid conditions Alyssa Stark / Villanova University, USA
15:10	The nanostructures underlining structural white in the olive fruit fly, ***Bactrocera oleae*** (Diptera, Tephritidae) Manuela Rebora / University of Perugia, Italy
15:50	Poster introduction Short introduction of posters #7–11
16:20	***Coffee break and Poster Session***
16:50	Superhydrophobicity in plants: evolution, structures, functions, and biomimetic applications Wilhelm Barthlott / Nees Institute for Biodiversity of Plants, Germany
17:30	Self-healing superhydrophobic materials by remaking surface chemical makeup and microstructures Atsushi Hozumi / AIST Chubu, Japan

18:10	How the gecko walks on almost any surface: lessons from multi-scale molecular simulation Florian Müller-Plathe / Technical University of Darmstadt, Germany
18:50	*End of talks and break*
19:00	***Poster Session***
19:45	*Dinner*

Wednesday, May 10

9:00	**Welcome**
	Session chair: Thomas Schimmel
9:05	The structural photonics of plant surfaces: optics, materials engineering and biology Rox Middleton / TU Dresden
9:45	Bacterial adhesion to solid surfaces: interplay of intermolecular forces, wettability and roughness Karin Jacobs / Saarland University, Germany
10:25	The surface chemistry of gecko toe pads Tobias Weidner / Aarhus University, Denmark
11:05	***Coffee break and Poster Session***
11:35	Smart surfaces based on magnetoactive elastomers Mikhail Chamonine / Regensburg University of Applied Sciences, Germany
12:15	Responsive polymer films through supramolecular assembly Stephen Schrettl / Technical University of Munich, Germany
12:55	***Lunch***
14:10	**Excursion** Guided tour through the medieval town of Limburg and Limburg cathedral
19:30	***Dinner***

Thursday, May 11

9:00	**Welcome**
	Session chair: Alyssa Stark
9:05	Bioinspired light switchable dry adhesives Anne Staubitz / University of Bremen, Germany
9:45	Biomimetic on gecko locomotion: learn from and go beyond biology Zhendong Dai / Nanjing University Aeronautics & Astronautics, China
10:25	Beyond biomimicry - next generation applications of bioinspired adhesives from microfluidics to composites Dan Sameoto / University of Alberta, Canada
11:05	***Coffee break and Poster session***
11:35	Biomimetics inspired from the evolution of insects Ming Bai / Chinese Academy of Sciences, China
12:15	Bioinspired architectures using biopolymer-based photoresists using direct laser writing Cordt Zollfrank / Technical University of Munich, Germany
12:55	***Lunch***
	Session chair: Dan Sameoto
14:25	Strength and deformation behaviour of bio-inspired surface for geotechnical applications Hans-Henning Stutz / Karlsruhe Institute of Technology, Germany
15:05	Keeping an permanent layer of air under water: perspectives of bio-inspired ship coatings based on the Salvinia effect Thomas Schimmel / Karlsruhe Institute of Technology, Germany
15:45	***Coffee break and Poster session***
16:15	Machine intelligence inspired by nature: from functional structured body surfaces to brain Poramate Manoonpong / University of Southern Denmark, Denmark
16:55	Stick insect adhesive systems: functional morphology and evolutionary drivers Thies H. Büscher / University of Kiel, Germany
17:35	**Closing remarks**
19:30	***Dinner***

ABSTRACTS

Tuesday

9:20

Insect structural coloration: from nanostructures to animal behavior

Rhainer Guillermo-Ferreira

Lestes Lab, Federal University of Triangulo Mineiro, Uberaba, Brazil

Animals exhibit a remarkable variety of optical effects and coloration patterns. In insects, the exoskeleton has nano- and micro-structures that produce stunning colors and, at the same time, act as a multifunctional biological system. For instance, males of some insects exhibit iridescent structures that are often used to repel rival males or to attract females. The same structures may function as a mean to camouflage and avoid predation, or as a thermoregulation mechanism acting as a thermal radiator. Our main goal is to study photonic structures and the coupled animal behavior inherent to these features. These extraordinary features are also of strong interest as an inspiration for the development of novel materials and technologies. This research seeks to unravel how nature produce and use the colorful patterns observed in insects of the huge Neotropical Biodiversity and, ultimately, prospect the application of the observable functional mechanisms in modern technology.

Tuesday

10:00

Iridescence from biological gratings in snakes and transparent fish

Qibin Zhao

School of Materials Science and Engineering,
Shanghai Jiao Tong University, China

Iridescence exists widely in plants and animals, and it originates from diverse photonic structures, most of which are on the surface. In animals, iridescence is considered to play important roles in communication, mating, camouflage, locomotion, etc., which are vital for their survival. Aside from the functions, to explore the structure origins and mechanism of the iridescence is also interesting because it provides a unique angle to understand the secrets of biological self-assembly and evolution. This talk will focus on our recent work of two distinct types of diffraction grating structures in nature: the reflective gratings in snake scales and the transmission gratings in transparent fish and discuss their biological significance. There are very few studies on the optical properties of the snake scales, and the iridescence in transmission of the transparent fish has not been reported. Discussions of the biological significance of the finds will also be included.

Tuesday

11:40

Butterfly wings with structural colors: from DNA to photocatalysis

Gábor Piszter

Institute of Technical Physics and Materials Science,
Centre for Energy Research, Budapest, Hungary

The photonic nanoarchitectures in butterfly wing scales are capable of manipulating light in unique ways. These nanocomposites of chitin and air have such sophisticated structures that are enviable compared to our current artificial nanomaterials. Therefore, it is worth investigating natural photonic nanoarchitectures and their biological function together, as this way we can gain knowledge that can be utilized directly in potential applications. We studied the structural colors of Common Blue butterflies generated by photonic nanoarchitectures which are known to be important in the sexual communication of these insects. The blue color of male butterflies was found to be species-specific and had consistent optical properties over time and within large geographical distances, which was also related to the population genetic structure of the species as revealed by microsatellites of the nuclear DNA. Due to this important biological function, the porous photonic nanoarchitectures in the wing scales of Common Blue males are reproduced with high precision from generation to generation, therefore they can be beneficially applied as biotemplates. We used the blue wing surface of laboratory reared butterflies in combination with atomic layer deposition of conformal ZnO and nanoparticle deposition to explore the optical and catalytic properties of such biotemplated semiconductor surfaces. The efficiency of the biotemplated photocatalysts was enhanced by increasing the effective surface on which the substances to be decomposed were adsorbed – due to the hierarchical organization of the butterfly wing from nanometers to centimeters – and by improving the efficiency of the photoexcitation process caused by the natural the photonic nanoarchitectures in synergism with conformal nanocoatings realized by standard materials science methods.

Tuesday

12:20

Biological hairs across scales

Guillermo Amador

Experimental Zoology Group, Wageningen University & Research, Netherlands

Hair, or hair-like fibrillar structures, are ubiquitous in biology, from fur on the bodies of mammals to setae on the footpads of flies to mastigonemes on the flagella of single-celled organisms. These long and slender protuberances are multi-functional and help mediate interactions with the environment. They can provide insulation from heat loss, sensory information, reversible adhesion, and superhydrophobicity. In this talk, I will present various functions that biological hairs were discovered to carry out, with the hairs spanning across five orders of magnitude in size, from the sub-millimeter-thick eyelashes of mammals down to the nanometer-thick matigonemes of swimming micro-algae. I will show that the lengths of mammalian eyelashes and insect ocular setae may be tuned to minimize airflow reaching the eye's surface, that the ability for climbing beetles to overcome soiling from micro-particles is dictated by the geometry of their adhesive fibrillar arrays, and that swimming is not enhanced by the presence of mastigonemes on the flagella of micro-algae so their function remains elusive. By investigating and revealing the versatile functions of hairs, I hope to motivate new, bio-inspired solutions across scales.

Tuesday

14:30

Performance of living biological adhesive systems in hot and humid conditions

Alyssa Y. Stark

Department of Biology, Villanova University, USA

Environmental parameters such as variable temperature and humidity historically challenge artificial adhesive systems, making them slip or peel inappropriately. This is particularly true for temporary adhesive systems that attach and detach for repeated use. In contrast, the adhesive systems of many live organisms are used over and over in climates such as the tropical rainforest. While synthetic adhesives often fail in conditions that simulate the tropical rainforest (e.g., high temperature and humidity), living systems, like those of ants and geckos, do not fail. Indeed, some appear to be optimized to be reused over and over in these challenging conditions. By investigating optimization of the natural system to variable climate-simulating treatments, we will be able refine and even reinvent the way we make bio-inspired synthetic adhesives that retain function in hot and wet environments.

Tuesday

15:10

The nanostructures underlining structural white in the olive fruit fly, *Bactrocera oleae* (Diptera, Tephritidae)

Manuela Rebora

Department of Chemistry, Biology and Biotechnology, University of Perugia, Italy

Body color and light signals have a fundamental role in insect inter- and intra-specific visual communication allowing species recognition, mating, prey capture, and predator avoidance. Insect exoskeleton with its multilayered internal organisation and its cuticular micro- and nanostructures, offers remarkable examples of structural colours in the animal kingdom. The nanostructures responsible for the production of structural white in *Bactrocera oleae* (Diptera: Tepritidae) are described. Ultrastructure and development of the white patches on thorax and head are analysed using scanning electron microscopy, transmission electron microscopy, and fluorescence microcopy. Reflectance spectra of the patches are measured. The white patches are due to modified air sacs under transparent cuticle. Air sacs show internal arborisations with beads in an empty space, constituting a three-dimensional photonic solid responsible for light scattering. The white patches show UV-induced blue autofluorescence due to the air sac resilin content. Sexual dimorphism in the spectral emission lays a structural basis for further investigations on the biological role of white patches in *B. oleae*. To the best of our knowledge, for the first time structural color produced by tracheal structures located under transparent cuticle is described in insects and a new function for air sacs is identified. The description of new photonic nanostructures in insects can be of interest for bio-inspiration.

Tuesday

16:50

Superhydrophobicity in plants: evolution, structures, functions, and biomimetic applications

Wilhelm Barthlott

Nees Institute for Biodiversity of Plants, University of Bonn, Germany

Surfaces play the crucial role in the interaction of all organisms with their environment. Only some 1.8. million out of the probably more than 10 million disappearing species ("Biological Role Models" of Bionics) are known [1]. A vast number of surface structures, chemistries and functionalities evolved – each of them perfectly adapted to its environment. Superhydrophobicity evolved already within precambrian land-living Cyanobacteria as a key evolutionary step for the transition from water to land [2].
However, physicists and materials scientists discovered surfaces surprisingly late for technical applications: up to the 1990th biological role models were almost exclusively animals and functions researched were dominated by mechanics, robotics and cybernetics. Plants and functional micro- and nanostructured surfaces [3] played almost no role up to 1995. The first crucial step was the discovery of the self-cleaning of hierarchically structured superhydrophobic surfaces ("Lotus Effect") between 1977 und 1997, which lead to a paradigm change in surface technologies.
A survey of superhydrophobic structures and chemistries from cyanobacteria to modern land plants and the highly diverse functionalities based on the Lotus- and Salvinia- Effect (self-cleaning, drag reduction, sensory functions, oil-water-separation) is provided.

[1] Barthlott et al. 2016, Bionics and Biodiversity. In "*Biomimetic Research for Architecture and Building Construction*" (Eds.: J. Knippers, et al.), Springer. http://www.springer.com/us/book/9783319463728.
[2] Barthlott et al. 2022, *Front. Plant. Sci.* doi.org/10.3389/fpls.2022.880439,
[3] Barthlott et al. 2017, *Nano-Micro Letters* 9(23). doi.org/10.1007/s40820-016-0125-1.

Tuesday

17:30

Self-healing superhydrophobic materials by remaking surface chemical makeup and microstructures

Atsushi Hozumi

National Institute of Advanced Industrial Science and Technology (AIST), Nagoya, Japan

The authors propose a nature-friendly approach to create self-healing superhydrophobic materials, on which severe physical and chemical damages can be easily healed by remaking surface chemical makeup and microstructures. Such materials can be prepared based on the "syneresis" of reactive organosilanes followed by hydrolysis/polycondensation reactions with moisture in air. The resulting superhydrophobic surfaces exhibited excellent self-healing properties against UV/ozone exposure or severe mechanical damages. The oxidized/damaged surfaces can be healed and regenerated superhydrophobicity by simply leaving samples in air for 30 min to several hours. Our superhydrophobic materials with self-healing abilities undoubtedly show great potential for applications in a variety of engineering fields.

Tuesday 18:10	**How the gecko walks on almost any surface: lessons from multi-scale molecular simulation**
	Florian Müller-Plathe
	Eduard-Zintl-Institute, Technical University of Darmstadt, Germany

The ability of geckos to walk on walls and ceilings is iconic. The role of the micromechanics of the gecko foot is well understood. The role of the chemistry, i.e. the beta-keratin of the gecko, is the topic of this talk. We have undertaken particle-based simulations on the atomistic scale (1 bead = 1 atom), the coarse-grained scale (1 bead = 1 amino acid) and the meso scale (1 bead = 2.5 keratin molecules). It turns out that the gecko has a base capacity of sticking to dry, hydrophobic surface, for example leaves. The change to a more hydrophilic surface (rock) or the addition of humidity increase the sticking power considerably. This is in parts due to the molecular flexibility, which allows polar amino acids to turn toward the substrate, as needed. In parts it is due to water-swollen keratin being more flexible on a nanometer-scale and, thus, being able to follow nanoscopic surface corrugations. The dominant contribution, however, is the mediation of surface-keratin contacts by individual water molecules. In contrast, capillary action of water plays no role.

Wednesday 9:05	The structural photonics of plant surfaces: optics, materials engineering and biology
	Rox Middleton
	Department of Biology, Technical University of Dresden, Germany

Plant surfaces are multifunctional metamaterials with myriad roles, from management of water and pathogens to performance as photonic surfaces. The study of animal coloration by nanostructure has uncovered a vast range of optical phenomena and nanostructure but recent results show that photonic structures in plants to open a wide field of novel biomaterials and light management strategies. I will present recent results on photonic nanostructures in plants, with particular focus on coloration and signalling function in fruits. These optical, structural and computational analyses demonstrate not only a new set of approaches to optical engineering through biomimetics and bioreplication, but also, through phylogenetic analysis, insights into plant anatomy, function and adaptation.

Wednesday

9:45

Bacterial adhesion to solid surfaces: interplay of intermolecular forces, wettability and roughness

Karin Jacobs

Department of Experimental Physics, Saarland University, Saarbrücken, Germany

Bacterial adhesion is often the initiator of biofilm formation and is therefore of elementary interest for many applications. The development of a fundamental understanding of this process is therefore essential. True to the motto "from the simple to the complex", experiments in a controlled reference environment are a good start to determine the forces responsible for adhesion and to assign their cause. Adding more and more complexity, both from the substrate side (roughness, changes in wettability) and from the surrounding medium (pure water, buffer, protein solution) can succeed in approaching the "real, natural" system from a controlled reference environment. [1]
The properties of the surfaces used (Si wafers to catheter surfaces) will be characterized using atomic force microscopy and described using integral geometric methods. The adhesion strength of single, live cocci (*S. aureus*, *S. carnosus*, *S. mutans*, etc.) will be determined using single cell force spectroscopy. MD simulations help to interpret the measured force-distance curves and give indications of which forces are dominant in a given system. I will discuss their shortcomings and give an introduction to different approaches that understand the adhesion process as the result of single stochastic interactions of many macromolecules with the substrate.
Finally, I will speculate about how our fundamental findings may transfer "from bench to bedside".

[1] C. Spengler, E. Maikranz, L. Santen, K. Jacobs, *Front. Mech. Eng.* 7 (2021) 661370.

Wednesday

10:25

The surface chemistry of gecko toe pads

Mette H. Rasmussen[1], Katinka Rønnow Holler[1], Joe E. Baio[2], Cherno Jaye[3], Daniel A. Fischer[3], Stanislav N. Gorb[4] & **Tobias Weidner**[1]

[1]Department of Chemistry, Aarhus University, Denmark

[2]School of Chemical, Biological and Environmental Engineering, Oregon State University, Corvallis, USA

[3]National Institute of Standards and Technology, Gaithersburg, USA

[4]Functional Morphology and Biomechanics, Kiel University, Germany

Gecko adhesion to surfaces has been fascinating biologists and material scientists for a long time. The attachment mechanism is based on the adhesive properties of fibrous setae at the tips of their toe pads. Spatula structures at the very ends of the setal fibrils, which are assembled from beta-sheet proteins, make the final surface contact. While the properties and surface interactions of the myriads of spatula located at the outermost ends of the setal arrays have been studied extensively, there are still open questions about the surface chemistry of gecko setae. The structure and alignment of proteins within the ultrafine spatula tissue, which can support the enormous mechanical strain, has been unknown. In addition, lipids have been shown to be involved in the surface contact and their role and location have been unclear. We have studied the molecular structure of gecko spatula using near-edge X-ray absorption fine structure (NEXAFS) imaging. Using this technique, we can probe the chemical state of the outermost molecular surface of the toe pads. We indeed found that the setae consist of a beta-sheet structure aligned with the adhesion direction of the setae. Such alignment may provide mechanical stability to the setae and resistance to wear across different length scales (1). We will also discuss evidence for a nanometer-thin ordered lipid layer that is covering the beta proteins (2) layer. Such a lipid structure will help protect the spatula structure from dehydration and mechanical strain and help promote self-cleaning processes.

[1] Holler KR, Rasmussen MH, Baio JE, Jaye C, Fischer DA, Gorb SN, et al. Structure of Keratins in Adhesive Gecko Setae Determined by Near-Edge X-ray Absorption Fine Structure Spectromicroscopy. *J Phys Chem Lett.* 2022 Mar 10;13(9):2193–6.
[2] Rasmussen MH, Holler KR, Baio JE, Jaye C, Fischer DA, Gorb SN, et al. Evidence that gecko setae are coated with an ordered nanometre-thin lipid film. *Biology Letters*. 18(7):20220093.

Wednesday

11:35

Smart surfaces based on magnetoactive elastomers

Mikhail Chamonine

East Bavarian Centre for Intelligent Materials (EBACIM), Regensburg University of Applied Sciences, Germany

Magnetoactive elastomers (MAEs) are hybrid materials comprising micro- and/or nanometer-sized magnetic particles (inorganic constituent) embedded into a soft polymer matrix (organic constituent). If the matrix is particularly soft (shear storage modulus of the resulting MAE < 30 kPa), the embedded micrometer-sized ferromagnetic particles can change their mutual arrangement (microstructure) in easily realizable magnetic fields (< 400 mT), trying to align themselves along magnetic field lines. This restructuring of filler particles leads to significant changes in their physical properties (elastic moduli, electrical conductivity, magnetic and dielectric properties etc.). Due to their exceptional magnetorheological properties MAEs are also known as magnetorheological elastomers. It has been recently realized that the restructuring of filling particles becomes noticeable on the MAE surface. Therefore, MAEs are very promising materials for rapid and reversible control of various surface properties by magnetic field. This talk will present a state-of-the art overview of the effects of magnetic field on different surface properties of MAE such as wettability, surface roughness, adhesion and friction. The emphasis will be on potential applications of MAE-based surfaces for control of wettability and handling of liquid droplets.

Wednesday

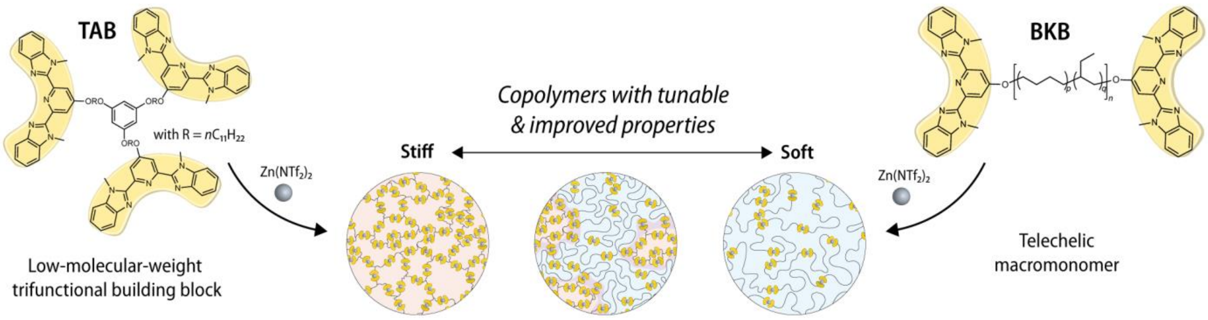
12:15

Responsive polymer films through supramolecular assembly

Stephen Schrettl

TUM School of Life Sciences, Technical University of Munich, Freising, Germany

The assembly of monomeric units that feature dynamic non-covalent interactions furnishes supramolecular polymers. Stimuli that weaken such interactions can trigger a temporary disassembly of the monomeric building blocks, which can impart the materials with useful responsive functionalities. In this presentation, we report on the use of supramolecular self-assembly to create polymer films that marry desirable responsive functionalities with tailored mechanical properties. Thus, a recently developed approach will be discussed that allows blending two building blocks to achieve superior mechanical properties. The ability to combine the building blocks in any ratio allows to prepare polymer films with a spatially modulated mechanical behavior, effectively mimicking the anisotropic properties of more complex natural materials. Moreover, this presentation will also discuss novel supramolecular approaches toward nanoparticle composite and highlight recently developed materials that display defined optical signals upon mechanically deformation.



Individual metallosupramolecular polymers are assembled from trifunctional (TAB) or telechelic (BKB) building blocks, and their combination affords copolymers with tunable mechanical properties.

[1] Sautaux, J., Marx, F., Gunkel, I., Weder, C. & Schrettl, S. Mechanically robust supramolecular polymer co-assemblies. *Nat. Commun.* 13, 356 (2022).
[2] Neumann, L. N., Oveisi, E., Petzold, A., Style, R. W., Thurn-Albrecht, T., Weder, C. & Schrettl, S. Dynamics and healing behavior of metallosupramolecular polymers. *Sci. Adv.* 7, eabe4154 (2021).
[3] Olaechea, L. M., L. Montero de Espinosa, L., Oveisi, E., Balog, S., P. Sutton, P., Schrettl, S. & Weder, C. Spatially Resolved Production of Platinum Nanoparticles in Metallosupramolecular Polymers. *J. Am Chem. Soc.* 142, 342–348 (2020).
[4] Cappelletti, C., Olaechea, L. M., Ianiro, A., Prado-Martínez, C., Oveisi, E., Weder, C. & Schrettl, S. Metallosupramolecular polymers as precursors for platinum nanocomposites. *Polym. Chem.* 13, 1880–1890 (2022).
[5] Calvino, C., Guha, A., Weder, C. & Schrettl, S. Self-Calibrating Mechanochromic Fluorescent Polymers Based on Encapsulated Excimer-Forming Dyes. *Adv. Mater.* 4, 1704603 (2018).
[6] Traeger, H., Sagara, Y., Kiebala, D. J., Schrettl, S. & Weder, C. Folded Perylene Diimide Loops as Mechanoresponsive Motifs. *Angew. Chem. Int. Ed.* 60, 16191-16199 (2021).

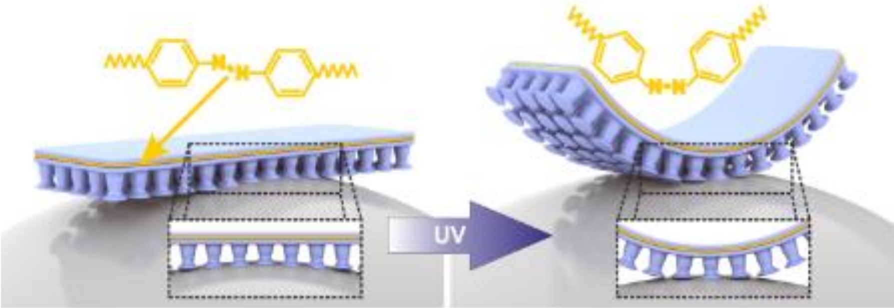
Thursday

9:05

Bioinspired light switchable dry adhesives

Anne Staubitz

Institute for Organic and Analytical Chemistry, University of Bremen, Germany



Light switchable liquid crystalline elastomers (lsLCEs) are capable of showing a photomechanical effect: they bend reversibly when exposed to light of the correct wavelength. This feature has been combined with a dry adhesive structure that can be found in beetles, allowing adhesion and peel-off solely controlled by light. Although the early specimens required UV-light to switch, the latest generation of ldLCEs can now operate with visible light, which is a major advantage in a biological context.

[1] E. Kizilkan, J. Strueben, A. Staubitz*, S. N. Gorb*, Bioinspired photocontrollable microstructured transport device. *Sci. Robot.*, 2, aak9454 (2017).

[2] E. Kizilkan, J. Strueben, X. Jin, C. F. Schaber, R. Adelung*, A. Staubitz*, S. N. Gorb*, Influence of the porosity on the photoresponse of a liquid crystal elastomer. *R. Soc. Open Sci.* 3, 150700/150701 (2016).

Thursday

9:45

Biomimetic on gecko locomotion: learn from and go beyond biology

Zhendong Dai, Jian Chen, Keju Ji

College of Mechanical and Electrical Engineering,
Nanjing University of Aeronautics and Astronautics, China

Many creatures such as beetles and geckos, adhere on vertical or inverted substrates by van der Waals forces and have the ability to move in the ubiquitous three-dimensional space. Adhesive materials inspired by these animals' adhesive organs have many potential applications for daily life, however robust and reversible adhesion, especially under extreme environments, is an inevitable challenge. Few reports studied the effect of environments on the performance of polymeric adhesion. Inspired by the adhesive hairy pads of beetles, we report a new approach to fabricate adhesive structure, which possesses the highest adhesive strength 25.47 N/cm2 at −100 °C, excellent adhesive durability under thermal cycling (from −100 to 100°C), and more importantly reversible attachment and detachment on frozen substrate. Beyond limits of the creature, we believe that it will have wide applications not limited to extreme environments such as space exploration and glacier rescue.

Thursday

10:25

Beyond biomimicry - next generation applications of bioinspired adhesives from microfluidics to composites

Dan Sameoto

Faculty of Mechanical Engineering, University of Alberta, Edmonton, Canada

For nearly 20 years, gecko-inspired adhesives have been investigated by scientists and engineers for their potential utility used in a wide variety of applications, from climbing robots, pick and place assembly, skin-adhesives and space systems. Fundamental investigations into behaviors like contact splitting, anisotropic adhesion behavior, self-cleaning and other factors have made enormous impact on scientific literature and understanding how nature's nanotechnology can be applied to artificial versions. It is fair to say however, that the commercial impact of gecko-inspired adhesives has not matched the previous success of products like Velcro – the most well-known brand of biomimetic products. In this talk I offer up examples where the utility of gecko-inspired and other biomimetic materials may have higher impact – primarily as a revolution in applications rather than in materials selection or geometry optimization. Three newer applications are highlighted – microfluidics, soft robotics and shape and stiffness tunable composites. For microfluidics, the use of either hydrophobic or hydrophilic structural materials greatly influences the wet adhesion properties for "dry" adhesives, but they can be structured with gaskets and internal features for both strong adhesion and fluid control with gases, water, oil, and even liquid metals. Within soft robotics, directionally sensitive and temperature tunable functionality have been used to grasp objects as variable as hard silicon to stretchable fabrics. Multi-mechanism adhesives with spatially variable geometry and material properties can be used in further improvements in functionality. Finally, I talk about our most recent work in developing the concept of gecko-jammed composites, where internal surfaces are the new "killer app" for biomimetic adhesives. Through optimized structuring and new techniques for reversible adhesion to occur at the internal surfaces of materials, a variety of shape and stiffness tunable structures for next generation healable composites can be achieved.

Thursday

11:35

Biomimetics inspired from the evolution of insects

Ming Bai

Institute of Zoology, Chinese Academy of Sciences, Beijing, China

Evolutionary biology is the backbone of biology, which provides the explanation of a gradual process in which a feature changes into a different form. This report attempts to interpret the origin and evolution of insect morphological adaptations from the perspective of insect evolution, as well as the micro- and nano- morphology of these adaptive features. This report mainly focuses on beetles (Coleoptera) representing the largest order of insects. The surfaces of legs, mouthparts, hind wings and the role of these structures in beetle behavior will be discussed. The functional morphological changes of related structures during the evolutionary history will be reconstructed.

Thursday

12:15

Bioinspired architectures using biopolymer-based photoresists using direct laser writing

Cordt Zollfrank

TUM Campus Straubing for Biotechnology and Sustainability,
Technical University of Munich, Germany

The polysaccharides cellulose and chitin ate the most abundant biopolymers on earth and they are considered as an almost inexhaustible natural resource for the increasing demand of environmentally friendly, biocompatible and biodegradable (bio-)polymeric materials. The synthesis of irradiation curable bio-based photoresists from cellulose and the chitin monomer N-acetylglucosamine is presented. Curing of the cellulose- and chitin-derivatives is generally possible in liquid and solid state via two-photon absorption. The developed biopolymer-based photoresist allows the three-dimensional structuring of cellulose and chitin-related derivatives at the submicron range via direct laser writing (DLW). This expands the operational fields of this photoresist, because writing in solid resists allows for structures that are more complex. The presented research includes the functionalization of cellulose to enable photo-crosslinking for generating biopolymer-based hierarchical architectures. This distinct chemical modification is a prerequisite for the fabrication of two- and three-dimensional structures by DLW. Potentially, disorder on the nano-scale can be created by the surface roughness of the DLW-fabricated structures and can be tuned via the concentration of the photoinitiator. An additional degree of disorder might be introduced through a self-assembled tilting and twisting of the written structures during the development process. This enables manufacturing of e.g. bioinspired photonic patterns. Moreover, the polysaccharide-based photoresists permit manufacturing of bioinspired architectures, which entirely consist of a natural biopolymeric material. Furthermore, the biopolymer photoresists are curable via one-photon absorption with a conventional UV-lamp in liquid as well as in dried state. Therefore, these cellulose-based photoresists can be also employed as biocompatible coatings in biomedical material applications. In contrast to common fossil-based photoresists, which are based on polymers obtained from fossil resources, our biopolymeric photoresists preserves resources through replacing those polymers by sustainable materials such as polysaccharides.

Thursday

14:25

Strength and deformation behaviour of bio-inspired surface for geotechnical applications

Hans Henning Stutz

Institute for Soil Mechanics and Rock Mechanics, Karlsruhe Institute of Technology, Germany

Studies about the soil-structure interface behaviour are important for the mechanism of understanding the bearing capacity behaviour of civil engineering structures in particular for geotechnical constructions. Recently, bio-inspiration have been applied more and more in geotechnical engineering. The presented results show the potential for the usage of generally anisotropic surface and the overall great potential of bio-inspiration in the future geotechnical implications. In the talk an overview of different bio-inspired surfaces and the testing results will be given. Besides the potential of micro- and nanostructures surfaces also the gain in understanding natural process of plants and animal will be illuminated, which offers a large source for potential research themes in the future.

Thursday

15:05

Keeping a permanent layer of air under water: perspectives of bio-inspired ship coatings based on the *Salvinia* effect

Thomas Schimmel

Institute of Applied Physics and Institute of Nanotechnology, Karlsruhe Institute of Technology, Germany

Ships use a considerable part of their total energy consumption to overcome friction with the surrounding water. This friction between ship and water could be reduced significantly by a lubricating layer of air between ship and water: Ships sliding in a hull of air. In close cooperation, scientists from the universities of Bonn, Karlsruhe and Rostock discovered the *Salvinia* effect, an effect which is demonstrated by a plant and which allows to keep a permanent air layer under water – opening perspectives for the development of novel, air-retaining surfaces. The physics of the *Salvinia* effect – including the recently-discovered air-spring effect – as well as the current state of artificial, air-retaining surfaces under water and their potential applications will be discussed.

Thursday

16:15

Machine intelligence inspired by nature: from functional structured body surfaces to brain

Poramate Manoonpong

The Mærsk Mc-Kinney Møller Institute, The University of Southern Denmark, Odense, Denmark

Living creatures can impressively perform versatile and robust locomotion. They can quickly adapt their movement to traverse a variety of substrates and deal with body damage. They can even take proactive steps to avoid colliding with an obstacle. Biological studies reveal that the complex locomotion behavior is attained by several ingredients grounding from functional structured (body) surfaces to neural control mechanisms (brain) and dynamic body-brain-environment interactions. In this talk, I will present "how we can realize these ingredients inspired by nature for complex machines (robots) so they can become more intelligent like their biological counterparts".

Thursday

16:55

Stick insect adhesive systems: functional morphology and evolutionary drivers

Thies H. Büscher, Stanislav N. Gorb

Department of Functional Morphology and Biomechanics, Zoological Institute, University of Kiel, Kiel, Germany

Adhesive pads are functional systems which evolved as a response to the environment. Within animals in general, attachment devices occur convergently in various lineages and insects in particular show an impressive diversity of such organs. The constraints, under which attachment structures have evolved, are often very similar to the representatives of different taxa. Therefore, strategies that solve similar problems often follow similar physical principles. However, the specific problems related to particular substrates differ between the actual habitats in different animals. Accordingly, species-specific substrate conditions are similar in the specific environments unrelated to the group of animals, but might be different for closely related species that settle different environments. Consequently, similar attachment organs evolved in a convergent manner and different attachment solutions can occur within closely related lineages. We used stick and leaf insects (Phasmatodea) as a model group of organisms to explore the functional performance of the attachment system within this lineage in light of their ecological background. Phasmids are herbivorous, but represent several different life traits that have an impact on the interaction with the corresponding substrates. For example, species that settle in the canopy are often winged and need to cope with the unpredictability of the substrate at landing, while ground-associated species often lack wings, deposit their eggs in the soil and climb only low growing vegetation for feeding. The morphology of the tarsal attachment system of phasmids reveals similar convergent adaptations in similar ecomorphotypes within different sublineages of phasmids. We approached the diversity of attachment structures in this lineage via different microscopy and experimental methods to elucidate the functional benefits of certain morphological features and link these findings with ecological context of the corresponding species.

POSTER OVERVIEW

No. 1 — **Micro structured and visibly pigmented polyolefin surfaces for visibly opaque and thermally scattering materials for camouflage applications**
Mehnab Ali / University of Alberta

No. 2 — **Garlic derived carbon dots: chemical structures and antioxidant properties**
Mattia Bartoli / Fondazione Istituto Italiano di Tecnologia

No. 3 — **Evolution of functional surface microstructures on leaf insect eggs (Phasmatodea: *Phylliidae*)**
Thies H. Büscher / University of Kiel

No. 4 — **Anti-icing properties of plant surfaces: the ice formation on leaves visualized by Cryo-SEM experiments**
Elena V. Gorb / University of Kiel

No. 5 — **Mechanical and adhesive properties of mucilaginous coat in seeds of *Ocimum basilicum* (Lamiaceae)**
Helen Gorges / University of Kiel

No. 6 — **Micro- and nano-scopic characters of structural colours in different altitude living shining leaf chafers (Insecta: Coleoptera)**
Yuanyuan Lu / Chinese Academy of Sciences

No. 7 — **Marine mammal parasites: surface adaptations of arthropod parasites to underwater attachment**
Anika Preuss / University of Kiel

No. 8 — **Influence of surface micro-structure in friction perception**
Sairam Saikumar / Leibniz-Institute for New Materials, Saarbrücken

No. 9 — **Development and testing of thermal "Buddha Board" techniques for infrared transmissibility control**
Xiaoruo Sun / University of Alberta

No. 10 — **Investigation of morphological and physical characteristics of the adhesive secretion in stick insects (Phasmatodea)**
Julian Thomas / University of Kiel

No. 11 — **Dry self-cleaning of photovoltaic panels with nanostructures inspired by the sandfish (*Scincus scincus*)**
Patrick Weiser / Karlsruhe Institute of Technology

Poster No. 1

Micro structured and visibly pigmented polyolefin surfaces for visibly opaque and thermally scattering materials for camouflage applications

Mehnab Ali, Xiaoruo Sun, Asad Asad, Shima Jalali, Patricia Dolez, James Hogan, Dan Sameoto

Mechanical engineering, University of Alberta, Edmonton, Canada

Tunable infrared (IR) camouflage materials are an area of high interest in camouflage and thermal heat management systems, which can rely on passive radiative heating and cooling. This work develops and characterizes strategies to pigment polyolefin polymers which are very transparent in thermal IR wavelengths (~8–12 µm) so that different visible coloration, yet high thermal transparency can be achieved simultaneously. To obtain tunable and tailored optical and IR properties, the effect of different geometries on micro-structured polyolefin surfaces is investigated. Polyolefins, specifically polyethylenes (PE) are chosen as the material of choice for this study due to their low emissivity, good durability, and high IR transparency properties along with their ability to be compounded easily with masterbatch pigments of visible colors. PE exists in a translucent or milky-white color in its natural state and is difficult to dye, or paint due to its low surface energy, so pigmentation of PE is achieved using custom compounding of master batches of pigments chosen for their high IR transparency and bold coloration potential to obtain both camouflage and visually appealing colors/ surface finishes for military and civilian applications. Visible appearance and IR transmission, are compared for different blends of LLDPE, HDPE, and pigment concentration. Thickness of pigmented, micro-structured sheets is found to be a significant impacting factor for IR properties, therefore the impact of three different thicknesses (50, 100 and 150 µm) is also investigated. These pigmented polymers can also be molded into lenticular lens patterns of varying pitch and height that highly scatter but minimally attenuate IR transmission. Our results show that visible and thermal IR appearance can be altered significantly through the combination of correct pigmentations and molded microfeatures and will allow for future camouflage and thermal metamaterials to be manufactured at scale with low cost materials.

Poster No. 2

Garlic derived carbon dots: chemical structures and antioxidant properties

Giulia Seganti[1], **Mattia Bartoli**[2,3] and Alberto Tagliaferro[1,3,4]

[1]Department of applied science and technology, Polytechnic of Turin, Turin, Italy

[2]Center for Sustainable Future, Italian Institute of Technology, Turin, Italy

[3]Consorzio Interuniversitario Nazionale per la Scienza e Tecnologia dei Materiali, Florence, Italy

[4]Faculty of Sciences, University of Ontario Institute of Technology, Oshawa, Canada

Garlic is a well-recognized source of antioxidant containing sulphur moieties[1] Nevertheless, the garlic active molecules are considerably labile and poorly compatible with biological environment. There are several approaches used to use garlic derivatives in chemotherapy[2]. An innovative approach developed by Yang et al.[3] was based on the conversion of raw garlic to polymeric carbon nanodots.

Carbon nanodots are high fluorescent nanoparticles with interesting properties of biocompatibility, water solubility and unique chemical features. Biomass derived carbon nanodots show very complex structures and it is quite hard to properly rationalize the relationship between their structures, properties and biological effects.

The research outcomes here reported represent a first attempt to produce a model able to correlate all the structural features of garlic derived carbon nanodots produced through hydrothermal synthesis that allowed to preserve the sulphur functionalities of the garlic material. We tested the nanomaterials antixodidant properties against ROS producing an interpretative model of the structural-properties relation based on the outputs of advanced characterization techniques (XPS, spectroscopically analysis and computational modelling).

[1] Borek, C., 2001. Antioxidant health effects of aged garlic extract. *J. Nut.* 131(3), pp.1010S-1015S.
[2] Cañizares, P., Gracia, I., Gómez, L.A., García, A., De Argila, C.M., Boixeda, D. and de Rafael, L., 2004. Thermal degradation of allicin in garlic extracts and its implication on the inhibition of the in-vitro growth of Helicobacter pylori. *Biotechnol. Prog.* 20(1), pp.32-37.
[3] Yang, C., Ogaki, R., Hansen, L., Kjems, J. and Teo, B.M., 2015. Theranostic carbon dots derived from garlic with efficient anti-oxidative effects towards macrophages. *RSC Adv.* 5(118), pp.97836-97840.

Poster No. 3

Evolution of functional surface microstructures on leaf insect eggs (Phasmatodea: *Phylliidae*)

Thies H. Büscher[1], Sarah Bank[2], Royce T. Cumming[3,4,5], Sven Bradler[2] and Stanislav N. Gorb[1]

[1]Department of Functional Morphology and Biomechanics, Zoological Institute, University of Kiel, Kiel, Germany

[2]Department of Animal Evolution and Biodiversity, Johann-Friedrich-Blumenbach Institute of Zoology and Anthropology, University of Göttingen, Göttingen, Germany

[3]Montreal Insectarium, Montréal, Quebec, Canada

[4]Richard Gilder Graduate School, American Museum of Natural History, New York, USA

[5]City University of New York, New York, USA

Leaf insects (Phylliidae) are herbivorous and famous for exhibiting impressive cryptic masquerade. They almost perfectly imitate angiosperm leaves and their eggs often resemble plant seeds. While adult Phylliidae are morphologically very similar, their eggs reveal a significant diversity in overall shape and exochorionic surface features.

Previous studies have documented the specialised attachment mechanism of one species with hierarchical exochorionic fan-like structures (pinnae), which are mantled by a film of an adhesive secretion (glue). The folded pinnae and glue respond to water contact, with the fibrous pinnae expanding and the glue being capable of reversible liquefaction. In general, the eggs of phylliids appear to exhibit varying surface structures that were suggested to represent specific adaptations to the different environments the eggs are deposited in. Here, we investigated the diversity of phylliid eggs and the functional morphology of their exochorionic structures.

Based on the examination of all known eggs of phylliids, we characterised eleven different morphological types. We explored the adhesiveness of these morphotypes and experimentally compared the attachment performance on a broad range of substrates with different surface roughness, surface chemistry and tested whether the adhesion is replicable after detachment in multiple cycles. Furthermore, we used molecular phylogenetic methods to reconstruct the evolutionary history of different egg types and their adhesive systems within this lineage. Our results suggest that the egg morphology is congruent with the phylogenetic relationships within Phylliidae. The morphological differences are likely caused by adaptations to the specific environmental requirements for the particular clades, as the egg morphology has an influence on the performance regarding the surface roughness. Furthermore, we show that different pinnae types and the adhesive glue evolved convergently in different species. While the evolution of the

Phylliidae in general appears to be non-adaptive judging on the strong similarity of the adults and nymphs of most species, the eggs represent a stage with complex and rather diverse functional adaptations including mechanisms for both fixation and dispersal of the eggs.

Poster No. 4

Anti-icing properties of plant surfaces: the ice formation on leaves visualized by Cryo-SEM experiments

Elena V. Gorb and Stanislav N. Gorb

Department of Functional Morphology and Biomechanics, Zoological Institute, University of Kiel, Germany

Tunable infrared (IR) camouflage materials are an area of high interest in camouflage and thermal heat management systems, which can rely on passive radiative heating and cooling. This work develops and characterizes strategies to pigment polyolefin polymers which are very transparent in thermal IR wavelengths (~8-12 µm) so that different visible coloration, yet high thermal transparency can be achieved simultaneously. To obtain tunable and tailored optical and IR properties, the effect of different geometries on micro-structured polyolefin surfaces is investigated. Polyolefins, specifically polyethylenes (PE) are chosen as the material of choice for this study due to their low emissivity, good durability, and high IR transparency properties along with their ability to be compounded easily with masterbatch pigments of visible colors. PE exists in a translucent or milky-white color in its natural state and is difficult to dye, or paint due to its low surface energy, so pigmentation of PE is achieved using custom compounding of master batches of pigments chosen for their high IR transparency and bold coloration potential to obtain both camouflage and visually appealing colors/ surface finishes for military and civilian applications. Visible appearance and IR transmission, are compared for different blends of LLDPE, HDPE, and pigment concentration. Thickness of pigmented, micro-structured sheets is found to be a significant impacting factor for IR properties, therefore the impact of three different thicknesses (50, 100 and 150 µm) is also investigated. These pigmented polymers can also be molded into lenticular lens patterns of varying pitch and height that highly scatter but minimally attenuate IR transmission. Our results show that visible and thermal IR appearance can be altered significantly through the combination of correct pigmentations and molded microfeatures and will allow for future camouflage and thermal metamaterials to be manufactured at scale with low cost materials.

Poster No. 5

Mechanical and adhesive properties of mucilaginous coat in seeds of *Ocimum basilicum* (Lamiaceae)

Helen Gorges, Alexander Kovalev and Stanislav N. Gorb

Functional Morphology and Biomechanics, Institute of Zoology, University of Kiel, Kiel, Germany

Free standing cellulose nanofibers in mucilaginous plant seeds have an important role in adhesion of the seed. These adhesive properties are associated with the seed dispersal and with the attachment to possible nutritious substrates, as well as with protection of the seed. The fibres generate low adhesion and friction when hydrated and, reversely, high adhesion and friction at certain amount of residual water, when drying. The reinforcement of the mucilage by cellulose fibres is associated with the mucilage mechanical properties. The alignment of the cellulose fibre arrays on the substrates, varying their geometrical and chemical properties, are important for the mucilage adhesive strength. However, the mechanisms underlying the mucilage behaviour and mechanical properties under load at different hydrating states are not fully understood. In order to gain information on mechanical properties of the mucilage, the mucilaginous seeds of *Ocimum basilicum* were imaged and analysed by various microscopy techniques, such as confocal laser scanning microscopy (CLSM) and scanning electron microscopy (SEM). Mechanical properties of the fibres and mucilaginous coat were examined in compression by the force tester Basalt 01. Moreover, the force measurements provided additional information about the adhesive force of the seed at different hydration stages. Our preliminary results show that the surface of the hydrated seeds of *O. basilicum* consist of free standing, straight cellulose fibre bundles, with small starch granules in between. In contact to a glass surface, the ends of the fibers split, which effect in increasing contact areas with the substrate. Hydrated seeds in water showed lower adhesion compared to hydrated seeds in dry environments. We will discuss the dependence of the mechanical properties and adhesive performance of *O. basilicum* seed mucilage on the hydration level and environmental conditions and speculate on possible mechanisms of these effects.

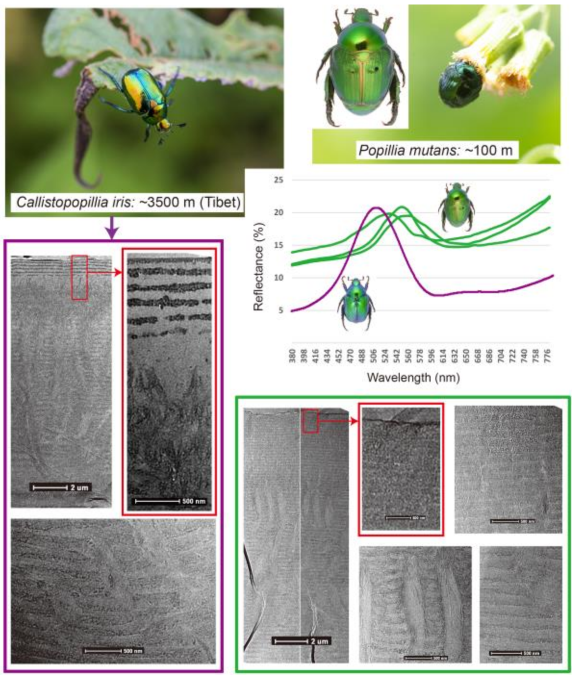
Poster No. 6

Micro- and nano-scopic characters of structural colours in different altitude living shining leaf chafers (Insecta: *Coleoptera*)

Yuanyuan Lu[1], Min He[1], Zhibin Sun[2], Ming Bai[1]

[1]Key Laboratory of Zoological Systematics and Evolution, Institute of Zoology, Chinese Academy of Sciences, Beijing, China

[2]National Space Science Center, Chinese Academy of Sciences, Beijing, China



Most of the shining leaf chafers (Coleoptera, Scarabaeidae, Rutelinae) are diurnal beetles and active in the leaves of various plants. Normally they have high saturation green colour and shining lusters which possible as camouflage, for example *Popillia mutans*. Among them, some special species, for example *Callistopopillia iris* distributed in highly altitude (2000–4000m) areas of Tibet with the strong shining green lusters. Here we studied elytra of species that respectively live in lower altitude and higher altitude for exploring the structural colour mechanism of the beetles.

The results of reflection spectrum (Lambda 950 spectrophotometer) showed: the wave crest of two green specimens of *Popillia mutans* are both in 520 nm, about 20% reflection; the green specimen of *Callistopopillia iris* is in 510 nm, and about 22% reflection. The differences are reflected in the *Popillia mutans* with a second wave crest in about 780 nm. Here we speculated that the second wave crest affected the degree of green colour shining.

Then the cross section of elytral cuticle recorded by Transmission Electron Microscope (TEM) showed that both species with the two-dimensional epicuticula and three-dimensional multilayer structured exocuticula. In addition, the epicuticula of *Callistopopillia iris* are five layers structure and every layer about 0.18 μm thickness while only one layer about 0.1 μm in *Popillia mutans*. The micro- and nano-scopic characters in cuticle of these two species are different also in the details of exocuticula. It seems like the size of multilayer stacks both in the epicuticula and exocuticula influenced the structural colour of different altitude species.

Further simulation research is needed and under going to quantitatively interpret the relevant mechanism. And the related results help us further explore the adaptation and evolution of beetles lived in different altitudes.

Poster No. 7

Marine mammal parasites: surface adaptations of arthropod parasites to underwater attachment

Anika Preuss[1], Thomas van de Kamp[2], Insa Herzog[3], Kristina Lehnert[3], Stanislav N. Gorb[1]

[1]Department of Functional Morphology and Biomechanics, Zoological Institute of the University of Kiel, Germany

[2]Karlsruhe Institute of Technology, Institute for Photon Science and Synchrotron Radiation, Karlsruhe, Germany

[3]Institute for Terrestrial and Aquatic Wildlife Research, University of Veterinary Medicine Hannover, Büsum, Germany

Marine mammals host a great variety of endo- and ectoparasites, which are adapted to their hosts in a co-evolutionary arms-race. However, only little is known about the biology of marine mammal arthropod parasites, but even less about physical aspects of their life in such a challenging environment. We hypothesized that the exoskeleton material and the cuticular structures of the seal louse ([*Echinophthirius horridus*]; Anoplura; Insecta), whale louse ([*Isocyamus deltobranchium*]; Cyamidae; Amphipoda; Crustacea), and naso-pharyngeal mite ([*Halarachne halichoeri*]; Arachnida; Acari) have evolved by adapting their morphology, surface structures and material properties to survive on gregarious and diving wildlife. By using scanning electron microscopy (SEM), we characterized anatomical specializations in these parasites to attachment, which enable their fixation to their hosts during dives, haul-out, currents, turbulence and social interactions. Furthermore, we determined remarkable adaptations in the material composition of the cuticle, including embedded rubber-like proteins and highly-sclerotized areas based on confocal laser scanning microscopy scans (CLSM) and histological sectioning. Moreover, we measured attachment forces of seal lice on seal fur revealing extremely high attachment forces up to 18,000 times the species' own body weight. To provide a potential explanation for these forces, we analyzed the musculature in the legs of seal lice by using Nano-CT scans. In the context of the entire study, we discuss convergent solutions to the challenges connected with marine wildlife as hosts and numerous structure-function relationships in the parasite attachment structures. Some results appear promising for transferring functional solutions from biological systems to materials science and engineering.

Poster No. 8

Influence of Surface Micro-structure in Friction Perception

Sairam Saikumar[1], Maja Fehlberg[1], Roland Bennewitz[1,2]

[1]INM - Leibniz Institute for New Materials, Saarbrücken, Germany

[2]Department of Physics, Saarland University, Saarbrücken, Germany

Friction is a key ingredient in tactile perception of everyday materials such as securing grip and lifting objects[1,2]. Despite this, there is still a lack of complete understanding in friction perception. We present two interesting cases which elicit the role of surface microstructure in the perception of friction. Skedung et al.[2] have shown that patterned surfaces through strain induced surface wrinkling have a minimum regime in fingertip friction. To answer the question if we observe this on randomly rough surfaces, we combine surface polishing and sandblasting techniques on Aluminium metal to manufacture self-affine randomly rough surfaces of average roughness (Ra) ranging from 0.2 to 6 µm. With strong dependence on fingertip moisture, we show promising first results that evidence the existence of a minimum friction regime between 1 and 3 µm Ra. In addition, we validate its direct correlation to perceived pleasantness through forced choice tasks.

Secondly, we investigated the perception of friction for tactile exploration of a unique set of samples whose fabric-like surfaces consisted of micropillars in a hexagonal arrangement. The measured fingertip friction in this case, is governed by the bending stiffness of the pillars which is controlled by the radius (20–75 µm), height (100–450 µm) and the elastic modulus[3]. In forced choice tasks, participants noticed relative differences in friction as small as 0.2, and even smaller when a sample with less than 100 µm distance between pillars is omitted from the analysis. In an affective ranking of samples upon active touch, the perception of pleasantness is anticorrelated with the measured friction.

The goal of these results is to enhance the understanding of perception of fingertip friction on both natural and engineered surfaces, thereby enabling rational design of materials.

[1] Okamoto, S., Nagano, H., Yamada, Y.: Psychophysical dimensions of tactile perception of textures. *IEEE Trans. Haptics* 6, 81–93 (2013).
[2] Skedung, L., Arvidsson, M., Chung, J.Y., Stafford, C.M., Berglund, B., Rutland, M.W.: Feeling small: exploring the tactile perception limits. *Sci. Rep.* 3, 2617 (2013).
[3] M. Fehlberg, K. Kim, K. Drewing, R. Hensel, R. Bennewitz: Perception of Friction in Tactile Exploration of Micro-structured Rubber Samples. *EuroHaptics 2022*, Springer Nature 2022, 21-29.

Poster No. 9

Development and Testing of Thermal "Buddha Board" Techniques for Infrared Transmissibility Control

Xiaoruo Sun, Mehnab Ali, Shima Jalali, Asad Asad, Patricia Dolez, James Hogan and Dan Sameoto

Mechanical engineering, University of Alberta, Canada

This work presents the development and characterization of a thermal "Buddha Board", which is a type of device that has well-designed surface microstructures so that it has unique optical properties and tunable IR transmissibility. Similar to the original Buddha Board, the thermal version relies on wetting to tune the visible and IR appearance. For visible Buddha boards a highly structured or porous surface that scatters visible light and normally appears white, is wetted with an index matched fluid (usually water) to reveal a different surface underneath it. This strategy is extended in this work to the thermal infrared regime using including micro channels, and micro/nano pillars and pores in structural materials that are mostly transparent to thermal wavelengths from 8–12 µm. Infrared transmissibility of the thermal Buddha Board is controlled by wetting with infrared transparent liquids and demonstrates a possibility of controlling the thermal emission of metamaterials and composites by increasing or decreasing thermal transparency of thin films. Microstructure geometries and features in the thermal Buddha Board need to be as a size scale on the order of the wavelength of the thermal radiation to have a substantial impact on reducing transmission and features can be designed to absorb without scattering, or scatter without substantial absorption. Other than the geometry, the materials also played an important role, therefore, several IR transparent materials are tested for their performance. These systems may be integrated with open surfaces or microchannels in future developments for thermal appearance tuning.

Poster No. 10

Investigation of morphological and physical characteristics of the adhesive secretion in stick insects (Phasmatodea)

Julian Thomas, Stanislav N. Gorb and Thies H. Büscher

Functional Morphology and Biomechanics, Institute of Zoology, University of Kiel, Germany

Insects are one of the most widespread animal lineages in the world and are found in a wide variety of habitats. This is likely a result of their strong ability to adapt to environmental factors and to locomote in different terrains. Adaptations facilitating insect locomotion involve two main attachment structures: (1) claws for attachment on rough substrates, (2) adhesive pads producing a fluid secretion for attachment on smoother surfaces. The influence of claws as well as adhesive pads on movement and attachment has been studied extensively, but the functional mechanisms of the adhesive secretion are yet to be further explored.

In this study, the appearance and the physical properties of the adhesive secretion of the stick insect Medauroidea extradentata were analyzed to reveal its effects on the pad adhesion. In order to observe the native droplets at a high resolution, the footprints were examined in a cryo-scanning-electron-microscope. This allowed the investigation of the frozen droplet morphology, which revealed that the adhesive secretion consists of several immiscible fluids, which have different proportions in the droplet and surface structure. The pad fluid droplets also showed strong interactions with contaminants. Furthermore, the change of volume over time of individual droplets was determined using a white light interferometer, which indicated different evaporation rates in different droplets. There were droplets that evaporated completely over short time and such whose volume remained constant, even for weeks.

The different morphologies and evaporation rates of the droplets may indicate that the adhesive secretion can support different functions of the pad, such as adhesion, evaporation reduction and self-cleaning.

Poster

No. 11

Dry self-cleaning of photovoltaic panels with nanostructures in-spired by the sandfish (*Scincus scincus*)

Patrick Weiser[1], Weibin Wu[1] , Marc Schneider[1], Markus Guttmann[1], Guillaume Gomard[2], Matthias Worgull[1], Hendrik Hölscher[1]

[1]Karlsruhe Institute of Technology (KIT) - Institute of Microstructure Technology, Germany

[2]Now at: Carl Zeiss AG, ZEISS Innovation Hub @ KIT, Germany

Soiling on solar panels is a serious issue in sunny but arid regions. Since soiling losses can accumulate to up to 80% [1], regular cleaning of the panels is required. Current techniques for cleaning range from simple manual approaches to expensive automated machinery. What practically all of these techniques have in common is the use of water to wash the dust particles of the surface. However, the places that are most suited for large solar farms are located in sunny, warm and arid regions of the world, where water is a scarce resource. We, therefore, present an approach to dry self-cleaning of solar panels, that aims to reduce losses by soiling without the use of water, manual labor, or expensive machinery.

This approach is inspired by the microstructures found on the scales of the sandfish (*Scinus scincus*) and several species of snakes. These reptiles live in arid and sandy regions and have evolved remarkable capabilities to move on and through the sand, which is a large part of their environment, very quickly and efficiently. The ability to move through sand is – in part – due to the structures found on their scales. These structures resemble flat steps or, in the case of snakes – step like structures with a finger like contour. Depending on the exact species the structures have a step height of 50-300 nm and a periodicity of around 3 μm. The structures result in an anisotropic friction, i.e., the friction coefficient is higher in one direction than in the other. This can be measured by atomic force microscopy, but has also a macroscopic effect. If a reptile scale is excited with an arbitrary vibration, e.g., through a small vibration motor, sand particles placed on it are preferably moving in the direction of the lower coefficient of friction and will therefore eventually fall off the surface, thereby cleaning it [2].

Our aim is to produce a technical surface that uses this effect to aid in the cleaning of solar panels. For that we varied different geometry parameters such as step height and periodicity of the steps as well as the parameters of the excitation vibration to find the optimal geometry and excitation for the transport of particles of different sizes. Furthermore, we are working on new roll to roll hot embossing techniques to produce large areas covered in these structures efficiently since many thousands of square meters of surface will be needed to cover even a small solar farm. Finally, we will conduct field tests with our surfaces on solar panels in different regions and climates of the world.

Figure 1: a) The sandfish (*Scincus scincus*) in its natural habitat. b) AFM scan of the scale of a sand-fish. The step like structures create anisotropic friction

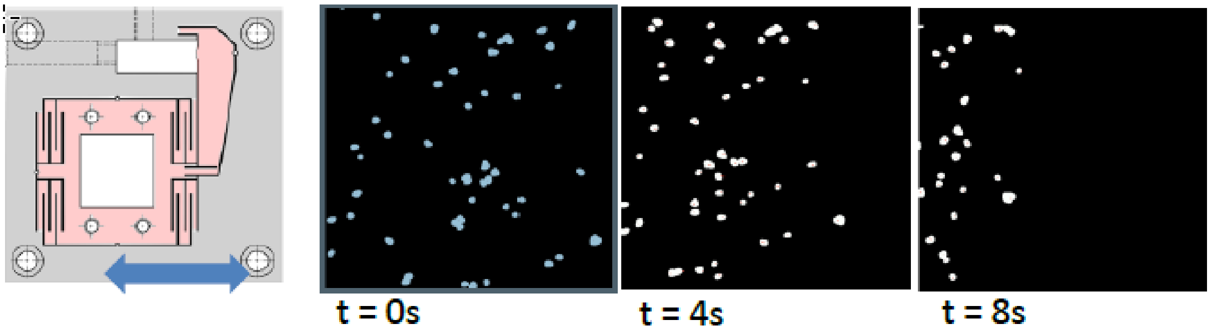


Figure 2: a) Schematic of the vibration stage used to test particle transport on reptile scales and artifi-cial samples. The area marked in red oscillates in the direction of the arrow. b) Sequence of screen-shots taken from the particle tracking system. One can observe how the particles are slowly moved to the left by the vibration.

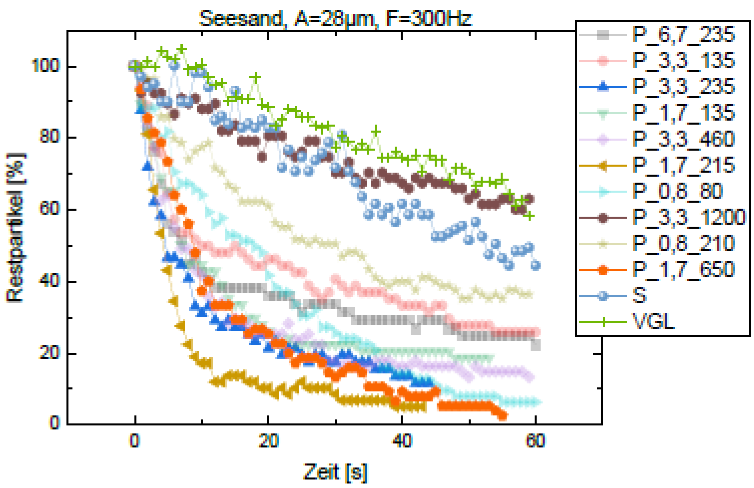


Figure 3: Measurement of residual particles left on different artificial samples over time. The excitation used in this experiment had a frequency of 300 Hz and amplitude of 28µm. Some combinations of step height and periodicity are superior to others.

[1] Schill, C; Brachmann, S; Koehl, M; Impact of soiling on IV-curves and efficiency of PV-modules. *Sol. Energy*, 2015. 112.
[2] Wu, W., et al., Snake-Inspired, Nano-Stepped Surface with Tunable Frictional Anisotropy Made from a Shape-Memory Polymer for Unidirectional Transport of Microparticles. *Adv. Funct. Mater.* 2021. 31(19).