LiNaBioFluid

Laser-induced Nanostructures as Biomimetic Model of Fluid Transport in the Integument of Animals

European Commission

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The project

Lizards and bark bugs as models for the functionalization of technical surfaces - this is the idea of the EU project "LiNaBioFluid". Both of these animals exhibit outstanding wetting properties. Moisture harvesting lizards, for instance, are specialists when it comes to surviving in extremely dry environments: The scaly structure on their integument enables them to passively collect small amounts of water which is then transported unidirectionally towards the snout through thin, half-open capillaries.

In contrast, bark bugs meet other challenges to survive. Due to their excellent wettability, they darken during rainfall as a camouflage strategy and become almost invisible on dark tree bark. As members of the true bugs, they also possess scent glands with sophisticated guidance systems to produce defense fluids. These fluids are transported via structured microchannels to particular body areas where they are then evaporated.

Such wetting and fluid transport properties can also be very beneficial for various industrial applications where fluid transport is involved.

The project "LiNaBioFluid" aims to understand the underlying wetting principles and fluid transport mechanisms by abstracting the animals' surface properties and transferring them to technical surfaces. Fast and directional capillary transport combined with wetting of large areas on technical surfaces could, for example, be an advantage when it comes to reducing friction and wear.

Within the project, the transfer of biomimetic features to technical surfaces is implemented by laser fabrication. Innovative laser processing strategies, including laser ablation with ultrashort pulse lasers and two-photon polymerization, are employed to fabricate hierarchical micro- and/or nanostructures which correspond to the surface topography of their biological models.

The highly interdisciplinary consortium includes seven partners from four European countries and combines expertise from the fields of zoology and biomimetics, physics, materials sciences, laser-matter interaction, production technology, mechatronics, life sciences as well as tribology. The project is funded by the EU program Horizon 2020 FET Open (reference no. 665337).

Biology

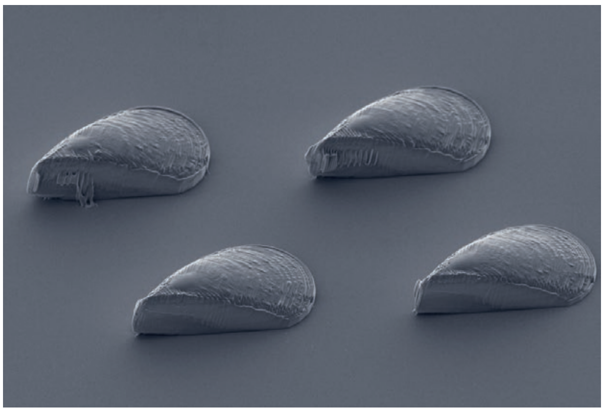
The skin of moisture harvesting lizards as well as cuticles of bark bugs exhibit specific topographies in the micro- and/or nanometre range that not only alter the wettability but also enable the directional transport of water or oily liquids. Within the project "LiNaBioFluid", these features are systematically analyzed in order to understand their functionality. The characterization of the biological structures includes the analysis of their topography, wetting properties, chemical composition and bio-mechanical function.

In addition, theoretical modelling is performed to help understand the physical functionality of water transport on the animal surfaces. The biological mechanism for the fluid transport is then abstracted and the identified functional principles are transferred to artificial structure designs.

– Measurements: The surface topography is determined by optical microscopy, scanning electron microscopy, atomic force microscopy and optical coherence tomography. The chemical composition is investigated by X-ray photo-electron spectroscopy and energy-dispersive X-ray spectroscopy. To analyze the wetting properties, contact angle measurements are performed and the fluid transport is characterized by high-speed video microscopy.

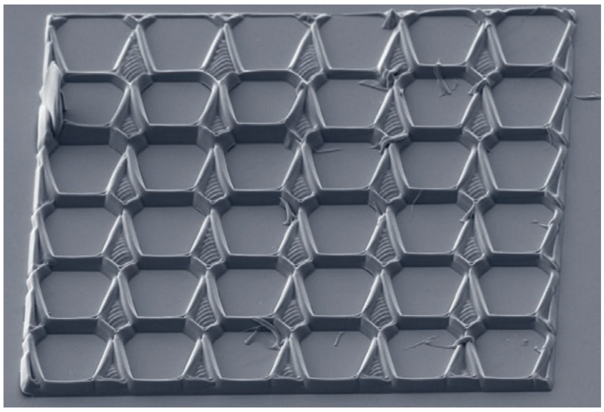
– Simulations: Fluid transport on bio-inspired surface structures is described by (semi-)analytical models based on the Young-Laplace equation and on pinning forces. In order to simulate boundary effects and complex geometries, computational fluid dynamics are applied.

– Participating partners: JKU and RWTH.



Organic materials

The integument of lizards or bark bugs mainly consists of natural organic biopolymers like chitin, waxes or keratin. To clarify the function of the diverse topographies found on these natural models, the identified topographies are abstracted and transferred onto different organic polymer materials. The abstracted replicas are produced either by direct laser ablation of flat polymer substrates or by an imprint process using silicon and/or epoxy



resins. Using two-photon polymerization, three-dimensional polymer structures are fabricated as well. This technique employs a short pulsed laser which writes small features of large variability into a photoresist. Applying these structuring processes, a huge variety of surface topographies with defined micro-geometry, polarity and rigidity is created. Ultimately, the wetting behavior of the manufactured surfaces is evaluated by systematic variation of the feature size and by comparison with the structures found in nature.

– Investigated polymeric materials are acryl, epoxy and silicone resins.

– Fabrication resolution: Two- and three-dimensional structures with minimum feature sizes down to one micron on a flat area or capillary channels up to one millimeter lateral dimension are fabricated.

– Fabrication geometries: Possible biomimetic feature designs include pillars, droplets, naps and open polygon shapes.

– Participating partners: JKU, RWTH

Inorganic materials

Many industrial applications such as slide bearings, for example, require surface functionalization processes for inorganic materials to optimize the wetting or friction behavior on different workpiece geometries. With femto- and picosecond pulse lasers, two different surface processing methods for these materials are pursued within the EU project "LiNaBioFluid". By direct laser ablation, complex-shaped topographical features with minimum dimensions in the range of several ten microns are realized. This method is well suited to imitate the microchannel system of the biological models that is able to transport liquid unidirectionally. Smaller periodic surface features with dimensions in the range of several hundred nanometers up to several microns are fabricated by self-organization. Possible biomimetic self-organized features include spikes, grooves and ripples with different periodicities. With these features, the wetting properties of the surface can be tailored from highly hydrophilic to highly hydrophobic characteristics.

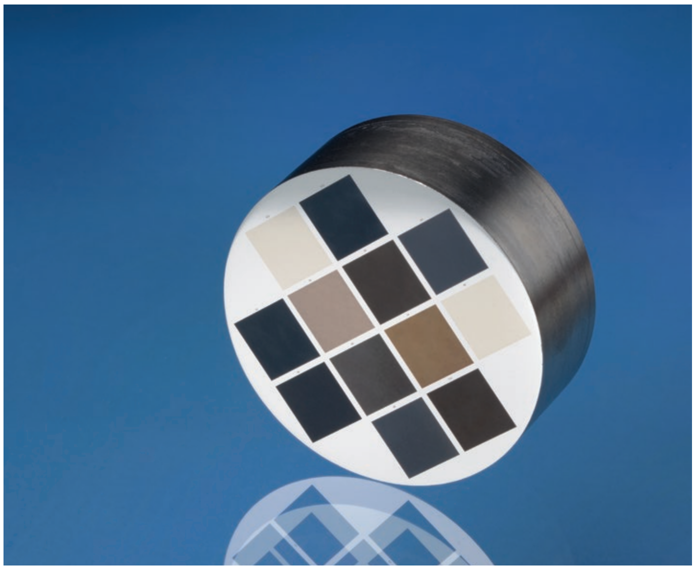
- Investigated inorganic workpiece materials are steel (100Cr6, 16MnCr5, 42CrMo4), titanium alloys, silicon.

- Workpiece geometries: Laser parameter screening and surface characterizations are performed on flat samples of several square centimeters size. At the end of the project, a 3-dimensional complex-shaped freeform demonstrator will be laser-structured.

- Measurements: The surface wetting behavior is determined with a contact angle measurement setup or with a high-speed camera. The friction and wear behavior of the different surface topographies is tested in a tribometer setup.

- Simulations: The formation of self-organized laser-induced surfaces features is simulated based on hydrodynamic approaches and Sipe's theory.

- Participating partners: BAM, CSIC, FORTH, Fraunhofer IPT, HTC



The Institute of Electronic Structure and Laser (IESL) belongs to the Foundation for Research and Technology-Hellas (FORTH) and is a multi-disciplinary science laboratory which focuses its research on materials science, technology and laser interactions with matter. Within the project, FORTH studies the fs-laser-induced generation of self-organized structures on inorganic material surfaces, both theoretically and experimentally. Also, the wetting properties of the various laser-structured biomimetic surfaces are further characterized and analyzed.

The Institute of Optics belongs to the Spanish National Research Council (CSIC). Currently, its research activities focus on nano- and ultrafast science which employs numerous laser structuring strategies, aiming to generate large area, homogeneous nanostructures in different materials. Within the project, CSIC fabricates laser-induced nanostructured surfaces in inorganic materials on large areas. Additionally, femtosecond pump-probe microscopy is performed during fabrication in order to unravel the formation process of nanostructures.

The Bundesanstalt für Materialforschung und -prüfung (BAM) is a senior scientific and technical German federal institute. BAM's division 6.4 provides many years of experience in the field of laser-matter interaction using short and ultrashort laser pulses. Within the project, BAM is investigating process parameters for generating different self-organized laser- induced structures, both experimentally and theoretically, on inorganic materials by fs-laser pulses and characterizes them with a particular focus on friction and wear.

The research group of biomimetics at the Institute of Biology II at RWTH Aachen University focuses on the characterization of biological surfaces which typically represent a highly specialized primary interface between a living organism and its environment. Within the project, the RWTH will mainly be responsible for the characterization of the biological surfaces of lizards and bark bugs as well as for the derivation of functional principles for surface wettability.

In the project "LiNaBioFluid", two institutes of the Johannes Kepler University (JKU) Linz are involved: The Institute of Applied Physics and the Institute of Biomedical Mechatronics. The activities of the Institute of Applied Physics relevant for the project are photo-induced structure formation and modification of polymer surfaces. The scientists at the Institute of Biomedical Mechatronics are mainly concerned with biomimetics, biological surface characterization, developing measurement devices in biology and theoretical modelling of biological processes.

The Fraunhofer Institute for Production Technology IPT offers tailor-made solutions in the fields of process technology, production machines, mechatronics, production metrology, as well as quality and technology management. Within the project, the Fraunhofer IPT provides expertise in laser structuring of complex shaped geometries with 5+4-axis machine solutions. In particular, the focus is set on functionalizing surfaces of large area freeform workpieces by micro- and nanostructures.

The High Tech Coatings GmbH (HTC) is a daughter company of Miba, one of the leading strategic partners of the international engine and automotive industry. The product portfolio includes sintered components, engine bearings, friction materials, power electronic components and coatings. In the project, HTC provides their expertise in applied tribology and lubrication and will be responsible for the design of model surfaces of a demonstrator as well as for related tribological tests.

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www.laserbiofluid.eu

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