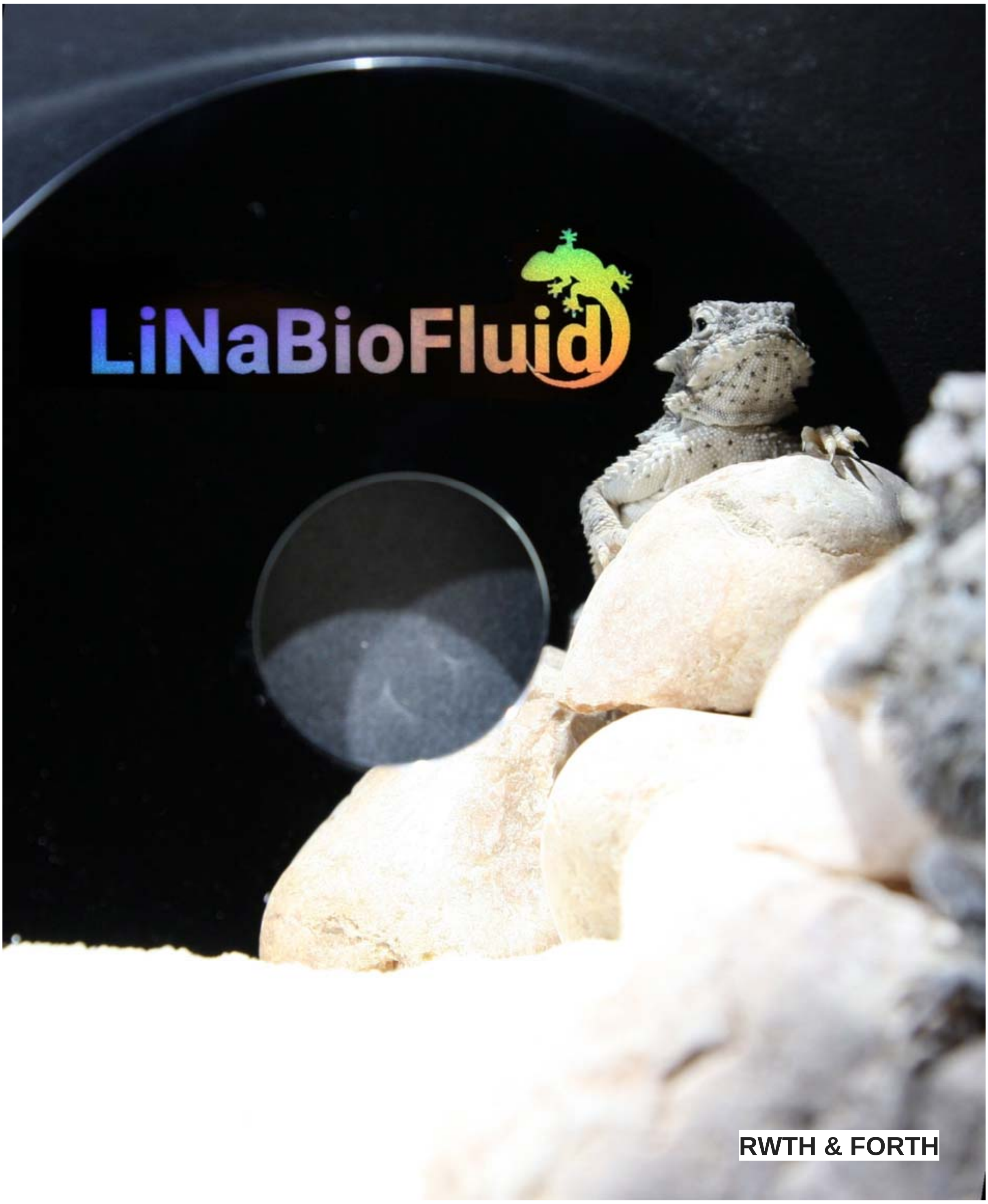


Deliverable 4.3

Laser-fabricated biomimetic structures up-scaled to manufacturing size and shape

Reporting period	from	**01.03.2017**	to	**31.12.2017**
Report completed and released		**19.12.2018**		

Corresponding work packages: *WP4*

Corresponding task: *T4.2 Scale-up to manufacturing size*

Contributing WP4 partners: *Fraunhofer IPT, CSIC, FORTH, HTC*

1. Objectives

This deliverable involves the identification of the optimum processing parameters for the fabrication of large-size (10 cm^2), non-flat areas, mimicking lizard- and bug-like surface structures on selected inorganic materials, employing high-repetition rate pico- and femtosecond lasers and beam scanning. The parameter space explored will include the parameters listed in D4.2 and additionally include input beam diameter, beam shape, focal length of scanning lens and dynamic beam expander settings. Optimized structures will be fabricated and their functional performance in terms of fluid transport tested.

2. Results

2.1 Laser parameters

The table below illustrates the different irradiation parameters explored by the two partners with laser processing capabilities (CSIC and Fraunhofer IPT), covering a broad parameter space.

	Wavelength	pulse duration	repetition rate	polarization
CSIC	1030 nm	350 -500 fs	10 – 500 kHz	linear
Fraunhofer IPT	532 nm	8 ps	80 - 1000 kHz	linear

Table 1: Laser irradiation parameters used by CSIC and Fraunhofer IPT.

2.2 Materials and sample forms investigated

As for the substrate materials studied, it was decided to concentrate on steel 1.7131 as defined in the project. HTC provided the samples that consisted of cylindrical shafts of 60 mm length and 26 mm in diameter, and a moderate degree of polishing.

2.3 Bug and lizard structures

Surface structures inspired by the microstructures of different European bug species (e.g. Dysodius Magnus) and moisture harvesting lizards were fabricated on steel shafts with ps and fs lasers. Two particular types of bug structures and a lizard structure were selected for this purpose, as shown in Fig. 1. On the millimeter scale, capillary channels (a) transport the water over the entire cuticle. The regions between capillary channels is covered by so-called naps in the micrometer scale (b) or nanometer scale (c).

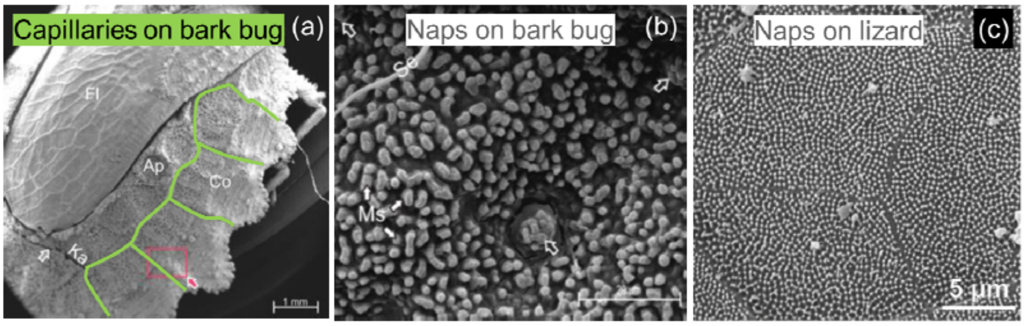


Fig. 1: (a, b) SEM images of Dysodius Magnus (bark bug). Taken from F. Hischen et al., Biology Open 6 (2017), 1209-1218 (c) SEM image of Sceloporus jarrovii (Yarrow's spiky lizard). Taken from U. Hermens et al., Applied Surface Science 418 (2017) 499–507

We succeeded in producing artificially structured surfaces in different materials that are inspired by these bug and lizard structures and also exhibit facilitated fluid transport for different test fluids. With regard to large-area designs, we furthermore succeeded in laser fabricating prototypes using cylinder-shaped shafts, covered by different kinds of structures (c.f. Figs. 2(a) and 4), with areas exceeding 20 cm^2.

For mimicking the nap structures, three different self-organized laser-induced structures were fabricated with a femtosecond laser system at CSIC, namely ripples (low-spatial frequency (LSF) LIPSS), grooves and spikes, as shown in Fig. 2(b-d). It was found that the spike structure best resembled the nap morphology of the bug cuticle and were similar in diameter (2-3 µm). The spike structure was also similar to the naps of the lizard structure but larger in size.

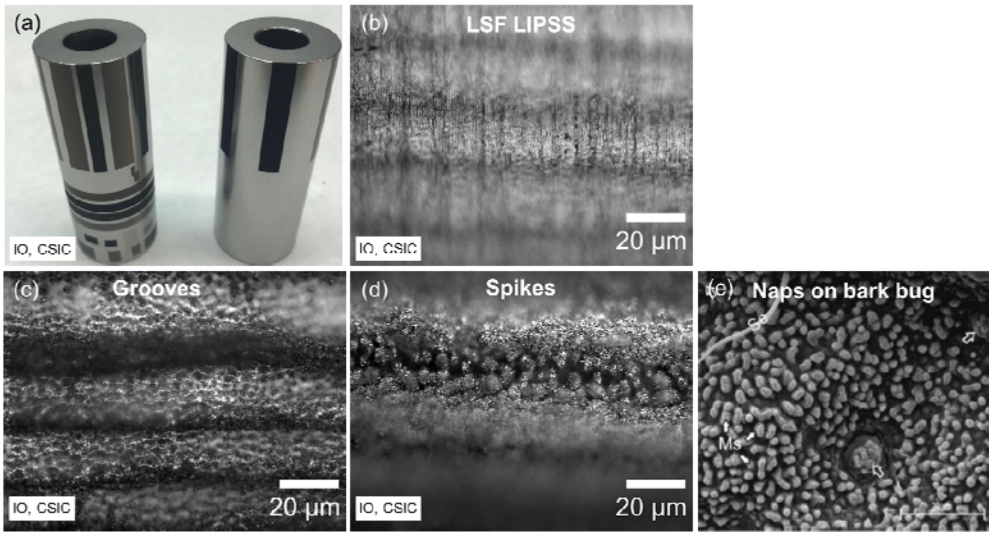


Fig. 2: Femtosecond laser-processed steel shafts, featuring stripe-like and annular regions with certain micro-/nanostructures. (b-d) Optical micrographs of different regions, showing three kinds of surfaces. The spike structure shown in (d) best resemble characteristic naps of the surface structure found in bark bugs (e).

The laser structured regions were tested for their oil transport properties by FORTH. To this end, the shafts were placed vertically in a petri dish that was partly filled with Shell Rimula oil (c.f. Fig. 3). A CCD camera recorded images of vertical rectangular-structured regions (5 mm x 30 mm) of the shaft, evaluating the upward fluid transport of the oil, against gravity. As can be seen in Fig. 3, significant upward transport was observed for all three structures, with the nap-like spike structures performing best, reaching a height of 9 mm after 20 min. For comparison, unstructured regions of the shaft did not show significant upward transport.

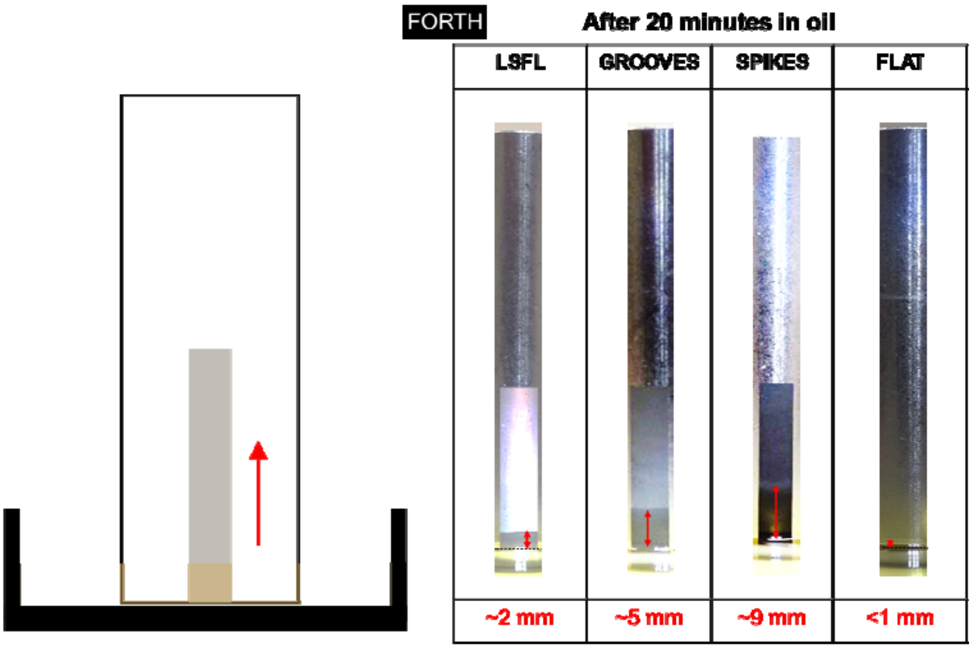


Fig. 3: (Left) Sketch of the setup for measuring upward transport of oil, based on a partly filled petri dish and the vertically placed shaft. (Right) CCD images of different shaft regions recorded after 20 minutes. The figures given below each structure indicate the height of the oil level above the initial level.

In order mimic lizard and bug-like structures on non-flat surfaces, two shafts have been laser-textured with a picosecond laser (8 ps, wavelength 532 nm) at Fraunhofer IPT in addition. On one shaft, LIPSS structures have been fabricated and on the other shaft, LIPSS structures with superimposed capillaries with different distances (about 10 µm depth, distances 25 µm, 50 µm, 75 µm, 100 µm) have been fabricated. The two shafts are shown in Fig. . Height measurements of the capillaries are shown in Fig. .

Fig. 4: Picosecond laser-processed non-flat steel shafts, featuring LSFL + capillaries (left) and LSFL with a size larger than 20 cm^2.

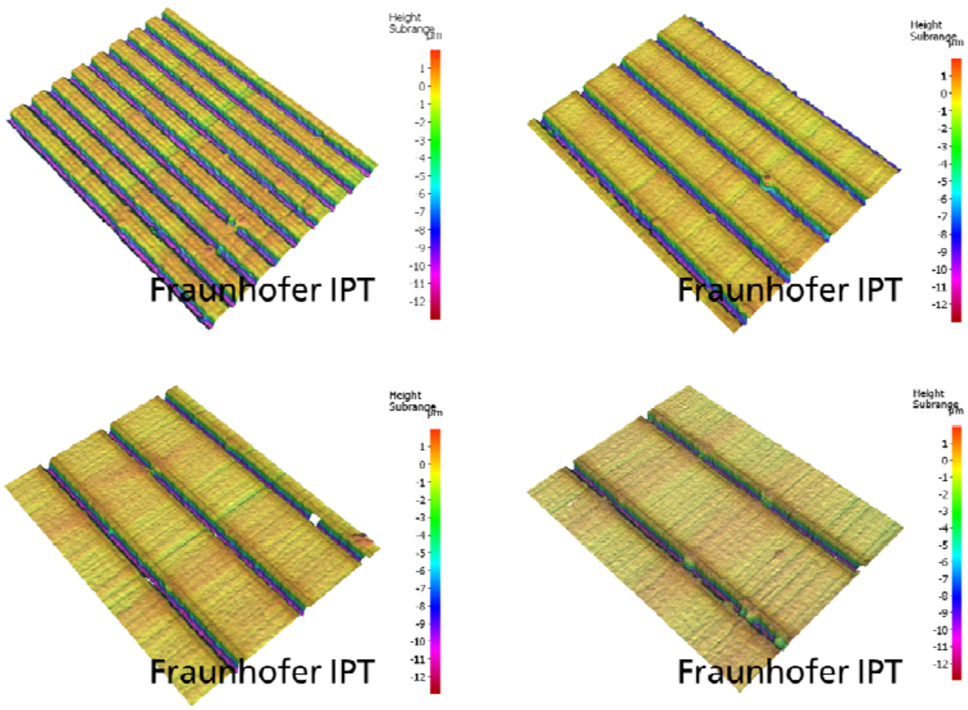
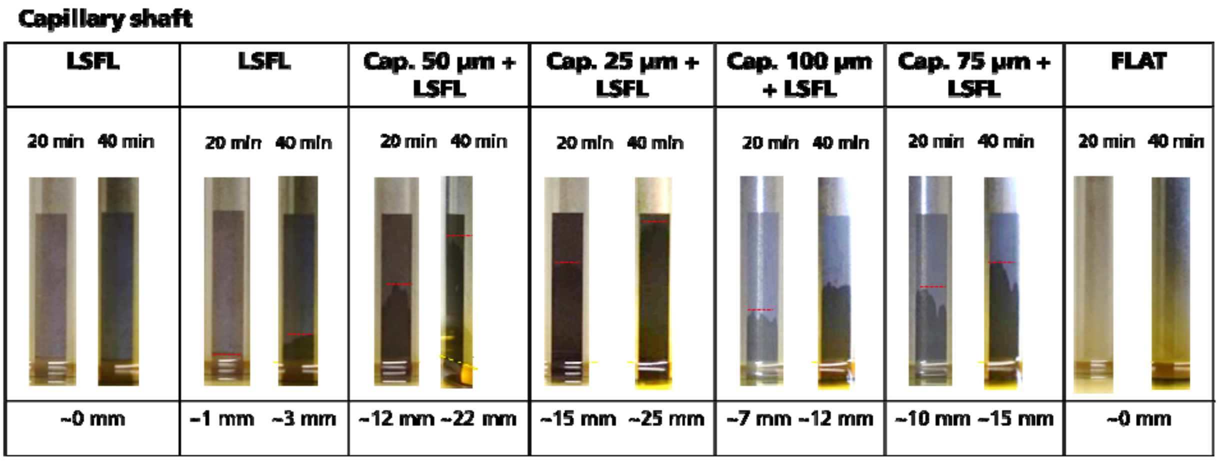
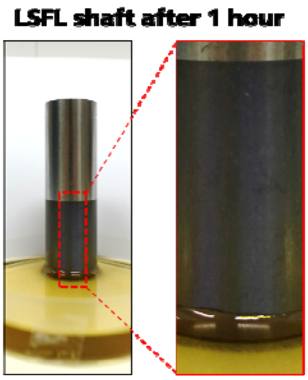


Fig. 5: Height measurements of the capillaries with different distances.

The laser-structured regions were tested for their oil transport properties by FORTH in the same way as the ones produced by CSIC. The results can be seen in Figure 6. The shaft that is only covered with LSFL and the reference show only minor fluid transport whereas the fluid transport against gravity increases for the capillaries in combination with LSFL. The wetting behavior is increased with decreasing capillary distance.





3. Evaluation of results and goals

The expected goal of D4.3, to fabricate functional biomimetic surface structures of large size (> 10 cm^2) on non-flat surfaces and obtain improved fluid transport compared to non-structured surfaces has been successfully reached. The particular system chosen, steel as a material and oil as a fluid demonstrates the beneficial influence of laser-structured surfaces for promoting lubrication for friction reduction, which is the final goal of the LiNaBioFluid project.