REVIEW

Laser processing of micro/nano biomimetic structures

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Funding information
National Natural Science Foundation of China, Grant/Award Numbers: 17105022, 52005059; National Science and Technology Major Project, Grant/Award Number: 2017YFA04009; Key Laboratory of Emerging and Frontier Technology of Sichuan Province, Grant/Award Number: 2020JYH04X001; Fundamental Research Funds for the Central Universities in China, Grant/Award Number: 2020CDJQY-A035; China Postdoctoral Science Foundation, Grant/Award Numbers: 2020M673126, 2020M673127; “Construction of double city economic circle in Chengdu City” scientific and technological innovation project, Grant/Award Number: KJZXZD2020011; Funds from Sichuan Province Key Laboratory of Artificial Intelligence, Grant/Award Number: 2019yrj01; Graduate Research and Innovation Foundation of Chongqing, Grant/Award Number: CYB20009

Abstract
Inspired by nature, many researchers have noticed that the micro- and nano-structures originated from organism’s surfaces which exhibit unique properties such as superhydrophilicity, drag reduction, structure colour have much use in academic value. However, conventional processing methods for mimicking biomimetic surface need multistep and is time wasting, not environmental friendly and uneconomic. Thanks to the development of ultrafast laser technology, the pulse duration can reach femtosecond scale, which can precisely realize micro- and nano-processing in one-step. Here, we introduce and demonstrate the principles of some typical properties. The typical structures caused by interaction between laser and material are discussed. Moreover, laser-processing methods for biomimetic surface are highlighted to achieve specialized performance.

1 INTRODUCTION

Nature has been providing inspiration to scientists and engineers throughout the development of science and technology. In the process of structural designs and optimization, functions with good performance can often be obtained directly by learning and imitating the shape of creatures in nature. With the progress of science and technology, simple shape imitation can no longer meet people’s needs for special functions. Scientists have found that the surfaces of many organisms have special micro/nanostructures with specialized properties. In the desert, the wings of Namib Desert beetle [1] have superhydrophobic riblets. They cooperate and draw droplets from air. Janus membrane developed from it can harvests droplets in dry air [2] and separates oil from water [3], which has huge potential in lack of water and preventing oil leaking. By applying the bionic structures onto the surface, devices can show better performance.

However, the structures on the surface of these organisms tend to be micro/nano scale and complex. When adopting conventional methods, the tools need to be dressed to be consistent with the structure. For example, when grinding micro bionic riblets, the grinding wheel is dressed as tooth along circumference [4]. Although the efficiency is high, the wear of the tools will cause the inconsistency of the structures.
What’s more, the material removal mechanism \cite{5,6} will further lead to uncertainty of the surface microstructure forming.

Many innovational methods are exploited for micro/nano manufacturing, such as reactive ion etching \cite{7,8}, lithography \cite{9}, chemical vapour deposition \cite{10}, electrochemical processing \cite{11}, template \cite{12}, self-assembly \cite{13} etc. But these methods have complicated procedures and multistep, which are time wasted. The waste from the manufacturing process also affects the environment.

Different from other methods, ultrafast laser stands out with its many advantages: (1) Good monochromatism, high coherence and strong directivity; (2) high resolution and precision; (3) unlimited materials. In addition to the above advantages, it also has good operability and flexibility, and one-step is enough for almost structures. Therefore, it has become a hot field in micro/nano structure field.

2 CHARACTERISTICS OF MICRO/NANO BIOMIMETIC SURFACE STRUCTURE AND ITS MECHANISM

Many creatures exhibit special functions because of their unique micro/nano structures on the surfaces. By studying the physical and chemical properties of these surfaces, scientists have analysed and obtained the reasons why biomimetic surfaces exhibit these properties, which provides a basis and method for artificial preparation of bionic surfaces.

2.1 Superhydrophobic surface

Superhydrophobic surface is the most common functional surface in nature and the most studied by scientists, no matter animals (water strider \cite{14}) or plant (lotus \cite{15}, pitcher plant \cite{16} and rose petal). Superhydrophobic surface have micropapillae, as show in Figure 1a,b \cite{17}, which enables the contact angle between surface and droplet more than $150^\circ$. Air trapped into micropapillae and micropapillae work together to lift the droplet, which makes surface superhydrophobic.

Droplet can adhere to some kinds of superhydrophobic surface, like rose petal shown in Figure 1c, which is called “petal effect.” On the contrast, when droplet is on some other superhydrophobic surface, the surface only needs to tilt a very small angle (less than $5^\circ$) to make droplet falls off. This kind of superhydrophobic surface has self-cleaning property and can be used to prepare self-cleaning surface. The most typical example in nature is the surface of lotus leaf which is called ‘lotus effect.’ Both petal and lotus leaf have the same micropapillae to which smaller nanofolds are attached, while the surfaces show different adhesion to droplets.

Based on the above phenomenon, Feng et al. \cite{19} found that lotus surface presents Cassie state while petal surface presents
Cassie impregnating wetting state, as shown in Figure 2a. Further observation revealed that droplet immerses onto nanofolds on petal, thus adheres to the surface. Nanofolds of the louts show opposite and play the same role as micropapillaes. Bharat et al. [18] studied the effect of distribution of nanofolds on the adhesion and found a larger pitch value (space between two nanofolds) and smaller peak-to-base height on microstructure may lead to high adhesion while maintaining superhydrophobicity.

2.2 Structure drag reduction

With the continuous reduction of the earth’s energy and the increase of people’s demand, how to improve the efficiency of energy has become a hot topic. Drag reduction is the most direct way to reduce energy consumption in physical movement. In the 70s, NASA inspired by sharkskin [20,21], as shown in Figure 3a, found that the tiny grooves can effectively reduce the wall friction surface. The discovery completely dispelled the idea that the smoother the surface is, the less resistance it brings. Scientists also gradually found birth feather (Figure 3b) [22] Rynchops beak (Figure 3c) [23] have the similar groove shape structures which can reduce friction when flying or hunting.

At present, there are three theories about the drag reduction mechanism of non-smooth surface of microgroove structure: Protrusion height, secondary vortex and micro bearing. Gallagher [24] first put forward ‘protrusion height’ theory. When the groove is arranged longitudinally, the increase of the thickness of the viscous decreases the velocity gradient in the near wall region. According to

\[ \tau = \frac{\partial u}{\partial y} \]  

the wall friction resistance is reduced and the drag reduction effect is achieved. When the groove is arranged transversely, there will be longitudinal vortex. It acts as a micro “bearing” for the upper fluid, thereby reduce wall friction reduction is obtained. Bacher [25] supported that secondary vortex is generated because of the interaction between vortex and the top micro groove. The “secondary vortex” interact with the streamwise vortex which weakens the transverse flow and maintain
low speed fluid in the grooves. It reduces the momentum exchange with the upper velocity, thus reducing the wall friction resistance.

### 2.3 Structure colours

All the things and organism present its unique colour and make up a chromatic world. In fact, some of them are coloured by pigment, the others are coloured due to their structured surfaces which are usually called structure colours. The wing of *Morpho* butterfly [26] is a typical example that exhibits metallic, iridescent, brilliant blue colour due to its photonic micro- or nanostructures (Figure 4a). The interference between light and two-dimensional (2D) or three-dimensional (3D) periodic micro-structures result in diffraction and scattering thus colourless materials can demonstrate different colours even with no pigment [27]. For example, Vorobyev and Guo [28] fabricated nanoprotrusions and nanovoids on aluminum, gold, titanium and platinum by femtosecond laser which presented kinds of colours different from its own colour without pigment. Livakas et al. [29] fabricated omnidirectional iridescent metal surfaces exhibiting diffraction at any angle of light incidence.

Structure colours can not only make gorgeous surfaces but also improve the efficiency of light absorption. Wu et al. [31] ablated quasi-ordered array of sharp conical microstructures on silicon surface in the SF$_6$ environment by pulse laser and the absorptivity of nearly 90% in the wavelength range from near UV to near infrared light was obtained. It was the first time black silicon was obtained. Papadopoulos et al. [32] produced omnidirectional antireflective glass with nanospikes exhibit a quasiperiodic arrangement and present random height and width distributions which show reflectivity smaller than 1% at different incident angle in the visible spectrum.

There are many similar examples in nature. It is because of the diverse micro-nano structures on the surface of organisms that their surfaces have a rich variety of properties. Imitation and reproduction of these structures can provide us with many potential applications. Laser machining, as a top-down processing method, has been widely used in micro-nano manufacturing due to the diversity and accuracy of its processing structures.
The typically laser-based biomimetic structures are shown in Table 1. From it, we can see the drag/friction reduction and structure colours surface are often hydrophobic at the same time. So many biomimetic surfaces have both hydrophobicity and its specific functionality.

### 3.1 Laser induced periodic surface structures

The laser induced periodic surface structures (LIPSS) was first observed in the 1960s, Birnbaum [33] observed a periodic fracture structures in the machined area when ablated germanium using ruby pulse laser at an incident angle of 75°. The structures were a series of parallel grooves. At the same time, Emmony et al. [34] also found a kind of fracture structures with the period as the laser wavelength when using nanosecond pulse laser. With further research, it was found that pulse laser can also produce such structures on materials such as semiconductors, metals, glass and polymers. The common phenomenon is called LIPSS. Usually, LIPSS (often known as ripples or gratings) show the periodic on the order of laser wavelength [35]. According to the periodic, the LIPSS can be divided into low spatial frequency LIPSS (that is the spatial periodic \( \Lambda \) near or a little less than wavelength) \( \lambda/2 < \Lambda < \lambda \) (which is also called near wavelength structure [36] and high spatial frequency LIPSS) HSFL (that is the spatial periodic \( \Lambda \) much less than wavelength) \( \Lambda < \lambda/2 \) (which is called subwavelength structure [37]. What’s more, LIPSS are usually vertical to the polarization direction.

For the forming mechanism of LIPSS, there are three theoretical explanations: interference between the scattered and cavity radiation [34], interference of laser with surface plasmons [38] and self-organization [39].

Emmony et al. [34] first presented the concept of surface scattering, which means interference between the scattered and cavity radiation caused by surface roughness. A calculation model was set up based on it:

\[
\Lambda = \frac{\lambda}{1 \pm \sin \theta}. \tag{2}
\]

where \( \Lambda \) is the periodic, \( \lambda \) is the laser wavelength, \( \theta \) is the incident angle, the plus and minus signs refer to backward and forward scattering, respectively.

Explanation of the second theory is that excited surface plasmons induce periodic energy distribution above the surface, and periodic structures are generated. The decrease of the period of LIPSS is due to the decrease of the wavelength of surface plasma with the decrease of electron number density. Based on above, the periodic can be calculated [40]:

\[
\Lambda = \frac{\lambda}{\lambda' \pm \sin \theta}. \tag{3}
\]

where \( \lambda' \) is the wavelength of surface plasmons. Besides, materials in the subablation conditions, which lead to superheated liquid, present another ripple formation. The surface tension gradient and recoil pressure will cause hydrodynamical effects, which is called capillarity-driven ripple formation [41]. What’s more, in multi-laser irradiation, microgroove and spikes will also show up due to hydrodynamics [42].

Reif [43] and Costache et al. [44] found the periodic of the LIPSS on BaF\(_2\) and CaF\(_2\) was much less than the value calculated by Equation (1). And the self-organization theory was proposed based on experimental phenomena. Due to multiphoton ionization, the surface will present a high non-equilibrium state where coulomb explosion happens. The explosion will generate shock wave pressure at the scale of GPa and periodic structures different from classic LIPSS is present.

### 3.2 Direct laser interference patterning

Compared with single pulse laser, direct laser interference patterning (DLIP) can yield high quality and diverse sub-wavelength texture and has advantages in rapid, large-scale...
and high efficiency. Two or more laser beams coherently overlap to produce patterns by laser interference and induce different energy distribution, so as to change the intensity distribution of laser incident on the surface. Figure 5 shows the intensity distribution of a typical double-beam laser interference system and its interference pattern. By changing the number and incident angle, different periods and pattern structures can be obtained.

For a multi-beam laser interference setup, the spatial periodic can be calculated \[ \Lambda = \frac{\lambda}{\sqrt{n \sin(\beta/2)}}. \] (4)

where \( \lambda \) is the wavelength; \( \beta \) is the angle between laser beams; \( n = 4 \) presents two-beam laser system; \( n = 3 \) presents three-beam laser system; \( n = 2 \) presents four-beam laser system.

It can be seen from the above formula that different amounts of laser beam and incident angles can be used to process surfaces of different periods, thus forming different patterned microstructures. Bieda et al. [49] used nanosecond two-beam laser ablated line-like periodic structures on stainless steel, titanium and aluminum, and studied laser interference induced temperature distribution and temperature gradients with different materials. Lasagni et al. [47] utilized two- and three-beam laser interference fabricated line- and dot-type periodic patterns which was thought to be caused by surface tension driven mechanism because of thermal gradient. Voisiatet al. [50] used four-beam laser interference produced a hole array pattern surface on thin film and investigated the effect of different phase shifts and energy on pattern. Rodriguez et al. [51] simulated patterns under different laser beams and the results were in good agreement with the structures discussed above as shown in Figure 6.

The uneven energy distribution caused by laser interference can greatly improve the processing efficiency of array pattern. Hauschwitz et al. [52] used four-beam laser fabricated 1520 spots with LSFL in 50 ms and 1016 spots with HSFL in 5 ms. Compared with the single beam method, the productivity was significantly improved. By adjusting distance between interference plane and focal plane, large throughput can be achieved. As shown in Figure 7, the higher the interference plane is, the larger the focal plane area is [53], which provides new method for large and efficient fabrication of micro/nano structures.
FIGURE 7  A setup with a clear deviation between the interference and the focal plane and an elliptical spot shape on a stainless steel sample fabricated by the setup [53]

FIGURE 8  Schematic of the fabrication steps and the morphology of the triple-scale micro/nanostructured superhydrophobic surfaces: (a–c) The two basic steps to build the structures, that is, ultrafast laser ablation and chemical oxidation; (d–d2) typical morphologies of the triple-scale micro/nano structures [62]

3.3  Hierarchical structure

LIPSS is single scale structure, and the property is limited. As a result, many creature’s surfaces have structures of different scales that work together to exhibit versatile properties. Such as, surface of *H. trionum* petals have many large bulged cells and cells are covered with nano-ridges [54–56]. Light interference happens between nano-ridges which causes near-UV structural colours. While, the large bulged cells don’t join the interference, instead changing the normal direction of nano-ridges. Thus, the receiving angle of the structural colour is broadened through hierarchical structures. The production of hierarchical structure is complex while by using pulse laser, the procedures can be much simplified.

For the single step laser fabrication of hierarchical structure, Zorb et al. [57] and Stratakis et al. [58] used one-step femtosecond laser irradiate on flat silicon substrate under reactive gas (SF₆) atmosphere and produced lotus leaf surface like micro- and nanostructure. Skoulas E. et al. [59] reported a one-step and scalable method which utilized the versatile angular profile and electric field symmetry of femtosecond. New complex multi-directional nanostructures, inspired by the Shark’s skin morphology, as well as superhydrophobic dual-scale structures mimicking the Lotus’ leaf water repellent properties were attained. Laser with different pulse duration can realize the microstructure of different scale, so the multi-scale hierarchical structure can be generated. Cardoso et al. [60] mimicked the lotus, used nano-and picosecond laser ablated micro cell and sub-microstructure on cell respectively which achieved superhydrophobic surface with a contact angle of $161.5\degree \pm 3\degree$. Chen et al. [61] used femtosecond laser fabricated micro grooves accompanied by in situ deposition which formed porosity.
By changing the interval of micro grooves multiscale micro—nano structures is produced. This structure can achieve broad-band ultra-low-reflectivity.

Combined with pulse laser and other machining methods, more complex and multifunctional multi-scale hierarchical machining can be realized. Pan et al. [62] combined ultra-fast laser ablation and chemical oxidation and produced a triple-Scale hierarchical surface structure, which was covered with periodic conical array and on the cone were nanograsses and microflowers as shown in Figure 8. The surface has superhydrophobic property, excellent anti-icing property and icephobic performance at the same time. George et al. [63] used femtosecond pulse laser ablated replicating laser-written patterns on polymethylmethacrylate. Then reduction of Ag particles combined with the patterns achieve surface enhanced Raman scattering signal enhancement and superhydrophobicity ultra-low contact angle hysteresis.

ACKNOWLEDGEMENT

This work was supported by the National Natural Science Foundation of China (No. U1908232, No. 52005059), the National Science and Technology Major Project (No. 2017-VII-0002-0005), Cooperation Project Foundation from Sichuan Provincial Science and Technology Department (No. 2021YFSY00049), the Natural Science Foundation of Chongqing (No. cstc2020jcyj-shX0008), the Fundamental Research Funds for the Central Universities in China (No. 2020CDJQY-A035), the China Postdoctoral Science Foundation (No. 2020M673126, No. 2020M673127), “Construction of double city economic circle in Chengdu Chongqing area” scientific and technological innovation project (No. KJCXZD2020011), the Fundation from Sichuan Province key Laboratory of artificial intelligence (NO. 2019RYJ01), Graduate Research and Innovation Foundation of Chongqing (No. CYB20009).

REFERENCES

1. Lei, J., Guo, Z.G.: A fog-collecting surface mimicking the Namib beetle: Its water collection efficiency and influencing factors. Nanoscale 12, 6921–6936 (2020)
2. Yin, K., et al.: Ultrafast achievement of a superhydrophilic/hydrophobic Janus foam by femtosecond laser ablation for directional water transport and efficient fog harvesting. ACS Appl. Mater. Interfaces 10(37), 31433–31440 (2018)
3. Yan, S.G., et al.: Unidirectional self-transport of air bubble via a Janus membrane in aqueous environment. Appl. Phys. Lett. 113(26), 261602 (2018)
4. Hockauf, R., et al.: Grinding of riblets with “beaver tooth” multi-layer tools. Proc. CIRP 71, 155–159 (2018)
5. Xiao, G.J., et al.: Grinding mechanism of titanium alloy: Research status and prospect. J. Adv. Manuf. Sci. Technol. 1(1), 2020001 (2021)
6. Fan, W.G., et al.: Microscopic contact pressure and material removal modeling in rail grinding using abrasive belt. P. I. Mech. Eng. B-J Eng. 235(1-2), 3–12 (2021)
7. Joint, F., et al.: GaAs manufacturing processes conditions for micro- and nanoscale devices. J. Manuf. Process 60, 666–672 (2020)
8. Pournia, M., et al.: Fabrication of ultra-high-aspect-ratio nano-walls and nano-structures on silicon substrates. J. Micromech. Microeng. 30(12), 125008 (2020)
9. Wang, J., et al.: Preparation of microneedle array mold based on MEMS lithography technology. Micromachines (Basel) 12(23), 23 (2020). https://doi.org/10.3390/mi12230023
10. Xu, S.S., Wang, Q., Wang, N.: Chemical fabrication strategies for achieving bioinspired superhydrophobic surfaces with micro and nanostructures: A review. Adv. Eng. Mater. 20200183 (2020). https://doi.org/10.1002/adem.20200183
11. Wang, G.Q., et al.: Ultrasound-assisted through-mask electrochemical machining of hole arrays in ODS superalloy. Materials (Basel) 13(24), 5780 (2020)
12. Li, R.Q., et al.: Template-free electrodeposition of ultra-high adhesive superhydrophobic Zn/Zn stearate coating with ordered hierarchical structure from deep eutectic solvent. Surf. Coat Tech. 403, 126267 (2020)
13. Garg, A., Nam, W., Zhou, W.: Reusable surface-enhanced raman spectroscopy membranes and textiles via template-assisted self-assembly and micro/nanoimprinting. ACS Appl. Mater. Interfaces 12(50), 56290–56299 (2020)
14. Hurchalla, G., et al.: Water repellency of hierarchically structured legs of water-walking stickers and fire ants. Surf. Innov. 7(3–4), 184–193 (2019)
15. Stratakis, E., Jeson, H., Koo, S.: Structures for biomimetic, fluidic, and biological applications. MRS Bull. 41(12), 993–1001 (2016)
16. Prum, B., et al.: Plant surfaces with cuticular folds are slippery for beetles. J. R. Soc. Interface 9(66), 127–135 (2012)
17. Zhang, Y.L., et al.: Biomimetic graphene films and their properties. Nanoscale 4, 4858 (2012).
18. Bhushan, B., Her, E.K.: Fabrication of superhydrophobic surfaces with high and low adhesion inspired from rose petal. Langmuir 26(11), 8207–8217 (2010).
19. L. Feng, et al.: Petal Effect: A superhydrophobic state with high adhesive Force. Langmuir 24, 4114–4119 (2008).
20. Xiao, G.J., et al.: Shark-skin-inspired micro-riblets forming mechanism of TC17 titanium alloy with belt grinding. IEEE Access 7(1), 107636–107648 (2019).
21. Xiao, G.J., et al.: Bionic microstructure on titanium alloy blade with belt grinding and its drag reduction performance. P. I. Mech. Eng. B. J. Eng. (2020). https://doi.org/10.1177/0954405420947744
22. Chen, H.W., et al.: Biomimetic drag reduction study on herringbone riblets of bird feather. J. Bionic Eng. 10, 341–349 (2013).
23. Martin, S., et al.: Discovery of riblets in a bird beak (Rynchops) for low fluid drag. Phil. Trans. R. Soc. A 374(2073), 20160134 (2016).
24. Gallagher, J.A., Thomas, A. S.W.: Turbulent boundary layer characteristics over streamwise grooves. AIAA Pap. 84–2188 (1984).
25. Bacher, E.V., Smith, C.R.: A combined visualization-anemometry study of the turbulent drag reducing mechanisms of triangular micro-groove surface modifications. AIAA Pap. 84–0548 (1985).
26. Stratakis, E., et al.: Laser engineering of biomimetic surfaces. Mat. Sci. Eng. R 141, 100562 (2020).
27. Kinoshita, S., Yoshioka, S.: Structural colors in nature: The role of regularity and irregularity in the structure. ChemPhysChem 6, 1442-1459 (2005).
28. Vorobyev, A.Y., Guo, C.L.: Colorizing metals with femtosecond laser pulses. Optics and Photonics News 19(12), 30–30 (2008).
29. Livakas, N., Skoulas, E., Stratakis, E.: Omnidirectional iridescence via cylindrically polarized femtosecond laser processing. Opto-Electron. Adv. 3(05), 190035 (2020).
30. Zhao, J.H., et al.: Ultrafast laser-induced black silicon, from micro-nanostructuring, infrared absorption mechanism, to high performance detecting devices. MT Nano 11, 100078 (2020).
31. Wu, C., et al.: Near-unity below-band-gap absorption by microstructured silicon. Appl. Phys. Lett. 78(13), 1850–1852 (2001).
32. Papadopoulos, A., et al.: Bionic omnidirectional antireflective glass via direct ultrafast laser nanostructuring. Adv. Mater. 31(32), 1901123 (2019).
33. Birnbaum, M.J.: Semiconductor surface damage produced by ruby lasers. J. Appl. Phys. 36, 3688–3689 (1965).
34. Emmony, D.C., Howson, R.P., Willis, L.J.: Laser mirror damage in germanium at 10.6 μm. Appl. Phys. Lett. 23, 598–600 (1973).
35. Bonse, J., et al.: Laser-induced periodic surface structures—a scientific evergreen. IEEE J. Sel. Top. Quant. 23(3), 9000615 (2017).
36. Höhm, S., et al.: Femtosecond laser-induced periodic surface structures on silica. Appl. Phys. 112(1), 014901.1–014901.9 (2020).
37. Har, M.H., et al.: Femtosecond laser nanostructuring of titanium metal towards fabrication of low-reflective surfaces over broad wavelength range. Appl. Surf. Sci. 371, 479–487 (2016).
38. Huang, M., et al.: Origin of laser-induced near-subwavelength ripples: Interference between surface plasmons and incident laser. ACS Nano 3, 4062 (2009).
39. Reif, J., Varlamova, O., Costache, F.: Femtosecond laser induced nanostructure formation: Self-organization control parameters. Appl. Phys. A 92(4), 1019–1024 (2008).
40. Han, Y., Qu, S.: The ripples and nanoparticles on silicon irradiated by femtosecond laser. Chem. Phys Lett. 495(4), 241–244 (2010).
41. Tshibidis, G.D., et al.: Dynamics of ripple formation on silicon surfaces by ultrashort laser pulses in subablation conditions. Phys. Rev. B 86(11), 115316 (2012).
42. Tshibidis, G.D., Fotakis, C., Stratakis, E.: From ripples to spikes: A hydrodynamical mechanism to interpret femtosecond laser-induced self-assembled structures. Phys. Rev. B 92(4), 041405 (2015).
43. Reif, J., Costache, F., Henyk, M., et al.: Ripples revisited: Non-classical morphology at the bottom of femtosecond laser ablation craters in transparent dielectrics. Appl. Surf. Sci. 197–198, 891–895 (2002).
44. Costache, F., Henyk, M., Reif, J.: Modification of dielectric surfaces with ultra-short laser pulses. Appl. Surf. Sci. 186, 352–357 (2002).
45. Bieda, M., Siebold, M., Lasagni, A.F., et al.: Fabrication of sub-micron surface structures on copper, stainless steel and titanium using picosecond laser interference patterning. Appl. Surf. Sci. 387, 175–182 (2016).
46. Lasagni, A., Manzoni, A., Mücklich, F.: Micro/nano fabrication of periodic hierarchical structures by multi-pulsed laser interference structuring. Adv. Eng. Mater. 9(10), 872–875 (2007).
47. Lasagni, A., et al.: Advanced design of periodical architectures in bulk metals by means of laser interference metallurgy. Appl. Surf. Sci. 254, 930–936 (2007).
48. Wang, Y.R., et al.: Direct patterning of periodic semiconductor nanostructures using single-pulse nanosecond laser interference. Opt. Express 28, 32529 (2020).
49. Bieda, M., Beyer, E., Andrés, E.: Direct fabrication of hierarchical microstructures on metals by means of direct laser interference patterning. J. Eng. Mater.—T ASME 132, 031015 (2010).
50. Voisiat, B., et al.: Picosecond-laser 4-beam-interference ablation as a flexible tool for thin film microstructuring. Phys. Proceeda 12, 116–124 (2011).
51. Rodriguez, A., et al.: Laser interference lithography for nanoscale structuring of materials: From laboratory to industry. Microelectron. Eng. 86, 937–940 (2009).
52. Hauschwitz, P., et al.: Towards large-scale LLIPSS fabrication by 4-beam ps DLIP. Opt. Laser Technol. 133, 106532 (2021).
53. Hauschwitz, P., et al.: Large-beam picosecond interference patterning of metallic substrates. Materials(Basel) 13, 4676 (2020).
54. Whitney, H.M., et al.: Floral iridescence, produced by diffractive optics, acts as a cue for animal pollinators. Science 323(5910), 130–130 (2009).
55. Vignolmi, S., et al.: Is floral iridescence a biologically relevant cue in plant-pollinator signaling? A response to van der Kooi et al. New Phytol. 205(1), 21–22 (2015).
56. Zhao, J.H., et al.: Laser interference lithography for nanoscale functional surfaces with microfluidic and tissue engineering applications. Micromachines 5(4), 013411 (2011).
57. Skoulas, E., et al.: Biomimetic surface structuring using cylindrical vector femtosecond laser beams. Sci. Rep-UK 7(1), 1–11 (2017).
58. Cardoso, J.T., et al.: Superhydrophobicity on hierarchical periodic surface structures fabricated via direct laser writing and direct laser interference patterning on an aluminum alloy. Opt. Laser Technol. 111, 193–200 (2018).
59. Chen, T., et al.: Broad-band ultra-low-reflectivity multiscale micro-nano structures by the combination of femtosecond laser ablation and in situ deposition. ACS Appl. Mater. Interfaces 12, 49265–49274 (2020).
60. Pan, R., Zhang, H.J., Zhong, M.: Triple-scale superhydrophobic surface with excellent anti-icing and icephobic performance via ultrafast laser hybrid fabrication. ACS Appl. Mater. Interfaces 13, 1743–1753 (2021). https://doi.org/10.1021/acsami.0c16259
61. Lasagni, A., Manzoni, A., Mücklich, F.: Micro/nano fabrication of periodic hierarchical structures by multi-pulsed laser interference structuring. Adv. Eng. Mater. 9(10), 872–875 (2007).
62. Lasagni, A., et al.: Advanced design of periodical architectures in bulk metals by means of laser interference metallurgy. Appl. Surf. Sci. 254, 930–936 (2007).
63. George, J.E., et al.: Flexible superhydrophobic SERS substrates fabricated by in situ reduction of Ag on femtosecond laser-written hierarchical surfaces. Sensor Actuat. B-Chem. 272, 485–493 (2018).