Direct Generation of Superhydrophobic Microstructures in Metals by UV Laser Sources in the Nanosecond Regime


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Generation of Modified Wettability Metallic Surfaces by Short Pulse Lasers

OUTLINE:

1. Introduction: The Search for Hydrophobic Surfaces
2. Basic Experimental Setup and Initial Results: Hydrophobicity Induced by Surface Patterning with Individual ns Laser Pulses
3. The Next Step: Extended Surfaces Patterning with ns Laser Generated Channels.
   a) Effect of repetition rate / processing speed
   b) Effect of hatch distance
4. Generation of Withstanding Superhydrophobic Surfaces with 2D-Micropillar Patterns
5. The Way for the Generation of Low Wettability and Bio-inspired Self-Cleaning Surfaces
6. Conclusions
The search for Hydrophobicity (1/3):

The search for Hydrophobicity (2/3):

\[ S = \pi d^2 / 4L^2 \]

The search for Hydrophobicity (3/3):


EXPERIMENTAL SETUP (BASIC): THE IRRADIATION SYSTEM

Substrate: Al
Thickness: > 50 µm
Wavelength: 355 nm
Laser Average Power: 500 mW
Pulse duration: 30 ns
Energy/pulse: ~ 2.50 µJ
Spot Diameter: 10-20 µm
Fluence (Single pulse): 0.81-3.25 J/cm²
Hatch distance: 10-50 µm
Pulse Rep. Rate: 25-250 kHz

UV Radiation allows smaller spot size!
INITIAL RESULTS

Morphology / Microstructure

P : 15 µm

P : 20 µm

P : 25 µm

P : 30 µm

P : 35 µm
• For a given range of processing conditions, a microwall is formed above the metal surface. This contributes to coexistence of different length scales (hierarchical microstructure) and the creation of an extra-structure allowing additional trapping of air, thus improving the composite interface between the surface and the liquid which motivates hydrophobicity.

• This complex structured can be appropriately controlled in order to provide a range of surface wettability (Contact Angle, CA) properties.
The SCA measurements were performed with 8-12 μL water droplets, showing a high degree of repeatability.

A clear hydrophobic effect (90° ≤ SCA ≤ 150°) was introduced by the generated microstructure.

For the particular case envisaged, an optimum value of SCA was obtained around P = 25 μm, reaching a maximum contact angle around 145°.

The result was attributed to the variability of the degree of hierarchical microstructure generated under each parametric choice.
NEXT STEP: CHECK FOR REPRODUCIBILITY ON EXTENDED SURFACES

Generation of near-Superhydrophobic surfaces with 1D-microchannels
Study on the effect of Rep. Rate

- Substrate: Al, SS, Si
- Thickness: 100 µm
- Wavelength: 355 nm
- Laser Average Power: 500 mW
- Pulse duration: 30 ns
- Energy/pulse: 2.56 µJ
- Spot Diameter: 10 µm
- Fluence (Single pulse): 3.25 J/cm²
- Hatch distance: 20 µm
- Pulse Rep. Rate: 25-250 kHz
RESULTS (I) Morphology / Microstructure

25 kHz  50kHz  100kHz  150kHz  200kHz

Si

Al

SS
RESULTS (I) Morphology / Microstructure
RESULTS (I)

Morphology / Microstructure
RESULTS (I) Analysis of Channel depth vs. Rep. Rate
EXPERIMENTAL SETUP (II)

Study on the effect of Hatch distance

Substrate : Al
Thickness : 100 µm
Wavelength : 355 nm
Laser Average Power : 500 mW
Pulse duration : 30 ns
Energy/pulse : 2.56 µJ
Spot Diameter : 15 µm
Fluence (Single pulse) : 2.83 J/cm²
Pulse Rep. Rate : 100 kHz
Hatch distance : 10-25 µm

UV Radiation allows smaller spot size!
RESULTS (II) Analysis of Channel depth vs. hatch distance

Ø=15 µm
F=2.83 J/cm²
f =100 kHz
d=10-25 µm

A: d=10 µm
B: d=15 µm
C: d=20 µm
D: d=25 µm
RESULTS (II) Analysis of Static CA vs. hatch distance
PARTIAL CONCLUSIONS

• High degree of hydrophobicity (near-superhydrophobicity) on different materials (Silicon, pure aluminum and AISI 304 Stainless Steel) plates has been achieved in a single processing step by means of ns lasers working at UV wavelengths and with final applied energies in the range of 100-150 J/cm² and instant energy densities in the range of 10⁸-10⁹ W/cm². Better, stable superhydrophobic properties can be achieved by means of 1D-microchannel patterning.

• The desired hydrophobicity has been achieved by means of the generation of complex microstructures consisting of mixed micro-nano channels and interspacing walls resulting from laser ablation and melting/recast approaching near-hierarchical surface structure patterns.

• The obtained degree of hydrophobicity has been observed to critically depend in a first term on the pulse overlapping pitch applied to the surface. Optimum values of contact angle (SCA) close to superhydrophobicity have been achieved with particular choices of pulse overlapping pitches achievable by means of the high accuracy provided by the used lasers (working in the UV).

• The key parameter of final micro-channel depth has been analyzed for different processing speeds/repetition rates, a clear deleterious effect having being observed for processing speeds beyond a critical value (around 100 kHz repetition rate / 25-40 mm/s linear process speed) for the three kinds of materials analyzed.

• Additionally, the obtained degree of hydrophobicity has been observed to depend critically on the hatch distance (distance between successive parallel 1D tracks), the existence of a threshold value drastically changing the wettability character of the treated surface having been found.
Generation of Withstanding Superhydrophobic Surfaces with 2D-Micropillar Patterns
EXPERIMENTAL SETUP (III)

Study on the effect of Hatch distance

- Substrate: Al
- Thickness: 100 µm
- Wavelength: 355 nm
- Laser Average Power: 500 mW
- Pulse duration: 30 ns
- Energy/pulse: 2.56 µJ
- Spot Diameter: 15 µm
- Fluence (Single pulse): 2.83 J/cm²
- Pulse Rep. Rate: 100 kHz
- Hatch distance: 10-25 µm

UV Radiation allows smaller spot size!
RESULTS (III) Comparison of CA for μ-Channels and μ-Pillars

Ø=15 μm
F=2,83 J/cm²
f =100 kHz
d=10-25 μm

A: d=10 μm
B: d=15 μm
C: d=20 μm
D: d=25 μm
RESULTS (III)

μ-Cells: The Key Feature for High Degree of Hydrophobicity
RESULTS (III)

µ-Cells: The Key Feature for
High Degree of Hydrophobicity

DISCUSSION: THE WAY FOR LOW WETTABLE SURFACES

DISCUSSION: THE WAY FOR LOW WETTABILITIY SURFACES

DISCUSSION: THE WAY FOR BIOINSPIRED LOW WETTABILITY SELF-CLEANING SURFACES

FINAL CONCLUSIONS

• The application of nanosecond laser pulses on flat surfaces of aluminium (Al) in a one-step process leading to the generation of extended areas of stable superhydrophobic behaviour has been reported.

• Both laser generated periodic structures consisting in laser channels and laser pillars have been successfully developed with the aid of a 30 ns pulse, 100 kHz repetition rate and 300 mW average power laser emitting at $\lambda = 355$ nm working at selected focus diameter and scan speed for different hatch distance values. The resulting micropatterns were evaluated by scanning electron microscopy (SEM) and confocal laser scanning microscopy (CLSM) in order to make apparent the material/geometrical parameters of the generated structures and a direct measurement of static contact angle (SCA) was performed in order to evaluate the wettability of the generated surface.

• A conceptually relevant methodology has been defined for the systematic generation of hierarchical-like micro/nano-structures fulfilling the conditions for the generation of superhydrophobic surfaces through the generation of $\mu$-cells able to serve as air trapping structures responsible for a substantially inhibited wettability of the substrate.

• This development, in its road to industrial implementation, is now considered as the basis for the systematic single-step generation of large scale extended surfaces with adjusted wettability properties as required by the different kinds of self-cleaning applications. Undoubtedly, the demonstrated possibility of use of ns lasers with their present day industrial robustness and their amenability to processing workstations with high throughput properties will contribute to the industrial implementation of the described developments.
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MAIN REFERENCES

Thank you very much for your attention!
MICROMANUFACTURING EXPERIMENTAL SETUP AT CLUPM