Superhydrophilic surfaces obtained by nanosecond laser treatment to enhance nucleate pool boiling heat transfer

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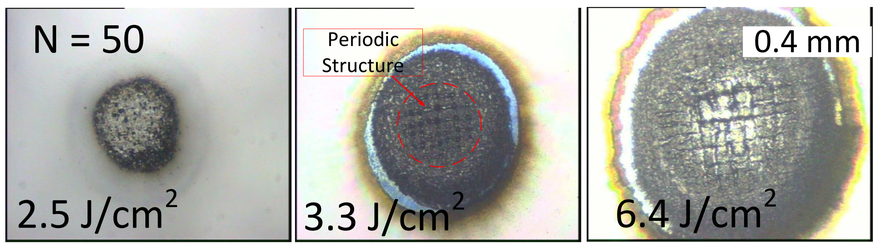
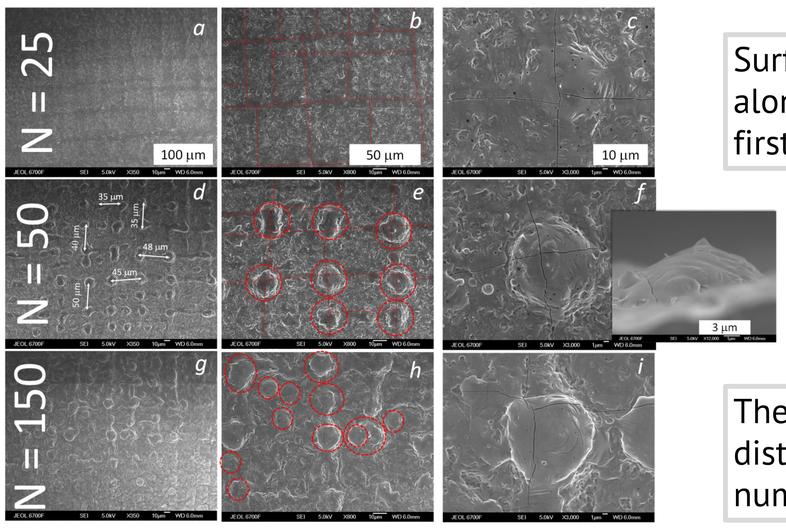
Motivation. The surface modification is one of the most promising and discussed methods to improve the boiling performance. To date there are a lot of techniques to modify a heating surface, but the search for the optimal, simple and reliable one is still an actual problem. The surface texturing using laser ablation was applied in a number of studies, which showed its great potential for heat transfer enhancement and critical heat fluxes increase during pool boiling on the metal surfaces. Recently we shown the formation of periodic surface microstructures on silicon surface during IR (1064 nm) laser ablatin in a narrow range of conditions. Silicon surface with such structures exhibits superhydrophilic properties which are retained during prolonged storage in air. In this work, we shown perspective of such surfaces for intensification of heat transfer in pool boiling process.

Nanosecond laser interaction on silicon. Self organized structure formation

Laser spots on monocrystalline silicon in air



At low fluence (< 3 J/cm2) the structures do not form
At high fluence (> 4 J/cm2) their destruction occurs.

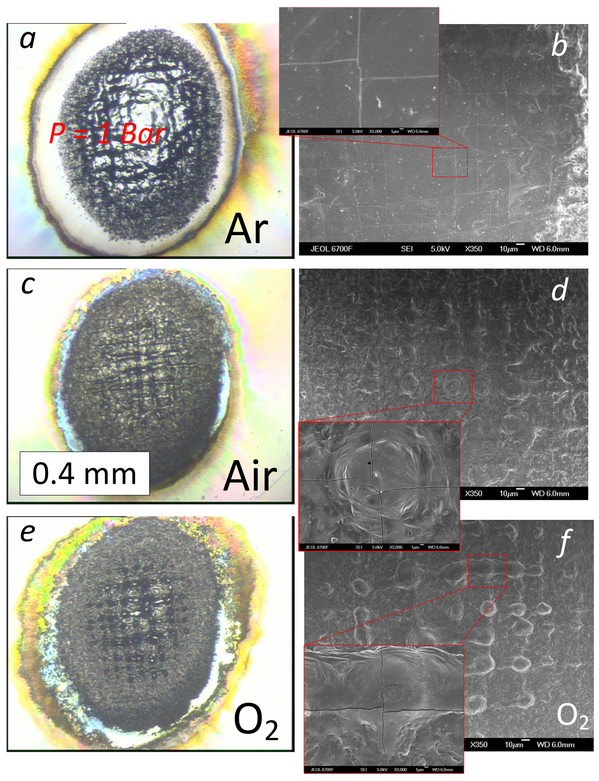


Surface cracking of silicon occurs along the crystal structure for the first 20 pulses

Structures are hills that grow in the suppression of cracks

The distribution of hills is disturbed with an increase in the number of laser pulses.

Laser spots on monocrystalline silicon in different gases

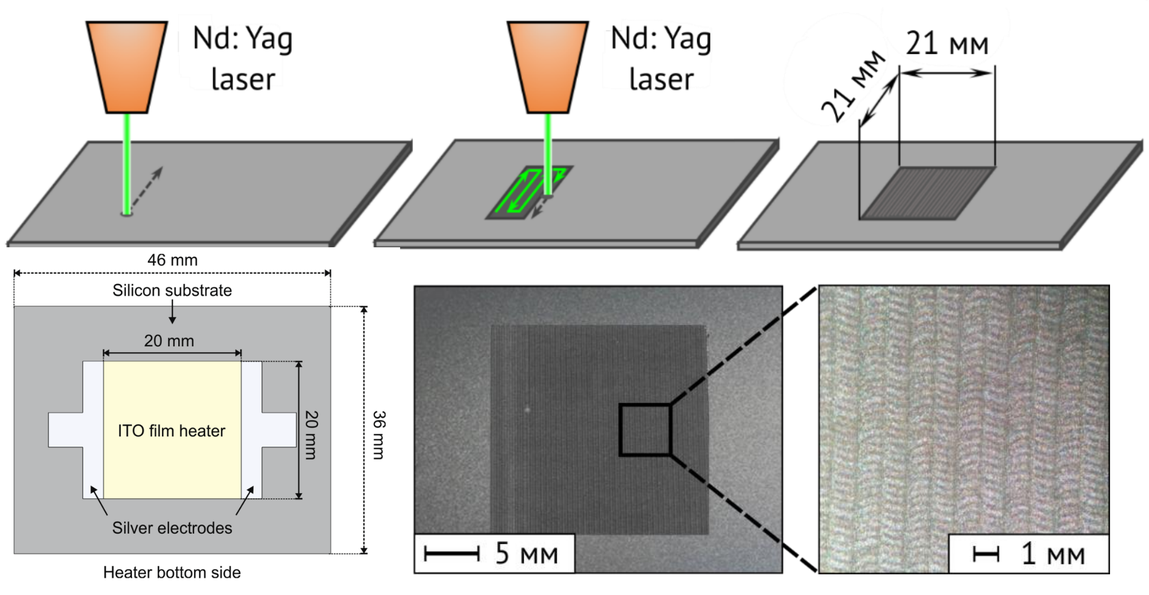


The formation of structures is not possible in a vacuum or inert background gas. It is necessary the present of O_2 in ambient.
The background pressure must be higher than **0.5 bar**

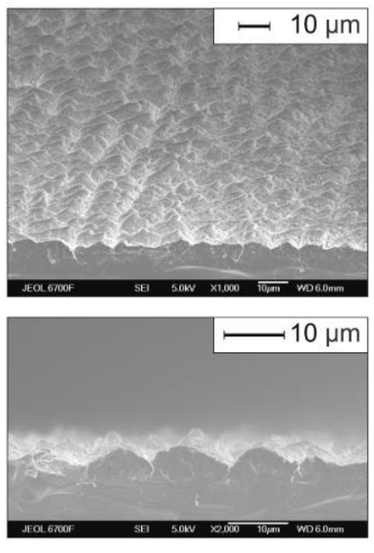
Narrow range of conditions:
Nanosecond laser pulses
IR wavelength (**1064 nm**),
F = **3 – 4** J/cm2
N = **50 – 100** pulses,
O_2 in background
The pressure > **0.5 bar**

Design of superhydrophilic heater surface

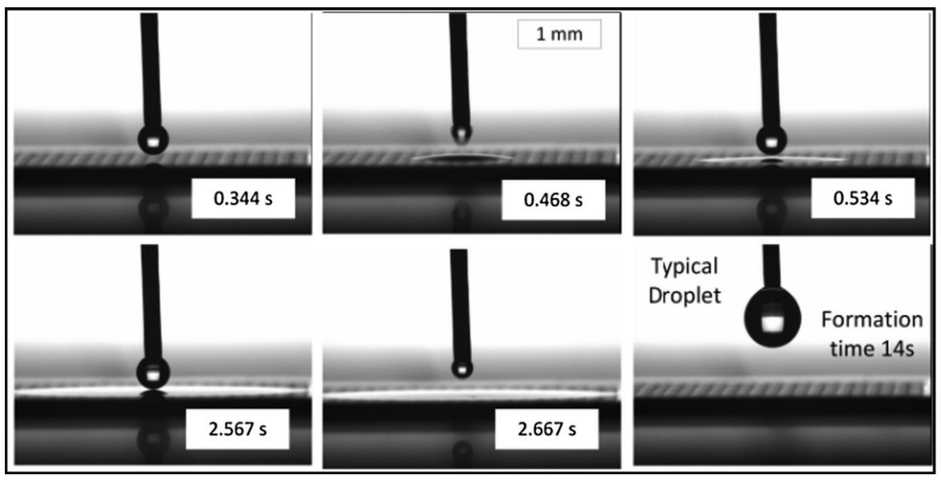
Treatment scheme



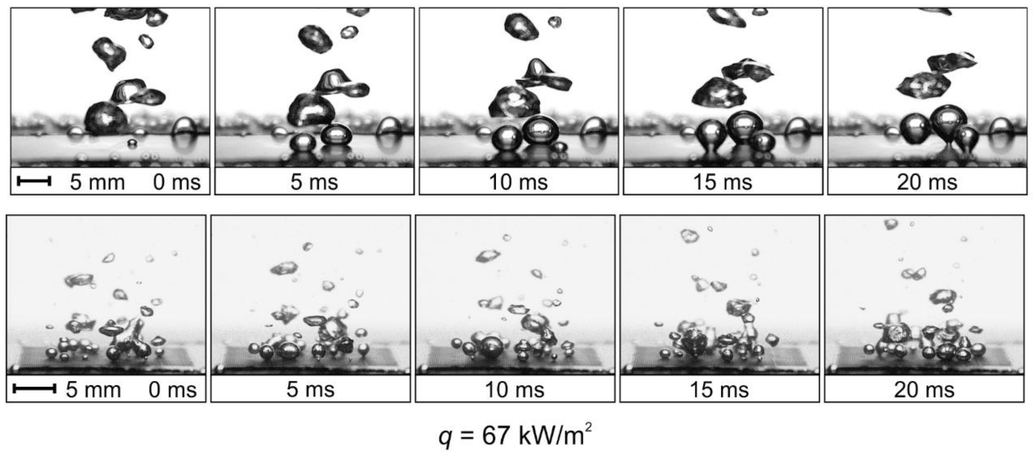
SEM cross-section images



Wetting test

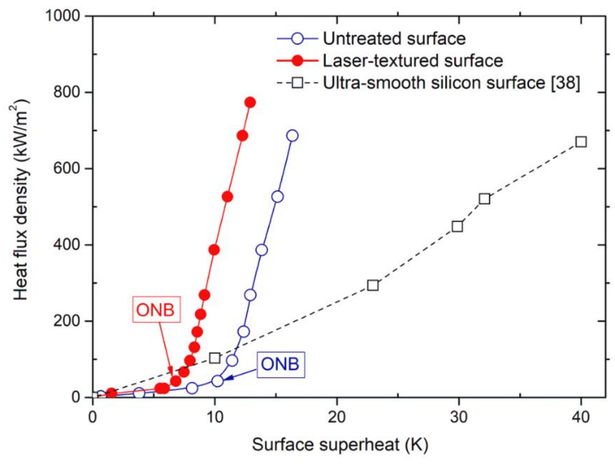


Pool boiling experiment

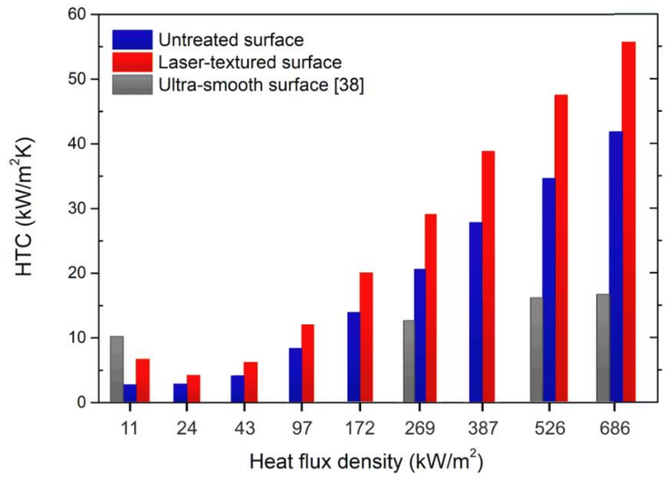


q = 67 kW/m^2

- Dramatically decreasing in the steam bubble size (by 4-6 times)
- Increasing the frequency of vaporization (by 7-10 times)



- The $q(\Delta T)$ curves for different experiment repeat
- Surface resistant to prolonged boiling
- Lower boiling threshold



The heat transfer intensification is in range of 33-43% in compared on rough silicon and 235% % in compared on ultra smooth surface

- **Conclusions . A self-organizing microstructure is formed on the silicon surface in a narrow range of nanosecond laser treatment conditions. The morphology is a microhillock at the intersections of cleavage cracks with porous structure at nanolevel. Structure formation is impossible in an oxygen-free atmosphere.**
- **Surface treatment in the found conditions of lead to stable superhydrophilic properties. The structure retains wetting properties for a long time and is suitable for further functionalization, for example, hydrophobization.**
- **The dynamics of vaporization noticeably changes on obtained surface. There is a decrease in the size of vapor bubbles (by 4–6 times) and an increase in the frequency of vaporization (by 7–10 times) relative to the untreated surface.**
- **A noticeable intensification of heat transfer during boiling of saturated water is demonstrated in range of 33 to 43% in compared on rough silicon and 235% % in compared on ultra smooth surface**

Some details of work may be found: **Starinskiy S.V.**, et .al // J. Phys. D. 2018. Vol. 51. P. 255307; **Starinskiy S.V.**, et al. //Appl. Surf. Sci. 512 (2020) 145753; **Serdyukov V**, et. al., Appl. Therm. Eng. 194 (2021) 117102