Enhancement of heat transfer at pool boiling on surfaces with silicon oxide nanowires

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Abstract. The boiling heat transfer on the local heaters with microstructured and nanomodified surfaces was studied. As nanomodified surfaces we used copper ones where the microropes of silicon oxide nanowires were grown. The aging of the nanomodified surface was observed after first series of experiments. It was shown that both finning and nanostructuring of the surface result in increase of heat transfer. The heat flux density of 1400 W/cm$^2$ was reached.

1. Introduction
Cooling the heated surfaces in various technologies is an important task, whose solution requires application of such processes as boiling. Today much attention is paid to development of the methods of heat transfer enhancement at boiling and increasing the critical heat flux [1]. One of directions is the study of the influence of various nanocoatings on heat transfer intensity. The review of recent studies on the influence of micro/nanomodified surfaces and coatings on heat transfer enhancement and critical heat flux increase at boiling is presented in [2]. There are another techniques for heated surfaces such as spray cooling, systems based on evaporation of a thin liquid layer or rivulet[3, 4], thermoelectric coolers. Dynamics of evaporation depends on the conditions in the layer [5]. For instance, the rupture of thin liquid layer can terminate the cooling process [6].

The aim of the present work is studying of pool boiling of water on the surfaces with different structure.

2. Experimental setup
In this work, we created an experimental setup for studying heat transfer from a local heat source. The test section is a PTFE cylinder with diameter 28 mm. The working liquid (distilled water) is supplied to the test section using a peristaltic pump, where a horizontal layer of liquid is formed. The thickness of the liquid layer is controlled by the amount of liquid (the geometry of test section is known) and varies depending on the operating parameters of the experiment (20-50 mm). In the center of the test section there is a local heating performed by a heater. The heating element is a cylindrical core made of copper. The upper part of the heater facing the liquid has diametrical dimension D = 5 and 1 mm. The source of heat is a nichrome wire wound around the lower part of the core. In order to minimize heat losses, the heating element was carefully insulated. The fiberglass was used as a heat insulator,
which was wound in several layers around the core of the heating element. It was estimated that the whole incoming power transferred to the liquid and heat losses did not exceed 20%.

Boiling heat transfer on the local heaters with nanomodified surfaces has been investigated. In this study, we carried out the experiments under the conditions of a large volume of liquid and maintaining the temperature of water at the level of saturation. The copper surfaces coated with a layer of silica, molybdenum or tungsten, where the microropes of silicon oxide nanowires were grown, were used as the nanomodified surfaces. The technology of their production is described in [7]. Unfortunately, a layer of silica on copper surfaces was destroyed after heating.

For the 1 mm diameter heater, special headers (heat sinks) have been developed, which is shown in Figure 2. These headers were heated and placed on a 1-mm-diameter heater cooled in liquid nitrogen, which provided good thermal contact.

![Figure 1. Scheme of experimental setup](image)

![Figure 2. Photo of the heat sink with finned surface for 1 mm heater](image)

3. Results
The results obtained on 1mm heater with different headers are shown in Figure 3. On finned surfaces, the superheat with respect to the saturation temperature decreases up to four times. More than three times the heat transfer coefficient increases in finned surface compared with the smooth. It should be noted that the type of finning did not have a significant effect on the boiling curve. Application of nanocoatings leads to an intensification of heat transfer in comparison with a smooth surface that is comparable with the use of radial finning. As a result of the experimental work, the heat flux density of 1400 W/cm² was reached.
Experimental data on the 5 mm heaters with the smooth and nanomodified surfaces are presented in Figure 4. On the surface with a molybdenum coating, we failed to grow the silicon oxide nanowires. The contact angle with a water drop on the resulting coating is 54° and it almost coincides with the wetting angle on the polished copper surface.

The best results were obtained on the copper surface with a sublayer of tungsten. On the intermediate layer of tungsten was obtained arrays of microropes and "cocoons", consisting of particles of tin coated with silicon oxide nanowires Figure 4a. The size of the cocoon and the distance between them was up to 1 µm. The contact angle with a water drop on the resulting coating, measured before the experiment, is 18°, and this is significantly less than that on the copper surface or molybdenum, tungsten coating.

According to Figure 5, the heat transfer coefficient for this coating is substantially higher than for a smooth molybdenum surface. Two series of experiments were performed with limitation of heating. After the first series of experiments, microropes were gone (Figure 4b), cocoons were left. During the second series of experiments, the area of nanomodified surface began decreasing, which was reflected in the boiling curve behavior. The coefficient of heat transfer decreased.
**Figure 5.** Heat transfer coefficient against overheating of heater surface relative to saturation temperature for heater D = 5 mm

4. **Conclusion**

In our experiments the layers of silica on copper surfaces were destroyed after heating. Arrays of microropes on heated surfaces with silica, molybdenum and tungsten sublayers disappear after boiling. The best results were obtained on the copper surface with a sublayer of tungsten. Surfaces with "cocoons" on tungsten sublayers were stable at boiling. It can be concluded that a new type of microfinning and nanocoatings provides heat transfer enhancement during boiling. Heat transfer coefficient of 80000 W/(m²K) was reached on nanomodified surfaces. The heat flux density of 1400 W/cm² was reached on microfinned surface.

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