Synthesis of silicon oxide microropes on the copper substrate with SiO$_2$ interlayer

E Baranov, S Khmel, A Zamchiy and E Shatskiy

Kutateladze Institute of Thermophysics SB RAS, 630090 Novosibirsk Ac. Lavrentiev ave. 1, Russia

E-mail: itpbaranov@gmail.com

Abstract. Nanostructuring of the surface is a promising technology for the processes of boiling. In this paper, we synthesized array of "microropes" from silicon oxide nanowires on the copper substrate with a silicon oxide intermediate layer by gas-jet electron beam plasma CVD method. The morphology for the synthesis time of 2 minutes 30 seconds and 5 minutes was obtained. The water droplet on the silicon oxide nanowires shows the measured contact angles 14° and 10° for deposition times of 5 min and 2 min 30 sec, respectively.

1. Introduction

Nanostructuring of the surface, which is used for the processes of boiling, is a promising technology by Surtaev and Serdyukov (2016). Most often, monocrystalline silicon wafers are used for nanostructuring. But copper heaters can be more promising and these heaters with silicon nanostructures are a very interesting system. In addition, one of the important properties of nanomodification is to change of the surface wettability.

In this paper, we synthesized array of "microropes" from silicon oxide nanowires on the copper substrate with a silicon oxide (SiO$_2$) intermediate layer. The morphology for the synthesis time 2 minutes 30 seconds and 5 minutes was obtained. The contact angle for the nanostructures was measured.

2. Experiment

2.1. Synthesis of the silicon oxide nanowires array

The silicon oxide nanowires were synthesized from mixture monosilane-argon (37 sccm) with gas diluent hydrogen (386 sccm) by gas-jet electron beam plasma CVD method by Zamchiy and Khmel (2014). Oxygen (3 sccm) was supplied directly into the vacuum chamber. The synthesis was carried out on the copper substrate with/without SiO$_2$ interlayer and with tin film mass thickness of about 60 nm. The substrate is copper core with a round head with diameter d=5 mm. The SiO$_2$ film was deposited by magnetron sputtering and the tin film was deposited by thermal vacuum deposition. The process of nanowire synthesis on the substrate with the catalyst consists of three stages: heating up to operating temperature (400°C), treatment of hydrogen plasma and the actual growth of nanowires by vapor–liquid–solid (VLS) mechanism. The synthesis temperature was 330°C.
2.2. Measuring techniques
The surface morphology was determined by the methods of scanning electron microscopy (SEM) using the JEOL JSM-6700F microscope.

The contact angle of the sample with water was measured by DSA-100 KRUSS device with high-precision system of liquid supply with a minimal dosing step of 0.1 µl.

3. Results and Discussion
Figure 1 shows the SEM image of the tin film on the copper substrate. It is seen that the tin wets the surface. Individual particles with a typical size of 500 nm do not have a fixed shape. After heating and treatment with hydrogen plasma, the surface morphology changes dramatically, no catalyst particles are observed in the SEM image. We assume that the heating of the tin above the melting temperature in combination with hydrogen plasma treatment causes chemical reactions between the copper substrate and the tin and leads to the formation of intermetallic compounds (Yin and Chauhan, 2008).

Figure 2 shows a SEM image of the copper substrate without SiO₂ interlayer after synthesis. Synthesis of the array of "microropes" from silicon oxide nanowires does not occur on this catalyst.

Figure 3 shows the SEM image of the tin film on the copper substrate with SiO₂ interlayer.

Figure 4 shows the SEM image of the tin film on the copper substrate with SiO₂ interlayer after heating and treatment with hydrogen plasma.
To solve this problem, it was decided to deposit the intermediate layer, which was supposed to have good adhesion with copper, and which is not wetted by tin. This intermediate layer was a silicon oxide with a thickness of 100 nm.

Figure 3 shows the SEM image of the tin film on the copper substrate with SiO$_2$ interlayer. Particles of tin catalyst have clear boundaries. Particle shape is round and oval. Similar morphology of the catalyst is suitable for synthesis of nanowires of silicon oxide (Khmel and Baranov, 2016).

Figure 4 shows the SEM image of the tin film on the SiO$_2$ interlayer after heating and hydrogen plasma treatment. The treatment promotes reduction of oxide layers on the surface of tin particles. Since the temperature is above the melting point of tin and since the particles are liquid, they become of a regular spherical shape. The particle size distribution is within 400–700 nm. X-ray EDS analysis showed the oxygen content in the catalyst particle to be about 3%.

The SEM image in Fig. 5 shows the silicon oxide nanowires array for deposition time of 5 min. Each microrope consists of numerous nanowires with average diameter of about 15 nm. Nanowires bunch is on the bottom of the catalyst particle, whereas the nanowires are absent at the top of it. Length of microrope was about 10 micrometer. Reducing the time of synthesis to 2 min 30 sec resulted in a decrease of the length of the microrope and change of the morphology. As can be seen in the Fig. 6, the length of the microrope has decreased to 1 micrometer. For single particles, the microrope is divided into several separate tails. Most likely, as the length of the microrope increases, they begin to act on each other forming an ordered array.

Analysis of the photograph of the water droplet on the silicon oxide nanowires grown on the copper substrate with SiO2 interlayer shows the measured contact angle were for deposition time 5 min - 14° (Fig. 7) and for deposition time 2 min 30 sec - 10° (Fig. 8). This confirms that the surface of the
silicon oxide nanowires array, synthesized in this work, is hydrophilic in nature (Baranov and Zamchiy, 2016). In addition, it was observed that the droplets on the surface have a very large imbibition layer. We assume that water penetrates easily into grooves constituting the relief in the case of Cassie impregnating wetting.

4. Conclusion
In this paper, the array of "microropes" from silicon oxide nanowires on the copper substrate by gas-jet electron beam plasma CVD method were synthesized. The silicon oxide intermediate layer with a thickness of 100 nm was deposited to solve the problem with wetting the copper substrate by tin. The morphology for the synthesis times of 2 minutes 30 seconds and 5 minutes was obtained. The water droplet on the silicon oxide nanowires, grown on the copper substrate with the silicon oxide interlayer, shows the measured contact angles of 14° and 10° for deposition times of 5 min and 2 min 30 sec, respectively.

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