Growth of the Carbon Nanotubes on the Meteorite Surface: the Influence of the Surface Texture

A. S. Begunova, R. V. Kamalov, G. A. Yakovlev and V. I. Grokhovsky, Ural Federal University, Ekaterinburg, Russia (n.s.begun@gmail.com)

Introduction: Iron meteorites have a unique structure formed in equilibrium processes. This makes it possible to use them as iron-nickel substrates for the synthesis of carbon nanotubes (CNTs) [1]. In this case, the meteorite acts both as a substrate and as a catalyst. There are several questions related to the influence of the substrate/catalyst on the growth of CNTs. For example, does catalysis take place at the atomic or cluster level [2]? This research is devoted to mechanisms of CNTs obtaining on the meteorite's surface. We used the Chinga ataxite (ungrouped iron). It contains the submicroscopic duplex plessite and kamacite spindles with enveloping taenite [3]. Previously [4], we have already described the results of the synthesis; it was noted that, in parallel with the growth of CNTs, the formation of hematite nanowires took place. For comparison, two samples of an iron-nickel-cobalt alloy (FNC20) containing 20 wt.% nickel and about 1 wt.% cobalt was used. To determine the effect of oxidation, one of the samples was thermally oxidized.

Materials and methods: The FNC20-1 and FNC20-2 samples are examples of a single-phase alloy obtained from Fe, Ni, and Co metal powders at a temperature of 1700°C. The average grain size was about 1 μm.The samples of Chinga meteorite and FNC20-1, FNC20-2 were prepared using standard metallographic polishing and etching with 1 wt. % nital during 5 minutes. This led to the revealing of a submicron structure of the Chinga sample. Then several areas were marked on the samples and were analyzed before and after the synthesis of nanomaterials. The nanomaterials on the Chinga meteorite and FNC20-1 were synthesized by a catalytic pyrolysis of ethanol using "CVDomna" commercial equipment for carbon nanotube growth. The samples was placed into a reaction chamber, then heated to 600°C at a pressure of 1 kPa. A vapor-gas mixture of ethanol and air was passed into the reaction chamber during 10 minutes at a linear increase in pressure to 15 kPa, then they were cooled to 400°C at a pressure of 1 kPa and then cooled under an ambient air. At first the FNC20-2 was oxidized at a temperature of 600°C and an air pressure of 15 kPa for 10 minutes, then it was observed with SEM. After that, the synthesis of nanomaterials was carried out on it as described above. The samples were studied with ZEISS Axiovert 40 MAT optical microscope before the synthesis and by scanning electron microscopy and energy-dispersive X-ray spectroscopy using Zeiss Sigma VP equipped with X-max detector by Oxford Instruments before and after the synthesis.

Results: We have found synthesized CNTs on the plessite surface of Chinga sample. The average diameters of CNTs were 20 nm. This is described in more detail in [4]. The average Ni content of plessite in the Chinga is above 16 wt.%, the Ni content of taenite is ~ 25 wt.%. Therefore, we used an alloy with 20 wt.% Ni to test whether the content of the element affects the growth of CNTs. As a result of synthesis, amorphous forms of carbon were found on the surface of the FNC20-1 sample. The surface of the FNC20-2 surface after the oxidation was covered with oxide film and hematite nanorods on top layer of the film. The diameters of the nanorods were ~ 30 nm and the lenths were ~ 1-2 μm. In some places, the film is cracked and peeled off with flakes. The surface under the flakes contained pits with the diameters 50-100 nm. After the synthesis of the nanomaterials some remaining hematite nanorods were found. In places where the oxide film came off in flakes, the surface after synthesis was different. It was covered with amorphous carbon, and rare CNTs with an average diameter of about 25 nm were found. As mention in [5] with an excess of catalyst, excessive release of soot begins, which leads to contamination of the CNTs. Thus, more CNTs could be found under the amorphous layers.

Discussion: We carried out experiments with two-phase plessite of Chinga meteorite and one-phase 20 wt.% Ni alloy. A precence of the CNTs on the meteoritic plessite and an absence of the CNTs on the meteoritic taenite, kamacite and one-phase artificial alloy showed that Ni content did not affect on the synthesis. Deeper etching led to a higher yield of CNTs on the sample Chinga [4]. Thus, we can conclude that the entire particle participates in the precursor gas catalysis, and when we provide comprehensive gas access to it through deep oxidation, the yield of CNTs is greater. On the other hand, oxidation of one-phase alloy has changed its surface. There we had hematite nanorods and heat theatment pits under the peeled flakes. Authors of [6] showed that the oxidation reduces the surface tension coefficient, which improves the saturation of the metal catalyst with carbon. So even non-catalytic materials provide the CNTs growth.

According to the [1, 5] and the experiments carried out we can propose the CNTs synthesis mechanism. The precursor gas (CO) gained access to individual high-nickel plessite particles, then Fe-Ni particles were saturated with C and it is excreted as a precipitate. In this case, the Fe-Ni particle remains on the substrate, and the end of the CNT goes up from it. The driving force of the process is the concentration gradient in the metal particle.

References: [1] Kumar M. Y. and Ando Y. (2010) *Journal of Nanoscience and Nanotechnology* 10:3739-3758. [2] Didik A. A. et al. (2003) *Inorganic Materials* 39:583-587. [3] Buchwald V.F. (1975) *The Regents of the University of California* 1:115-124. [4] Begunova A. S. et al. (2022) *Journal of Raman Spectroscopy* 53: 472-484. [5] Ding F. (2006) *Applied Physics Letters* 88:133110. [6] Rumelli M. H. et al. (2005) *Nano Letters* 5: 1209.

Acknowledgments: The reported study was funded by RFBR, project number 19-32-90243 and the Minobrnauki project FEUZ 2020-0059.